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Exc.

Advanced Power Assessment for Czech Lignite Task 3.6 -- Part II

Topical Report

Everett A. Sondreal
Michael D. Mann
Greg W. Weber
Brian C. Young

December 1995

Work Performed Under Contract No.: DE-FC21-93MC30097

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
University of North Dakota
Grand Forks, North Dakota

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Morgantown Energy Technology Center
P.O. Box 880
Morgantown, West Virginia 26507-0880

By
University of North Dakota
Energy & Environmental Research Center
P.O. Box 9018
Grand Forks, North Dakota 58202-9018

December 1995

THE SECOND INTERNATIONAL CONFERENCE ON
ENERGY AND ENVIRONMENT:
TRANSITIONS IN EAST CENTRAL EUROPE

October 31 – November 1, 1994

Prague, Czech Republic

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Grand Forks, ND 58202-9018 USA

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Director
EGÚ Prague, PLC
19011 Prague
Czech Republic

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ENERGY AND ENVIRONMENT CONFERENCE ADVISORY COUNCIL

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Kevin L. Dodman, European Editor
Power Engineering International
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International Coal Letter
Brussels, Belgium

Paul Dolan, Director, Environmental Services
Thermo Energy System Corp.
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Josef Dorůška
Energy Policy Section
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Praha, Czech Republic

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Praha, Czech Republic

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Technology
Brookhaven National Laboratory
Upton, New York, USA

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Stone & Webster Engineering Corp.
Boston, Massachusetts, USA

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Warszawa, Poland

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Washington, DC, USA

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Eschborn, Germany

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Electric Power Research Institute
Washington, DC, USA

Milan Fara
EGÚ Praha a.s.
Běchovice, Czech Republic

Marie Fechtnerová, Manager, Ecological Control Department
ČEZ a.s. (Czech Power Company)
Nuclear Power Plant Temelin
Temelin, Czech Republic

Anne M. Fiala, Manager, EERC Office Services
Energy & Environmental Research Center
University of North Dakota
Grand Forks, North Dakota, USA

János Ficzer, Production Manager
Tisza Power Plant
Tiszaujváros, Hungary

Peter Foltin, Chief Executive
Credit Anstalt Securities Slovakia
Bratislava, Slovakia

Rudolf Foniok, Leader of Department
Research Mining Institute (VVUÚ)
Ostrava-Radvanice, Czech Republic

Stephen E. Fortino, Senior Project Coordinator
Texaco, Inc.
White Plains, New York, USA

Paul E. Fredette, Vice President, Sales & Marketing
United Sciences Inc.
Gibsonia, Pennsylvania, USA

Mark C. Freeman, Chemical Engineer-Coal Combustion
Division
U.S. Department of Energy
Pittsburgh Energy Technology Center
Pittsburgh, Pennsylvania, USA

Jiří Gavor, Consultant
ENA Ltd.
Praha, Czech Republic

Ken E. Gelle, Managing Director
NRG Energy Inc.
Minneapolis, Minnesota, USA

Robert H. Gentile
KFx Atlantic Partners
Arlington, Virginia, USA

Hal Gluskoter, Geologist
U.S. Geological Survey
Reston, Virginia, USA

Frank M. Goedicke
Buhler Ltd.
Uzwil, Switzerland

Gerald H. Groenewold, Director
Energy & Environmental Research Center
University of North Dakota
Grand Forks, North Dakota, USA

Deb J. Haley, Assistant to the Director
Energy & Environmental Research Center
University of North Dakota
Grand Forks, North Dakota, USA

Jay Haley, Senior Design Engineer
Energy & Environmental Research Center
University of North Dakota
Grand Forks, North Dakota, USA

Vladimír Hančl, Division Manager Třeboradice
Praha Heating Plant Co. a.s.
Praha, Czech Republic

Levi Hanson, Development Director
POWER International, a subsidiary of The Cincinnati
Gas & Electric Company (CG&E)
Josefov, Czech Republic

Andrej Hanzel, Technical Development Group Manager
Slovakian Energy Company s.p.
Bratislava, Slovakia

Jaroslav Hanzlovský, Assistant Specialist
ČEZ a.s. (Czech Power Company)
Praha, Czech Republic

William G. Harvey, Business Development Manager
PowerConsult/PowerGen
Powel Technology Centre
Nottingham, United Kingdom

Jiří Herštus
Public Relations
AGE Ltd.
Praha, Czech Republic

Frank Hollmann, Project Manager
New Energy Markets
Stuttgart, Germany

Aleš Holub, Director, Coal Amendment Plant
Most Coal Company a.s.
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Horn Associates
Builth Wells, Wales, United Kingdom

Josef Hrubý, Director
EGÚ Praha a.s.
Běchovice, Czech Republic

L. Wally Jacobson, Sr. Director, Engineering and Projects
POWER International, a subsidiary of The Cincinnati Gas &
Electric Company (CG&E)
Josefov, Czech Republic

Károly Jakob, Director
Refining and Marketing Division
MOL Hungarian Oil and Gas Company
Budapest, Hungary

Josef Janota, Senior Project Manager
EGÚ Praha a.s.
Běchovice, Czech Republic

Sven A. Jansson, Chief Engineer, Manager Science &
Technology
ABB Carbon AB
Finspong, Sweden

Luboš Jarolímek, Development Director
POWER International, a subsidiary of The Cincinnati Gas &
Electric Company (CG&E)
Josefov, Czech Republic

Kevin D. Jennison, Performance Analysis Section
Leader
Black & Veatch
Kansas City, Missouri, USA

Pavel Jílek, Head of Group
Ministry of Environment of the Czech Republic
Praha, Czech Republic

František Jirouš
Mechanical Engineering Department
Technical University Praha
Praha, Czech Republic

Jarsoslav Joch
Price Waterhouse Corporate Finance
Praha, Czech Republic

Tim D. Johnson, Manager, PowerConsult
PowerGen PLC
West Midlands, United Kingdom

Michael L. Jones, Associate Director
Energy & Environmental Research Center
University of North Dakota
Grand Forks, North Dakota, USA

Stephen L. Joyce, Journalist
International Environment Reporter
Praha, Czech Republic

Wojciech Jozewicz, Program Area Manager, Process
and Emission Control
Acurex Environmental Corporation
Research Triangle Park, North Carolina, USA

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Flame Research Committee
Praha Technical University
Praha, Czech Republic

Josef Kašparů, Managing Director
ČEZ a.s. (Czech Power Company)
Počerady, Czech Republic

Takács Éva Kaszáné, Advisor
Hungarian Power Companies (MVM Rt)
Budapest, Hungary

Václav Kindl, Director, Technical Division
ČEZ a.s. (Czech Power Company)
Praha, Czech Republic

Pavel Klika, Director Pruněrov Power Plants
ČEZ a.s. (Czech Power Company)
Kadaň, Czech Republic

Otto L.O.M. Koenders
Coal Gasification/Business Development
Shell Internationale Petroleum Maatschappij B.V.
The Hague, The Netherlands

Jonathan Kohn
KFx Atlantic Partners
Arlington, Virginia, USA

Erich Kohout, Production Technician
ČEZ a.s. (Czech Power Company)
Kadaň, Czech Republic

Vladimír Kohout
Teplárny Brno a.s.
Brno, Czech Republic

Stanislav Kolar, Program Director
Agency for Clean Environment
Praha, Czech Republic

Petr Kopic, Marketing Manager
Energoprojekt Praha a.s.
Praha, Czech Republic

František Kopřiva, Managing Director
Citibank a.s. Praha
Praha, Czech Republic

Naim Kosaric, Professor
Faculty of Engineering Science
University of Western Ontario
London, Ontario, Canada

Erhard Kotz, Sales Manager
Severočeské Doly a.s.
Chomutov, Czech Republic

Gusztáv B. Kovács, Assistant Chief Maintenance Department
Vértesi Erőmű Rt
Oroszlány, Hungary

Zdeněk Křivský, Executive Director
North Bohemia Economic Association
Ústí nad Labem, Czech Republic

Vit Kühnel, Research Hydrogeologist
Energy & Environmental Research Center
University of North Dakota
Grand Forks, North Dakota, USA

Boris N. Kuznetsov, Professor/Director
Institute of Chemistry of Natural Organic Materials
Siberian Division of Russian Academy of Sciences
Krasnoyarsk, Russian Federation

Rod C. Leas, Project Director
NRG Energy Development GmbH
Berlin, Germany

Louis A. Licht, Research Scientist
Civil & Environmental Engineering
The University of Iowa
Iowa City, Iowa, USA

Matti Lilja, Marketing Manager
IVO International Ltd.
Brno, Czech Republic

Blažo R. Ljubičić, Research Engineer
Energy & Environmental Research Center
University of North Dakota
Grand Forks, North Dakota, USA

Oldřich Lošták, Sales Director
Most Coal Company a.s.
Most, Czech Republic

Dušan Ložek, Development Perspectives Group
Manager
Slovakian Energy Company s.p.
Bratislava, Slovakia

Michal Lukeš, Manager Div. 30
Research Mining Institute (VVOÚ)
Ostrava-Radvanice, Czech Republic

Miroslav Mader, Marketing Director
First Machinery Plant Brno
Brno, Czech Republic

Ichiro Maeda, Manager
Tokyo Electric Power Company
London, United Kingdom

Plamen G. Mandjoukov, Head of TPP Department
Energoprojekt s.p.
Sofia, Bulgaria

Michael D. Mann, Senior Research Manager
Energy & Environmental Research Center
University of North Dakota
Grand Forks, North Dakota, USA

Oscar E. Manz, Consultant
Manz Associates
Alvarado, Minnesota, USA

Sharon K. Marchant, Business/Financial Advisor
U.S. Department of Energy
Pittsburgh Energy Technology Center
Pittsburgh, Pennsylvania, USA

Holý Marek, Manager, Coal Project
BP Plzeň s.r.o.
Plzeň, Czech Republic

Marco Martini, Senior Staff, Direction of Energy Department
ENEA (Italian Agency for New Technologies, Energy and the
Environment)
Rome, Italy.

Jan Marxt, Director of Gas Department
METALIMEX Ltd.
Praha, Czech Republic

Philippe J.F.G. Mathieu, Professor
Institut de Mécanique
University of Liège
Liège, Belgium

Vladislav Mazáč, Regional Center Director
Energoprojekt Praha a.s.
Ostrava, Czech Republic

Norman W. Merriam, Senior Engineer
Western Research Institute
Laramie, Wyoming, USA

Philip C. Metcalf, International Business Development
Manager
Stone & Webster Engineering Corporation
Boston, Massachusetts, USA

David Millar, Marketing Manager, Europe/Russia
Intera Information Technologies
Abingdon Oxon, United Kingdom

C. Lowell Miller, Associate Deputy Assistant Secretary
Office of Clean Coal Technology
U.S. Department of Energy
Washington, DC, USA

Bedřich Moldan, Director
Charles University Environmental Centre
Praha, Czech Republic

Karen Morehouse, Director, Centers & Special Programs
U.S. Environmental Protection Agency
Washington, DC, USA

Vladimír Musil, Project Team Manager
ČEZ a.s. (Czech Power Company)
Praha, Czech Republic

Strahil I. Natzkov, Chief Expert, Assistant Professor
TOTEMA Ltd.
Sofia, Bulgaria

Sidney G. Nelson, President
Sorbent Technologies Corporation
Twinsburg, Ohio, USA

Marko Nikolov
TOTEMA Ltd.
Sofia, Bulgaria

Thomas P. Niquette, Sales Manager
Horizon Coal Services
Butte, Montana, USA

Vladimír Novotný, Deputy Minister of the Environment
Federal Ministry
Praha, Czech Republic

Jan W. Nowok, Research Scientist
Energy & Environmental Research Center
University of North Dakota
Grand Forks, North Dakota, USA

Earl Osterstock, Director - Commercial Development
Air Products and Chemicals
Allentown, Pennsylvania, USA

Jitendra G. Patel, Vice President, New Technology
Tampella Power Corporation
Atlanta, Georgia, USA

Helena Pavlíková, Research Scientist
Chemical Engineering Department
Technical University Praha
Praha, Czech Republic

Jan Pech, Manager, Clean Air Projects
U.S. Tennessee Valley Authority
Chattanooga, Tennessee, USA

Luděk Peleška, Specialist
ČEZ a.s. (Czech Power Company)
Praha, Czech Republic

Joe Peyton, Engineer
Southern Electric International
Birmingham, Alabama, USA

David Plavcan
Black & Veatch International
Neu-Isenburg, Germany

František Pracný, Production Deputy General Director
First Northwestern Heating Plant Co. a.s.
Komořany-Most, Czech Republic

Peter A. Pritchard
General Electric Co.
Schenectady, New York, USA

Krzysztof Puzanowski, Deputy Manager, Energetics
Division
Katowice Mine a.s.
Katowice, Poland

Petr Říha, Director, Energetics Division
Synthesia a.s.
Pardubice, Czech Republic

Vladimír Rösel
Fieldstone Private Capital Group
Praha, Czech Republic

Vladimír Rouček, Advisor to General Planning Director
Most Coal Company a.s.
Most, Czech Republic

Alfred Schieb, Senior Project Manager
Rheinbraun
Cologne, Germany

Erhard Schmeling, Marketing Director
NRG Energy Development GmbH
Berlin, Germany

Hans Peter Schneider, Sales Manager
Buhler Ltd.
Uzwil, Switzerland

Hans Schnitzer, Sales Manager
Buhler Ltd.
Uzwil, Switzerland

Jerald L. Schnoor, Professor
University of Iowa
Iowa City, Iowa, USA

Miklós Schwardy, General Director
Tisza Power Plant
Tiszaújváros, Hungary

Gustav Šebor, Dean, Technical Environment Protection
Department
Chemical Engineering Department
Technical University Praha
Praha, Czech Republic

Miloslav Šedina
EGÚ Praha a.s.
Běchovice, Czech Republic

Karel Šik, Director
Hodonín Power Plants
ČEZ a.s. (Czech Power Company)
Hodonín, Czech Republic

Janusz Sikora
Gliwice Coal Company
Gliwice, Poland

Jan Šiller, Production Director, Energetics Division
Chemopetrol a.s.
Litvínov, Czech Republic

Jiří Skalička, Deputy Director, Production and
Technology
Prunéřov Power Plants
ČEZ a.s. (Czech Power Company)
Kadaň, Czech Republic

Jeff Sletten
Custom Coals Corporation
Pittsburgh, Pennsylvania, USA

Václav Směták
Marketing Center
EGÚ Praha a.s.
Běchovice, Czech Republic

Željko Šmit, Project Manager
L&C Steinmüller GmbH
Gummersbach, Germany

Donna M. Smith, Outreach Assistant
Energy & Environmental Research Center
University of North Dakota
Grand Forks, North Dakota, USA

Gerry C. Snow, Director, Technical Support
POWER International, a subsidiary of The Cincinnati
Gas & Electric Company
Josefov, Czech Republic

Jaroslav Šolc, Principal Hydrogeologist
Energy & Environmental Research Center
University of North Dakota
Grand Forks, North Dakota, USA

Everett A. Sondreal, Principal Research Advisor
UND Energy & Environmental Research Center
Grand Forks, North Dakota, USA

Ivan Souček, Head of Strategic Planning Department
Kaučuk a.s.
Kralupy, Czech Republic

Barry J. Southam, President & CEO
Wahlco Engineering International Ltd.
Santa Ana, California, USA

Jozsef Spilko, Business Development Manager
GEA-EGI
Budapest, Hungary

Tamara Spilková, Environmental Department Manager
ČEZ a.s. (Czech Power Company)
Praha, Czech Republic

Jaromír Staněk, Chief Engineer
Most Coal Company a.s.
Most, Czech Republic

Oldřich Starý, Associate Professor
ČVUT, Czech Technical University
Praha, Czech Republic

Edward N. Steadman, Deputy Associate Director
Energy & Environmental Research Center
University of North Dakota
Grand Forks, North Dakota, USA

George Stein
Radio Free Europe/Radio Liberty Inc.
Munich, Germany

Miloš Štěp, Chief Inspector, Energetics
State Inspection of Energetics for the Czech Republic
Praha, Czech Republic

V. Štosek
EGÚ Praha a.s.
Běchovice, Czech Republic

Bohumil Straka, Chief Engineer, Coal Amendment Plant
Most Coal Company a.s.
Most, Czech Republic

Pavel Straka, Research Scientist
Institute of Rock Structure and Mechanics
Academy of Sciences of the Czech Republic
Praha, Czech Republic

Felix Taubman, Vice President
ECI International, Inc.
New York, New York, USA

František Titl, Coal Amendment Specialist
Most Coal Company a.s.
Most, Czech Republic

Ian M. Torrens, Director
Division of Environmental Control
Electric Power Research Institute
Palo Alto, California, USA

Radek Trtílek, Manager, Waste Management Center
Nuclear Power Plant Temelin
ČEZ a.s. (Czech Power Company)
Temelin, Czech Republic

Thomas B. Trumpy, Counsel
ILC S.P.R.L.
Brussels, Belgium

Miroslav Tupý
First Machinery Plant Brno
Praha, Czech Republic

Radovan Turyna
EGÚ Praha a.s.
Běchovice, Czech Republic

Ladislav Ullman
Technical Development
Elektrárna Počerady
ČEZ a.s. (Czech Power Company)
Počerady, Czech Republic

Milena Vágnerová, Coal Utilization Specialist
Most Coal Company a.s.
Most, Czech Republic

Tomas Vagoun
Greenbelt, Maryland, USA

Hans van der Sloot, Head of Soil and Waste Research
ECN
Petten, The Netherlands

Zdeněk Vlček
Energoprojekt Praha a.s.
Praha, Czech Republic

Diana Vorsatz
Lawrence Berkeley Laboratory
Energy and Environment Division
Berkeley, California, USA

Tomáš Varcop, Consultant
Andersen Consulting
Praha, Czech Republic

Josef Vavroušek, Chairman
Society of Sustainable Living
Praha, Czech Republic

Jaroslav, Veselský, General Director
Moravian-Silesian Heating Plants a.s.
Ostrava, Czech Republic

Miloslav Vitek, Head of Marketing Department
Ostrava-Karviná Mines
Ostrava, Czech Republic

Vlastislav Vitů, Division Director Třeboradice
Praha Heating Plant Co. a.s.
Praha, Czech Republic

Miroslav Votava, Boiler Engineer
ČKD Dukla a.s.
Praha, Czech Republic

Johannes Waltz, Research Economist
Tokyo Electric Power Company
London, United Kingdom

Warrack G. Willson, Senior Research Advisor
Energy & Environmental Research Center
University of North Dakota
Eagle River, Alaska, USA

Walter Wolowodiuk, Sr. Vice President
Foster Wheeler Development Corp.
Livingston, New Jersey, USA

Brian C. Young, Senior Research Manager
Energy & Environmental Research Center
University of North Dakota
Grand Forks, North Dakota, USA

Monta W. Zengerle
Leiter Sektion Umwelt
Morrison Knudsen Deutschland
Theissen, Germany

Marie Zitková, Consultant
Andersen Consulting
Praha, Czech Republic

INTRODUCTION

On November 1-5, 1994, the EERC and the Power Research Institute of Prague (EGÚ Praha) cosponsored their second conference since 1992 in the Czech Republic, entitled "Energy and Environment: Transitions in East Central Europe." This conference was a continuation of the EERC's joint commitment, initiated in 1990, to facilitate solutions to short- and long-term energy and environmental problems in East Central Europe. Production of energy from coal in an environmentally acceptable manner is a critical issue facing East Central Europe, because the region continues to rely on coal as its primary energy source. The region's energy infrastructure must be methodically upgraded as new technology is phased in during the coming decades.

With the theme "Partnerships for a Better Quality of Life," the conference and its associated workshops attracted more than 300 industry representatives, government officials, and researchers from 20 countries. Nations represented at the conference included the Czech Republic, the United States, Belgium, the United Kingdom, Italy, France, Switzerland, Sweden, the Netherlands, Poland, Romania, Germany, Slovakia, Bulgaria, Hungary, Austria, the Ukraine, Russia, Yugoslavia, and Canada. Among the topics addressed were conventional and advanced energy generation systems, the economic operation of energy systems, air pollution controls, power system retrofitting and repowering, financing options, regulatory issues, energy resource options, waste utilization and disposal, and long-range environmental issues.

Prior to the conference, EERC staff met with the East Central European Advisory Council which was formed in 1993 to provide guidance on the conference mission and program. A similar council was formed in the United States. The EERC is continually exploring potential opportunities for partnerships with East Central European organizations and companies.

The goal of the conference was to develop partnerships between industry, government, and the research community in East Central Europe and the United States to solve energy and environmental issues in a manner that fosters economic development. Partnerships have been developed in the areas of systems technology, environment, resource evaluation, and social economics. Other objectives were to:

- Provide a forum for East Central European professionals involved in science, engineering, business, and government to discuss energy and environmental situations and needs.
- Stimulate an exchange of practical scientific ideas and engineering technologies between East Central European and U.S. professionals.

Both Prague conferences have assisted in facilitating solutions for long- and short-term energy and environmental problems in East Central Europe by bringing together people, ideas, and technologies that can be applied to specific problems in a systematic manner. Conference topics were carefully chosen and balanced to provide a global perspective against which local and regional issues could be evaluated.

Completion of the second international conference in Prague was a step toward major economic development and job creation opportunities through the export of American technologies to East Central Europe. The conference assisted participants in building relationships leading to partnerships that, in turn, create opportunities. Strategic contacts made by conference participants have led to major projects and, more importantly, a continuation of the communication process, which leads to

opportunities for equal partnerships. The 1994 Prague conference also demonstrated the EERC's long-term commitment to East Central Europe.

The Prague conference attracted key, quality people—CEOs and decision makers—from a variety of industry, government, and research organizations. Another important result of the conference was discussions on removing socioeconomic barriers in East Central Europe and encouraging movement toward a market economy while continuing to address the concerns and the needs of the region.

Keynote Presentations

ELECTRICITY INDUSTRY DEVELOPMENT TRENDS AND THE ENVIRONMENTAL PROGRAMS IN THE CZECH REPUBLIC

Petr Karas, Board Chairman

ČEZ, a.s. (Czech Power Company)
Prague, Czech Republic

ABSTRACT

The process of industrialization in the Czech Republic, which is more intensive than in other parts of central Europe, has been under way since the mid-nineteenth century. Over the last 40 years, large-scale industrial activity was based on extensive use of domestic primary energy sources, especially brown-coal/lignite. The escalation of this usage inflicted heavy devastation to large portions of industrial zones and, as a result, worsened living conditions through atmospheric pollution and other environmental impacts in large regions of central Europe.

The Czech electricity industry and ČEZ, a.s. (the nation's principal electricity generator, responsible for meeting eighty percent of national electricity demand, and operator of the nationwide EHV transmission system) has been challenged to cope with all environmental issues by the end of 1997, in compliance with the strict limits set by the Clean Air Act of 1991, which are comparable to standard implemented in advanced industrial countries.

A review of the critical environmental issues is presented and the role of the individual and of the State is analyzed.

The approach of ČEZ, a.s., towards a better natural environment and its response to legal environment provisions have been incorporated into the company's development program. It comprises decommissioning the most obsolete fossil-fuel fired power stations; rehabilitation of thermal power plants; supplementing the coal/lignite-fired units selected for future operation with FGD systems and retrofitting them with DENOX equipment; a larger share of nuclear electricity generation after the completion of the Temelin NPP (2 units of 1000MW each) and, last but not least, initiating DSM (demand-side management) programs of energy-electricity savings in the Czech Republic.

CONDITION OF THE ECONOMY AND ITS TRANSFORMATION

Crafts and industrial production have been developing on the territory of the present Czech Republic since the second half of the nineteenth century, progressing at a higher pace than that witness in other regions of Central Europe. Industrialization, production, and commerce developed rapidly, hand in hand with the process of electrification in the period between the two World Wars. Czechoslovakia of that period meant not only an isolated haven of democracy in Central Europe, but also the showcase of successful development of economy, trade, and finance and hence also a first-rate standard of living for the population in global terms.

The nineteen-forties to nineteen-eighties saw the process of the strict implementation of centrally planned economy, together with the strong emphasis on the heavy industry which resulted in a development of industrial activities based on domestic raw materials. In the power sector, the trend meant extensive usage of low-grade brown coal/lignite resulting, ultimately, in the fact that industrial regions of the country, as well as those in the neighboring Poland and the eastern regions of Germany, have been rated as the most devastated regions of not only the central, but the whole of Europe.

With the renewal of democracy in the early nineteen-nineties, the transformation of the Czech economy towards a free-market economy was started. In the process of privatization and production restructuring, changes of orientation of industrial companies, emergence of new businesses in production, trade, and services, major structural changes have also been undertaken in the electricity sector of the Czech Republic.

However, to be successful in the transformation of the Czech economy, it is also necessary that the electricity industry—even if exposed to multiple impacts of "turbulent environment" of changes outside and inside the sector—fulfill its vital role in maintaining failproof supplies of electricity at acceptable prices which is required not only for the international competition within the interconnected power systems in Central Europe, but also for maintaining the competitive edge of the prices of goods and services of domestic production on the global markets.

POWER INDUSTRY IN EUROPE UNTIL THE YEAR 2000

Currently, discussion has been under way in Europe on the access of third parties as recommended by the Bruxelles-seated European Union Administration. Both Europe and the U.S. have been considering restructuring electric power industry so that it should serve better and more cost-effectively to its clients. Strong emphasis on the environment and its protection has been an integral component of any such considerations. Assuming the Czech economy achieving a steady condition by the year 2000, any such considerations shall apply also for the Czech power sector. There will be competition between different generating entities, some of which will be international companies. We shall have competition from international power transmission networks, as well. About 60–70% of the power capacities, however, are expected to remain owned by domestic investors. Besides, it is highly probably that the chances of utilities with rated power capacity under 10 thousand MW to succeed in the future competition will be substantially lower. By the year 2000, the market of direct contracts between power producers and major customers is expected to develop. This is the outline of the future developments as seen from the Czech view-point in the European context.

THE ENVIRONMENT

Mines, or rather open pit mines, are what anyone passing through the industrial regions of our country, especially North-West Bohemia, cannot possibly miss and must regret.

Large-scale exploitation has cruelly interfered with the landscape and its natural patterns of life. Human lives and culture were stricken equally hard a blow, as were the air we breath and the water we drink. Power installations have been major contributors to the emissions and imissions of air pollution. And the disposal of ashes and sludge pools play their role in disfiguring the landscape, as well.

What is the age of our power installations, our coal/lignite-firing power plants? The age of ČEZ installations ranges from 10 to 35 years, power stations owned by other utilities or by the industry tent to be even older. The efficiency of ČEZ power stations ranges from 29 to 34%, that of plants operated outside ČEZ being even lower. None of our coal-firing plants currently meets the criteria set forth under the Clean Air Act.

The industry, especially the chemical sector, but also local sources and households have been other major contributors to the current pollution levels, especially so in the critical areas of the Krusne hory basin in North Bohemia in or Ostrava region and in some large urban centers. The compounded effect of these factors in combination with car-related pollution has resulted in environmental situation under which the man is still able to survive but, at the cost of deteriorating health. And such a condition affects the physical and even the mental health.

THE ROLE OF MAN

The role of man as the perpetrator of the situation is, metaphorically speaking, schizophrenic. While on the one hand, the man enjoys the products of the energy cycle, stimulating it by his own needs, on the other hand, he or she is the victim of its vicious effects. Apparently, to be happy and comfortable, the man needs no megawatts, kilowatt-hours, or even giga-joules. What he needs is heat, light, and the assistance of machines and instruments—comfortable life at the standard of the late 20th century.

ROLE OF THE GOVERNMENT

What are the effects influencing the power sector from the level of the government? The government sets forth the business framework by initiating Acts, by issuing regulations, price regulations but also by repressive limitations. The Energy Act and other regulatory provisions form the basic legal framework for business in the power sector.

What we have been missing is a clear-cut position on the issue of carbon dioxide. We know the problem is being discussed in Western Europe and the U.S. Also in Rio de Janeiro, the problem of CO₂ emissions was defined as a global issue. However, we have not yet taken a clear-cut position on the issue. In practical terms, the government policies could be expressed in the form of e.g. a carbon tax. The incorporation of the likely rates applicable under such a carbon tax in the costs of different variants of retrofit and new projects can have major implications for the viability of the future technologies.

Another factor, the energy tax, has been considered in the Czech Republic, but so far without any clear conclusions. The tax and customs policies can assist in preference of energy savings, or reduction of the energy necessary to achieve the goals. Dedicated subsidies, grants, and favorable loans are other tools of stimulations applicable by the government. Suitable depreciation policies for systems being built to reduce the environmental impact of the power sector are another important factor.

By its Clean Air Act, the Government has clearly taken a positive and dedicated stance in environmental protection. The economic impact of the Act means a heavy burden for the Czech economy. Nevertheless, ČEZ, a.s., has strictly respected all the provision of the laws and their requirements have been incorporated in the development program.

EFFORTS OF ČEZ IN ECOLOGY

The success of the future development in our countries is determined by whether or not the man succeeds in creating a friendly caring attitude towards the nature. This is both the economic and ethical obligation. The causes must be remedied, the effects cured and sustainable development must be established.

Time is a major factor here. We have to define what can be done immediately, what can be accomplished in the short-term perspective and what must be planned over a long time. However, all these three areas start from now on.

The remedy of causes - this means the elimination of emission sources on the one hand and the drop of excessive demand for power on the other. The rectification of impacts is aimed to cater for the man, the human race and living nature. But only economically and intellectually strong entities can help those currently involved in the fight for the turn-around in our thinking towards the permanently sustainable development. And this kind of synergy can result in the desired positive outcome.

Emergency measures adopted in the time of crisis are the first step along this route. In a case of adverse atmospheric situation, there is nothing more for ČEZ to do but timely and sufficiently reduce the output of fossil-fuel fired power installations. We often are assisted in dealing with the smog emergencies

by our partners from the neighboring countries, such as BAG and VEAG of Germany. Many times, assistance has been offered from Switzerland and, naturally, from our Slovak, Polish or Hungarian colleagues.

Decommissioning of power generating units is another measure currently being adopted. The objectives of the programme declared by us have been respected, and the total of 1000 MW decommissioned capacity of obsolete generating units is to be accomplished by the end of 1994.

Improving the power generating technologies has been another major effort aimed at eliminating the adverse environmental effects of our power sources. The aim is also to reduce the percentage share of coal-firing plants in the power generation.

Currently, some 3000 MW in the North-West Bohemian region are at different stages of the desulphurisation technology backfitting, these stages ranging from contract execution to system commissioning. The FGD system was commissioned on two 200 MW units of the Pocerady power station this year. At the same time, the generating technologies are being retrofitted so that to reduce the fly-ash and NO_x pollution.

One fact to make the picture clearer: over the last decade, the power generating installations in the Podkrusnohori (N-W Bohemian) region succeeded in reducing the fly-ash pollution by 80 % compared with 1982. The pollution by sulphur dioxide has been reduced by 30%. In spite of these achievements, the current situation fails to meet the requirements of the Clean Air Act and additional projects need to be implemented for the power plants designed to remain for future service.

The introduction of new technologies is seen as another option, not only in terms of diversification but, primarily, in terms of significant improvement of the conversion efficiency between the primary energy and electricity. Some reconstructions designed to introduce the fluidized-bed combustion technology have been under way.

Nevertheless, some technologies, such as the pressurized fluidized-bed combustion, however elegant, tempting and efficient, have remained problematic in terms of reliability and price.

The combined steam/gas cycle technology using internal combustion turbines is considered by us to be a feasible diversification option, and it is targeted to be applied first in smaller co-generation projects.

Our scope also includes renewable power sources, a somewhat controversial subject especially in terms of hydraulic power.

Demonstration wind power generating systems have been studied in co-operation with the Czech Academy of Sciences. The first wind power generating installation has been commissioned and measurements and evaluation have been under way.

Our programme of flue-gas cleaning has envisaged the investment of CZK 30 thousand million, the completion of the Temelin nuclear power plant representing another CZK 40 thousand million. The construction of the Dlouhe Strane pump-storage HPP would cost CZK 2.7 thousand million. The project of transmissions systems compatibility with those of Western Europe requires the investment of CZK 5.4 thousand million. The spent nuclear fuel interim storage facility in Dukovany will cost another CZK 5.2 thousand million. Additional major costs are involved in rehabilitation of the fossil fuel fired power stations.

Excessive demand for energy is the other side of the problem. To start with, allow me to mention the problem of efficiency of our power and heat generating plants. The efficiency of our power plants has continued to improve steadily over the recent years and the energy necessary for electricity generation has thus kept decreasing. A principal change, however, may be expected to occur only if a substantial change of the generating technology is accomplished, resulting in increasing the current 34% efficiency to some 45% or even to over 50%, e.g. by using the combined steam/gas cycles.

Reducing the transmission losses is another specific problem of the power sector. While the losses figure achieved in our system has been at a very good standard, any percentage fraction of additional saving would be welcome.

There have been reserves in the stimulation of investments aimed to reduce power demand in households, as well as with small-scale customers and the industry. While the residential programme can be outlined in a relatively straightforward manner, a comparable programme applicable for the industry has not been reached until now

The stimulation aimed to reduce household electricity consumption may be substantially enhanced by repressive stimuli, such as raised electricity prices. Moreover, a permanent trend towards improved culture of energy utilization is perceived to be the major factor of impact. The term itself is close to a similar category used in the nuclear field, safety culture, meaning a specific philosophy or way of thinking. In the area of 'energy culture', a programme oriented at children, schools and educational institutions has been implemented by our company with the ultimate aim of improving the culture of energy utilization.

What can be done at the moment besides the regulatory measures and provisions designed to eliminate and rectify the adverse effects on the man, on the human health? To some extent, those under the biggest threat can be helped. These are children and pregnant women. This means funding for the medical sector.

CONCLUSIONS

I am sure that the audiences of the 2nd International Conference on Power and Environment will hear numerous critical comments concerning the procedures adopted to improve the environment. life and health in the Czech Republic and in other heavily burdened regions of Central Europe. All these observations will serve as invaluable stimuli for us, as well as the professional findings presented in the papers read at the Conference.

Let me conclude by welcoming the conference participants, especially our esteemed foreign guests, and by wishing success to the event.

STRATEGY FOR DEVELOPMENT OF THE POLISH ELECTRICITY SECTOR

Jarosław Dybowski, Deputy Director, Electricity Trading Department

Polish Power Grid Company
Warsaw, Poland

ABSTRACT

This paper represents the strategy for development of the Polish Electricity Sector dealing with specific problems which are common for all of East Central Europe.

In 1990 Poland adopted a restructuring program for the entire energy sector. Very ambitious plans were changed several times but still the main direction of change was preserved. The most difficult period of transformation is featured by several contradictions which have to be balanced. Electricity prices should increase in order to cover the modernization and development program but the society is not able to take this burden in such a short time. Furthermore the new environment protection standards force the growth of capital investment program which sooner or later has to be transferred through the electricity prices. New economic mechanisms have to be introduced to the electricity sector to replace the old ones noneffective, centrally planned. This process has to follow slow management changes. Also, introduction of new electricity market is limited by those constraints. However, this process of change would not be possible without parallel governmental initiation like preparation of new energy law and regulatory frames.

- 1. MAIN FEATURES OF POLISH POWER SYSTEM**
- 2. PRESENT ORGANIZATION**
- 3. MAIN GOALS OF RESTRUCTURING PROCESS**
- 4. MEANS TO ACHIEVE THE GOALS**
- 5. ELECTRICITY MARKET**
- 6. INTEGRATED RESOURCE PLANNING**
- 7. ALL SOURCES BIDDING**
- 8. LONG TERM CONTRACTS**

1. MAIN FEATURES OF POLISH POWER SYSTEM

32 000 MW - installed capacity

24 000 MW - peak demand

where

7 000 MW in operation for over 20 years

1 500 MW in operation for over 30 years

Absolute predominance of fossil fuels

/hard coal and lignite/

97% of gross production

94% of installed capacity

2. PRESENT ORGANIZATION

33 independent distribution companies

1 transmission company

/Polish Power Grid Company joint-stock state owned/

34 independent power plants

3. MAIN GOALS OF RESTRUCTURING PROCESS

- * cheap electricity for customers, without subsidies**
- * electricity supply security**
- * environment protection improvement**

4. MEANS TO ACHIEVE THE GOALS

diversification of ownership

merging of existing generators and CHP's

competition on generation

reduction of monopoly on transmission and distribution

free access to the transmission grid /TPA/

cost transparency

least cost planning

demand side management implementation

power plant's rehabilitation program

interconnection with UCPTE systems

fuel diversification

environmental retrofitting

5. ELECTRICITY MARKET

- * market for new and modernized capacities**
 - negotiated long term contracts /capital repayment/**
 - initial contracts based on standard costs**
- * continuous development of spot market**
 - limited by metering facilities**
- * introduction of Bulk Supply Tariff resulting in diversification of customer level prices**
- * only at the beginning of market transformation, Polish Power Grid Company is the only contractual buyer of all electricity produced by professional power plants and CHP's**

6. INTEGRATED RESOURCE PLANNING

Economic study performed by Polish Power Grid Company represents the least cost development program considering both supply and demand side management.

Main conclusions from up to date performed studies:

- * till 2000 possibilities of 1700 GW/a energy and 550 MW capacity savings**
- * rehabilitation and modernization of the units 200 MW and above is economically more effective than new capacities**
- * for some units lifetime extension up to 270 000 operational hours should be considered**
- * the new peak capacities should be contracted about 2000**
- * the new base load capacities should be contracted beyond 2000**

7. ALL SOURCES BIDDING

Polish Power Grid Company as monopolistic buyer, acting on behalf of all customers is obliged to develop an objective process of electricity acquisition considering both supply and demand resources:

- * PPGC organize competitive bidding for modernized and new generation resources**
- * PPGC organize competitive bidding for DSM projects**

8. LONG TERM CONTRACTS

The main purposes of long term contracts are:

- * to create guarantee mechanism for investors facilitating project financing
- * to ensure security of electricity supply

Today's revenue from electricity trading does not cover full capital costs what results in limitation of long term contracted capacity

Long term contracts shall be signed only with the best evaluated offerents

Contractual prices shall result from competitive negotiations process

Till now PPGC has signed two long term contracts:

- * Bielsko Biala CHP project financed by EBRD
- * Turów lignite fired power plant with fluidized bed boilers performed by ABB/Pyropower and financed by Polish Banks Consortium

FOSSIL FUELS IN A SUSTAINABLE ENERGY FUTURE

Thomas F. Bechtel, Director

Morgantown Energy Technology Center
U.S. Department of Energy
Morgantown, West Virginia, USA

ABSTRACT

Throughout much of the world, the most widely available and economical fossil fuel with prospects for long term supply is coal. Unfortunately, in most of the highly industrialized parts of the world, the popular press and most of the technical literature provide the public; policy makers, and politicians with a perspective on coal-as-an-energy-resource that is almost too simplistic to be of any value in the strategic-planning and decision-making processes. In summary, it goes like this: "Coal is a vast global resource which can be delivered to the energy user at a lower per-Btu price than any other fuel source. The United States is the Saudi Arabia of coal; its political and economic stability assure supply dependability and a continuing commitment to technology development aimed at cost effective and environmentally compatible utilization. Unfortunately, the conversion of coal into thermal, electrical, or clean liquid or gaseous fuel energy forms is and will continue to be so damaging to the environment that we must do everything possible to avoid its inclusion in our energy future." The words change, the accents vary, and the alternatives offered depend on the advocacy role of the speaker; but the message persists. The pro-coal speaker has a difficult challenge; we all remember the miner's dirty faces and "black lungs," the culm and gob piles and abandoned pits that scar the landscape, the dirty stacks, the "acid rain"-damaged forests and lakes, and the ash and sludge ponds that threaten the water supply.

The global environmental activist community, both the responsible and irresponsible segments, have successfully exploited these concerns with both the production and utilization of coal to put it into disfavor with government policy makers throughout much of the world. However, the reality of its low cost and its ready local availability in many economies, where value-added in fuel production is critically important from a trade balance perspective, makes efforts to overcome those negative images critically important. My message is that most, if not all, of those images could be blurred by technology that is available or in advanced stages of development.

The coal industry in the United States has become a world leader in safety, productivity, and environmental protection in the mining of coal. The "pick-and-shovel" miner with mangled limbs and black lung disease has been replaced by the highly skilled technicians that lead the world in tons per man-hour. The gob piles, polluted streams, and scared land are a thing of the past. The complementary efforts of the DOE and EPRI-funded programs in coal utilization R&D and the Clean Coal Technology Program commercial demonstrations, have positioned the power generation industry to utilize coal in a way that doesn't pollute the air or water, keeps electrical power costs low, and avoids the mountains of waste material.

This paper reviews the potential for advanced coal utilization technologies in new power generation applications as well as the repowering of existing plants to increase their output, raise their efficiency, and reduce pollution. It demonstrates the potential for these advanced coal-fueled plants to play a complementary role in future planning with the natural gas and oil fired units currently favored in the market place (1). The status of the US program to demonstrate these technologies at commercial scale is reviewed in some detail.

INTRODUCTION

The realities of the global energy marketplace makes this a watershed period for the fossil energy RD&D programs in the US and Europe. Paradigm-shifting events around the world have brought into focus a set of strategic realities that must be considered in concert with budget realities in assessing future directions for all energy RD&D programs.

The slow-down in the growth of electric power use in the US and Europe, caused by the rational application of conservation and renewable technologies and slower economic growth, seems to be an almost permanent reality. The threat of open access by all energy suppliers and users to electrical transmission capacity coupled with the growing independent power industry have made inter- and intra-company competition in and among what used to be regulated monopolies or government agencies a new reality. This will put severe cost pressure on traditional power generation utilities as they struggle to retain large industrial baseload customers. In the US market, the realities of schedule and cycle time make it apparent that little more can be done in the R&D program to affect decisions by electric utilities on the 1995 and 2000 compliance targets in the Clean Air Act revisions of 1990. Prior R&D efforts and the Clean Coal Technology Program demonstrations have made a difference in those decisions and will continue to do so well into the next century. Future R&D must focus on the issues involved in building new generation capacity in the US under the environmental caps of the post-2000 period and on helping the global community to satisfy the legitimate needs of emerging economies for more electrical energy without contaminating their and our environments.

The competitive advantage that natural gas holds in current new power generation investment decisions in served areas in both the US and Europe is undeniable; the open question is how long this edge will last as new resource development, storage, and delivery investments are made and recovered by the natural gas supply industry. The emergence of the giant energy companies as key players in the gas supply scene has been accelerated by deregulation in the US and the disintegration of political/trading blocks and industrial privatization in Europe, providing the global energy companies the opportunity to go from supply to user without the intervention of monopolistic and/or politicized middlemen.

It is also clear that global environmental concerns will focus attention on other countries beyond the US and western Europe, which in the aggregate use 4 times as much coal as the US and are expected to show dramatic growth in power demand. While many benefits accrue to these countries if locally-available natural gas is used in new generation plants and more cost-effective methods are devised to reduce pollution in their existing plants, the better and more cost-effective global environmental answer is to insure that the US's new high-efficiency clean coal technologies win over dirtier conventional technology in those applications where coal is the only practical fuel choice.

While its benefits have been clearly demonstrated in highly-developed mature economies and its principals apply universally, conservation can not be the sole answer in developing countries which are at a very low point on the electricity-use/industrial-productivity curve. In spite of its technical maturity and broad experience base, conventional pulverized-coal-steam-boiler/back-end-air-pollution-control technology is often not the best choice for new generation facilities in these developing countries. Our US Department of Energy Fossil Energy planning team is convinced that advanced clean coal technologies represent enormous potential for US exports as part of teaming arrangements with local manufacturers and constructors in global environmental markets.

The sections which follow provide brief descriptions of the advanced power systems that we feel will be most competitive in future central-station power generation markets around the world:

PRESSURED FLUIDIZED BED SYSTEM

The first generation Pressurized Fluidized Bed Combustion (PFBC) combined cycle power generation system is illustrated in Figure 1. In this system, the hot combustion products are fed to a gas turbine which provides substantial power generation as well as driving the combustion air compressor. The combustion gas temperatures are typically 1600° to 1700°F. Since the system makes large quantities of steam both in the combustor and in the heat recovery steam generator, most of the power generation occurs on the steam turbine side of the combined cycle. The benefits resulting from this system are an efficiency approaching 40 percent and an appreciable reduction in the projected cost of energy (COE). This system is modular, so that relatively small increments can be added without losing economies-of-scale. Sufficient data is available to design and construct a first generation PFB demonstration plant capable of achieving the overall system performance goals using reasonable design procedures. As a demonstration of this technology, the American Electric Power Service Corporation (AEP) was selected to construct and operate a 70 MWe combined-cycle plant at the Tidd Power Station, Brilliant, Ohio, under the Clean Coal Technology (CCT) Program (2).

This unit has operated very well after some start-up problems and along with units in Spain and Sweden are delivering on the promise of the technology. Contingent on the load growth in the AEP system, this technology will also be demonstrated on an appreciably larger size plant (approximately 330 MWe) under the US DOE CCT Program. Experience with the TIDD unit has allowed AEP engineers to substantially improve the projected performance and reduce the estimated unit cost of this proposed plant; the learning curve is moving in the right direction. If built and started-up as planned in the 2001-2 period, this unit will complement those being built in Japan using the same or similar design concepts. Another PFBC system design concept by Pyropower-Westinghouse (3) is scheduled for demonstration in 1997 at a Mid-West Energy plant in Iowa as part of the CCT Program; this 160 MW unit promises better performance and cost characteristics than TIDD.

The second generation, advanced-cycle PFB system is illustrated in Figure 2. The second generation system major performance goals are a thermal efficiency approaching 45 percent and a COE at least 20 percent below that of a conventional PC system. To achieve these goals, the bed temperature and the gas turbine inlet temperature are higher than the previously described first generation PFB system. System features include high pressures, gas reheat, topping combustion, carbonizer, and intercooling. Advance gas turbines offering high performance matching this cycle are expected to be available in the 1990's. This cycle has been validated in pilot scale tests at the Foster-Wheeler facility in Livingston, NJ, will be the first unit tested at the Advanced Power System Integration Test Facility in Wilsonville, AL, and will be, demonstrated at commercial scale in 1998 at the Air Products Four Rivers Project (4) as part of the CCT Program.

INTEGRATED GASIFICATION COMBINED CYCLE SYSTEM

Overall schematics of several IGCC systems are shown in Figures 3 and 4. The IGCC process can be viewed as consisting of four major subsystems - coal preparation, gasification, heat recovery, cleanup, and power generation. The basic conventional (first generation) IGCC system, as shown in this figure, includes: (1) a fuel storage/deeding system, (2) an air/oxygen supply system, (3) a gasification reactor, (4) a gas cooling system, (5) a gas cleaning system, (6) a liquid waste product system, (7) a solid waste product system, (8) a combustion turbine/generator system, (9) an exhaust heat recovery steam generator system, (10) a makeup water supply system, and (11) a steam turbine-generator-condenser system.

The second generation IGCC systems (fixed bed with steam injection and fluid bed combined cycle) eliminate (4) the gas cooling, (6) the liquid waste product system, and (11) a steam turbine/generator/condenser system while simplifying (2) an air/oxygen supply system, and

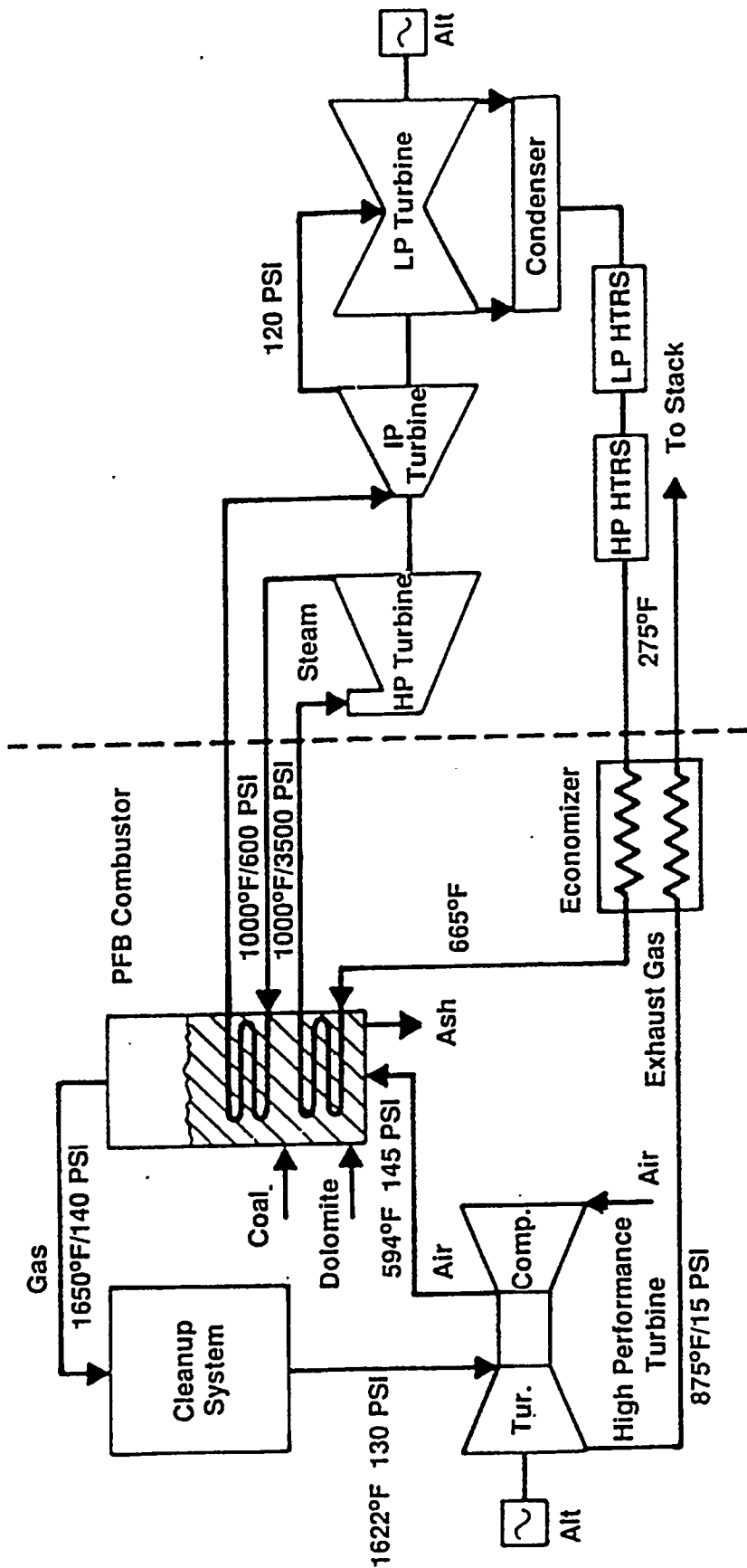


Figure 1

Steam-Cooled, Combined-Cycle PFBC

Second Generation Advanced Cycle PFBC System

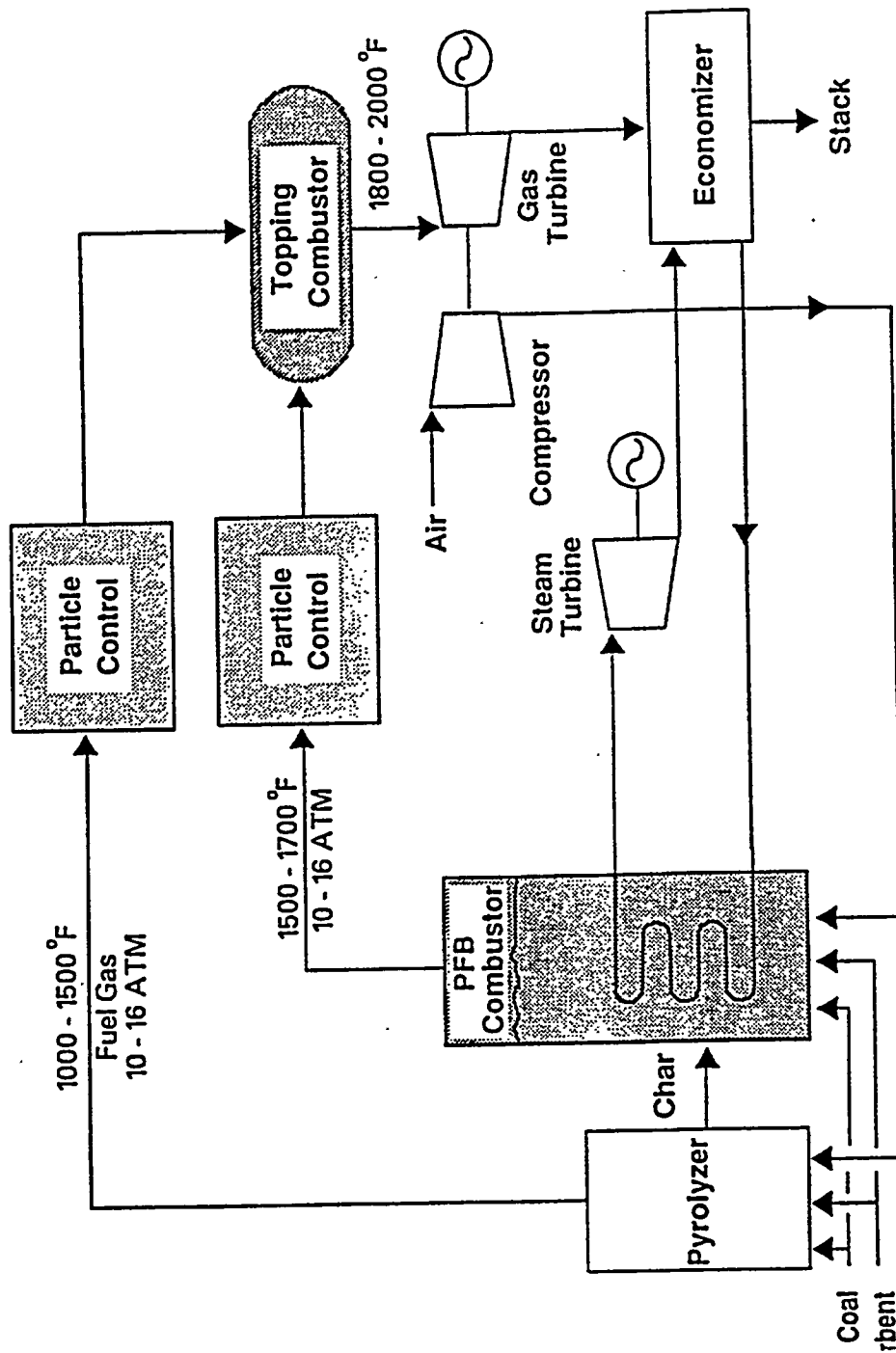


Figure 2

Integrated Gasification Combined Cycle (IGCC)

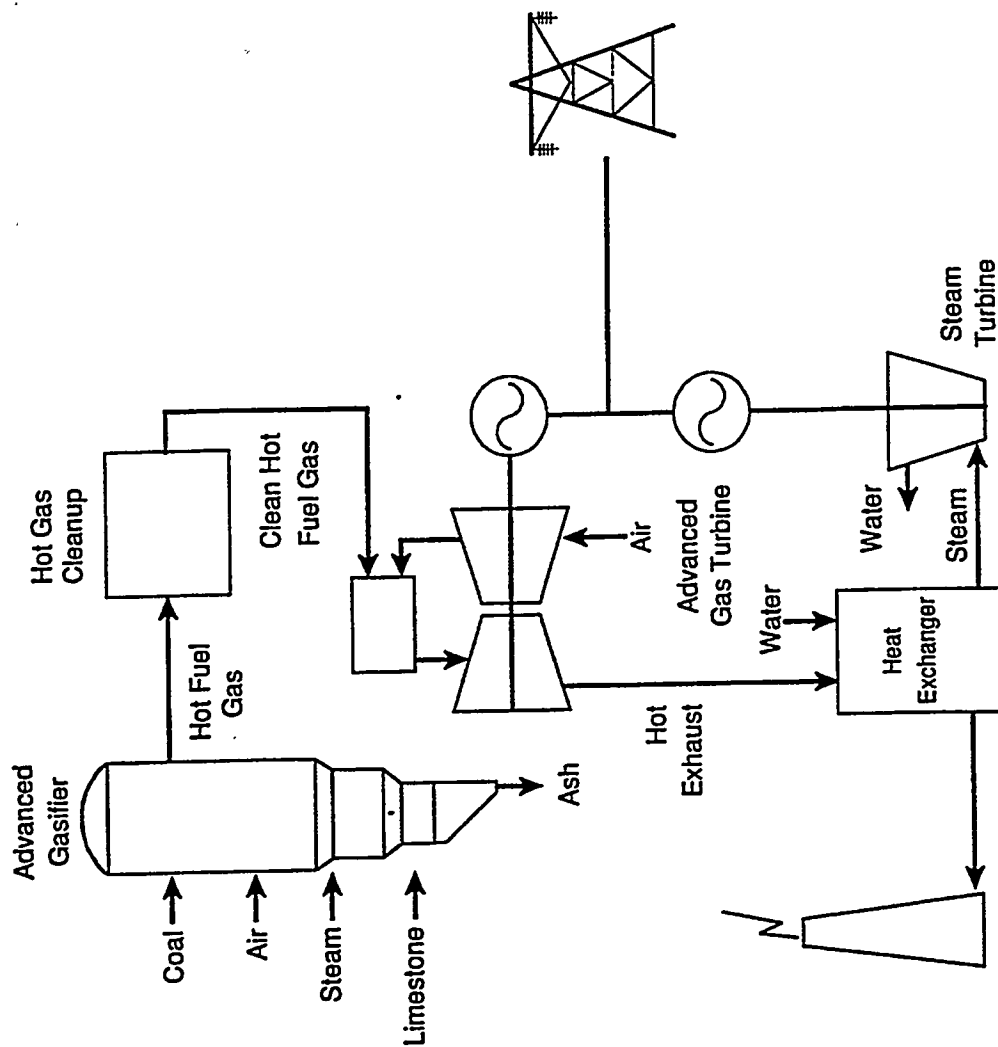
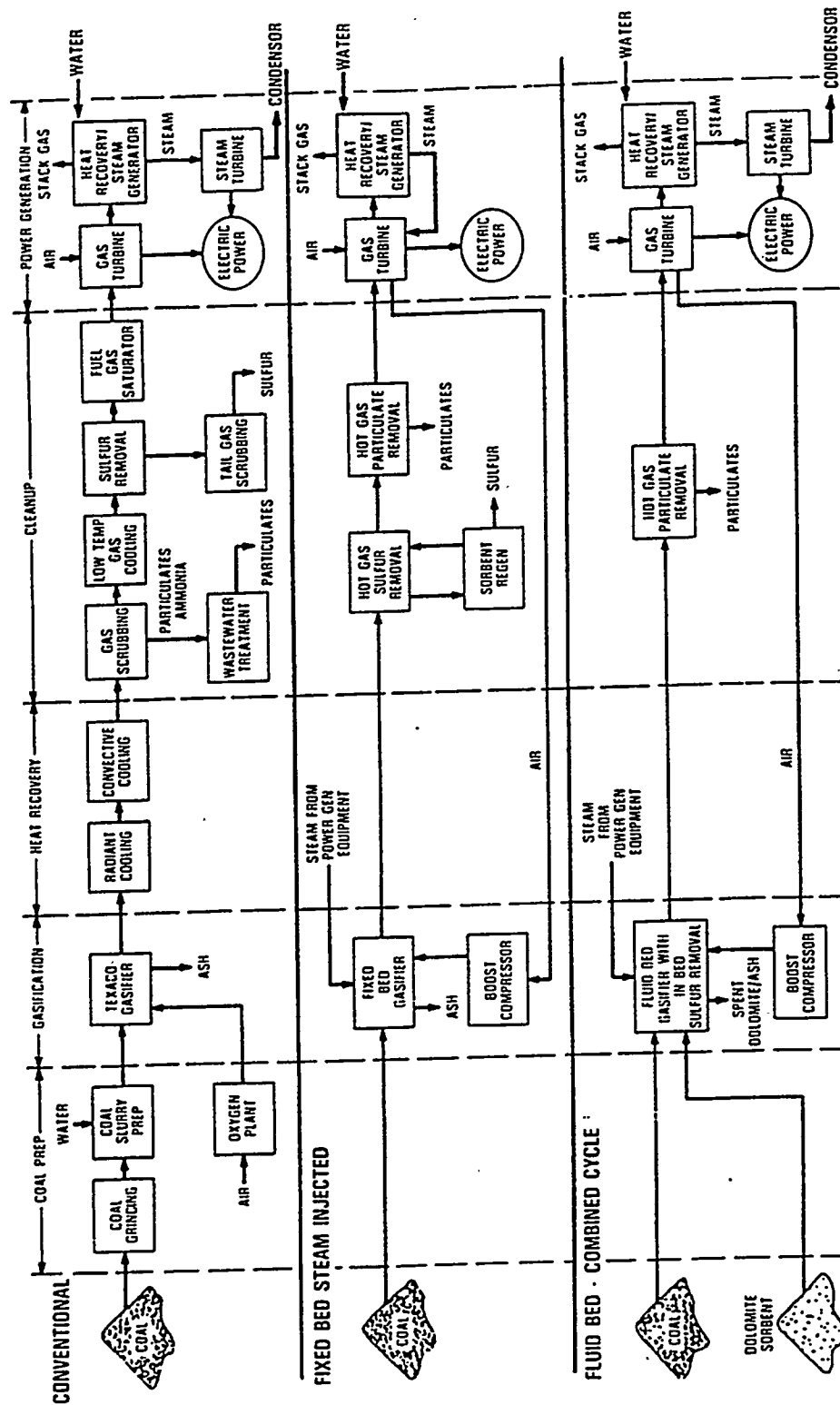


Figure 3

IGCC System Simplification



Electric Power Generation Systems

86-113-A TC2

Figure 4

(5) a gas cleaning system. Simplicity in the second generation IGCC system comes from the use of air-blown gasification, hot fuel gas cleanup, elimination of heat exchangers by temperature matching components, and potentially, the use of an inter-cooled, steam-injected, high-pressure ratio gas turbine to eliminate the steam turbine system. The use of hot gas cleanup system is responsible for the changes to items 4, 5, and 6. The second generation IGCC offers the potential for significant improvement in capital cost and efficiency relative to the first generation IGCC system as indicated by the schematics of Figure 4.

Several IGCC demonstrations are included in the CCT Program; they include the Texaco-based system (5) at Tampa Electric's Polk Station (1996 start-up), the Dow-based unit (6) being built by DESTEC at the Public Service of Indiana's Wabash River plant (1995 start-up), the KRW technology-based (7) unit being built by Foster-Wheeler at Sierra-Pacific's Pinon Pine station in Nevada (1997 start-up), the British Gas/Lurgi-based unit (8) being built by a consortium at Baltimore Gas & Electric's Crane Station (1999 start-up), the integrated blast furnace unit based on COREX technology being negotiated for a Geneva Steel mill in Utah (1999 start-up), and units based on IGT's and Shell's gasification technologies which are under contract but are seeking sites with viable power purchase agreements. This diverse suite of demonstration projects make the future prospects for IGCC look especially promising; there is little doubt about its environmental excellence - these projects along with others being built around the world based on a broad range of technology concepts should make the operational performance and cost issues a thing of the past. METC is assuring that technology advancement is not neglected as we focus on building demonstrations; we are continuing development efforts on gasification and hot-gas clean-up in conjunction with various research organizations and power system/subsystem contractors.

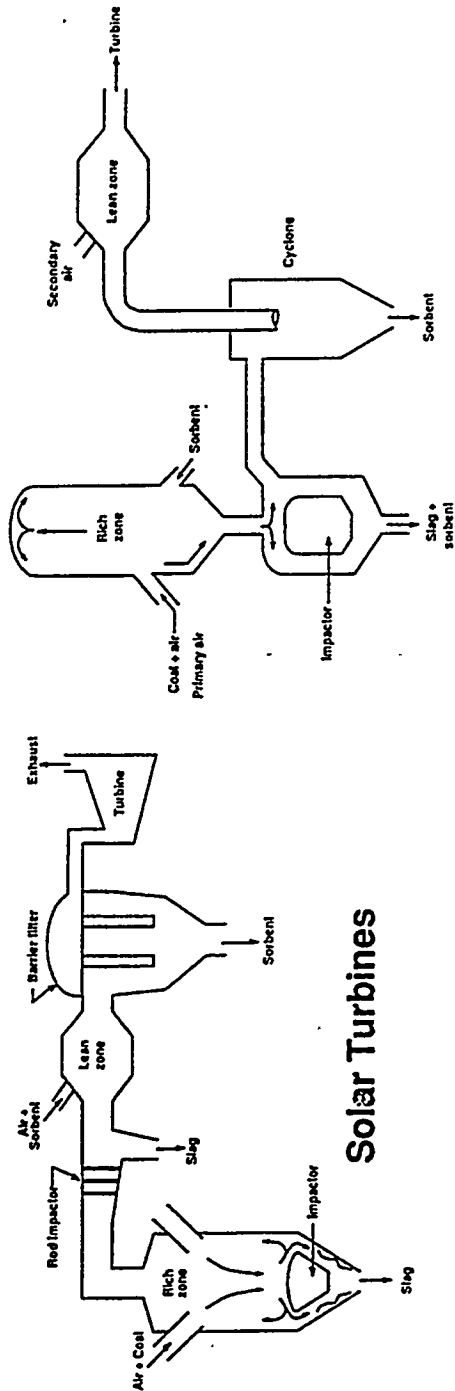
DIRECT COAL-FIRED TURBINE SYSTEM

The DCFT system offers the potential of low capital cost with reasonably high efficiency making the DCFT system attractive for mid-range peaking, as well as baseload applications. Because of this high commercialization potential, DOE carried three different systems through proof-of-concept development (Figure 5). All three of these system designs employ off-board combustors, rich/lean axial staging for combustion and NO_x control, arrangements of sorbent injection and removal for sulfur control, and arrangements of cyclones and/or barrier filters for particulate control. The Westinghouse and Solar first-stage combustors capture mineral matter as slag whereas the Allison design quenches the exiting gas to solidify the material for subsequent capture. A sulfur sorbent (limestone or dolomite) is injected in different locations: the first stage (Westinghouse and Allison) and the second stage (Solar). The Westinghouse and Solar concepts deliver the gas to the turbine at 1850°F; whereas the Allison system supplies the turbine gas at 1970°F. Since the Allison design places the second-stage combustor downstream of a barrier filter, the fuel-rich gas can be fired to a high turbine inlet temperature within the limits of the gas heating value. Although, the proof-of-concept work was promising in all three cases and commercial interest was high, the lack of progress in making either the dry or slurried highly-beneficiated coal fuel cost competitive with oil or natural gas in the foreseeable future led us to put this technology on the shelf and redirect our R&D investments toward coal-fired systems with greater commercial promise and reasonable time horizons. However, the component development experience on hot ducting and combustion has been transferred directly to the PFBC and EFCC programs; this will keep the DCFT enabling technology progressing and will provide ready answers if and when the fuel cost equation changes.

EXTERNALLY-FIRED COMBINED CYCLE

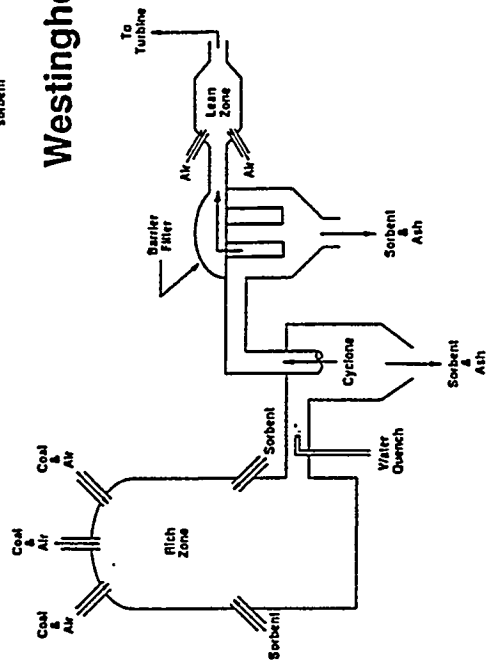
The externally-fired combined cycle shown in Figure 6 permits the use of almost any fuel in a highly efficient gas turbine combined cycle by isolating the atmospheric combustion stream from the

Direct Coal Fueled Turbine Systems



Solar Turbines

Westinghouse Electric/AVCO



GM/Allison Gas Turbines

Figure 5

Externally Fired Combined Cycle (EFCC)

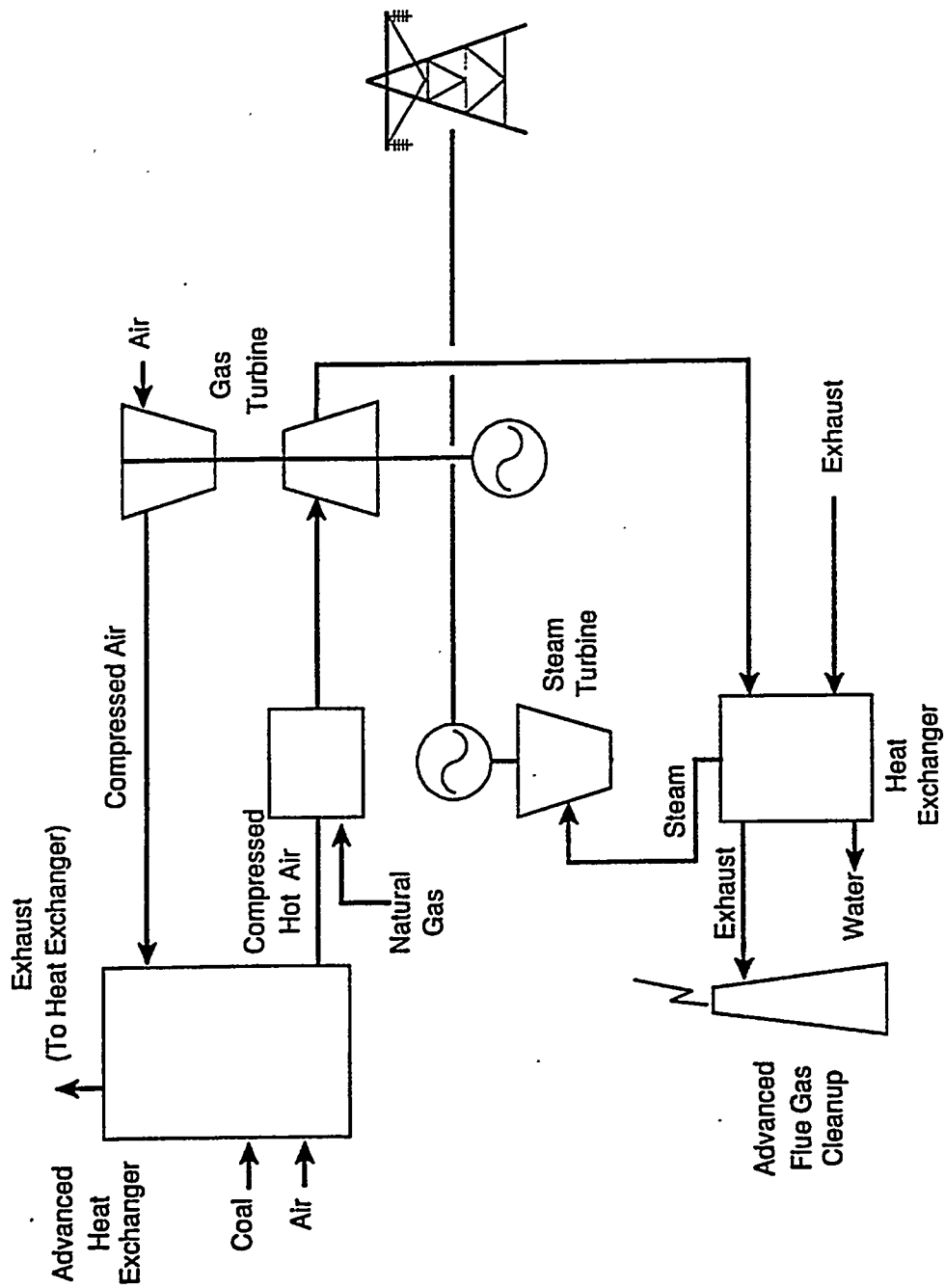


Figure 6

pressurized working fluid (air or an air-steam mixture) with a ceramic recuperative heat exchanger. The recuperative characteristic is achieved by using the gas turbine exhaust as combustion air after it has passed through the heat recovery steam generator. As noted (10), this system can produce combined cycle net HHV efficiencies in the 47-48% range at turbine inlet temperatures of 2300°F, which translates into a maximum ceramic component temperature in the 2600-2700°F range. While this is a substantial challenge to the ceramic industry, it is consistent with the R&D goals currently being pursued in US-DOE ceramic composite development programs. The cycle remains attractive at lower inlet temperatures and with the addition of water injection to enhance the recuperative characteristics of the cycle can be cost effective in small systems without the steam turbine bottoming cycle. This cycle is currently being developed on an accelerated schedule by the Morgantown Energy Technology Center in cooperation with HAGUE International. The 25 million BTU/hr. pilot unit is currently in start-up at HAGUE's Kennebunkport, Maine facility. Electric utility scale demonstration at the 65 MW size is scheduled for 1997 at Pennsylvania Electric Company's Warren Station as part of the DOE's Clean Coal Technology Program.

DOE/INDUSTRY ADVANCED POWER SYSTEMS INTEGRATION TEST FACILITY

It has been clear for a long time that the development of advanced power systems could be accelerated by the availability of a flexible facility to test new components at reasonable scale over a range of operating conditions. The facility would bridge the gap between pilot work on components, often at simulated operating conditions, and the commercial scale demonstrations done as part of the Clean Coal Technology program. The objective of the DOE/Industry ADVANCED POWER SYSTEMS INTEGRATION test facility is to design, construct, and operate a dedicated facility which will allow long-term testing of advanced power system components at temperatures, pressures, and gas conditions characteristic of full scale operation. Southern Company Services, Inc. (SCS), the overall manager of this DOE program, has selected Alabama Power Company's Wilsonville power plant to host this test facility. The program is structured to allow many industrial suppliers to have their technologies tested at this facility with EPRI serving as a technical advisor to the overall program management. The facility is planned to have the flexibility to simulate characteristics of gasifiers and PFBs, provisions for chemical control tests, parametric particulate control devices tests, and capability for extended operation. The present program schedule has the facility designed by mid-1994, with construction performed and initial operation by late 1995-early 1996.

MARKET SITUATION

The traditional part of the electric power industry as it exists today in the US and Europe has some classical textbook attributes:

- Low Growth
- Many-many-many competitors
- Many low-margin vendors
- Little, if any, product differentiation
- Great difficulty in finding sites for new manufacturing capacity, even if needed.
- Severe price competition becoming even more so with open access.
- A distribution system that is difficult to expand
- An ageing manufacturing plant
- High capacity utilization levels; approaching 85% at peak.

Put simply, we're dealing with a "mature" industry which is dependent on "mature" technology provided by "mature" suppliers for its bread and butter. It has all the characteristics classically attributed to "maturity" and as such is not inclined to invest in technology for future capacity growth. Instead the emphasis is on getting the most from existing business assets; working on the marginal cost of existing operations and eliminating base cost, all with minimal investment. This translates into a strategic focus on product cost reduction, improved reliability to enhance capacity utilization, excellent customer service,

and shortening cycle time for responding to customer needs. That set of drivers usually forces such organizations to spend their limited R&D funds working at the end of the product life cycle curve, where the emphasis is on operating risk reduction; one can't take much product development or application risk with small profit margins. A business in that situation literally "bets the business" in attempting rejuvenation through R&D on "paradigm shifting" products. Since dis-integration, read that divestiture, puts an emphasis on owning only those assets that contribute directly to short-term profit, there is almost no attention to major system improvements. What power generation investor in that situation will take a potential bottom-line hit to bring new capacity on line, knowing that the incremental capacity cost will necessarily be borne by the captive customers, if there is such a thing? The lure of increasing capacity factors on existing assets by price-cutting to win base load customers from competitors will be irresistible. The transition will be difficult and the short-term profitability impact will be substantial and, in fact, unacceptable to many utilities captive to this industry's traditional high equity capital structure as a consequence of their regulatory situation.

As technology managers and investors, we're faced with the basic question; what does technology have to offer this deregulated, dis-integrated industry with extremely tight constraints on siting, discharges and product distribution?

In our minds, the most important asset in this future is existing permitted sites, both the aged plants of the utilities and the industrial sites of their customers, both relatively free of Nimbyism. We see the traditional utilities fighting IPP's to invest to build capacity on the potential customers site. If the customer company is young and healthy and looking to vertically integrate production, it may build its own capacity and in effect compete with the utility. If, on the other hand, the customer is in a mature industry situation, it may welcome the opportunity to divest a steam supply facility and let the utility play out its "customer-retention" strategy in competition with other potential suppliers.

METC's program is committed to helping the industry exploit this asset to the fullest; we're convinced that repowering is the most attractive technology-driven answer to the industry's current dilemma. Repowering offers a way to upgrade existing assets, coincidentally grow capacity, and reduce the cost-of-electricity relative to other alternatives. (10) For the neophyte, repowering is usually most cost-effective when it uses the steam turbine-generator, condenser, coal storage and handling facilities, and waste handling facilities at the existing location. Although specific requirements are sometimes less severe, one generally needs to meet the steam turbine's design point steam conditions, require no more coal, generate no more waste, and require no additional electrical transmission right-of-way. The opportunity is great. While only 18GW of new coal capacity is projected for the US market by 2010 (Figure 7), more than 60GW of existing capacity will be >50 years old by that time, with >30 GW in the 65-250 MW range of interest for repowering. All of these plants are eligible for the Clean Air Act's four year compliance bonus if repowered with Clean Coal Technology. Similar opportunities for repowering exist in Eastern Europe; they will become more attractive as these economies accelerate their growth (Figure 8).

The technologies in the METC portfolio (Figure 9) that fit the bill in the repowering game are integrated gasification combined cycle (IGCC), pressurized fluidized bed (PFB), externally fired combined cycle (EFCC), and the advanced gas turbine system (ATS). Each option offers enhanced efficiency which promises increased dispatch hours, helping to write-off the capital investment, while displacing older, less environmentally-attractive generation. A few examples of how the various options could work help to make the point. Figures 10, 11, 12, and 13 taken from reference (10) will help to consolidate the thoughts expressed in the next few paragraphs.

Future Domestic Power Markets, 1995 - 2010, GW

	High Estimate	Midpoint Estimate	Low Estimate
New Capacity	342	206	117
Repowering Capacity	142	73	36
Life Extension Capacity	229	212	164
Totals	713	491	317

Figure 7

Future Worldwide Power Markets Excluding U.S., 1995 - 2010, GW

	High Estimate	Midpoint Estimate	Low Estimate
New Capacity	1130	1035	940
Repowering Capacity	390	196	98
Life Extension Capacity	645	585	470
Totals	2165	1816	1508

Figure 8

METC Business Sectors and Products

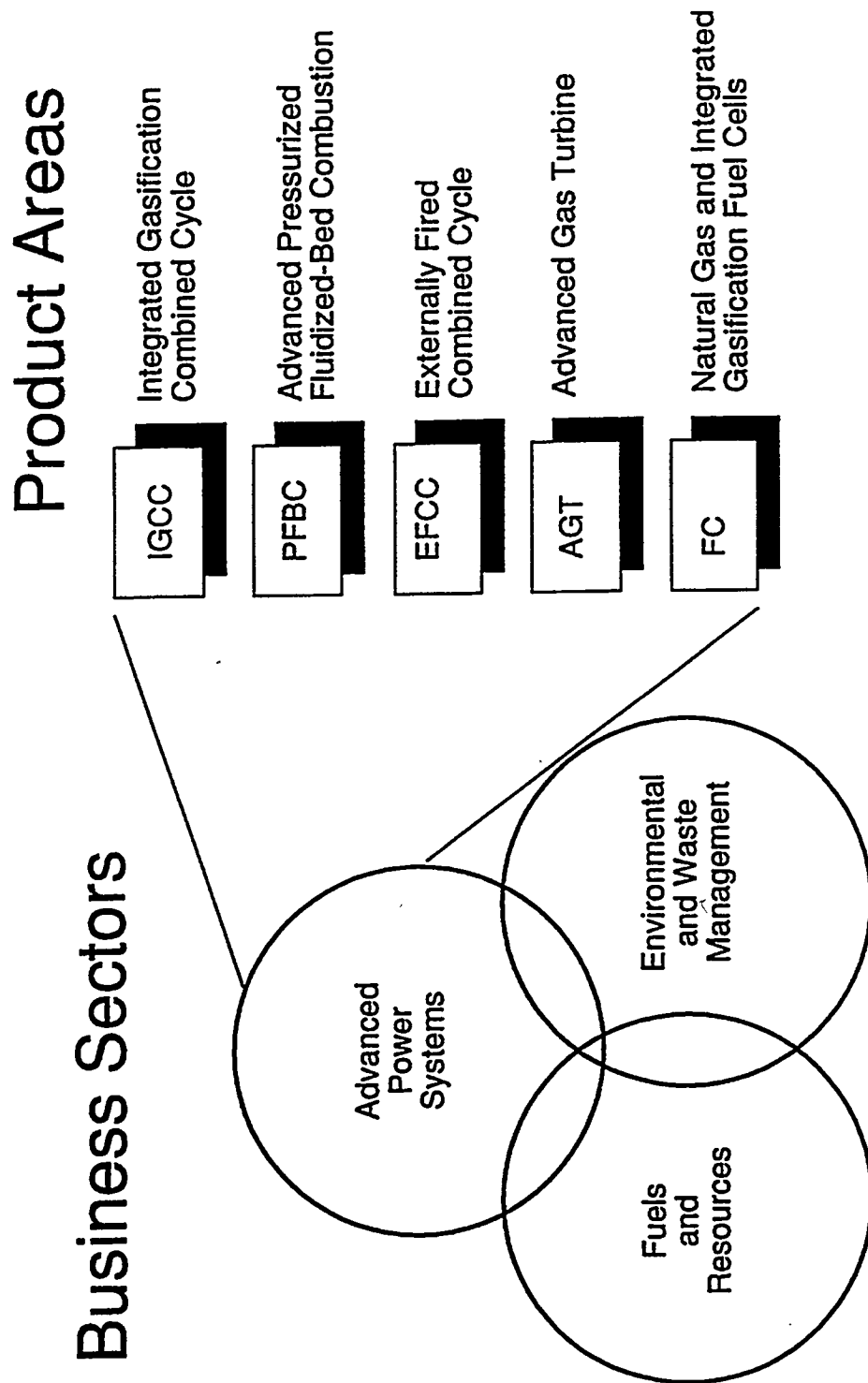


Figure 9

Repowering Flexibility in Adding Capacity

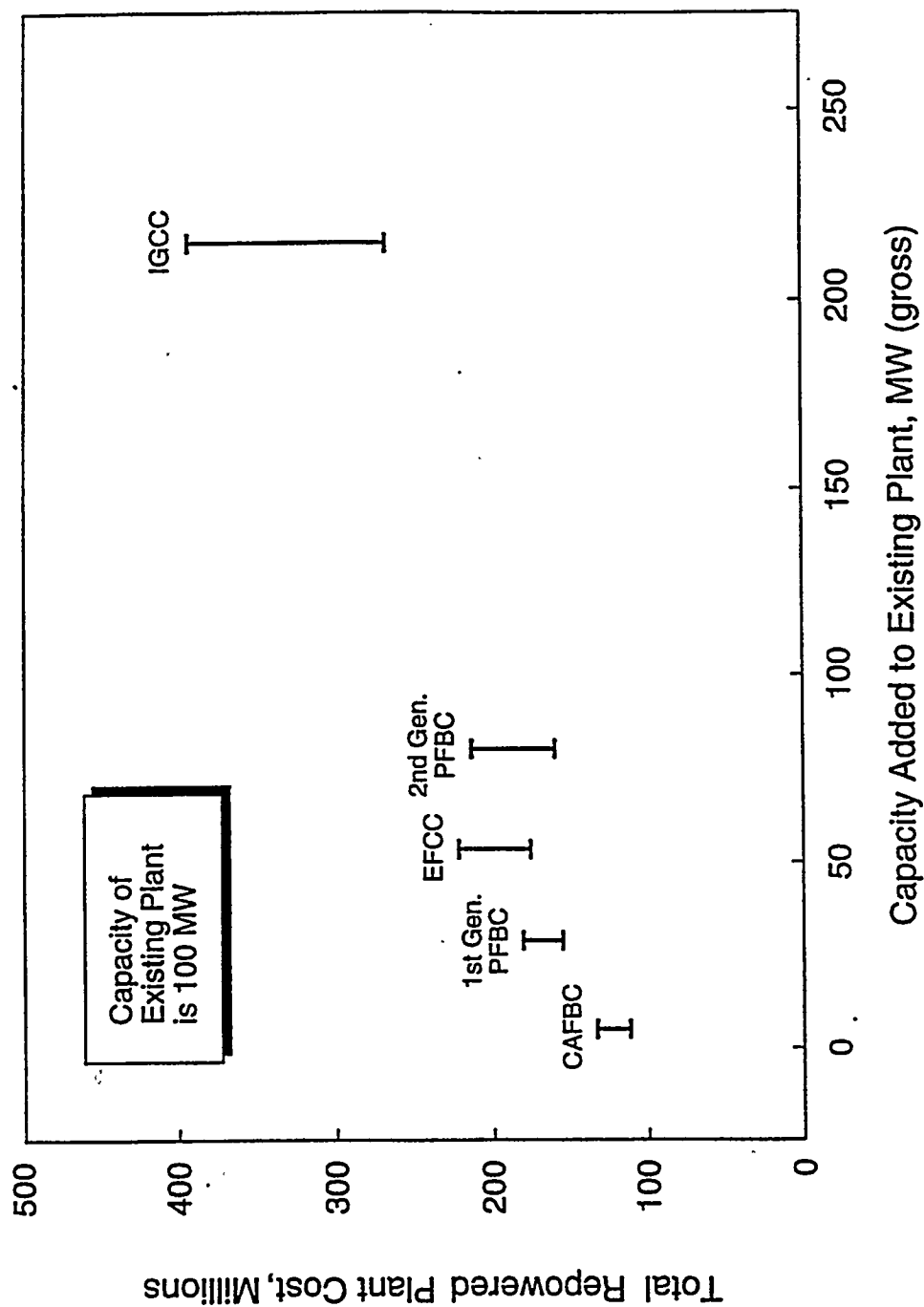


Figure 10

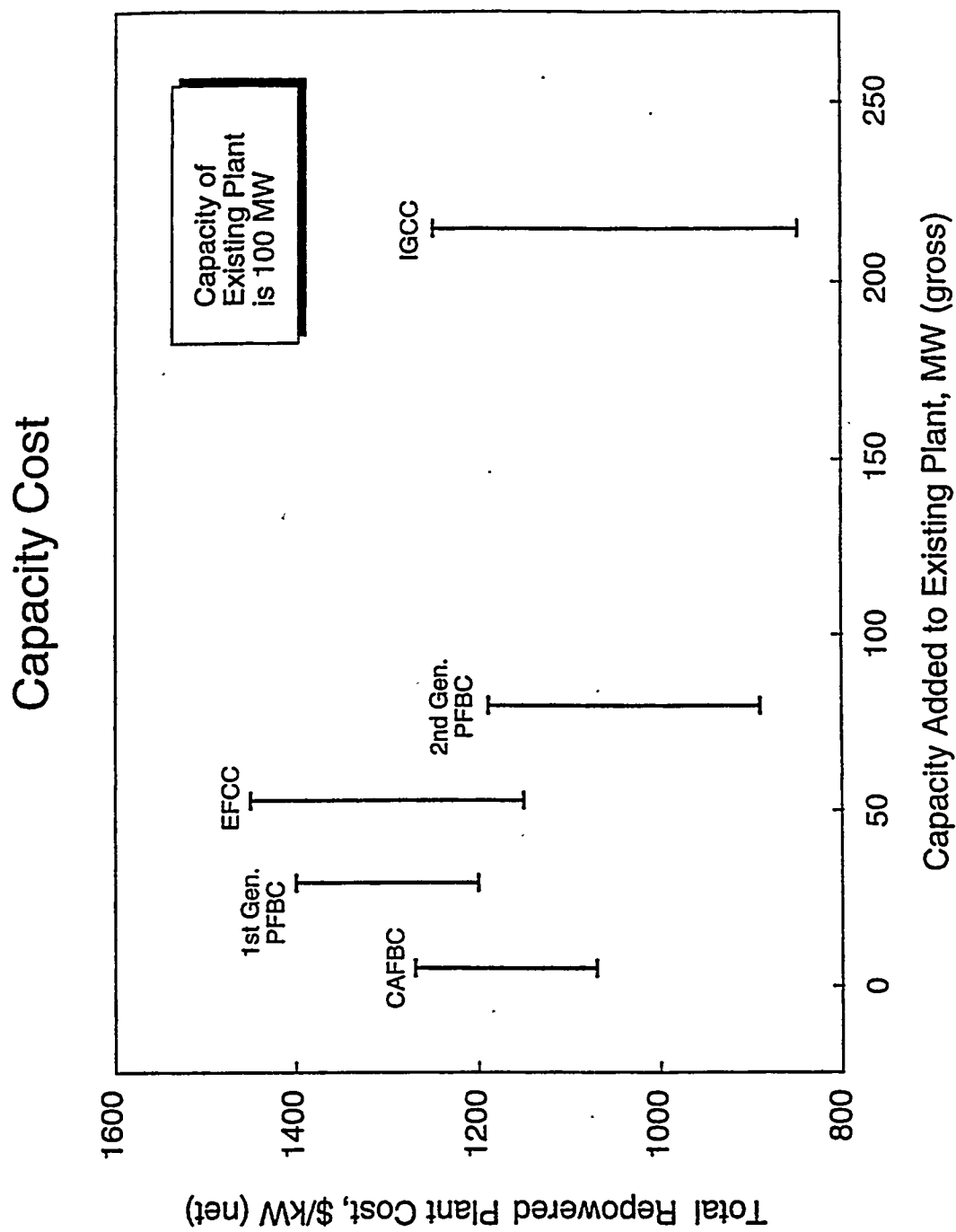


Figure 11

Repowering Flexibility in Plant Efficiency

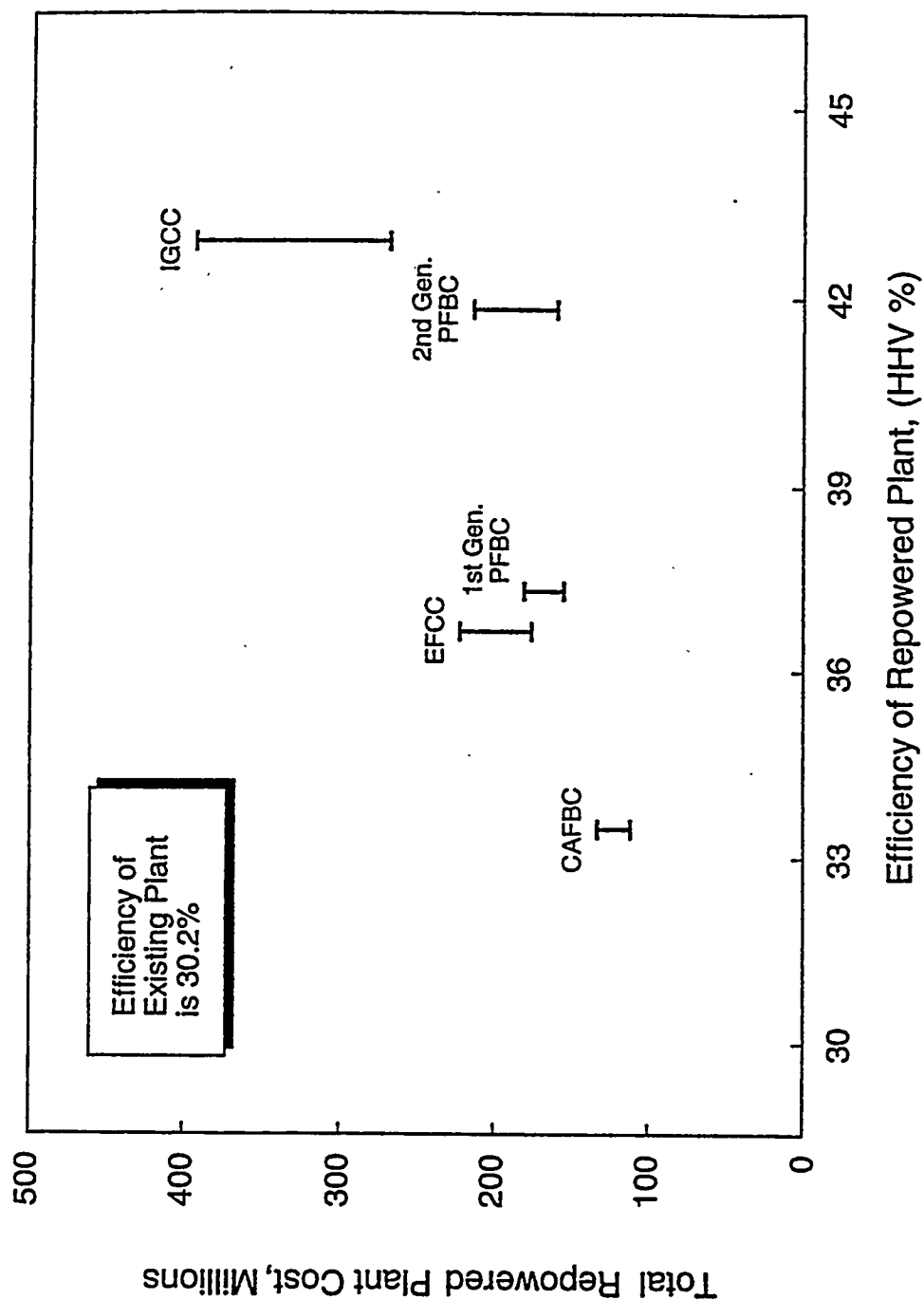
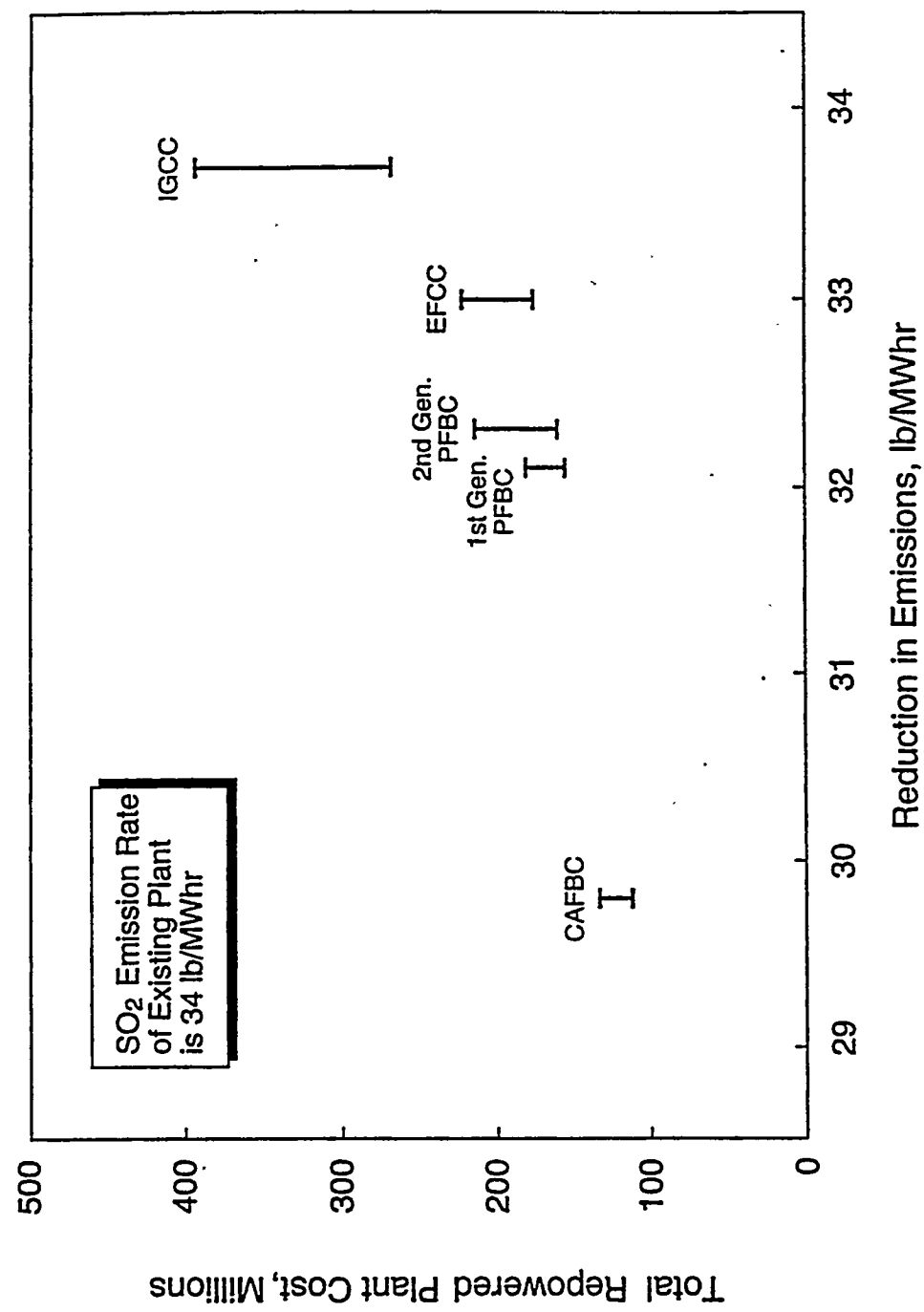


Figure 12

Repowering Flexibility in Reducing Sulfur Dioxide Emissions



M95000078W

Figure 13

The IGCC, which in its most cost-effective configuration increases plant output by 150-200% over its original steam turbine rating, can be a bad match in fuel, waste and transmission capacity unless we're talking about a multiple steam turbine plant. For example, if we start with 2-100 MW steam turbines operating at 30% efficiency and convert one of them into an IGCC and retire the other, we end up with a 250-300 MW combined cycle at 50+% efficiency. That translates into a 25-50% increase in output and a 25-10% decrease in fuel use. The waste reduction could be even higher depending on the pollution control option that would have been required for retrofit-technology based CAA compliance.

The PFB approach results in an output increase in the 35-50% range, resulting in an excellent repowering option. If we repower an existing 200 MW plant with first generation PFB, we end up with 250-300 MW plant operating at 40% efficiency; a 25-50% increase in output and a -6%/+12.6% change in fuel use. The big advantage vis a vis IGCC is in cost; we use the entire steam turbine capacity and add a gas turbine that is 1/3-1/2 the size of that employed on the IGCC. A second generation PFB plant could do even better in the two turbine situation. If one turbine is converted and the other retained, the output increases by 70-100MW at a system efficiency of 40-41%. A 35-50% increase in output while the fuel use change is in the +1/+10% range. Both steam turbines are used and the gas turbine is only 1/2 that used in the IGCC case. Both PFB approaches are environmentally attractive because of excellent in-bed sulfur capture and excellent NO_x performance.

The EFCC is most attractive in smaller industrial application, where it can be used with a variety of combustors to meet a broad range of process steam needs without significant loss in cycle efficiency. Although the system tends to cost-optimize at the 70-100% power increase level, it also provides extreme fuel flexibility, which heavily impacts the definition of optimum.

Using the advanced gas turbine to do natural gas repowering can be extremely attractive, particularly if we employ staged construction to preserve the IGCC option and employ a gasifier that is not a net user or producer of steam. However, it suffers from the same deficiency as IGCC in producing a 150-200% increase in output relative to the existing steam demand.

We know that the global power generation market will be focused on new generation; we know that these same technologies will dominate these global new-plant markets, but that the relative competitive situation between technologies will change. However, we cannot ignore the role that low cost electrical power plays in the area of keeping economies globally-competitive. In mature economies, repowering is the key to meeting this objective as the power generation industry transitions toward open markets. Recent EPRI and GRI studies (11, 15, 16, 17) reach the same conclusion; however, not surprisingly, they disagree on fuel choice. Natural gas retains its capital cost edge in repowering, so the fuel cost differential debate is critical for decision makers. By focusing our R&D effort at METC on gas turbine-based systems, we are striving to keep the fuel option open.

We believe that government must be in league with the "paradigm shifters" that can remake your industry and offer attractive investment opportunities. We must focus on forging the future, not preserving the past. If you look closely at our past and current performance, you won't find METC working on better pulverized coal boilers, better steam turbines, or better scrubbers; you'll find us working on the AFB which gets rid of 2 out of 3 of those components. You'll find us working to make gas turbines reliable base load generators that break the 40% efficiency barrier in a cost effective way with fuel flexibility that even gas turbine devotees wouldn't promise. You'll find us working on fuel cells, the ultra-clean, ultra-efficient, quiet, direct conversion machine that eliminates the concept of working fluid. We are determined to give this mature industry a second life based on technology that delivers what the industry's customers expect. Unless our customers succeed, we have no reason for being.

CONCLUSION

The wide-spread commercial deployment of advanced coal-fired power generation technologies will require capital investment by a user community that has sufficient technical sophistication to deal with the technology risk adversity that permeates a global economy driven by short term money managers; the Clean Coal Technology Program is a US Federal attempt to help. Figure 14 shows the magnitude of this effort in the advanced coal-based power systems area. There are even more projects in retrofit environmental technology and industrial processes to make new fuel forms and to displace coke making in the steel industry; a total of 42 projects with more than seven billion dollars of public and private investment. The management of the US Department of Energy has struggled with its traditional conservative risk-adverse culture to insure that the bureaucratic burden that goes with it does not neutralize the benefits that the help can bring. We are determined to bring our new customer-oriented institutional values to bear; even though they came along a little late for the CCT program.

We may have the technical ability to respond positively to the "Available, Cheap, and Dirty" image, but there are some other fundamental technical, economic, and institutional realities that will affect the role of coal in our energy future. For example, the coal marketer controls a much smaller percentage of the delivered cost of electricity-from-coal than do the suppliers of oil and natural gas; the nuclear fuel supplier shares that problem in spades. Consequently, his incremental cost reduction actions have little bearing on fuel use decisions for new power plants, but predictability of cost and supply does. The coal industry provides one of the US's best productivity improvement and cost stability stories; but their share of their "only" market continues to erode. The variable cost/sales price ratio for coal production is far higher than oil or natural gas; this is particularly onerous to the seller of coal after accelerated investment payback for the latter. Hence, coal has less capability to respond to price competition in soft markets; cheap natural gas is having a field day in current markets. Coal has one customer; it cannot depend on other markets to smooth business cycles. Conversion efficiency for conventional coal-fired power plants has been flat for the last thirty years; the combustion turbine combined cycle has provided a bonanza for the oil and gas-based energy service supplier. Environmental management issues in siting and operation have stressed the coal user community to the point that it no longer seems to be worth the agony to save the rate payer money. Any new energy conversion system will have higher capital cost than the average imbedded cost in the system. Hence, anything he does equates to rate shock; if it's a large high capital cost plant the impact is severe. Even if it will pay back in future years with stable fuel costs, he opts for the low capital cost system with the expensive fuel that promises to become even more expensive in the future and he lets a cogenerator or independent power producer build and operate the plant so that capital cost risk belongs to someone else. It's pay me now or pay me later; the "now generation" resoundingly answers -- later. Add in the environmental fear-mongering on global warming and you can see why Wall Street has discounted the coal industry and the manufacturers of coal production and utilization equipment; there is only interest in those who might heal the wounds in the existing coal utilization infrastructure. "COAL: How clean?; How soon?; How much?" is a complex story; we've offered some scenarios for a happy ending, but ones that call for suppliers and users willing to bet equity capital on new technology and offer new supplier relationships to the electrical power generation industry.

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Locations of METC Coal-Based Advanced Power Technology Integration Sites

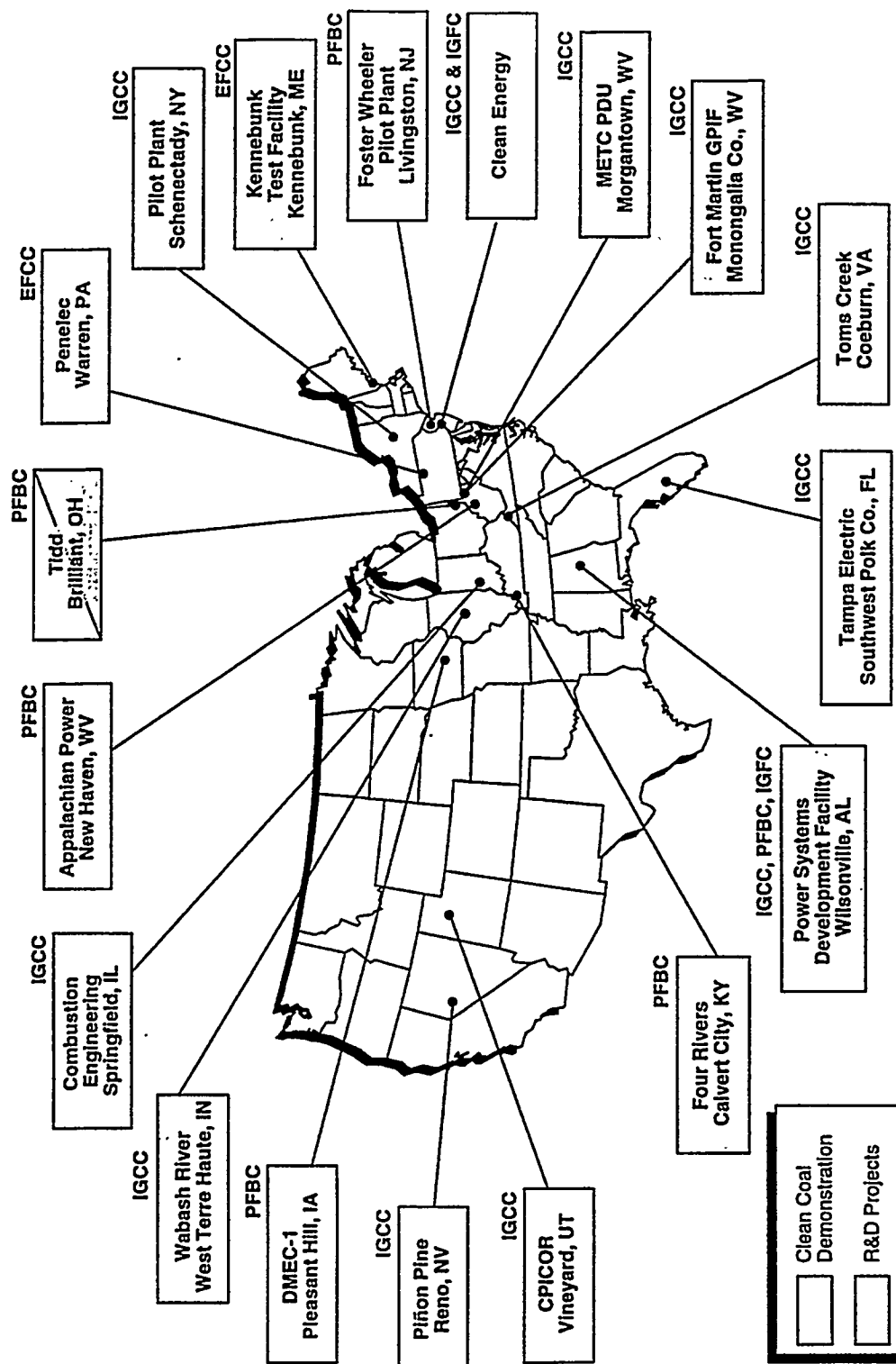


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ELECTRICITY AND THE ENVIRONMENT: BUILDING PARTNERSHIPS THROUGH TECHNOLOGY

Kurt E. Yeager, Senior Vice President, Strategic Development
Ian Torrens, Director, Environmental Control

Electric Power Research Institute
Palo Alto, CA, USA

ABSTRACT

The vision for electricity in the world today transcends its role as just an energy medium and focuses on its ability to furnish ever greater productivity of labor, capital and primary energy resources. Its efficiency and precision, through innovative technology, have become essential assets for resolving the interrelated economic, environmental and energy security issues facing the world.

As a result, electricity has become a major differentiating factor in the global economy. For example, the fraction of all primary energy converted to electricity is typically used as a rough indication of regional prosperity. This index reflects the importance of electricity in both creating and harvesting technological innovation. Electricity's advantages in focusing and amplifying physical power during the first century are being complemented in the second by its even greater advantages for focusing and amplifying the power of knowledge.

As its importance grows, electricity will likely expand in the next half-century to provide over half the world's energy demands while providing the means for the most effective conservation of natural resources. In a world where the greatest social challenges arise from poverty and ill-health, the efficient development of resources to mitigate these global challenges should remain top priority.

The alternative is to artificially contain economic development as a basis for conserving and allocating resources. This had led to failed economic and political systems throughout history because they ultimately place the highest price on those who can afford the least.

Collaborative R&D organizations such as EPRI are acting as new catalysts and partners to transfer technology on a world-wide basis. With respect to Central and Eastern Europe, this effort focuses on new, more cost-effective innovations for the generation and delivery of electricity because obsolete and inefficient technology is contrary to our mutual interest in achieving efficient and sustainable economic development. EPRI stands ready to assist in this international endeavor.

I. THE ENERGY EFFICIENCY CHALLENGE

After a lengthy period during which energy consumption growth kept pace or even exceeded GDP growth worldwide, a decoupling occurred following the energy crises of the 1970s, especially in the developed countries. World GDP grew more than 85 percent between 1970 and 1992, while energy consumption increased 66 percent (1).

For the OECD countries, GDP grew significantly faster than energy consumption, as a result of shifts away from the industrial sector and towards the service sector, reductions in energy intensity within sectors, and improvements in energy efficiency throughout the economy stemming from relative energy price increases (Figure 1). In the non-OECD countries (including those of Eastern Europe and the former Soviet Union), energy consumption grew slightly faster than GDP partly as a result of electrification, industrial development, growth in private vehicle ownership, and continued low energy prices (Figure 2).

Electricity, Energy, and GDP

Developed Countries

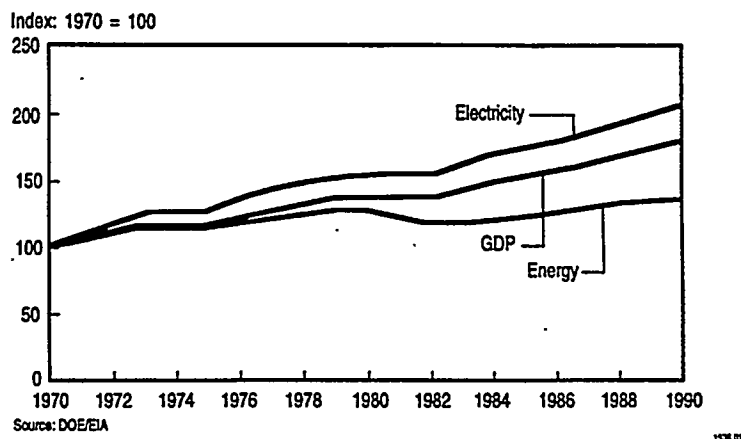


Figure 1

Electricity, Energy, and GDP

Developing Countries

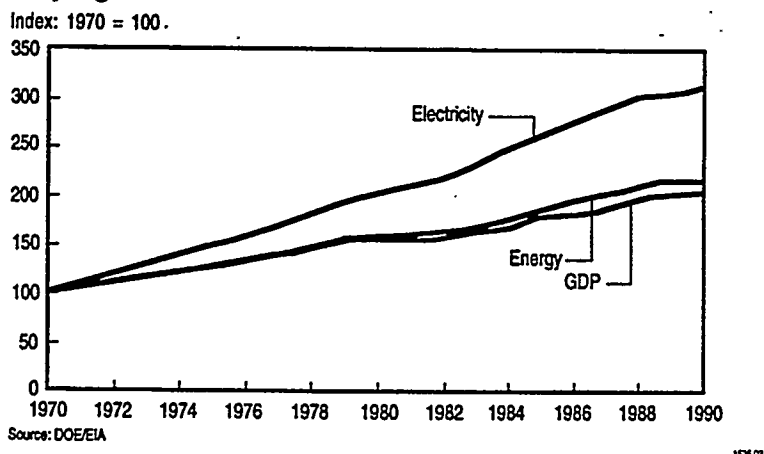


Figure 2

As a result of these opposing trends, the gap between OECD and non-OECD energy consumption per unit of GDP widened significantly between 1970 and 1990 (Figure 3). By 1990 the OECD was able to produce a unit of economic output using little more than half the energy required by the non-OECD world.

Energy Consumption per Dollar of GDP: Developed vs Developing

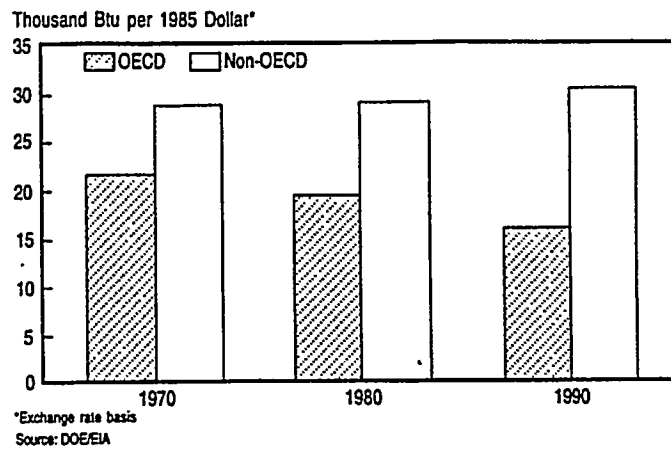


Figure 3

Figure 4 shows some individual country positions on a plot of 1990 energy consumption per dollar of GNP against GNP per capita. The distribution pattern suggests three distinct country groupings:

- (1) OECD countries, with relatively high incomes and low energy consumption per unit GNP;
- (2) Developing countries, with low incomes and relatively low energy consumption per unit GNP;

Economic Development and National Energy Use Patterns

1990 Energy Consumption per Dollar of GNP vs. Per Capita GNP for 83 Countries

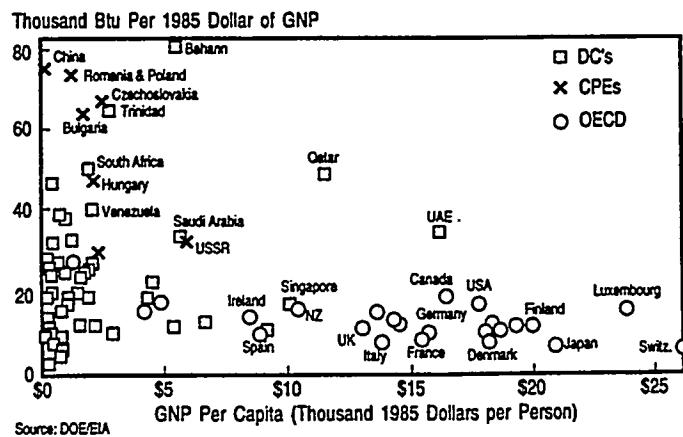


Figure 4

- (3) Former centrally planned economy countries, with low per capita incomes and high energy consumption per unit output.

Historical data over the past 150 years suggest that energy intensity in every nation reaches a peak as it develops industrially and then declines (Figure 5). Also, the peak value for a specific country has tended to be lower for those whose industrial development falls later in this period. This suggests, first, that developed countries will continue to find ways to reduce energy intensity, and second, because of technological advances, that countries industrializing today can do so with greater energy efficiency than did nations in the past. However, countries that have kept or are keeping energy prices artificially low

Energy Intensities of Industrialized Countries

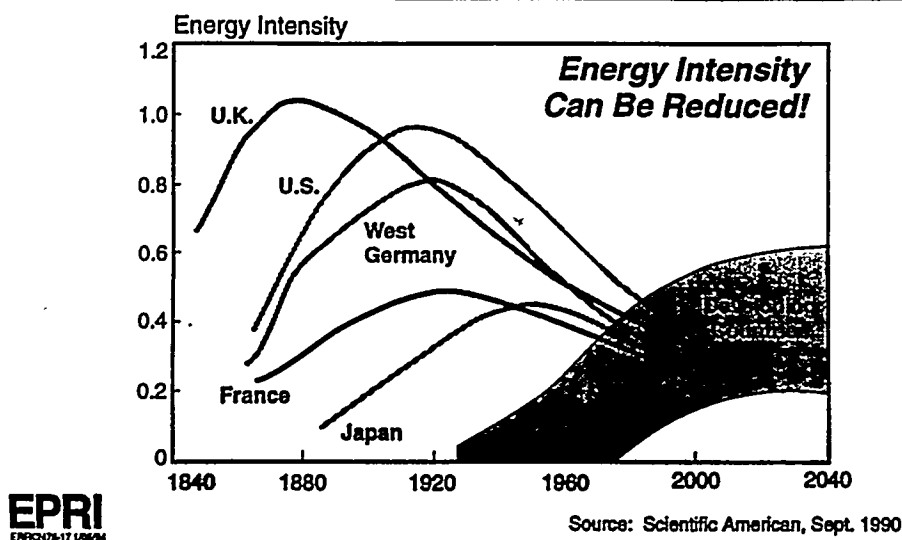


Figure 5

inevitably raise the level of the peak and postpone the decline in energy intensity, as well as building into their economies inefficient modes of energy use (e.g. energy waste in space heating) that render the decline more difficult and capital intensive.

II. ELECTRICITY: DRIVER FOR ECONOMIC DEVELOPMENT

Electricity is a key to understanding many of these trends and projecting them into the future. Throughout the first electrical century, electricity has been a prime agent of progress, providing the foundation for increased productivity of labor, capital, and primary energy resources; and for rapid growth in prosperity, health, and quality of life. In so doing, it has become more than just an energy alternative; rather its efficiency and precision are now essential to resolving the interrelated economic, environmental and energy security issues facing the world today (2).

Between 1899 and 1985, U.S. use of electricity grew rapidly compared with capital, about 2.5 times as fast. At the same time, nonelectric energy use increased at only half the rate of growth in capital input — a comparison that signifies the strong affinity of electricity for long-term technological progress (3).

More recently, during the economic expansion of the 1980s, electricity growth paralleled the growth of the U.S. Gross Domestic Product (GDP) while real electricity price declined 16% and overall energy efficiency improved 11%. Today the United States uses little more energy than it did in 1973, yet it produces 40% more goods and services.

The picture as regards the relationship of electricity growth to economic growth is similar for other developed countries. Figure 1 includes the course of electricity growth, comparing it to GDP and total energy consumption growth for the OECD countries between 1970 and 1990. Electricity consumption doubled during these two decades, while GDP and energy consumption grew 80 percent and 36 percent respectively. Figure 6 tells a similar story for the G-7 countries, where electricity per unit GDP was virtually flat over the period though energy per unit GDP fell substantially. Electricity grew partly through

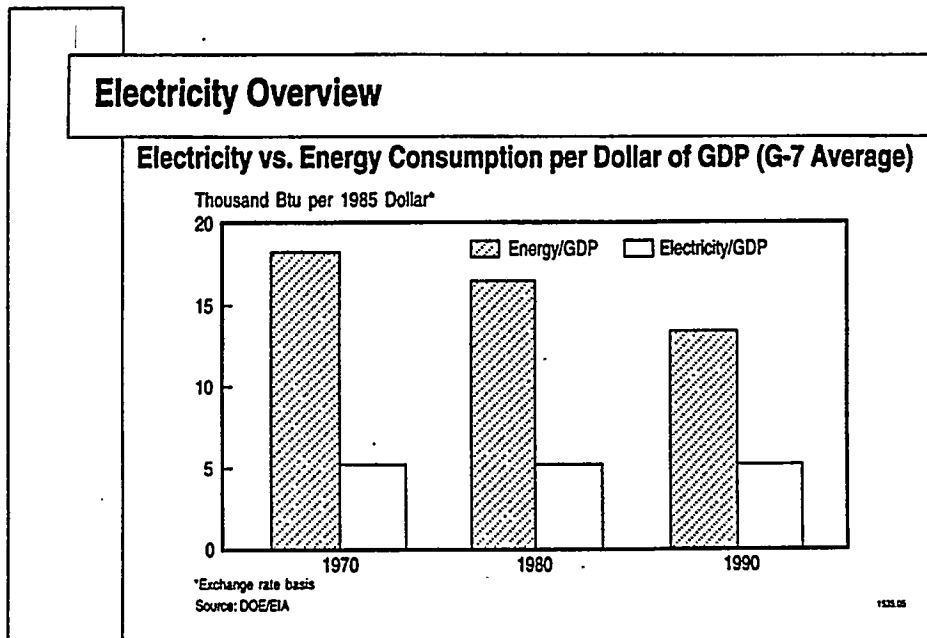


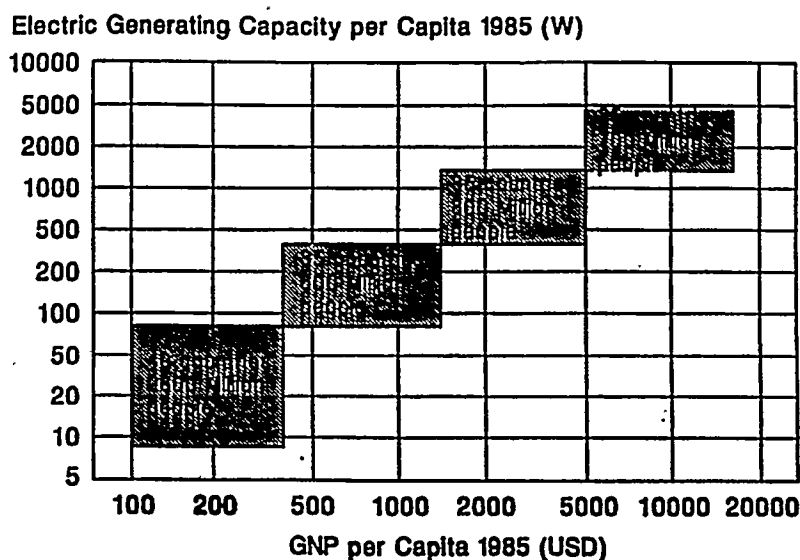
Figure 6

penetration of home appliances, though use of electricity for air conditioning and heating (often by heat pumps) also increased, especially in the U.S.A and Japan. Electricity use by the industry sector also increased rapidly.

The developing world shows a strong trend towards electrification during this period, with electricity consumption tripling in the two decades (see Figure 2). Unlike the developed countries, however, the developing world did not manage to decouple total energy growth from GDP growth (see Section I.).

Despite recent strong growth in the developing world, large disparities remain, and one very clear fact is that economic development and prosperity are inextricably linked to electricity. North America, Japan and Western Europe have a hundred times more generating capacity per capita than the group of least-developed countries which represent over half the global population (Figure 7). These industrialized nations, with less than 25 percent of the world's population, generate about 75 percent of the world's electricity. Thus on average the industrial world's citizens on a per capita basis use ten times as much electricity as do residents of the developing world. The ready availability of this energy carrier has catalyzed the creation of new wealth and step-function jumps in living standards; has provided a vital

PROSPERITY AND ELECTRIC ENERGY



Source: ASEA Brown Boveri

0550K.44

Figure 7

component of the combat against disease; and has underpinned the explosion of instant communications spanning the globe.

Looking to the future, sustained productive improvement in energy efficiency through electrification in the United States and other advanced industrialized countries means that the rate of increase in primary energy consumption is expected to shrink, by 2010, to less than half the annual rate of GDP growth (4). But because electrotechnologies will become even more efficient and, together with emerging innovations, will continue to substitute for the less efficient direct use of fossil fuels, the United States is expected to be using at least 20 to 35 percent more electricity per year in 2010 than it is today.

Electrification is becoming a key differentiating factor in the global economy as well. With a population of 5.5 billion today, the world is growing at a rate of 1 billion people per decade, creating unprecedented demands on resources. At the same time, the world economy is growing. Taken together, population growth and economic growth will result in world demand for energy that, by the middle of the 21st century, could be two to four times current levels.

III. ELECTRICITY AND TECHNOLOGICAL INNOVATION: KEY TO SUSTAINABILITY AND ENVIRONMENTAL QUALITY

The significance of today's statistics and tomorrow's forecasts is that future global economic growth, particularly of the developing regions, will be associated with very large increases in electricity generation. The trends that will shape the 21st century are being created by, and will require, an abundance of electricity delivered safely and cleanly to the farthest reaches of the globe. During the coming decade alone, the developing countries, as they emerge to claim their share of the global economic pie, propose to add nearly 400 gigawatts of new generating capacity. This addition is equivalent to one-half the total U.S. power generation capacity today. This investment in electricity production is not just desirable but essential to the efficient utilization of the finite resources on which a sustainable global economy depends.

The amount of pressure on global resources is determined by three factors: population, economic growth, and technological progress. Barring catastrophe, population growth rates will change only slowly for at least the coming decades, and economic development cannot be constrained without sentencing the majority of the world to increasing poverty as a result. If the world population doubles as expected by 2050, and the per capita economic growth increases at 2 percent per year, then - all else being equal (i.e., if development and market penetration of technology were to remain frozen) - the demand on natural resources would increase five-fold.

Technological innovation is the one factor under our control that can offset these resource pressures. Technology can improve the productivity and efficiency of activities as well as stimulate substitution of one form of natural resource for another. Without technological progress there is little doubt that we would be swamped by the global changes resulting from economic and population growth.

A major enabling factor for sustainable development, electricity, through technological innovation, is the energy carrier that can most efficiently and productively convert the widest possible range of raw energy resources to meet the growing needs of humankind. Electricity has the potential to expand in the next half-century to satisfy more than half the world's energy demands while providing the means for the most effective conservation of the world's natural resources. As such it will be an essential component of the realization of sustainable development in a 21st Century world of 10 billion humans.

When it comes to protecting the environment on a more national, regional or local scale, it is clear that the quality of life and electricity availability are intimately related. As far as environmental protection is concerned, electricity may be part of the problem, but it is also very likely to be part of the solution. The efficiency and precision of electricity provide a means to address many pressing local and regional environmental concerns. Replacing relatively inefficient direct-energy-based processes with more efficient electric-based technologies will help conserve primary energy resources and reduce environmental impact. At the same time, new electric-based technologies will provide innovative ways to resolve specific environmental problems (5):

- Electronic adjustable-speed drives allow the speed of motors to be precisely varied without loss of efficiency or damage to the motor, saving energy and improving process control;
- Electric arc furnaces are more flexible in size and more economical than coke ovens, can melt 100 percent scrap steel;
- Infrared heating for industrial drying and curing is an alternative to conventional gas ovens for setting finishes on many products, including painted car bodies and home appliances;
- New electric technologies such as electro-pyrolysis, microwave disinfection or plasma processing can either destroy infectious medical wastes without incineration, or disinfect and shred the waste, permitting disposal in municipal landfills.
- Ozone treatment of effluents is proving effective in reducing toxics in waste treatment;
- Electric vehicles, which are typically 60 percent more energy efficient than gasoline vehicles, also promise important environmental and energy security benefits.

These are just a few opportunities that show the advantages of electricity as a means of tackling difficult environmental problems.

The question for this Conference is, how can a country in East Central Europe address the difficult energy and environmental problems that it faces and how can electricity be of assistance in this?

IV. STRATEGIES FOR EAST CENTRAL EUROPEAN ECONOMIES IN TRANSITION

Countries in the East Central European region face the difficult transitions from centrally planned to market economies; from artificially low subsidized energy prices to cost-based prices; and from relatively low levels of concern for the environment to consciousness of the need and urgency of a massive effort to clean it up and pollute less. Add to this an industrial infrastructure not well adapted to the needed changes, and an acute shortage of capital, and the difficulties seem daunting.

Nevertheless, the potential for improvement in overall energy efficiency, as represented by the energy/GNP ratio, is high in the emerging economies of East Central Europe, as shown in Figure 8 (6). An efficiency-maximizing strategy towards electricity development and use will be an important contributor towards reconciling economic growth and environmental quality, in this region just as in other parts of the global economy.

Eastern Europe: 1988 Energy/GNP Ratio (Barrels oil equivalent / thousand US dollars)

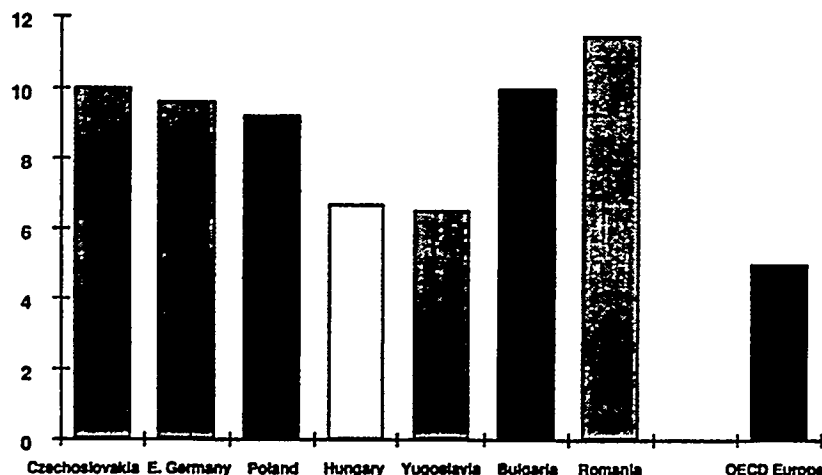


Figure 8

The following sections will discuss the role of electricity as both past polluter and future tool for environmental improvement in this region.

Environmental Issues from Power Generation in East Central Europe

Large deposits of hard coal and brown coal (lignite) make solid fuel the basis for most electricity and heat generation in a number of East Central European countries. This has produced environmental consequences sometimes of very serious proportions. Contributing to the air, water and ground pollution of the most affected regions are electric power plants, but also home heating units, steelworks, central heating plants, coal mines, and coke ovens. Smoke or particulate pollution has been the most serious impact in the past, and though the situation has improved considerably with the use of electrostatic precipitators in electricity generation plants and other large sources, there remain multiple smaller sources of smoke emissions that are either not controlled or inadequately controlled. Also, regional pollution issues are becoming so acute in some areas that existing precipitators on large plants will need to be upgraded.

Sulfur and nitrogen oxide emissions from coal combustion have been to a large extent uncontrolled in countries of this region. Their role in acid deposition and regional ozone formation has been well-documented. With national and international programmes in OECD European countries reducing their emissions of these gases very substantially, there are international as well as national pressures to achieve SO₂ and NO_x emission reductions in East Central Europe. Carbon dioxide emissions are becoming an issue in relation to potential global climate change in the international debate. As far as this region is concerned, the scope for energy efficiency improvement is sufficiently large that, if realized, CO₂ emissions per unit of GDP could be reduced substantially over the next decade.

Control of gaseous emissions, especially from existing sources, inevitably puts additional strain on the environment locally, through addition of solid and liquid waste disposal problems. This has been the case in many areas when particulate controls were upgraded. The installation of flue gas desulfurization for SO₂ removal adds further large percentages to the solid or semi-solid by-products produced in electricity generation. The latter can be avoided by modifying the process to produce gypsum of sufficient quality for commercial use, as in many German and Japanese power plants. However, some added costs of control are imposed, and a geographically convenient market for the gypsum must be found.

Coal gasification provides the lowest emission route for coal utilization, in terms of both gaseous and solid by-products. This, however, requires large new investments, and the technology is not amenable to upgrading existing power plants at minimal cost, which is the most immediate need in most Eastern European countries.

Strategies for Cost-Effective Emission Reduction

This is an especially important consideration for improving environmental quality in East Central Europe (7). Strategies for environmental improvement are constrained principally by availability of capital, so that it is of vital importance to seek the maximum improvement per unit of investment in pollution reduction. The situation is complicated by the widespread use of often low-grade coal in combustion installations of all sizes from individual heating furnaces up to large generating plants. The challenge is to develop strategies that are feasible, can obtain the greatest reduction per unit expenditure and do so in a timely manner, can solve short term pollution problems without adding to longer term ones (e.g. the solid waste disposal issue), and can attract the needed foreign investment.

One clear winner is of course to upgrade the fuel supplied to small coal combustion installations, where sophisticated post-combustion controls are not economically feasible. For large installations like power plants and district heating systems, the transitional strategy is less evident. Reduction of particulate emissions from under-performing ESPs or other control devices seems to be the most urgent task to improve the local environmental quality, and a number of "fixes" are available or under development costing less than the replacement of the control device (8).

Sulfur emission reduction is probably the second priority in the strategic approach to environmental improvement. Cleaning the coal at the mine is a relatively low cost means of removing a good fraction of the pyritic sulfur, as well as increasing the calorific value of the fuel. Some 30-50% of SO₂ emissions can be removed by sorbent injection in the boiler (90 percent or more in a fluidized bed boiler), at relatively low capital cost, but at the cost of increasing the amount of solid waste to be disposed as well as changing the nature of the waste. Today's flue gas desulfurization systems remove up to 99% of SO₂ and produce re-usable gypsum. However, they are relatively costly in terms of capital.

If NO_x emission reductions are judged to be necessary, it must be remembered that the power generation sector is not as predominant in the national NO_x emission inventory as for SO₂. Mobile sources usually contribute a substantial fraction of NO_x emissions, especially if vehicles have not been equipped with catalytic converters. If, taking this into account, it is judged necessary to reduce power plant NO_x emissions, the most cost-effective approach, and the one being adopted in the United States in response to the 1990 Clean Air Act Amendments, is to retrofit low-NO_x burners on existing boilers, achieving some 50% emission reduction. Already now, and increasingly over the next two or three years,

experience is being gained in the U.S.A. on the performance of new low-NO_x burner systems retrofitted to power plants, and on how to tune the boilers to optimize NO_x emission performance over different load ranges.

The strategy adopted by a utility or government in a transition economy will depend on the structure and geography of coal-fired generation capacity, the overall goals, the time-frame, and the availability of capital. If new generation is needed and the capital can be raised, it may make sense to leap to the cleanest coal technology - a coal gasification combined cycle plant; alternatively, a pressurized fluidized bed combustion plant or, more conventionally, a pulverized coal plant with the highest efficiency advanced FGD may fit the bill (9). Work at EPRI to support utilities considering new fossil units is focused on a series of state-of-the-art power plant (SOAPP) concepts. They are modular, fuel flexible and designed for on-off cycling capability, with ambitious efficiency and reliability goals. EPRI's SOAPP Workstation is a software package aimed at produce the design specifications for a new or upgraded plant, which may be pulverized coal, fluidized bed, or gas turbine-based coal gasification, in a format easily accessible to utilities.

If, as is more often the case, environmental improvement must be obtained through emission reduction from an existing plant, the choice is less simple. Factors such as remaining life, coal quality, space available for equipment retrofit, water availability, lime or limestone quality and price, by-product disposal facilities, and potential market for gypsum, all play a role. For a plant which is nearing the end of its projected life - say within a decade - the lower capital cost sorbent injection technology may make eminent good sense for modest sulfur removal benefits.

Overall, significant benefit/cost improvements may be realized by undertaking a system-wide analysis and optimization of the cost of pollutant emission reduction, either from the electricity generating sector itself or from a combination of the highest emitting sectors of industry. For example, EPRI's Clean Air Technology (CAT) Workstation integrates a number of computer codes into a system aimed at helping decision-makers choose between alternatives for a specific system of power plants and fuels, based on minimum cost or other selected criteria. Analyzing the consequences of decisions on controlling specific power plants using a range of technologies, can provide useful insights and help make scarce resources go further.

Today's Emission Reduction Technologies versus Tomorrow's

Eastern European countries also need to take into account the time factor in their pollution reduction strategies. R&D is helping to develop innovative, more cost-effective technologies for electricity generation and environmental control. This takes time, however, so that the benefits which clean coal technologies promise may be delayed if rapid, short-term emission reductions are required. The issues here are:

- (1) How much more costly is a rapid emission reduction using today's technologies than the same reduction would be over a longer time period that allows time for research, development, demonstration and deployment of less expensive technologies for achieving the same or greater overall emission reduction?
- (2) Will the rapid emission reduction provide environmental and health benefits which are greater than the increment in cost as compared to that of a longer term emission reduction strategy?

The answer will probably depend on the perceived health and environmental impact of existing levels of emissions, the degree of confidence in the projection of reduced cost in future due to technological development, and the availability of funds to improve the situation.

V. INTEGRATING SOLUTIONS THROUGH TECHNOLOGICAL INNOVATION

For East Central European countries, the barriers that they face in making the transition and upgrading their economies, especially that of availability of capital, mean that they must seek to exploit as far as possible technological innovations that can accelerate the process at reasonable cost.

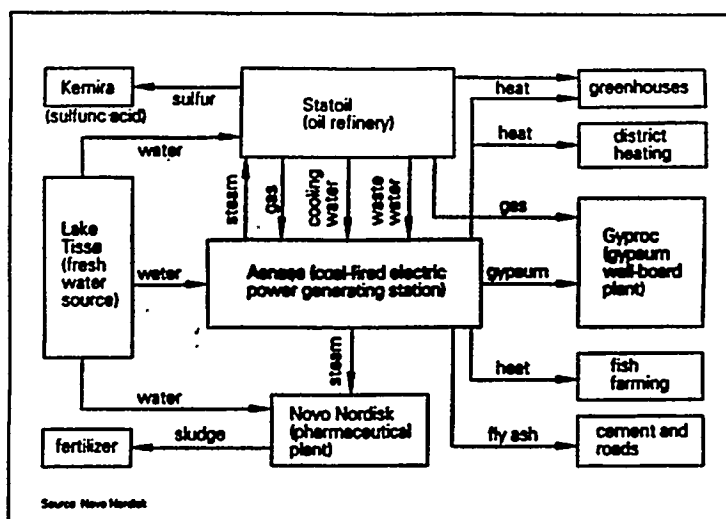
We have entered an era of accelerating technological innovation, led by the microprocessor and telecommunications revolution but accompanied by tremendous innovative bursts in other fields such as biotechnology. These advances are revolutionizing the economies of the advanced industrialized countries and affecting their citizens' lifestyles. There is every reason to try to harness their potential to the task of upgrading the economic infrastructure, and renewing the environment and quality of life, of the European economies in transition. Again, electrification is the key.

The development of advanced electronic devices has led to a revolution in communications, information processing, and remote control which is dramatically changing the way businesses relate to their customers. For the first time, truly real-time interactive services are possible. These commercial advancements result from the \$1 trillion, 20 year global investment in the microprocessor revolution. The resulting versatility of distributed electronic intelligence can now link design, engineering, fabrication, production management, product distribution and field service through a common network and database. Such electronic integration allows businesses to be reorganized for maximum speed and flexibility in response to a constantly changing competitive environment. The same goes for individuals. Today a personal computer needs only a telephone socket to become part of a worldwide network and enable its operator to communicate globally via the InterNet. Tomorrow the shape of the socket may be a lesser hurdle as cellular communications via satellite move into the global arena.

Today's desktop (or laptop) computers are not expensive in terms of the cost of capital equipment. So their potential is high for the power of networked knowledge and computerized telecommunications to underpin the re-development of economies with well-educated work forces like those of East Central Europe. Nor are the optical fibers that increasingly will link the computers expensive compared to the copper the fibres replace - the opportunity is there for countries whose telephone system suffers from past under-investment to leapfrog into the era of the information superhighway. Some people who never had a telephone in their home may indeed never need to have one there, communicating instead for work or leisure via the multi-media computer/television/telephone in a single box!

The systems optimization approach, mentioned in Section IV.2 in regard to pollutant emissions reduction, can be taken a major step further via the concept of industrial ecology, reducing the need for "end-of-pipe" clean-up. Here - just as individuals may add to their productive value by becoming part of a world wide web of networked knowledge - so whole industries and urban residential/commercial areas can add to their value, and reduce their impact on the environment, by becoming closely interacting systems rather than relatively isolated components and individual sources of pollution. Industrial ecology provides the basis for connecting different processes and pollutant-producing activities into an operating web that minimizes the total amount of material that goes to disposal sinks or is lost in intermediate processes. The focus thus changes from merely reducing waste from a particular process (pollution control), to minimizing waste produced by the larger system as a whole (10).

A frequently cited example of practical industrial ecology is the cooperation between the Danish utility Asnaes and a web of other industry in the Kalundborg region of Denmark - an oil refinery, a biotechnology plant, a gypsum wallboard manufacturer, a sulfuric acid producer, cement producers, a district heating system, and local agriculture, horticulture and pisceculture (Figure 9) (11). Water, energy, chemicals and organic materials flow from one company to another, decreasing waste production as well as air, water and land pollution.



Schematic of Industrial Ecosystem involving Electric Utility at Kalundborg, Denmark

Source: Tibbs, Reference 11

Figure 9

This type of approach may be especially promising as East Central European countries renew and redevelop their industrial and their urban infrastructure, with a view to reducing energy waste and environmental degradation. An industrial ecology approach bringing all of the potential stakeholders into the planning of new investment projects could yield dividends in both economic and environmental terms.

VI. BUILDING PARTNERSHIPS

These are just a few examples of the many opportunities, present and prospective, for electricity to play a vital role in the 21st century economies of countries of this region, just as it will across the globe, harnessing and amplifying the power of knowledge as it harnessed and amplified physical power in this century. Electricity is the principal hope of conserving resources, protecting the environment cost-effectively, and improving the quality of life for a 10-billion person world.

Historical experience suggests that the process of technological diffusion on a global basis realistically takes 50 to 100 years. Concerted efforts to speed the diffusion of new ways to produce and use electricity cleanly open the very real prospect of accelerating the advance of science and technology in service to the world. The result will encourage sustainable economic development, as well as moderate both population growth and pressure on natural resources. This is good public policy and a good business opportunity for electricity. It may well prove to be the central challenge of the 21st century, however, because the more advanced and wealthier countries will have to recognize that it is in their self-interest to first invest in their potential competitors if they are to fuel their own growth (2).

In many different ways, the partnership process between the OECD countries and those of the East Central European region is well under way. The present Conference provides evidence of this. Still, much of the partnership activities fall into traditional categories and are triggered by immediate short-term needs. This is both necessary and valuable. However, it should be supplemented by efforts at innovative thinking aimed at exploiting brand new technological possibilities to speed up and perhaps redirect the economic renewal in a way that will enable countries of the region to join the ranks of the advanced industrial world before the new century dawns.

As this paper has tried to demonstrate, electricity is likely to be the key to exploiting these innovative possibilities. Collaborative R&D organizations such as EPRI are acting as new catalysts and partners to transfer technology on a worldwide basis. With respect to East Central Europe, this effort focuses on new, more cost-effective and cleaner technologies for the generation (including power plant upgrading) and delivery of electricity; and new electro- technologies that can upgrade existing electricity use technologies or replace less efficient and more polluting direct use of fossil fuels. EPRI stands ready to assist in this international endeavor.

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ADDRESSING CONCERNS AND ACHIEVING EXPECTATIONS

C. Lowell Miller, Associate Deputy Assistant Secretary of Clean Coal Technology

U.S. Department of Energy
Washington, DC, USA

Approximately 2-1/2 years ago many of us were gathered here in Prague at a similar conference with a similar name, "Energy and Environment: Transitions in Eastern Europe." Over 300 professionals from 26 nations attended. The objective of the conference was to:

- Facilitate the Solution of Long and Short Term Energy and Environmental Problems in Eastern Europe by Bringing Together People, ideas and technologies which could be applied to specific problems in a logical step-by-step manner.

It was conceded at the time that the long term solution would consist of thoughtfully integrated steps and that the conference was the first step. We are here in the Czech Republic again this week to continue what was started. As before, this conference continues to:

- Provide a forum to identify and discuss cost-effective environmentally acceptable energy and environmental technology options and their associated socioeconomic issues.
- Stimulate the Formation of business partnerships
- Identify key barrier issues hindering technology applications and identify implementation pathways that eliminate or avoid obstacles to progress.

This week's conference is not the second but the third step of the journey towards achieving the stated objectives of the effort. The second step was an Eastern European Training Program conducted in 1992 at the University of North Dakota's Energy & Environmental Research Center. Attended by over 30 representatives from Bulgaria, Hungary, the Czech and Slovak Republics, and Poland, the training course was designed to train senior managers and decision makers:

- In practical techniques for evaluating state-of-the-art clean coal technologies
- In operational methods for improving cost efficiency and environmental control and
- To assist in the transition from central planning to market based decision making

With this conference the step-by-step process thus continues. But as we look at what has been accomplished, it is important to remember the journey to the objectives we really want to achieve will be long and, at times, difficult. As we try to gauge the length of that journey and the size of the obstacles to be overcome we find that others have observed:(1)

"Building industrial economies and finding competitive places in the world economy is not the work of months or years, but that of decades and generations. . . Some scholars put the time of transition of industrial structures from take-off to arrival at 40-60 years; three generations from aspiration to achievement"

Unfortunately, the pressures now existing and increasing on the importance of the environment, on the role of energy in achieving desired standards of living, and on the associated socio-economic

issues require that we identify and implement every means to accelerate the schedules associated with building competitive industrial economies or achieving the objectives of this and the previous conference.

It has been generally accepted that the solution to these energy, environment and economic problems are to be achieved through technology and cooperation in technology transfer. The technology transfer to which we refer must allow aspiring nations to improve economic performance while at the same time dealing responsibly with reasonable environmental concerns. The three steps represented by these conferences and the training course may or may not be significant activities in technology and cooperation in technology transfer depending upon whether or not they achieve their defined objectives.

It is far too early to expect that the steps thus taken have or can achieve the objectives stated or will be successful in providing solutions to the energy, environmental and economic issues addressed by the many experts that have participated this week. However, there are principles generated by other experiences, past lessons learned, and even earlier mistakes that can be applied to what has been accomplished to date to determine the direction and confirm the validity of the path being taken.

Four recommendations have been given (2) to guide formulation of successful programs for technology cooperation and transfer. These include:

- (1) Get the process right:
 - Create the proper policy environment and let markets dictate technology choice
 - Increase technical cooperation and R & D programs involving developed and developing countries and the private sector.
- (2) Be comprehensive:
 - Consider the overall energy system and not just discrete pieces.
 - Concentrate on high pay-out areas
 - Cover all aspects of the technology transfer process
- (3) Invest in People:
 - Transfer experience and not just technology
 - Improve managerial and technical capabilities in receiving countries
 - Provide long-term training and assistance as well as technology
 - Emphasize public/private partnerships in energy management and training
- (4) Target Financial Assistance:
 - Increase the relative share of funding for energy efficiency, policy development, and training
 - Provide assistance during the transition phase to market-based energy pricing

Given these recommendations that guide the development of successful programs in technology cooperation and transfer, the question that follows is, of course, are the three steps taken in this activity, of which we are a part, steps on the right path to successfully implementing a technology cooperation and transfer process? Again, revisiting the recommendations with self-evaluation in mind:

- Are we getting the process right? In that regard the conference agenda provides the opportunity to learn of technical and socioeconomic issues, explore capital and financing requirements, discuss key regulatory policies, and investigate energy resource options while at the same time, advocating the importance of letting the markets dictate technology choice. The workshops conducted during the first two days of this conference that included participation by representatives of developed and developing countries as well as the private sector were a forum for the exchange of R & D data and for increasing technical cooperation. The key criteria of the first recommendation are being achieved.
- Is the effort comprehensive? Looking again at the criteria for this principle, we can confirm that the subjects presented do cover the overall energy system and not just discrete pieces. The workshops of the first two days as well as many of the technical sessions serve to provide key aspects of each component part as well as the overall integrated system operating within the regulations that apply. However, being comprehensive also requires concentrating the effort on the high pay-out areas. These are defined (3) as the areas with the highest potential economic and environmental payoffs for a nation whether related to energy consumption or energy supply. In this regard, the 1992 World Development Report lists the following percentages in consumption of commercial energy in a sample of eight developing countries in 1988 as:

- Industry	34%
- Electricity Generation	31%
- Household and Service	21%
- Transport	14%

These figures confirm that the industrial and electricity sectors of the economy consume 65% of commercial energy. A quick review of associated studies indicates that efficiency gains of 20 to 40% may be possible in these sectors. These are the same sectors that dominate the subjects of interest in each activity that constitute our three steps. I would conclude that the work in progress is comprehensive.

- Is the process investing in people? Step two of the process, the Eastern European Training Program, was a major investment in people. It was an effort to transfer experience and not just technology. While it is an activity that shows that this criteria of a successful technology cooperation and transfer program is being satisfied, it is an activity that must be revisited and continued. It is important to plan and implement the next phase of the training program and to initiate further transfer of experience.
- Are we targeting financial assistance? This fourth recommendation, and the last, is the most difficult to apply. In most cases the administration of financial resources is not within our unrestricted control. However, absent the capability to distribute funds, the experts at these conferences have discussed the issues that dominate the acquisition and control of funds for use in implementing energy projects. Innovative financing methods, principles guiding the formulation and functioning of new business ventures as well as options to the direct use of capital are being explored. To that extent the principle is being applied.

In reviewing the correlation between the recommendations for implementing a successful technology cooperation and transfer program and the degree to which the associated criteria are satisfied by the content of the two conferences and the technical training course it is apparent that the path being followed by these activities will lead to a successful technology cooperation and transfer process.

Confirming that these activities are or will become a successful technology cooperation and transfer program is more important than establishing the success or failure of a series of what might be considered loosely connected events. Past experience has shown that technology and cooperation in the transfer of technology are critical elements in addressing concerns and attaining expectations as well as critical

elements in the implementation and functioning of successful partnerships. By confirming that the two conferences and the training course are leading to a successful technology cooperation and transfer program, we are establishing that the activity has the associated ability to address the concerns of those we seek to work with and becomes a promise that the expectations generated are real and can be attained.

This is a result that more than justifies the amount of effort each of you have made to make this conference a success.

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STREAM A
TECHNICAL ISSUES

Conventional Energy Systems I – Economic Operation of Existing Energy Systems

Session A1

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Institute for Energy
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OPTIMIZATION OF TECHNOLOGY AND BOILER CONTROL TO IMPROVE ECONOMICAL AND ENVIRONMENTAL PARAMETERS

V. Štosek
P. Neuman
V. Měchura
Z. Mašek

EGÚ Prague
Prague, Czech Republic

ABSTRACT

For cutting emissions NO_x and CO in the Czech Republic are mostly applied primary measurers. At the same time measuring and control systems are innovated. Analog control systems are replaced by digital and computer network is developed in the power energy generation.

It enables application of sophisticated information and diagnostic systems. It is shown how the EGÚ designs modification of technology equipment, measurement and control systems to increase efficiency and cut NO_x emission levels at 110 MWe units at Pruneřov power station and 200 MWe units at Tušimice before and after reconstruction are presented.

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ASH FORMATION, DEPOSITION, CORROSION, AND EROSION IN CONVENTIONAL BOILERS

Steven A. Benson, Deputy Associate Director
Michael L. Jones, Associate Director

Energy & Environmental Research Center
University of North Dakota
Grand Forks, North Dakota, USA

ABSTRACT

The inorganic components (ash-forming species) associated with coals significantly affect boiler design, efficiency of operation, and lifetimes of boiler parts. During combustion in conventional pulverized fuel boilers, the inorganic components are transformed into inorganic gases, liquids, and solids. This partitioning depends upon the association of the inorganic components in the coal and combustion conditions. The inorganic components are associated as mineral grains and as organically associated elements, and these associations of inorganic components in the fuel directly influence their fate upon combustion. Combustion conditions, such as temperature and atmosphere, influence the volatility and the interaction of inorganic components during combustion and gas cooling, which influences the state and size composition distribution of the particulate and condensed ash species. The intermediate species are transported with the bulk gas flow through the combustion systems, during which time the gases and entrained ash are cooled. Deposition, corrosion, and erosion occur when the ash intermediate species are transported to the heat-transfer surface, react with the surface, accumulate, sinter, and develop strength. Research over the past decade has significantly advanced understanding of ash formation, deposition, corrosion, and erosion mechanisms. Many of the advances in understanding and predicting ash-related issues can be attributed to advanced analytical methods to determine the inorganic composition of fuels and the resulting ash materials. These new analytical techniques have been the key to elucidation of the mechanisms of ash formation and deposition. This information has been used to develop algorithms and computer models to predict the effects of ash on combustion system performance.

INTRODUCTION

The effects of ash on the performance of conventional boilers depends upon the inorganic composition of the fuel and operating conditions. Ash in conventional power systems is known to be a major problem that results in the loss of millions of dollars annually as a result of decrease in efficiency, unscheduled outages, equipment failures, and cleaning. The many ways in which the detrimental effects of ash manifest themselves in a boiler system include fireside ash deposition, corrosion and erosion of boiler parts, and production of fine particulates that are difficult to collect. The literature on ash-related issues is immense. Overviews of ash-related issues and compilations of work by many investigators can be found by referring to the work of Couch (1994), Williamson and Wigley (1994), Benson and others (1993), Benson (1992), Bryers and Vorres (1990), and Raask (1988, 1985). There are many more reference sources too numerous to mention in this paper.

Significant advances have been made in the past ten years in understanding and improving methods to predict ash behavior in conventional combustion systems. Increased understanding comes from being better able to determine the inorganic components in the coal, ash, and slag materials. This understanding has been made possible through the development of advanced methods of coal and coal ash analysis that have been specifically tailored to characterize fuel and fuel-derived ash components (Skorupska and Carpenter, 1994, Jones and others, 1992). These advanced methods are based primarily on computer-controlled scanning electron microscopy (CCSEM), which allows for the determination of the chemical and physical characteristics of coal minerals, fly ash, and deposits. These methods provide a basis for a mechanistic understanding of ash formation and deposition and provide

information that can be used to assess corrosion and erosion of boiler parts. The ash formation and deposition mechanisms have been converted to algorithms and included in computer models to predict ash formation and deposition (Benson and others, 1993).

This paper provides an overview of analytical techniques to characterize coals and coal-ash-related materials, mechanisms of ash formation and deposition, and relationships to corrosion and erosion of boiler parts. The application of computer codes to predict coal ash deposition will also be discussed.

COAL INORGANIC COMPOSITION

The inorganic components in coals have been referred to as "mineral matter," "minerals," "inherent/extraneous ash," and other names by the many individuals who work with coal. The range of descriptions of the inorganic constituents in coal is almost as large, depending upon the perspective of the individuals describing the ash forming species. The term "inorganic components" best describes all ash-forming constituents, including both organically associated inorganic species and mineral grains. Theoretically speaking, coal does not contain ash. The inorganic part of the coal is transformed into ash during combustion.

The inorganic components in coal occur as discrete minerals, organically associated cations, and cations dissolved in pore water. The fraction of inorganic components that are organically associated varies with coal rank. Lower-rank subbituminous and lignitic coals have high levels of oxygen. Approximately 25% of the oxygen is in the form of a carboxylic acid group. These groups act as bonding sites for cations such as sodium, magnesium, calcium, potassium, strontium, and barium (other minor and trace elements may also be associated in the coal in this form). In addition, some elements may be in the form of chelate coordination complexes with pairs of adjacent organic oxygen functional groups.

Mineral grains are usually the most abundant inorganic component in coals. The major mineral groups found in coals include silicates and oxides, carbonates, sulfides, sulfates, and phosphates. In order to predict the behavior of inorganic constituents during combustion, detailed information must be obtained on the abundance, size, and association of mineral grains in the coal. In addition, the association of the mineral grain with the coal matrix must be determined and classified. A mineral associated with the organic part of a coal particle is said to be *included*. A mineral that is not associated with organic material is referred to as *excluded*. Figure 1 illustrates the associations in inorganic components in coal.

In order to determine the size, abundance, and association of mineral grains in both high- and low-rank coals, CCSEM and automated image analysis (AIA) are the preferred techniques to analyze polished cross sections of coal epoxy plugs (Steadman and others, 1991). The CCSEM technique is used to determine the size, shape, quantity, and semiquantitative composition of mineral grains in coals (Jones and Benson, 1987; Zygarić and others, 1990). Table 1 illustrates the range of mineral abundance and type for several coals from the U.S. Quantification of the type and abundance of organically associated inorganic elements in lower-ranked subbituminous and lignitic coals is currently performed by chemical fractionation (Benson and Holm, 1985). Chemical fractionation is used to selectively extract elements from the coal based on solubility, which reflects their association in the coal. Briefly, the technique involves extracting the coal with water to remove water-soluble elements such as Na in sodium sulfate or those elements that were most likely associated with the groundwater in the coal. This is followed by extraction with 1M ammonium acetate to remove elements such as Na, Ca, components remaining in the residue after all three extractions are assumed to be associated with the insoluble mineral species such as clays, quartz, and pyrite. Table 2 summarizes the results obtained from the analysis of a lower rank coal that contains high levels of organically associated cations.

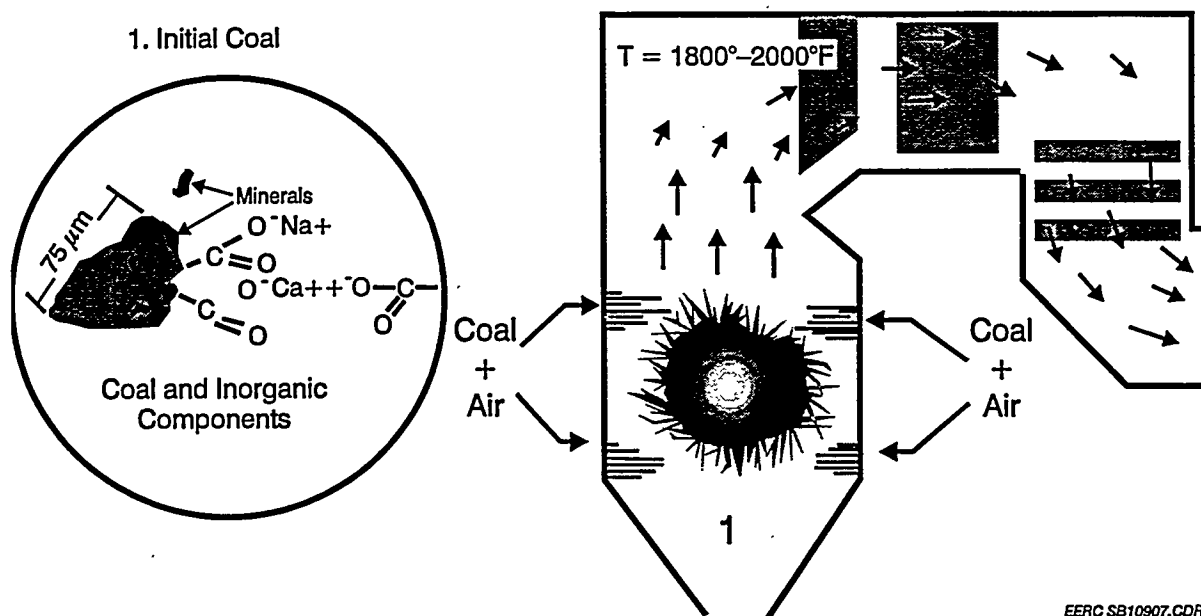


Figure 1. Associations in inorganic components in coal.

ASH FORMATION

The inorganic coal components undergo complex chemical and physical transformations during combustion to produce ash in the form of vapors, liquids, and solids sometimes referred to as "intermediates." The partitioning of the inorganic components during combustion to form ash intermediates depends upon the association and chemical characteristics of the inorganic components, the physical characteristics of the coal particles, the physical characteristics of the coal minerals, and combustion conditions. Coal composition and combustion conditions directly influence the size and composition of intermediate ash species; the size and composition of the intermediate ash species directly influence slagging, fouling, corrosion, and erosion problems in combustion systems.

The physical transformation of inorganic constituents depends upon the inorganic composition of the coal and combustion conditions. The inorganic components illustrated in Figure 1 can consist of organically associated cations, mineral grains that are included in coal particles, and excluded mineral grains. There is a wide range of combinations of mineral-mineral, mineral-coal, mineral-cation-coal, and mineral-mineral-cation-coal associations in coal. These associations are unique to each coal sample. The physical transformations involved in the formation of ash intermediates illustrated in Figure 2 include coalescence of individual mineral grains within a char particle, shedding of the ash particles from the surface of the chars, incomplete coalescence owing to disintegration of the char, and convective transport of ash from the surface of burning char. The transformations of the included mineral grains depend upon the combustion characteristics of the char particle. During combustion, most of the nonvolatile inorganic species remain with the char. A very small amount of ash is found associated with the volatiles (Sarofim and others, 1977). Therefore, the mode of char combustion influences the mechanism of fly ash formation. The size distribution of the resulting fly ash is multimodal (Sarofim and others, 1977; Benson and others, 1993; Kauppinen, 1992).

TABLE 1

Distribution of Minerals in Selected U.S. Coals as Determined by CCSEM Analysis (wt% mineral basis)

Mineral	U.S. Lignite					U.S. Western Subbituminous					U.S. Eastern Bituminous				
	Maximum (Wt %)	Minimum (Wt %)	Average (Wt%)	Standard Deviation (Wt%)		Maximum (Wt%)	Minimum (Wt%)	Average (Wt%)	Standard Deviation (Wt%)		Maximum (Wt%)	Minimum (Wt%)	Average (Wt%)	Standard Deviation (Wt%)	
Quartz	40.4	12.4	22.7	10.6		60.9	17.3	33.3	14.6		18.1	13.2	15.2	1.7	
Iron oxide	1.8	0.4	1.1	0.7		1.7	0.0	0.5	0.5		2.6	0.0	0.9	0.9	
Periclase	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	
Rutile	1.2	0.1	0.7	0.4		4.9	0.1	1.1	1.4		0.6	0.0	0.2	0.2	
Alumina	0.5	0.0	0.1	0.2		0.2	0.0	0.0	0.1		0.3	0.0	0.1	0.1	
Calcite	12.7	0.1	3.4	5.4		11.2	0.0	1.7	3.3		9.5	0.0	3.1	3.7	
Dolomite	0.1	0.0	0.0	0.0		0.2	0.0	0.0	0.1		2.9	0.0	0.5	1.1	
Ankerite	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	
Kaolinite	45.9	3.7	18.9	16.6		51.1	10.9	28.6	13.3		22.7	11.2	14.9	3.7	
Montmorillonite	5.9	0.1	2.0	2.3		21.6	0.2	5.4	6.2		8.0	1.7	4.5	1.9	
K-Al-Silicate	3.9	0.1	2.0	1.7		4.1	0.5	2.5	1.2		27.4	9.2	14.0	6.3	
Fe-Al-Silicate	0.4	0.1	0.2	0.1		1.0	0.0	0.2	0.3		12.0	0.1	2.6	4.3	
Ca-Al-Silicate	6.0	0.2	2.0	2.3		2.9	0.2	1.4	0.9		3.6	0.0	0.7	1.3	
Na-Al-Silicate	0.2	0.0	0.1	0.1		0.1	0.0	0.0	0.0		0.5	0.0	0.1	0.2	
Aluminosilicate	4.1	0.2	1.7	1.5		10.4	0.2	2.3	2.9		3.5	0.9	1.8	0.9	
Mixed Al-Silica	0.3	0.0	0.1	0.1		1.3	0.1	0.5	0.3		2.9	0.0	0.8	1.0	
Fe-Silicate	0.0	0.0	0.0	0.0		0.1	0.0	0.0	0.0		0.4	0.0	0.1	0.1	
Ca Silicate	0.3	0.0	0.1	0.1		0.3	0.0	0.1	0.1		0.6	0.0	0.1	0.2	
Ca Aluminate	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	
Pyrite	58.9	1.8	27.0	21.0		12.3	2.6	7.2	3.1		35.9	0.0	23.2	13.0	
Pyrrhotite	3.0	0.1	0.8	1.3		0.5	0.0	0.1	0.1		0.5	0.0	0.2	0.2	
Oxidized Pyrrho.	2.7	0.1	0.8	1.1		0.1	0.0	0.0	0.0		2.0	0.0	0.6	0.7	
Gypsum	3.5	0.0	1.2	1.4		0.1	0.0	0.0	0.0		5.8	0.0	1.7	1.9	
Barite	7.0	0.7	4.3	2.3		2.5	0.0	1.2	0.9		0.0	0.0	0.0	0.0	
Apatite	0.0	0.0	0.0	0.0		0.8	0.0	0.2	0.3		0.1	0.0	0.0	0.0	
Ca-Al-P	5.6	0.4	2.1	2.1		12.6	0.1	5.5	4.3		0.0	0.0	0.0	0.0	
KCl	0.0	0.0	0.0	0.0		0.1	0.0	0.0	0.0		0.0	0.0	0.0	0.0	
Gypsum/Barite	0.1	0.0	0.1	0.0		0.4	0.0	0.1	0.1		0.0	0.0	0.0	0.0	
Gypsum/Al-Silic.	1.0	0.1	0.4	0.3		1.1	0.0	0.4	0.4		0.5	0.0	0.2	0.2	
Si-Rich	3.0	1.3	2.0	0.6		5.7	0.1	2.0	1.5		3.9	1.8	2.7	0.7	
Ca-Rich	1.6	0.0	0.5	0.7		0.3	0.0	0.0	0.1		0.5	0.0	0.3	0.2	
Ca-Si-Rich	0.0	0.0	0.0	0.0		0.1	0.0	0.0	0.0		0.2	0.0	0.1	0.1	
Unknown	7.1	4.4	5.7	1.0		13.6	2.2	5.6	3.3		22.1	3.8	11.7	6.4	

TABLE 2

Chemical Fractionation Results for a Selected Subbituminous Coal Composite					
Element	Initial ($\mu\text{g/g}$)	Removed H_2O , %	Removed HN_4OAc , %	Removed HCl , %	Remaining, %
Silicon	11,211	7	16	0	77
Aluminum	8312	6	0	43	51
Iron	2795	15	0	42	43
Titanium	841	4	20	12	64
Phosphorous	765	16	33	51	0
Calcium	12,427	7	70	22	2
Magnesium	3257	13	72	10	5
Sodium	416	100	0	0	0
Potassium	175	8	0	0	92

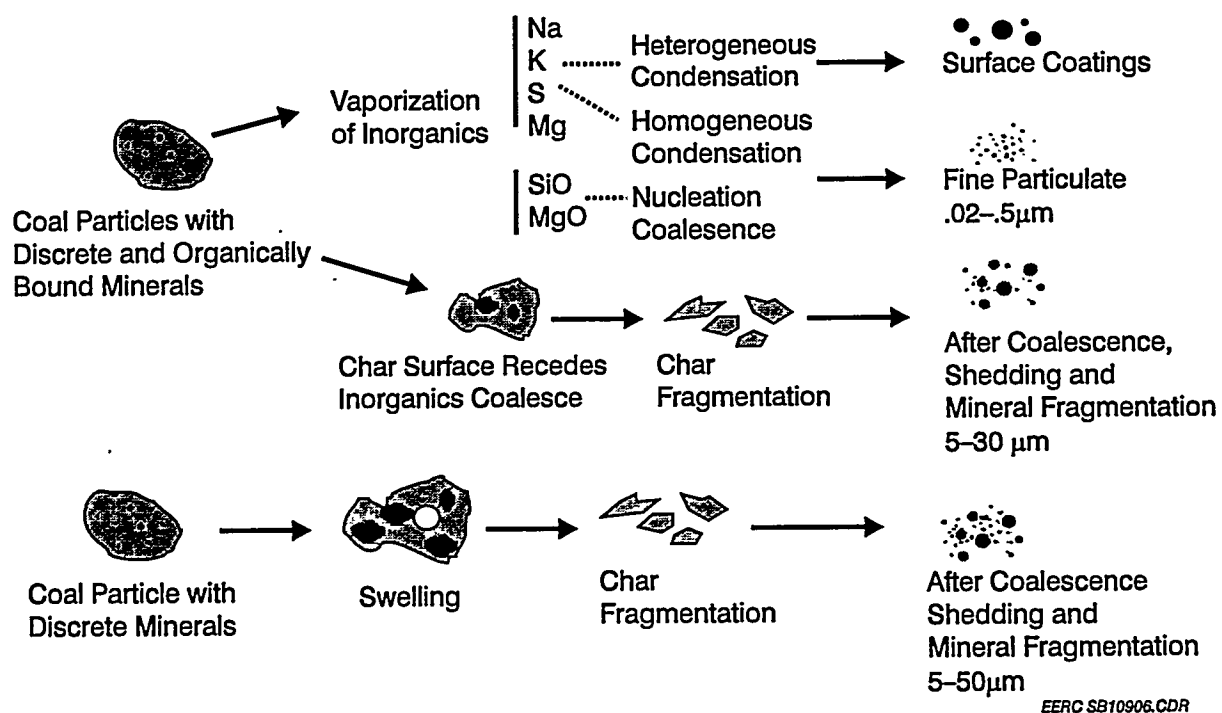


Figure 2. Mechanisms of ash formation.

The inorganic constituents may exhibit two extreme behaviors during combustion: one case is that each mineral grain forms one ash particle; the second is that one ash particle is formed per coal particle. This was the approach taken by Field and others (1967). The differences exhibited for different coals are likely related to char characteristics. For example, the formation of one fly particle per mineral grain may be exhibited for coal particles that swell and become hollow and porous during combustion. The degree of swelling is likely dependent upon coal composition or maceral distribution and combustion conditions. A highly vesicular char particle is likely to burn by several expanding combustion fronts, causing disintegration of the char particle, thus producing smaller char particles. Ash particles have sufficiently high surface tension on the char particles and do not wet the surface. Depending upon the distribution of minerals and other inorganic components, there may be little or no coalescence. Therefore, the ash particles may be similar in size to the original minerals in the coal, producing one ash particle per mineral grain. In the case of the formation of one fly ash particle per coal particle, coalescence of mineral grains plays a significant role. Coalescence is significant for nonswelling coal particles that burn as a shrinking sphere. The shrinking sphere model would produce one fly ash particle per coal particle. Limiting cases can be defined for fly ash particle-size evolution. These cases include a fine limit and a coarse limit (Loehden and others, 1989). The fine limit is the case where each mineral grain forms a fly ash particle. The coarse limit is where each coal particle forms a fly ash particle. In most cases, the actual fly ash size falls between these limits. In cases where mineral fragmentation occurs, the fine limit on size is exceeded. In addition, shedding or convective transport of small ash particles originating from organic associations or submicron mineral grains can also contribute to fine particle formation.

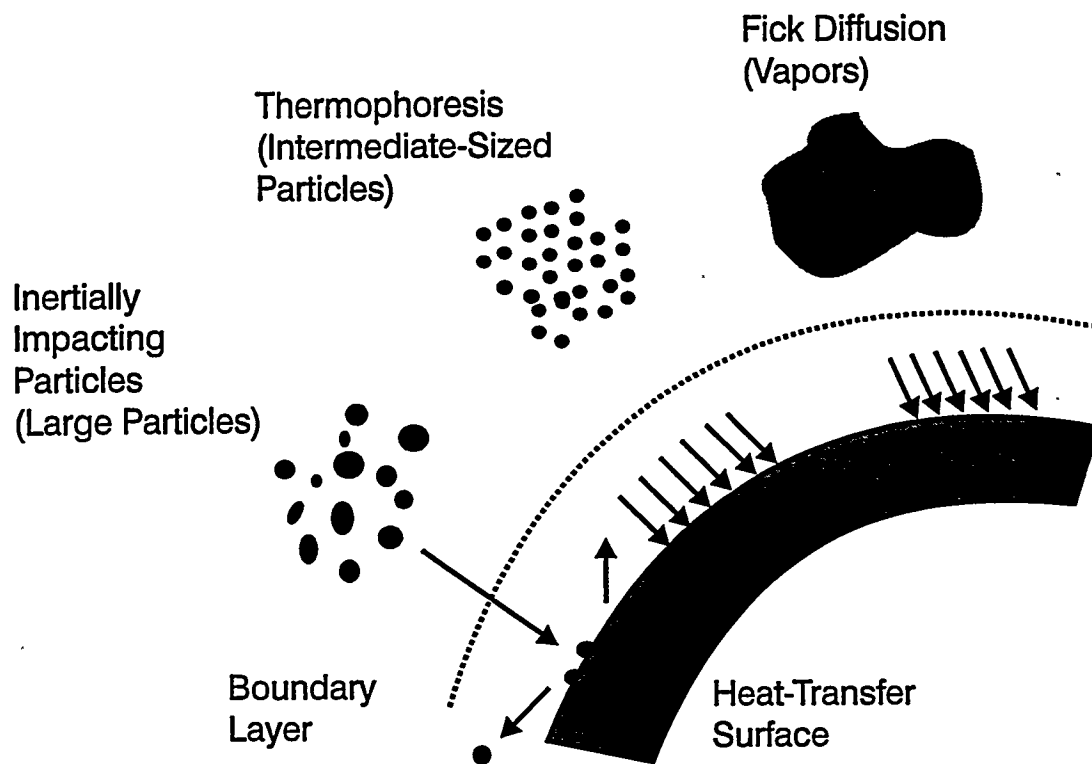
Vaporization and condensation of inorganic elements contribute to the formation of fine particulate when the vapors condense homogeneously. In addition, these vapors can condense on surfaces of entrained ash particles and ash deposits, producing low melting point phases. The volatility of an inorganic species depends upon coal particle temperature, relative volatility of the species, and the form of the element in the coal. During the combustion of a coal particle, the atmosphere surrounding the particle contains reducing and oxidizing zones that can influence the volatility of an element. Near the surface of the particle, reducing conditions in the gas phase are expected because of the burning of the carbon material. The reducing condition produces more volatile reduced species than would occur under oxidizing conditions.

In lower-rank lignitic and subbituminous coals, organically associated inorganic elements such as sodium, calcium, magnesium, and potassium have the potential to vaporize during combustion. The evidence for vaporization and condensation of sodium and potassium is abundant. The reactions of calcium and magnesium are less clear. During combustion of the coal and char particle, a boundary layer at the surface of the particle is highly reducing. This zone may be sufficiently low in oxygen to allow for the vaporization of calcium and magnesium. If the calcium and magnesium were to vaporize, it is likely that once they reach an environment that contains some oxygen ($\approx 3\% \text{ O}_2$) they would rapidly oxidize, producing submicron particulates.

ASH DEPOSITION

The transport of intermediate ash species (i.e., inorganic vapors, liquids, and solids) is a function of the state and size of the ash species and system conditions such as gas flow patterns, gas velocity, and temperature. Several processes are involved in the transport of ash particles. These processes have been described by Raask (1985) and Rosner and others (1986). The primary transport mechanisms are illustrated in Figure 3. The small particles ($<1 \mu\text{m}$) and vapor-phase species are transported by vapor-phase and small-particle diffusion. These species are characteristically rich in flame-volatilized species that condense upon gas cooling in the bulk gas or in the gas boundary layer next to the tube.

The mechanism of ash particle transport in the intermediate size range of particles as illustrated in Figure 3 is that of thermophoresis. Thermophoresis is a transport force that is produced as a result of a temperature gradient in the direction from hot to cold. This transport mechanism is important for particles $<10 \mu\text{m}$. Electrophoresis is another transport mechanism that may be important with respect to the formation of deposits. The initial deposit layers are more pronounced when firing a coal that produces an abundance intermediate- and small-sized particles.



EERC SB10919.CDR

Figure 3. Primary ash transport mechanisms to heat-transfer surfaces in utility boilers (Benson, and others, 1993).

Coals that produce an abundance of fine particles characteristically contain low levels of mineral grains and high levels of organically associated inorganic components. The initial white-colored layer formed on all sides of the tube are less than 5 μm in diameter. The massive deposit on the upstream side of the tube is a result of particles greater than 5–10 μm transported to the surface by inertial impact. Inertial impact accounts for the bulk of the deposit growth. Particles that inertially impact have sufficient inertial momentum to leave gas stream lines and impact the tube. For small particles, the drag effect will be great enough to change the direction of the particles, allowing them to flow past the tube. The chances of a particle impacting a surface depend upon inertial momentum, drag force on the particle, and position in the flow stream. Gas velocity has a significant effect on the size of ash particles that will impact the surface. For example, in a gas turbine with a gas velocity on the order of 100 m/s, particles with diameters greater than 1 μm will impact. In typical utility boilers, the gas velocity is 10–25 m/s, and particles with diameters of 5–10 μm will impact.

The characteristics of a deposit depend upon the chemical and physical characteristics of the intermediate ash species, geometry of the system (gas flow patterns), gas temperature, gas composition, and gas velocity. Deposits that form in the radiant section, called "slag deposits," are illustrated in Figure 4. Deposits that form in the convective pass on steam tubes are called "fouling deposits" (Figure 5). Slag deposits are usually associated with a high level of liquid-phase components and are exposed to radiation from the flame. Slag deposits are usually dominated by silicate liquid phases, but may also contain moderate-to-high levels of reduced iron phases. In addition, the initiating layers of slag deposits may consist of very fine particulate that can produce a reflective ash layer. Fouling deposits form in the convective passes of utility boilers and, in most cases, do not contain the high levels of liquid phases that are usually associated with slagging-type deposits. The fouling deposits contain low levels of liquid phases, usually consisting of a combination of silicates and sulfates that bind the particles together. The formation of these deposits on heat-transfer surfaces can significantly reduce heat transfer. Heat transfer through a deposit is related to the temperature, thermal history, and physical and chemical properties of

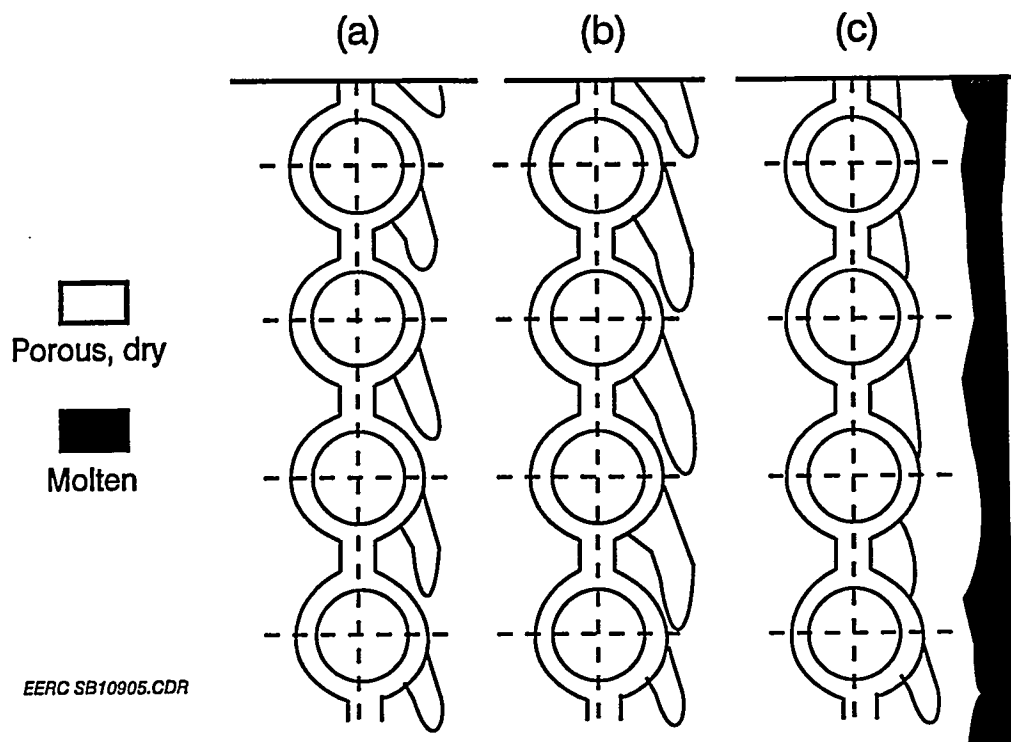


Figure 4. Waterwall slag deposit (Couch, 1994).

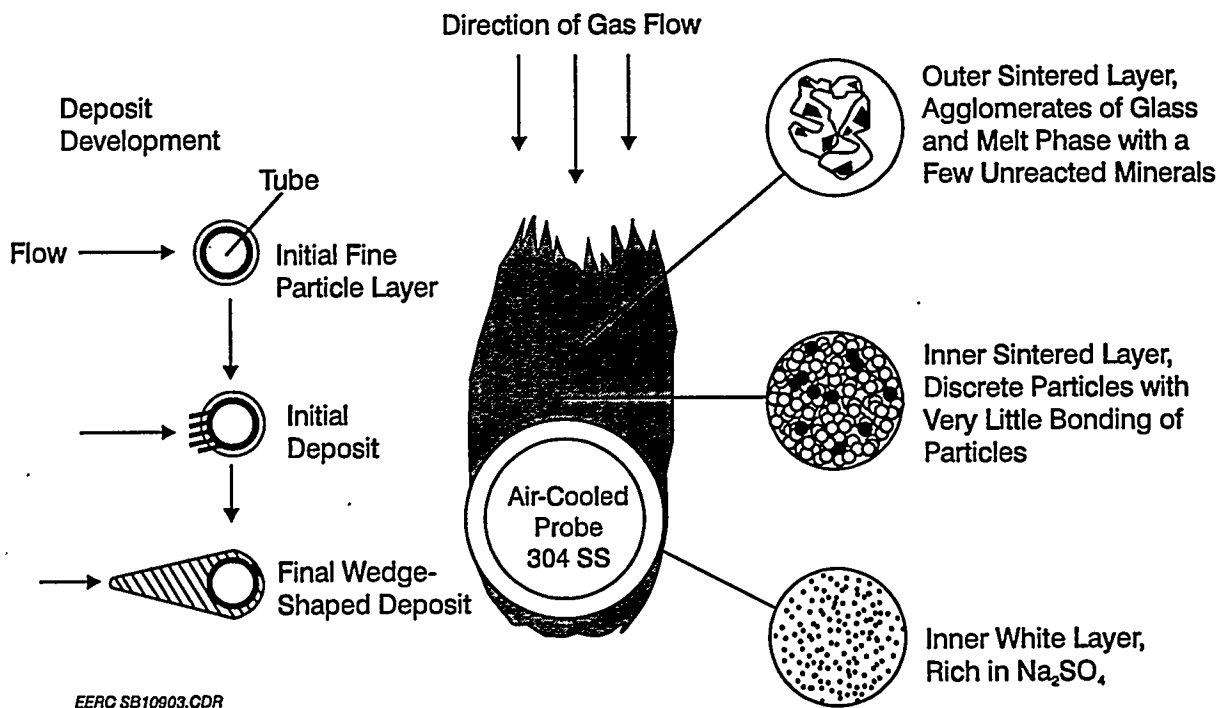


Figure 5. Convective pass fouling deposit (Couch, 1994).

the deposited material. Heat transfer through a deposit of a given thickness is affected by thermal conductivity, emissivity, and absorptivity.

EROSION

Erosion of boiler fireside heat-transfer surfaces is dependent upon coal composition and system operating conditions. Fireside surfaces are exposed to the transport of particulate and gaseous species carried with the flue gas through the system. Wastage of metal occurs by two primary mechanisms: erosion and corrosion. In the case of erosion, coal mineral properties have been related to sliding abrasion wear and particle impaction wear (Raask 1988). The particle properties that influence erosion include size, density, shape, hardness, and cohesive strength (fragmentation upon impact). System characteristics and operating conditions such as gas flow patterns and velocity influence particle trajectories, impaction efficiencies, and impaction angle; gas and metal temperatures; calorific value; and load conditions. Relationships have been developed by Raask (1988) to predict erosion. The abrasion index (AI) has been found to be related to the quartz content (coal basis) of the coal, q , pyrite content (coal basis) of the coal, p , and the ash content, a .

$$AI = q + 0.5p + 0.2a \quad [\text{Eq. 1}]$$

The extent of damage to fuel-handling and combustion equipment is dependent upon the mass flow rate of coal through the system as well as the characteristics of the coal. The wear propensity, W_p , is written in the form

$$W_p = AI \times M \quad [\text{Eq. 2}]$$

where M is the coal mass feed rate to the system. Erosion rates, W_e , (Creelman and others, 1994) can be determined by

$$W_e = I_a C V^{3.5} \quad [\text{Eq. 3}]$$

where I_a is the erosion index, C is the concentration of ash particles in the gas stream at the point at which erosion takes place, and V is the velocity. The erosion index, I_a (Raask 1985) is defined as

$$I_a = (x_1 + 0.5)I_g + (x_1 q_1 + 0.5 x_2 q_2)I_q \quad [\text{Eq. 4}]$$

where I_a , I_g , and I_q are the erosion index for ash, spherical glass fly ash, and quartz particles; x_1 and x_2 are the weight fractions of ash in the $>45\mu\text{m}$ and 5- to $45\mu\text{m}$ ash size fractions; and q_1 and q_2 are the quartz contents in those fractions.

PREDICTING ASH BEHAVIOR

Assessing Ash Behavior

Three scanning electron microscope/electron microprobe analyses (SEM/EMPA) techniques—computer-controlled scanning electron microscopy (CCSEM), scanning electron microscopy point count (SEMPC), and automated image analysis (AIA)—are presently used in ash behavior research of combustion and gasification systems at the Energy & Environmental Research Center (EERC) (Jones, and others, 1992). These techniques permit the study of transformations of inorganic constituents from the initial stages of coal conversion through the transformations that occur during ash deposition and slag formation. Their specific applications include 1) determination of the size, composition, and association of minerals in coals; 2) determination of the size and composition of intermediate ash components; 3) determination of the degree of interaction (sintering) in ash deposits; and 4) identification and quantification of the components of ash deposits and slags, including liquid-phase composition, reactivity, and crystallinity. By using SEM/EMPA for coals throughout all stages of utilization a continuity of data is achieved.

Advanced Indices

The EERC has derived indices that rank low-rank coals according to their fouling propensity in utility boilers (Weisbecker and others, 1992). The approach taken was to gain a very complete inorganic characterization of discrete minerals and organically associated inorganic components from advanced methods of analysis, including CCSEM and chemical fractionation a characterization of their relationship to ash behavior was developed for full-scale systems. Full-scale boiler performance was based on the general degree of fouling and the ability of the unit to maintain load. An index was derived that correlates certain applicable parameters of the inorganic composition and the general performance or experience at the full-scale utility boiler. The usefulness of these indices has been demonstrated by their repeated use by several utilities in the midwest United States that are screening Powder River Basin coals for use in their coal-fired boilers. A low-temperature index has been developed that pertains more to fouling that would occur in lower-temperature regions of a boiler, such as in the primary superheater or economizer. A high-temperature index has been formulated that pertains to fouling in higher-temperature zones, such as in the secondary superheater or reheater.

Ash Particle-Size and Composition Distribution

A computer model entitled ATRAN (ash transformations) was developed to predict the particle-size and composition distribution (PSCD) of ash produced during the combustion of coal (Zygarlicke and others, 1992; Benson and others, 1992). This technique uses advanced analytical characterization data, boiler parameters, and a detailed knowledge of the chemical and physical transformations of inorganic components during combustion to predict the PSCD of the resulting ash. The PSCD of the ash directly impacts deposit growth, deposit strength development, and ash collectability.

The PSCD of the ash is predicted from the abundance and distribution of the inorganic components in the coal. Bulk ash analysis, CCSEM, and ultimate analysis are used to characterize the coal. The resultant balance provides the compositions of the minerals with their associations to the coal, organically associated constituents, and submicron particles. The discrete minerals are represented by a database (size and composition) of individual particles as determined from the CCSEM analysis, while the organically associated and submicron constituents are represented by a bulk composition analysis only. The discrete minerals are further divided into locked and liberated species.

The ATRAN code allows for the fragmentation and coalescence of minerals. Vaporization, condensation of volatile organically and mineral-associated inorganic components with the mineral grains. The three resultant data sets—locked fly ash, liberated fly ash, and submicron fly ash particles—are characterized and combined on a mass basis, producing the resultant particle-size and composition distribution of the ash.

Ash Deposition

LEADER (Low-Temperature Engineering Algorithm of Deposition Risk) is a computer code designed to predict low-temperature fouling potential of a coal based on analysis of the inorganic components of the coal, boiler design, and firing rate (Hurley and others, 1991). The code requires specific inputs about the amount and associations of the inorganic components in the coal. The CCSEM and chemical fractionation, along with the standard ash composition and proximate-ultimate data, are used as inputs. The code first determines the ash size and composition distributions using the ATRAN code. These distributions are then used to determine the deposition rate of the upstream inner layer and downstream deposits; strength development in these deposits; and the loss of heat-exchange efficiency because of the deposits. The deposition rates are a function of the particle-size distribution of the ash and of the gas velocity and temperature. Strength development rate is a function of the composition of the deposited ash. Heat-exchange efficiency loss is a function of deposit depth and thermoconductivity. The deposit growth and strength development rates are also expressed as a shedding index (SI) equal to the ratio of the deposition rate and strength development rate.

SUMMARY AND CONCLUSIONS

Ash deposition on heat-transfer surfaces has been examined for many years and has resulted in voluminous literature on the subject. However, a precise and quantitative knowledge of the chemical and physical transformations of the inorganic components in coal during combustion has not been obtained because of the inability to quantitatively determine the inorganic composition of coal and to understand the complexity of the processes involved. At present, accurate prediction of the fate of the inorganic constituents during combustion as a function of coal composition and combustion conditions is not possible using currently accepted methods of analysis. For example, the composition of the coal ash produced under American Society for Testing and Materials (ASTM) ashing conditions is used in most methods as a crude guide to predict the behavior of inorganic constituents of a specific coal during combustion. The ashing technique can be used to predict average properties of the ash since all the inorganic components are combined and allowed to interact during the ashing process. However, examination of fly ash shows that many different types of particles are present, each having its own composition and probably its own melting behavior. The wide variation of fly ash types is related to the wide variability in the abundance and distribution of inorganic constituents in the coal.

The extent of ash-related problems depends upon the quantity and association of inorganic constituents in the coal and upon combustion conditions. The inorganic constituents are distributed within the coal matrix in several forms, including organically associated inorganic elements; coal-bound, included minerals; and coal-free, excluded minerals. The types of inorganic components depend upon the rank of the coal and the environment in which the coal was formed. Low-rank coals contain higher levels of organically associated cations. Low-rank subbituminous and lignitic coals contain high levels of oxygen that can act as bonding sites for various cations. Approximately 25% of the oxygen is associated as carboxylic acid groups. These groups can act as ion exchange sites for cations such as sodium, calcium, magnesium, potassium, strontium, and barium. Higher-ranked coals do not contain high levels of organically associated inorganic elements because of the lower levels of oxygen. The primary mineral groups that are found in all coals consist of clay minerals, carbonates, sulfides, oxides, and quartz.

During combustion, the inorganic materials are transformed into inorganic gases, liquids, and solids. As discussed above, these species are referred to as intermediates. Studies of the final ash product (fly ash) indicate a multimodal size distribution. The submicron-size particles form as a result of homogeneous condensation of flame-volatilized species. Flame-volatilized species may also condense heterogeneously on the surfaces of larger particles. The larger particles, sometimes referred to as residual ash, are largely derived from mineral grains. The composition and size distribution of the larger particles result from transformations or interactions between discrete mineral grains in higher-rank coals. In lower-rank coals, the interaction of the organically associated elements with mineral grains occurs as well as mineral-mineral interactions. Processes such as ash mineral coalescence, partial coalescence, ash shedding, and char fragmentation during char combustion and mineral fragmentation all play an important role in the size and composition of the final fly ash.

The accumulation of ash particles on heat-transfer surfaces depends upon the ability of the particles to be transported to and form strong bonds with the heat-transfer surface. The transport mechanics for submicron particles to the surfaces include diffusion, thermophoresis, and electrophoresis. Larger particles are transported to the surface by inertial impaction. The formation of the strong bond depends upon the characteristics of the reacted layers on the steel surface (formation of the reacted layers depends upon the type of steel and the ash characteristics); temperature of the steel surface; melting behavior of the ash particles; and the thermal and chemical compatibility of the deposit and steel surface (surface layers of steel/residual ash). Once a strongly bonded surface layer has accumulated, the temperature of the surface can act as a collector of impacting ash particles. In addition, the deposited ash particles can react with gas-phase inorganic species. The formation of an interconnected liquid phase at the surfaces of a newly formed deposit may be accelerated, depending upon the reactivity of the molten phases with the solid phases.

The chemical and physical characteristics of deposits found in utility boilers vary widely. In general, deposits are microscopically highly heterogeneous. Under a microscope, the deposits consist of pores, unreacted ash particles, a liquid-phase matrix material that bonds the deposits together, and crystalline material. The types of phases responsible for the liquid-phase components are temperature-dependent

owing to the stability of the chemical species. For example, higher-temperature deposits contain high levels of silicate phases that bond the deposit together. Lower-temperature deposits that form in the convective passes of utility boilers have high levels of sulfate phases that bond the particles together. The heterogeneity changes with temperature and location in the boiler. High-temperature deposits usually contain more liquid matrix material, depending upon the composition of the ash particles. Typically, the deposits found in the radiant section of the utility boiler are more homogeneous as a result of assimilation of particles into a liquid phase. These deposits are primarily silicate-based, and the physical characteristics of the deposit are dictated by the physical and chemical properties of the silicate liquid phases. Iron-rich phases including silicates, sulfides, oxides and metallic iron also contribute to the formation of slag deposits. As temperatures decrease, the degree of assimilation or melting of the deposited material decreases. In addition, the participation of the silicate phases to bond the deposit together decreases.

At lower temperatures, the sulfate bonding mechanism becomes a factor in deposit formation. This is a problem characteristic of convective pass fouling problems when firing coals that contain high levels of alkali and alkaline-earth elements. Two primary types of fouling mechanisms have been defined: a high-temperature fouling, where silicates dominate, and a low-temperature fouling, where sulfates dominate. In high-temperature fouling deposits, the bonding mechanism is primarily silicate, but some participation of sulfate bonding may occur at the deposit-tube interface. In low-temperature fouling, the bonding mechanism is sulfate. Silicate-rich fly ash particles are present in the deposit, but are bonded together with sulfate-based phases.

The methods used by the utility boiler operator to alleviate poor heat transfer caused by the accumulation of ash deposits, in most cases, include sootblowing and load drop. The effects of coal composition and operating conditions on the frequency of sootblowing and the extent of load drop need to be effectively predicted. Poor heat transfer can be predicted using a model that is sensitive to coal properties, operating conditions, and system geometry. These models need to predict coal-specific behavior that aids in selecting coal operating conditions.

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BOILER-TURBINE LIFE EXTENSION

Dipl.eng. Strahil Natzkov

TOTEMA Ltd.
Sofia, Bulgaria

Dipl. eng. Marko Nikolov

CERB
Sofia, Bulgaria

ABSTRACT

The design life of the main power equipment – boilers and turbines is about 10⁵ working hours. The possibilities for life extension are after normatively regulated control tests. The diagnostics and methodology for Boilers and Turbines Elements Remaining Life Assessment using up to date computer programs, destructive and nondestructive control of metal of key elements of units equipment, metal creep and low cycle fatigue calculations. As well as data for most common damages and some technical decisions for elements life extension are presented.

PRESENTATION

TP built in Bulgaria mainly in the period of 70's are designed according to the existing for the period norms of about 10⁵ working hours. During operation under the influence of temperature, time and tension, in the metal take place processes of structure and phase conversions, resulting as a rule in reducing its strength and plastic characteristics. The rate and the degree of losing its properties are defined by many factors, but the main of them are: operating parameters, cyclic tension, metal structure and its properties. Besides the design coefficient of assurance for different heat equipment make it usable beyond its design period of operation. For that reason it is necessary to perform observations and closely examinations of the metal after 10⁵ hours of operation in order to define its remaining life, ensuring operation reliability.

On other hand the fuel balance of the country and the new ecological requirements determine the necessity of respective reconstructions and rehabilitation of key equipment for economically expedient period of operation (about 15-20 years more). This requires to determine the capabilities and conditions for prolonging the main equipment life to 200.10³ hours of operation. The criterion for wearing and for the actuality of rehabilitation of TP is the remaining life of the key equipment as their damage requires long time for changing and is quite expensive, on one hand and it causes dangerous effect on safety operation on other hand.

Such elements are: drum, piping, headers and elbows in the boiler area, the main piping, the housing of the turbine valves, the high and medium pressure cylinders and the rotors of the turbine.

The determination of the remaining life for the heat equipment is done for each one according to the following scheme of investigation:

- nondestructive control and geometrical measurements;
- examination of the metal and laboratory strength examinations;
- limit and creep strength examinations;
- strength calculations for determining the maximum operative stress;
- determination of the remaining life.

The nondestructive control is done in order to find out if any cracks or other inadmissible defects of metallurgical or operational character are available. The geometry measurements (thickness, residual

deformations, oval, form of the cross-section and so on) are necessary as initial data for the strength calculations.

Examination of metallographic micro structure is also done with portable microscopes and metallographic impresses in their capacity of nondestructive methods.

Some authors propose direct remaining life evaluation according to nondestructive methods at the place where the equipment is situated. Such is the case of quantity and position determination of micro pores at the edge of the grains, formed as result of creeping. The results obtained by such examinations, are not directly used, because we are not convinced enough, that they are correct.

According to remaining life evaluation method by means of the available pores dew to creeping, when they are connected in micro cracks, the element is to be scraped. The experience shows that some deeper cleaning or even second polishing when the reducing of the thickness is less than 0.1 mm is enough these "micro cracks" to disappear completely. It is an example of prematurely scraping of an element, what in fact has any remaining life. Of coarse we are not rejecting the possibility of new micro cracks dew to creep in conditions of high temperature operation to appear in the metal. The doubts are about the possibility to determine the remaining life only by means of nondestructive metallographic analysis.

The main aim of the on spot metallography in our praxis is the state analysis and evaluation of the changes of the metal structure as a result of long operation. The long experience in low-alloy heat-resisting steel examinations allow us to predict with quite good accuracy the passing strength properties as a result of micro structural investigations.

Information for the passing state and mechanical properties of the separate details is obtained by: visual and endoscope inspection, penetrating test detection, magnetic-particle flaw detection, magnetic-luminescence flaw detection, ultrasonic flaw detection, hardness measurement by portable hardometers and in the present moment we are gathering statistic data to determine the mechanical properties for some steels by means coercitive force. These methods are quite necessary for the right choice of control samples for laboratory testing.

The laboratory tests we carry out, consist in determining the chemical composition and comparing it with the design steel chemical composition. In many cases phase composition (carbide) analysis is carried out in order alloy elements quantitative redistribution between the matrix and the carbide phases to be specified. These processes influence the heat resisting capabilities of the low-alloy steel.

Metallographic analysis of the structure is done for all laboratory tests. The evaluation is done by comparing with standard structures. If such standard structure is not available for a definite kind of steel, the evaluation is done by the previous laboratory experience. The metallographic tests in laboratory conditions allow closely examinations to be carried out with structural observation along the whole cross-section of the detail, including observation about presence of micro-pores along the inside and outside surfaces. Out of the comparison between the longitudinal and cross-section specimens might be evaluated the possible anisotropy in the strength properties of the metal. Special attention is paid to contamination with nonmetal substances and for only Mo-alloyed steels - for graphitization. The analysis of the metallographic results allows to explain the reasons for changes in the mechanical and heat-resisting properties and because of that during final evaluation of the remaining life of the heat equipment elements it is necessary to take the structure state of metal into account.

The results of short-term mechanical testing under standard and high temperature give direct information about the strength and plastic properties of the metal. That is why they are carried out each time when it is possible to work out test samples. The evaluation is done by comparison with the required for the definite type of steel standard parameters and also with data obtained for similar equipment. Decision for long-term testing is taken on the basis of total evaluation of all the indicators after the nondestructive control and the laboratory tests are carried out. The short-time strength properties under operating temperature are used to define the loading during long-term strength and creep testing.

During key equipment remaining life evaluation ALGOR software is used, based on finite elements method. Figure 1 shows as an example elbow <F128M><217><F255D> 273x25 from main piping of a boiler, with maximum oval 9% and operating pressure 10 MPa and operating temperature - 540°C. The calculated maximum reduced stress is 10 MPa. In the case the maximum reduced stress is compared with the permissible for the kind of steel used and decision for the remaining life is taken.

The support system is of great significance for the remaining life of the pipings. System that is not correctly designed might create great compensation stress. In the case again we use ALGOR software to calculate the deformation, loading and the stress in each point of the piping for a definite type of loading.

We have done the evaluation of 45 main pipings, 7 turbines and 5 drums according to the above scheme. For some of them there were some limit conditions as decreasing the operation parameters, cycles, rate of heating and nondestructive control in shorter than the standard terms.

For the predominant part of the equipment the remaining life evaluation is not final and would be subjected to any correction after carrying out of the necessary testing. That is due to the fact that the norms allow us to prolong the remaining life maximum with 50000 hours for each test, although the calculated wearing for most of the key equipment being in operation for 10^5 hours and without any defects in the process of testing is approximately 50%.

The praxis shows that the most common cases are:

Turbine rotors

Cracks in the thermal channel of the labyrinth and diaphragm sealing. Figures 2 and 3 show such an example. The cracks due to thermal fatigue in the zone of stress-raisers. The cracks are entirely removed by reborring and then calculation is done to obtain the new reduced stress. Thus the period of operation of the turbine is prolonged.

Turbine casing

Cracks along the inside surface of the valve box inlet of the turbine casing. The cracks dew to high operating stress and thermal fatigue, derive from casting defects - figure 4. The defects are entirely removed and further a repair by means of restoring stress. The turbine is in operation now.

Superheater headers

Cracks along the whole inner surface of the headers and also along the edges of the openings - figures 5 and 6. The cracks are of operational character. The conclusion is to start using temporary but in conditions of often testing before their change.

Sprays

Cracks along the inner surface of the headers, the edges of the openings and the protective casing - figure 7. The reason for the cracks is thermal fatigue and shock dew to damage of the spray device, the water handling tube or the spray nozzle. The spray header is changed and the spray device is changed and improved.

Steam gathering chambers

Cracks along the inner surfaces and along the edges of the openings as a result of high operating stress and exceeding the operation temperature - figures 8 and 9. The steam gathering box is changed to new one. The thermal and stress conditions are improved by equalizing the steam temperatures and by increasing the wall thickness.

As a result of the testings carried out and out of the experience up to now, it might be said that there are real possibilities by partial change, carrying out a definite repair works and satisfying definite conditions to prolong the life of key heat equipment - boilers and turbines - to approximately 180.10^3 - 200.10^3 operating hours. This possibility determines the expedience of carrying out of simultaneous reconstructions and modernization in TP with a view to the new ecological requirements and the structure of fuel balance.

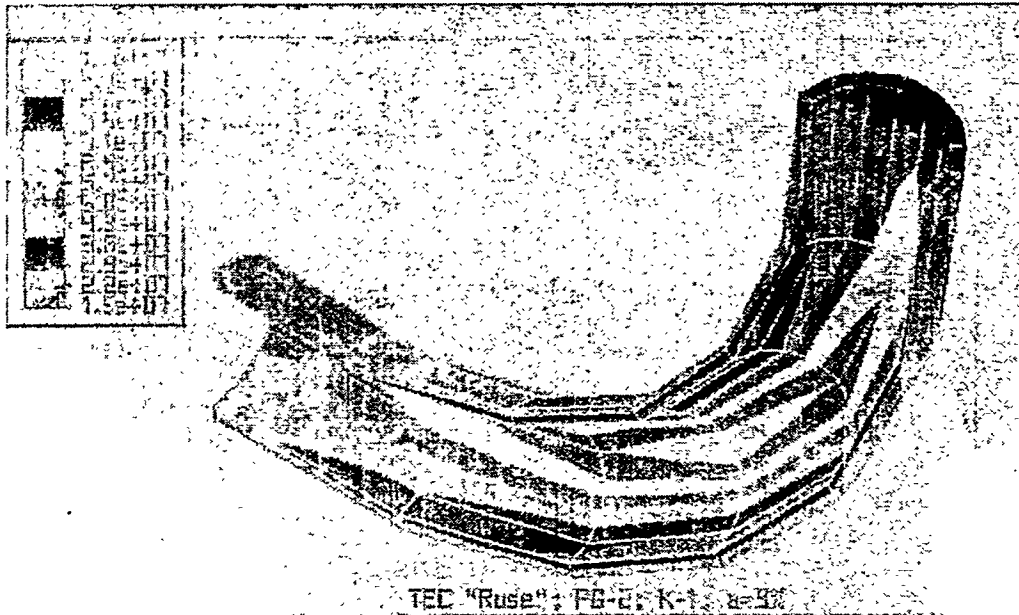


Fig. 1

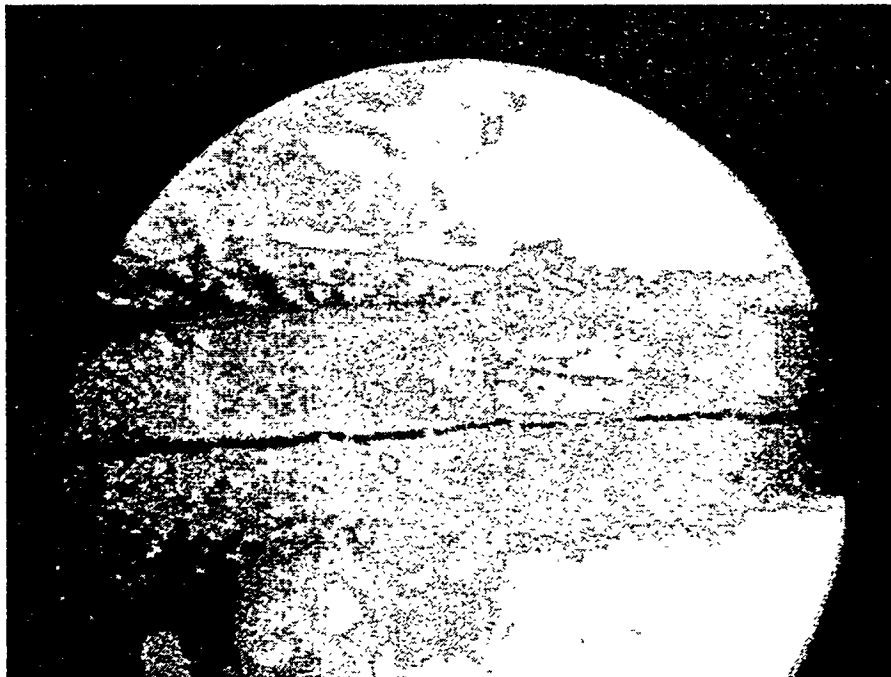


Fig. 2



Fig. 3



Fig. 4

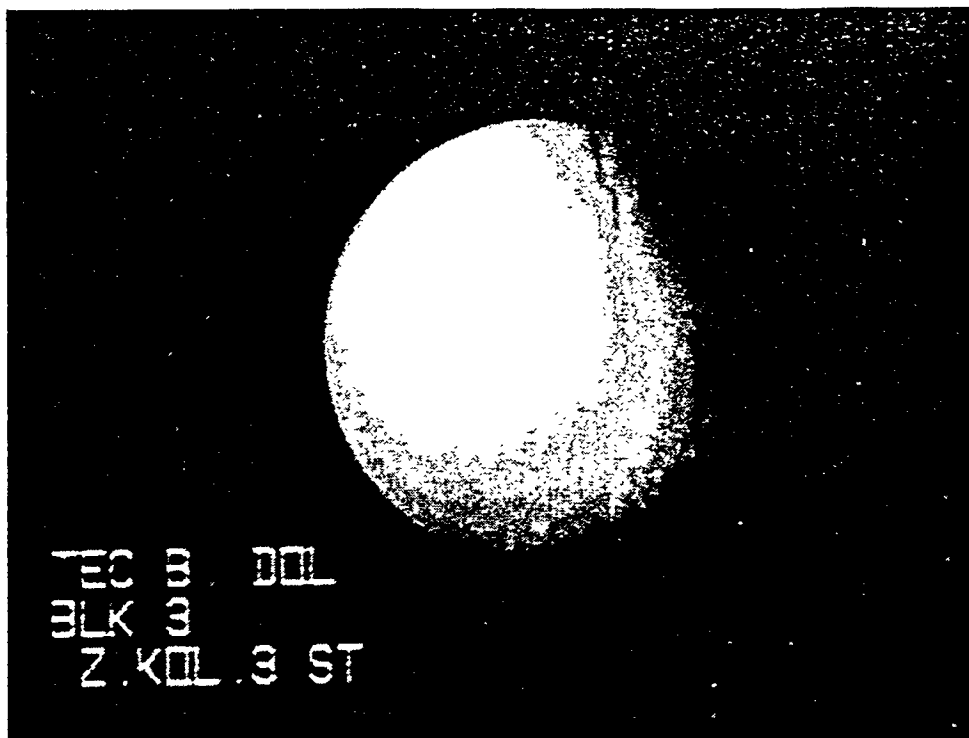


Fig. 5

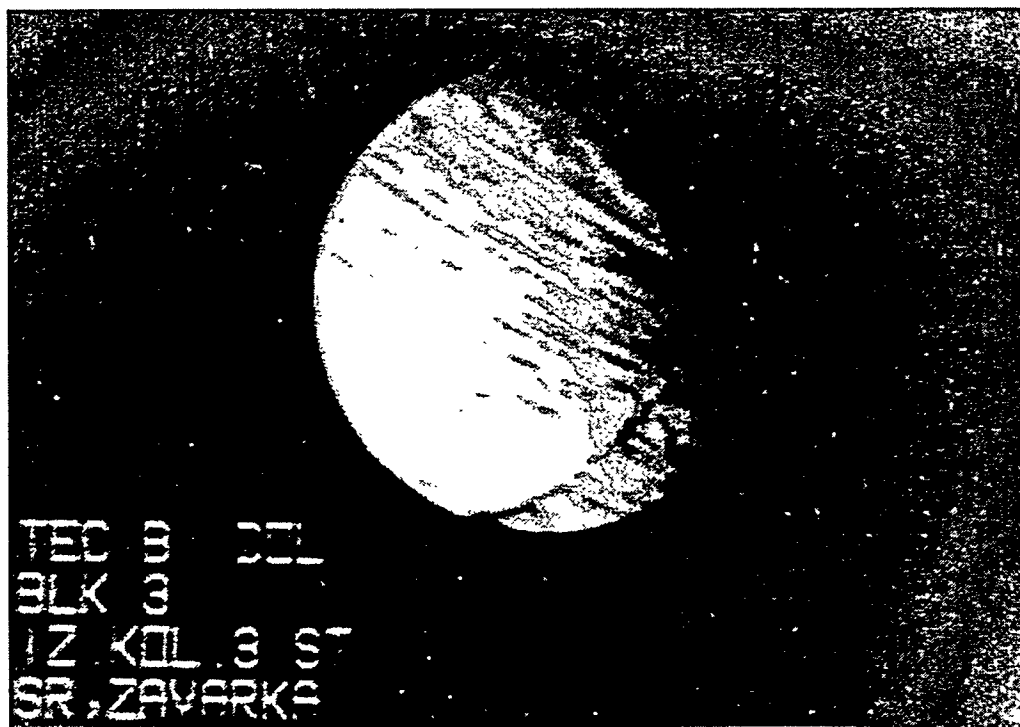


Fig. 6

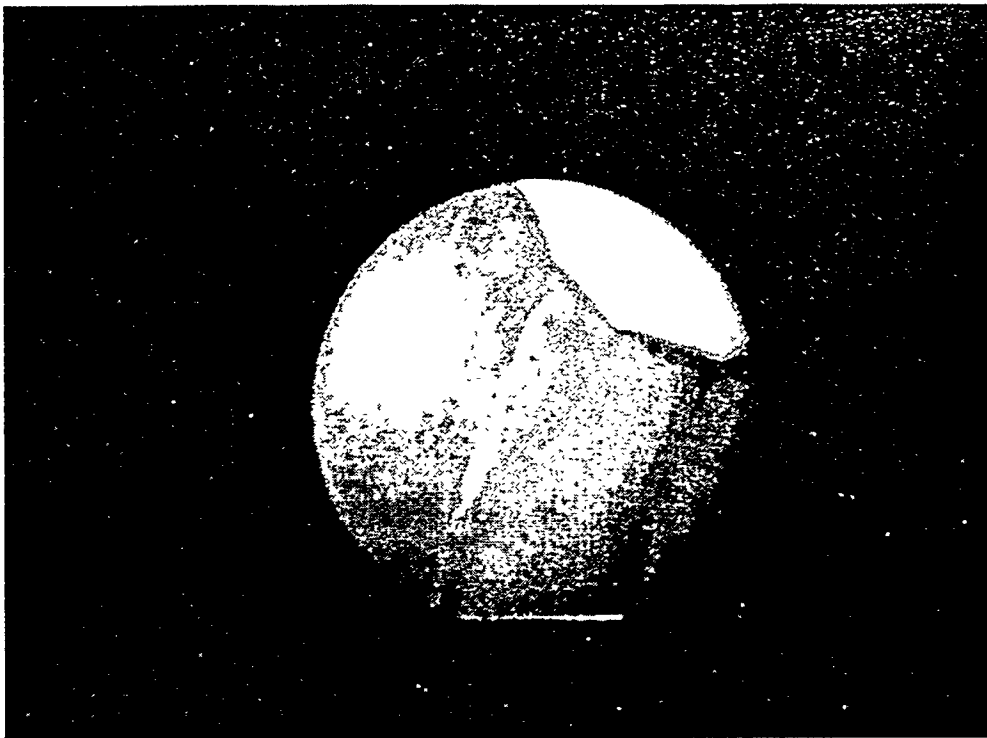


Fig. 7



Fig. 8

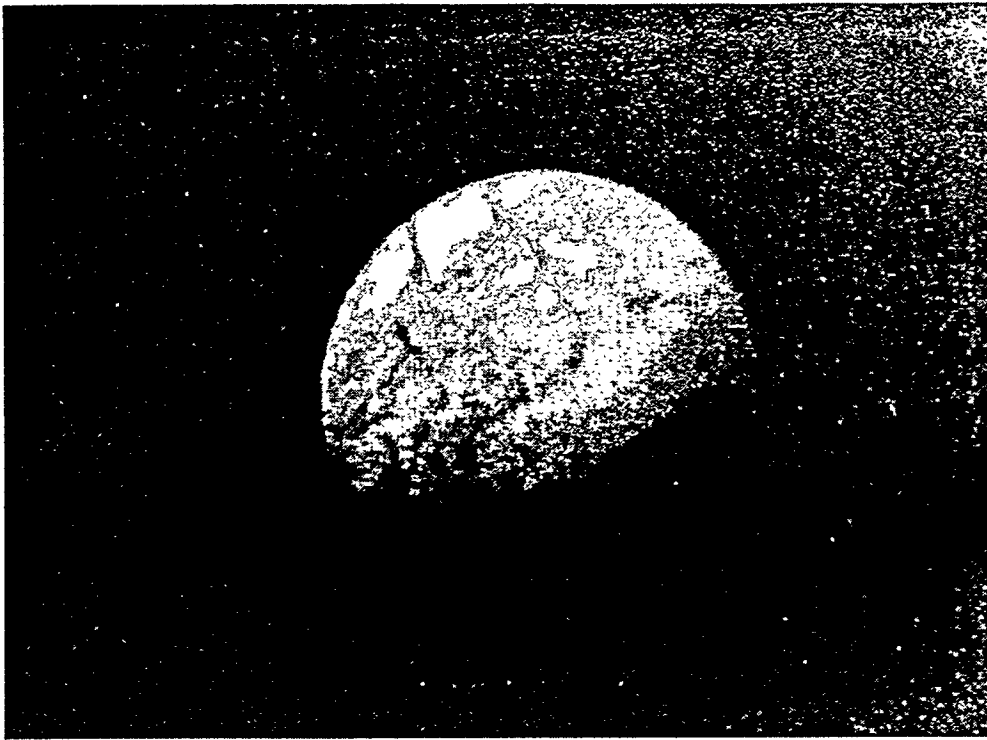


Fig. 9

Conventional Energy Systems II – Boiler Emissions Control

Session A2

SESSION COCHAIRS:

***Michael Mann, Senior Research Manager
Energy & Environmental Research Center
Grand Forks, North Dakota, USA***

***Josef Kašparů, Director
ČEZ, Power Plant Počerady
Czech Republic***

KEY ISSUES FOR LOW-COST FGD INSTALLATIONS

William DePriest, Manager of Air Quality Control Services
James M. Mazurek, Analysis & Technologies Engineer

Sargent & Lundy LLC
Chicago, Illinois, USA

ABSTRACT

This paper will discuss various methods for installing low-cost FGD systems. The paper will include a discussion of various types of FGD systems available, both wet and dry, and will compare the relative cost of each type. Important design issues, such as use of spare equipment, materials of construction, etc. will be presented. An overview of various low-cost construction techniques (i.e., modularization) will be included. This paper will draw heavily from Sargent & Lundy's database of past and current FGD projects together with information we gathered for several Electric Power Research Institute (EPRI) studies on the subject.

INTRODUCTION

As a result of Title IV of the 1990 Clean Air Act (CAA) Amendments in the United States (U.S.), and similar sulfur dioxide (SO₂) reduction programs throughout Europe, technology advances and regulatory procedures have dramatically reduced the cost of SO₂ emission reductions from power plant stacks. Today, in the U.S., advanced flue gas desulfurization (FGD) techniques in electric utility plants are being assessed and demonstrated under Clean Coal Technology initiatives of the U.S. Department of Energy and other publicly and privately funded programs. Also, the application of mature technologies under a new regulatory accounting system has facilitated significant design application advances and overall reduced costs. These factors have contributed to the economic competitiveness of modern FGD technology.

In both Europe and the U.S., commercial advances in wet, semi-dry, and dry FGD technologies can be expected to improve cost-effectiveness noticeably. Cost improvement is already being seen in major wet FGD systems recently constructed as a result of the 1990 U.S. CAA Amendments. Commercial advances in semi-dry and dry processes in western Europe are also impressive, and may be adapted for future high sulfur coal retrofit projects throughout the world.

These FGD commercial advances realized from acid rain legislation in the U.S. and Europe can be applied in regions such as East Central Europe, where the burning of high-sulfur, high-ash coal and lignite has led to severe air pollution problems in some areas. These nations are addressing these air pollution problems by phasing-in emission regulations for new and existing plants. Most coal-fired power plants in the region are large (> 600 MW) and somewhat old (> 20 years). Therefore, cost-effective FGD retrofits are imperative.

SELECTION OF FGD PROCESS

In general, the FGD processes available for use in power plant SO₂ reduction include the nonpromoted wet limestone process which operates in either a forced-oxidized or inhibited-oxidized mode; magnesium-enhanced wet lime process; promoted or organic acid enhanced wet limestone process, and a host of dry and semi-dry lime processes. It should be noted, however, that although the lime-based dry technologies are a viable alternative and proven technology for many utility and industrial applications, the economics of these processes become less favorable relative to wet processes for

conditions where high collection efficiencies (>90%) are required for moderate-to-high sulfur fuels and retrofit applications.

Table 1 compares capital costs and SO₂ removal efficiencies for retrofitting a typical 600 MW unit burning high sulfur bituminous coal (3%) with different types of FGD technologies. The capital costs are conceptual but can be used for generic comparative purposes. A complete economic analysis is a site-specific process which takes into account availability of reagent, availability of process water, solid waste disposal considerations, etc. These conceptual costs are based on Sargent & Lundy's (S&L) experience in the U.S., western Asia, and the Pacific Rim and the S&L-developed and EPRI-sponsored State-of-the-Art Power Plant (SOAPP) Workstation. The SOAPP Workstation is a tool available to electric utilities for conceptually designing or retrofitting power plants.

The capital requirements for the various wet calcium-based technologies fall in the range of \$120-\$140 per kilowatt (kW). Actual definitive capital costs will be dependent on project-specific design criteria and site-specific conditions and constraints. The semi-dry technologies include those technologies where a discrete vessel for SO₂ capture is employed independent of the particulate collector. The capital requirement for these technologies includes an estimate of the capital costs required to modify the particulate collector as necessary to maintain the particulate emission limit. The dry injection technologies are limited to primarily calcium-based processes. Sodium-based processes are also commercially viable but are highly dependent on the cost and availability of the sodium-based reagent, sulfur in the fuel, required SO₂ removal efficiency, and waste disposal options to be economically viable. Therefore, sodium-based technologies are not deemed to be an attractive option in East Central Europe.

TABLE 1

FGD Capital Costs and SO₂ Removal Efficiencies

FGD Technique	Typical Capital Cost (\$/kW) (1994)	Typical SO ₂ Removal Efficiencies
Wet calcium-based technologies		
Limestone	\$120-\$130	90-95%
Lime	\$125-\$135	90-95%
Magnesium-enhanced lime	\$135-\$140	90-95%
Semi-dry lime-based technologies		
Spray dryer	\$80-\$100	75-85%
Circulating fluid bed	\$120-\$130	75-85%
Dry lime-based injection technologies		
In-duct injection	\$60-\$70	50-60%
In-furnace injection	\$65-\$75	50-60%

Wet calcium-based technologies have been the dominant mechanism for SO₂ control at power generating facilities throughout the world over the last 25 years. Therefore, the remainder of this paper will focus on the design issues that greatly affect the cost of FGD installation when using the wet calcium-based technologies.

FGD DESIGN ISSUES

Number of Absorber Modules

The number of absorber modules included in the FGD system design has a significant impact on the overall cost. During the 1970s and 1980s, the number of absorber modules and the spare absorber philosophy for FGD systems was strongly influenced by the governing environmental regulations. For example, New Source Performance Standards (NSPS) in the U.S. were written such that if an FGD system without a spare absorber were malfunctioning and not capable of treating the flue gas, then the boiler/turbine/generator unit would not be allowed to operate. Under the NSPS, a spare absorber module was required if the utility owner wanted to incorporate an emergency bypass around the FGD system. When evaluating the economics associated with the spare absorber module, the utility owner had to balance the capital cost of the spare absorber module against the risk of incurring replacement power charges because of the loss in plant availability on account of a malfunctioning FGD system. When the capital cost of a spare module was evaluated against the replacement power cost for a large unit, even small availability differences indicated that the spare module was the clear economic choice. For this reason, many of the FGD systems that were installed during the NSPS era included spare absorber modules.

Conversely, the 1990 U.S. CAA Amendments do not address the issue of absorber redundancy, but rather focus on the absolute quantity of SO₂ emitted by a plant in a given year. The decision to install a spare scrubber on a unit is still left to the discretion of each utility, but the decision criteria is markedly different.

This new 1990s approach to SO₂ compliance coupled with a much more mature technology (and the associated reliability improvement) has allowed system designers to make significant cost reductions. These cost reductions are primarily realized in the capital investment but they also have an effect on the operating and maintenance expenses.

Table 2 shows the capital cost savings that can be realized by exploiting the FGD reliability improvements achieved in the 1970s and 1980s by changing the number and size of absorber modules for a project.

In this table, 3 - 50% absorbers represent the design philosophy employed during the 1970s and early 1980s when the technology was in its formative years and there were significant technology risks. The technology has fully matured and risk mitigation with redundant absorbers is no longer a necessity. The other design philosophies in Table 2 represent various degrees of movement away from the spare absorber concept and the capital savings that can be realized.

TABLE 2

Effect of Absorber Redundancy on Capital Cost	
DESIGN BASIS	% CAPITAL SAVINGS
3 - 50% absorbers	Base
2 - 67% absorbers	10-15%
2 - 50% absorbers	20-25%
1 - 100% absorber	35-35%

Collection Efficiency

Historically in the U.S., the SO₂ collection efficiencies required for FGD systems were dictated by the NSPS regulations. The "sliding scale" incorporated into the 1978 NSPS regulations was a function of coal sulfur content and generally resulted in SO₂ collection efficiencies in the range of 70% to 90%. The averaging time used in determining compliance was also a significant FGD system design factor. Under the NSPS, the compliance time frame for meeting SO₂ emissions involved a short-term averaging period, from as low as 3 hours to as high as a 30-day rolling average. Since the averaging period was short, system designers were forced to use costly spare equipment, and in many cases, utilize technologies at less than their optimum.

Conversely, compliance with the SO₂ reduction program under the 1990 U.S. CAA Amendments is determined on an annual basis. Under this scenario, the utility could conceivably bypass the absorbers during an emergency or a planned shutdown of the FGD system and still comply. By designing the FGD system to overscrub during normal operation and banking SO₂ allowances, they could "catch up" for planned or unplanned outages where the FGD system is bypassed and, in so doing, prevent the unit's annual SO₂ emissions from being exceeded. As a result, the optimal collection efficiency is determined on the basis of a minimum present worth cost per ton of SO₂ removed. An approach to the regulations such as those used in the 1990 U.S. CAA Amendments might also be appropriate in East Central Europe.

Absorber Materials of Construction

The selection of the materials of construction to be used in the absorber module will have a significant impact on the cost of the entire FGD project. The physical and chemical environments resulting from the expected operating conditions will be the determining factor. The three process variables that define the corrosion environment within the absorber module are the flue gas temperature, the slurry pH, and the slurry steady-state concentration of halide ions. The factors that influence the erosiveness of the process liquor or slurry include the slurry solids content and the velocity of the slurry in the various piping systems and the impingement on the internal vessel surfaces.

Traditionally, the absorber modules designed and put into operation over the past 15 years have predominantly used either an alloy or a nonmetallic liner. The corrosion resistance requirements for the various stainless steels and alloys suitable for FGD application will vary dependent upon the operating conditions. Generally, increasing the corrosion resistance of alloy liners will necessitate increasing contents of molybdenum, nickel, and chromium in the alloy, with a corresponding increase in cost. The nonmetallic liners available include principally organic linings such as resins, rubbers, and fiberglass reinforced plastics. Selection of the appropriate organic liner is generally not highly dependent on the chemistry of the system, but good performance will only be realized if stringent quality control measures are implemented during the coating application.

As a result of the flood of FGD systems installed to comply with the 1990 U.S. CAA Amendments, several high performance alloys have been developed. A cladding of carbon steel with a thin "wallpaper" of a corrosion resistant nickel-based alloy has been proven to be a cost-effective and trouble-free absorber lining alternative. Also, other advanced alloys are proving to be cost-effective when evaluated over the entire life of the plant.

Table 3 represents the relative costs of various liner materials of construction.

Selection of the appropriate materials of construction will vary for the different operating conditions in the different sections of the absorber. Expected maintenance requirements for the candidate materials will also influence their selection and in many ways influence the overall system design criteria. As an example, an FRP lined absorber is expected to require more frequent maintenance than a solid alloy absorber. Therefore, the absorber sparing philosophy may be different for the lined system than for the solid alloy system. Consequently, some (or all) of the savings in liner materials of construction may be offset by the need for a spare absorber.

TABLE 3

Material of Construction Costs	
MATERIAL (1/4" Plate)	SPECIFIC COST (\$/ft ²) (NEW, INSTALLED)
Alloys	
Solid C-276 or C-22	\$170-\$175
Solid 317 LIMN-SST	\$35-\$40
Solid A255	\$130-\$135
Clad C-276/C-22	\$90-\$95
Wallpaper C-276/C-22	\$45-\$50
Linings	
Rubber	\$30-\$35
FRP Coatings	\$20-\$25

Mist Eliminators

As has been demonstrated in Europe and Japan by many system suppliers, and now being increasingly utilized in North America, the vertical arrangement of wet scrubber mist-eliminator elements can offer considerable cost savings over the more typical horizontal design. The vertical design allows higher gas flow velocities and therefore improved small droplet removal efficiency to help limit liquid and solid particles in the stack discharge. The higher gas velocities reduce the size, and in some cases, the cost, of the mist eliminator section of the module.

Booster Fans

A major energy saving in booster-fan horsepower is accomplished by fan placement downstream of the scrubber, operating at the reduced system temperature corresponding to the flue-gas wet bulb. The lower temperature means lower gas-flow volume at the fan and reduced horsepower requirements.

U.S. experience, beginning more than 20 years ago, has consistently pointed to hot-side fan placement (downstream of the electrostatic precipitator) to avoid impeller corrosion, fouling, and imbalance. During the 1980s, however, continued positive field experience in Germany with wet-scrubber mist eliminator systems coupled with the correction of design problems experienced in early FGD installations in the U.S. has been encouraging fan placement downstream of the scrubber. A modest energy savings can be realized with this fan placement.

FGD CONSTRUCTION ISSUES

Modularization

Shop prefabrication of absorber vessels can substantially reduce the amount of field erection labor required for FGD construction while improving the quality of the construction. A good example of shop prefabrication is the American Electric Power Corp.'s Zimmer Station, which made extensive use of prefabrication of the absorber modules for their magnesium-enhanced lime FGD system. Each of the six

modules (40.5 feet in diameter and 55 feet high) was fabricated in two segments by a fabricator in New Orleans, and barged up the Mississippi and Ohio River to the site. The bottom piece weighed almost 80 tons, while the top piece weighed nearly 100 tons. All connections and the majority of the internals such as spray headers and nozzles, and mist eliminator wash headers and nozzles, and mist eliminator blade assemblies were installed prior to shipment.

The potential degree of shop prefabrication is dependent on loading capabilities at the assembly point, unloading capabilities at the generating station, and shipping restrictions in between. The extensive prefabrication practiced at the Zimmer Station was possible because of the proximity of the fabricator and the generating station to navigable waterways. However, even at sites where barge delivery is not possible, lesser degrees of prefabrication can reduce the field erection period and typically more expensive field fabrication, thereby reducing construction costs.

Construction Schedule

Figure 1 presents a typical schedule for the engineering, procurement, fabrication, erection, and start-up of a wet limestone FGD system.

The schedule may be used in the development of unit specific project schedules. However, the applicability of the displayed activity duration must be assessed for each specific retrofit application. Specific items that need to be addressed include:

- Scope of demolition.
- Scope of balance of plant systems or structures to be relocated or modified.
- Difficulty of access to construction areas including, but not limited to, overhead lines, underground facilities, nearby structures, and site roads.
- Site preparation requirements.
- Craft and construction material resource availability.

The schedule indicates an overall time period of approximately 30 months for award of a contract for the FGD system through installation and start-up. The critical activities in this schedule include the procurement and fabrication of all associated equipment in the FGD system.

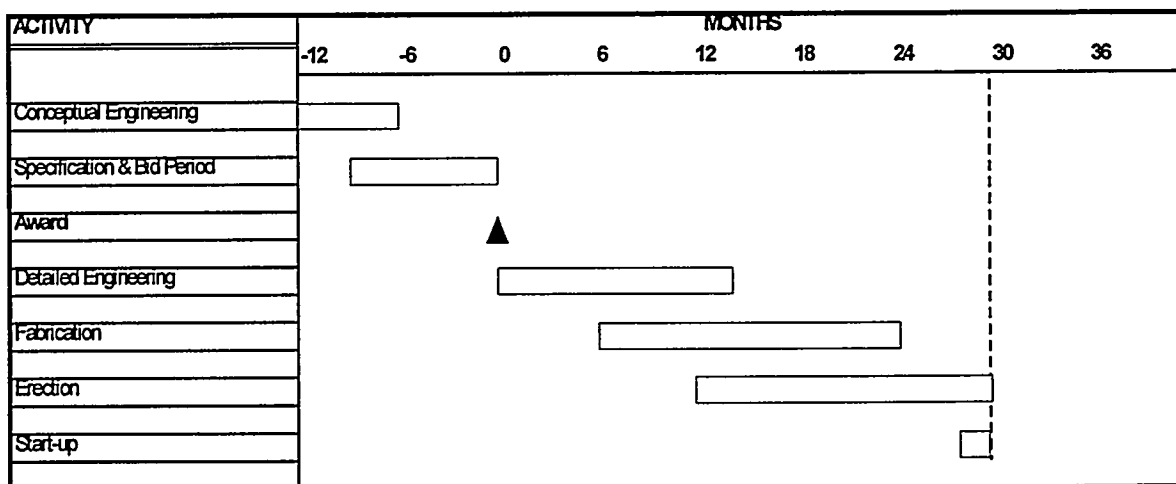


Figure 1

CONCLUSION

Extensive experience in FGD systems as a result of the 1990 U.S. CAA Amendments and similar SO₂ reduction programs throughout Europe has helped to optimize FGD designs resulting in cost-effective retrofit applications. The changing of the regulations from a command-and-control regime (i.e., the NSPS in the U.S.) to a market-based compliance system has had a significant impact on the design philosophy for FGD technology, and consequently, the cost of installing such technology. Because of the interaction of these many complex issues, the following general observations or conclusions can be made:

- Redundancy in absorber modules is no longer a major design issue. Current SO₂ regulations and mature FGD technology will result in the use of fewer and larger absorber modules than was common in the past.
- Collection efficiency has become of greater importance with the advent of the market-based SO₂ allowance program in the U.S. As a result, FGD design is being optimized around the configuration that results in the lowest cost per ton of SO₂ removed.
- Selection of absorber materials of construction has become a major economic decision. High performance and cost effective alloys have become available that reduce the potential for corrosion in the absorber module. A better understanding of lining systems has increased their reliability and reduced the need for redundant absorbers.
- Construction techniques such as modularization have played a major role in reducing construction time and costs for FGD installation.

As a result of the advances made in FGD design and the changes in the regulatory environment, the capital costs of FGD systems have significantly declined over the past few decades. Figure 2 presents the progression made in lowering costs for wet FGD installation. The 1970s saw the application of a new technology for SO₂ control on power plants as a result of the NSPS in the U.S. The high costs represent some of the growing pains experienced with this technology. The continued use of this technology in the 1980s benefit from these growing pains by reducing costs around 33%. The costs in the 1990s represent FGD systems constructed in response to regulations that allowed annual averaging rather than hourly averaging and encouraged optimum technology utilization. Systems that are procured in the mid-1990s for operation in 2000 should continue to exploit technology advancements and reliability improvements such that there is a lesser need for equipment reliability risk mitigation. The result should be a continued reduction in capital cost.

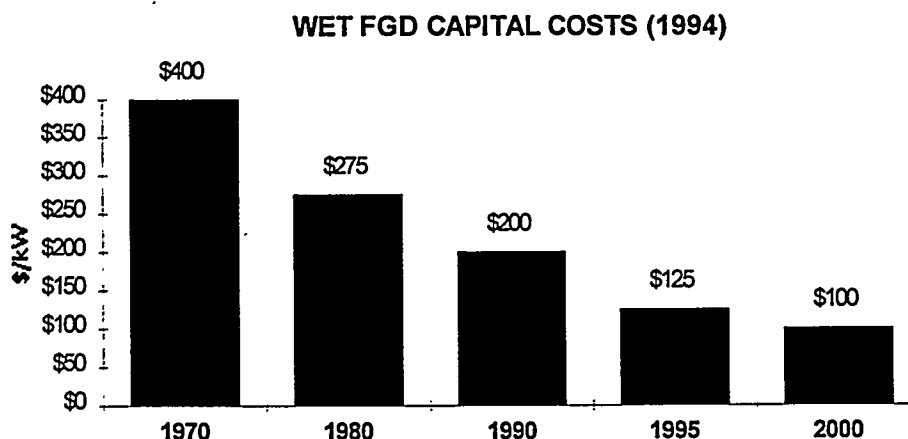


Figure 2

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FLUE GAS CONDITIONING TODAY

Barry J. Southam, P.E., President and CEO
E. L. Coe, Jr., Consultant

Wahlco Engineering International Ltd.
Santa Ana, California, USA

ABSTRACT

Many relatively small electrostatic precipitators (ESP's) exist which collect fly ash at remarkably high efficiencies and have been tested consistently at correspondingly high migration velocities. But the majority of the world's coal supplies produce ashes which are collected at much lower migration velocities for a given efficiency and therefore require correspondingly large specific collection areas to achieve acceptable results.

Early trials of flue gas conditioning (FGC) showed benefits in maximizing ESP performance and minimizing expense which justified continued experimentation. Trials of several dozen ways of doing it wrong eventually developed a set of reliable rules for doing it right. One result is that the use of sulfur trioxide (SO_3) for adjustment of the resistivity of fly ash from low sulfur coal has been widely applied and has become an automatically accepted part of the option of burning low sulfur coal for compliance with the Clean Air Act of 1990 in the U.S.A. Currently, over 100,000 MW of generating capacity is using FGC, and it is estimated that approximately 45,800 MW will utilize coal-switching with FGC for Clean Air Act emission compliance. Guarantees that this equipment will be available to operate at least 98 percent of the time it is called upon are routinely fulfilled.

INTRODUCTION

Acceptance of the process called flue gas conditioning (FGC) as an engineering solution to a common environmental problem of efficiently collecting high resistivity dusts in electrostatic precipitators (ESP's) has come slowly. To start with, the process is mis-named. It is not the gas which is conditioned, but the particles of dust in the gas, or in the most common application, the fly ash. Adjusting the resistivity of fly ash particles by application of a dilute acid solution to their surfaces is an easily understood and straightforward task. A layer of dust on the ESP collecting plates which has a sufficiently high electrical resistivity will interfere with the collection process and reduce, sometimes drastically, the rate at which the dust is collected. Fly ash from burning pulverized coal having low sulfur contents often exhibits high resistivity, and requires ESP's two or more times larger for a desired efficiency than would be the case if the ash resistivity were somewhat reduced. It has been found that injection of small quantities of sulfur trioxide (SO_3) into the flue gas stream can be a very effective and easily controlled method of adjusting ash resistivity to an optimum value for ESP collection. Table 1 indicates the high degree of acceptance and widespread application FGC has received.

The installations listed in Table 1 have been made by several manufacturers whose services are available around the world. All the installations shown have been built in the past 20 years and nearly all are in service at the present time. Early experimental units are not included in the table as most of them were subsequently removed from service after having given their sponsors the opportunity to develop designs and techniques for the production, installation and operation of SO_3 FGC systems. The use of this equipment to economically obtain maximum ESP capture of fly ash which would otherwise be collected at lower rates because of high resistivity has been conclusively proven.

TABLE 1

Sulfur trioxide flue gas conditioning installations		
Location	Number of Boilers	Total Mw.
U.S.A.	258	70, 534
Africa	22	8,600
Australia	6	1,650
Belgium	14	1,590
Canada	18	7,800
France	8	1,060
Germany	30	2,645
Hong Kong	13	5,610
Italy	17	4,470
Korea	8	4,160
Poland	8	670
Spain	3	470
Taiwan	2	1,000
United Kingdom	27	12,000
Total	434	122,259

SULFUR TRIOXIDE GENERATORS

With very few exceptions all commercial SO_3 FGC systems installed to date are based on catalytic conversion of sulfur dioxide (SO_2) which is either supplied in liquid form or obtained by burning elemental sulfur. Elemental sulfur is the preferred feedstock for long-term permanent operations because its operating costs are lower, but liquid SO_2 is used for trials and small or short-term situations where reduced capital costs can offset increased feedstock expense. The catalytic conversion design was chosen over other methods by which SO_3 may be made available partly because it is flexible and easily controllable, but mainly because it minimizes the quantity and the difficulty of handling hazardous materials resident in the system.

Figure 1 is a diagrammatic representation of a typical sulfur-burning system for SO_3 conditioning. Molten sulfur, a common item of trade in the chemical industry available throughout the U.S., is delivered by thermally-insulated tank trucks fitted with steam coils for melt-out. In locations where sulfur cannot be delivered in molten form, bagged or bulk solid sulfur may be supplied for melting on site. The sulfur grade is designated as "Bright Yellow" which contains very low levels of contaminating materials. The exact analysis varies slightly among suppliers, but completely lacks chemicals which could act as catalyst poisons and contains only very small quantities of hydrocarbons. Storage in insulated steel tanks with steam-blanketing provisions for fire suppression is standard, but concrete-lined pits are sometimes used. Tanks and molten sulfur piping are heated by steam controlled to a saturation temperature of approximately 140°C at which the sulfur has ideal flow characteristics. Steam tracing is strongly preferred because of the ease with which controllable highly uniform temperatures can be maintained throughout

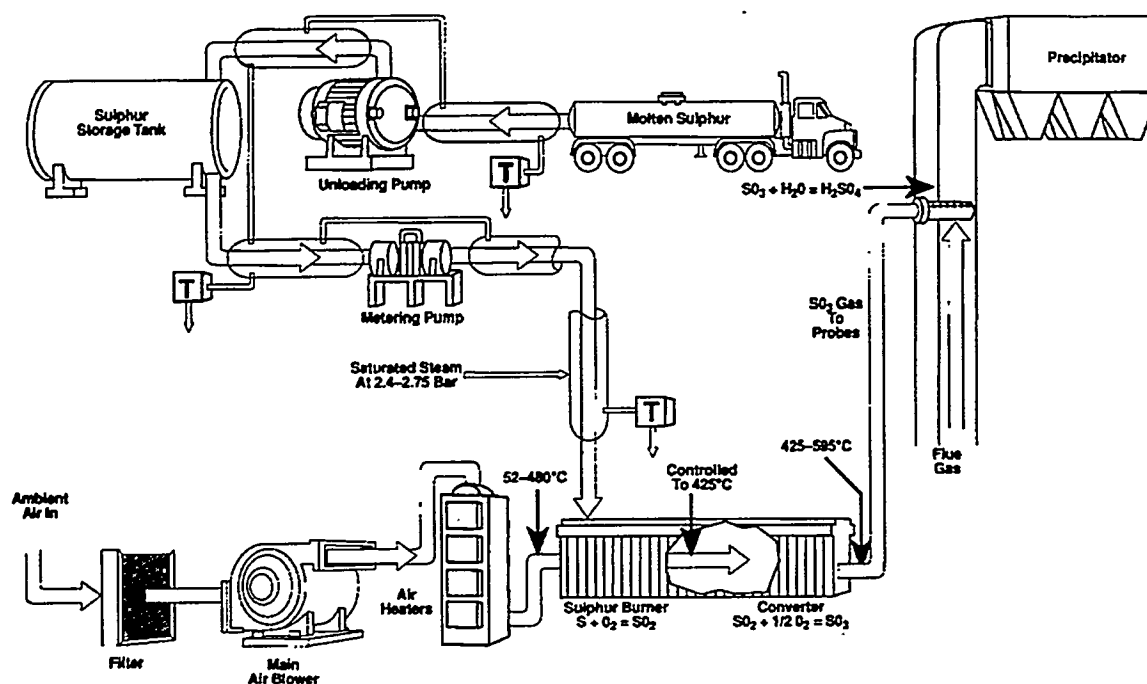


Figure 1. Sulfur-burning SO₃ conditioning system.

the system. Sulfur metering pumps are supplied in duplicate so that one may be serviced while the other is in operation. Even though extensive precautions are taken to maintain cleanliness of the sulfur and piping, it is impossible to eliminate all possible chances of contamination and therefore impossible to guarantee continuous unimpeded pump operation over long periods of time. Emission compliance often depends upon continuous operation of the flue gas conditioning system, so it is usually considered that the cost of an installed spare pump is justified.

Combustion of the sulfur to generate SO₂ is obtained by introducing sulfur into an air stream which has been electrically preheated for startup purposes to the temperature at which the catalyst becomes active. Since this temperature exceeds the autoignition point of molten sulfur, burning is initiated immediately upon the introduction of sulfur and SO₂ is delivered to the catalyst for conversion to SO₃. Roughly 2220 kilocalories of heat are generated per kilogram of sulfur burned. This replaces a portion of the startup electrical heat input, and at full system rating all the required heat to maintain the catalyst at operating temperature is supplied by sulfur combustion. Clearly, operation of the system in this manner allows the generation of any quantity of SO₃ from zero to full system rating as a function of any selected control signal used to determine the rate at which sulfur is delivered.

CONTROL SYSTEMS

Prior to the last couple of years controls for SO₃ FGC installations consisted of safety and sequencing devices plus load-following apparatus to modulate the rate of delivery of SO₃ in proportion to boiler load. The level of SO₃ to suit a given coal was determined experimentally by the operator by manual adjustment of a proportioning factor between the boiler load signal and the SO₃ generation rate while observing the effect on ESP operation and emissions. It was generally found that the setting for a given coal, once determined, was seldom subject to much variation so it was possible for most stations to make initial determinations for the various coals they fired and use those values with little need for subsequent adjustments. These control functions were implemented with relay logic and analog controls,

and permitted operation with a minimum of attention from station personnel. They were reasonably satisfactory for most applications.

There were, however, plants where the coal being burned at any given time might be unidentified or mis-identified so that previous experience was of no value in determining the injection rate setting and there were some stations burning "spot" coals received in small quantities where constant determination of new settings was required. There were also locations where difficulty was encountered in determining optimum settings through unfamiliarity with ESP operation. For these reasons, as well as the desirability of freeing the operators from the task of identifying which coal was being fed to the burners, and especially the times at which a particular coal started and ended, effort was directed to automatic determination of the optimum SO_3 rate. A first attempt was based on the idea that the rate would be a function of the sulfur content of the coal, and that quantity could be inferred from measurement of flue gas SO_2 . This proved to be partially workable, but did not adequately account for ash chemistry or ash quantity differences between coals with the same sulfur contents. Another aborted attempt relied on the increase in ESP power input accompanying SO_3 injection, but seemed to have an unbreakable habit of running to maximum system rating whether that injection rate was optimum or not. Excess injection of SO_3 will tend to make the ash resistivity in the ESP too low, decreasing its collection efficiency and causing severe rapping puffs. If SO_3 injection is ahead of the air preheater acid condensation and corrosion may occur at the cold end surfaces.

Controls are now available implemented with solid state apparatus which digitally store the operating characteristics of the ESP as a function of the injection rate setting and, for any coal being fired, determine the characteristic in use and proceed to the optimum point of that curve. Periodic perturbations of the setting are made to determine that the set point remains optimum. If not, a new optimum is determined, and the new characteristic is stored for future reference. Besides freeing the operator from necessity for closely monitoring the fuel and adjusting the set point, these controls retain a history of operation which can be retrieved for information on control and system performance.

DETERMINING INJECTION RATES

Those who have studied factors affecting the resistivity of fly ash in a flue gas atmosphere are familiar with the hump-backed characteristic of resistivity as a function of temperature. Generally, resistivity has a maximum value at a temperature around 150°C with decreasing values above and below the maximum point as illustrated by Figure 2. In determining the amount of SO_3 to be injected to reduce the ash resistivity to a desired lower value, one would think that the maximum rate would be required at the maximum unconditioned resistivity point, with decreasing amounts at higher and lower temperatures. That is, a hump-backed curve of injection rate reflecting the unconditioned resistivity characteristic would be expected. An interesting discovery made in the development of SO_3 flue gas conditioning is that the amount of SO_3 required to attain a desired level of resistivity follows the expected dome-shaped curve with respect to temperature only up to a point, after which it breaks off to a rapidly rising characteristic as seen in Figure 3. The inflection point between the two portions of the curve is a function of the surface chemistry of the ash, occurring at relatively low temperatures for acidic ashes and at higher temperatures for basic ashes. The range of variation of the inflection point temperature appears to be approximately from 120°C to 200°C for coals available world-wide. If the flue gas temperature is above the inflection point, the portion of the injected SO_3 which is greater than the level of the dome-shaped portion of the curve does not attach to the ash and will be passed through the ESP. In the rare cases where a wet scrubbing system follows the ESP the excess SO_3 will be captured; otherwise an objectionable blue plume will be formed if the emitted SO_3 concentration approaches 10 ppmv or more. In either case SO_3 and the feedstock used to produce it are being wasted. Of course, this problem may be avoided by changing to a coal which produces an ash having its inflection point temperature above the flue gas temperature, or by reducing the flue gas temperature to a value below the inflection point. If neither of these is possible, as is often the case, it has been found that the simultaneous injection of ammonia (NH_3) with the SO_3 will condition the ash surface to accept resistivity adjustment without excess SO_3 being required. As an example, at the Hudson Station of Public Service Electric & Gas of New Jersey where operating temperatures in portions of the ESP exceeded the inflection point, injection of 15 ppmv of SO_3 resulted

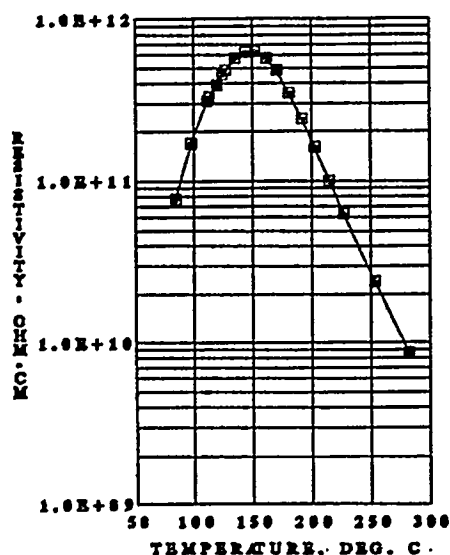
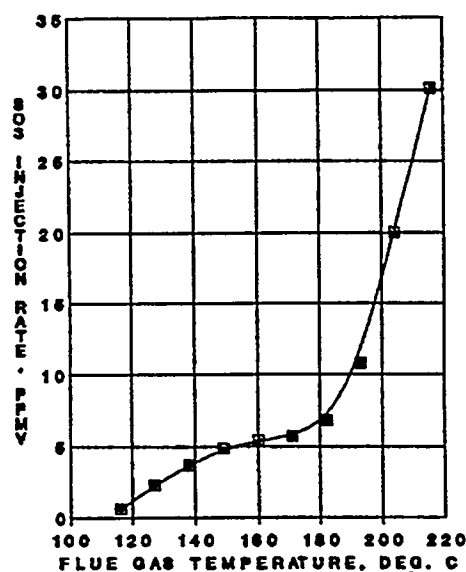


Figure 2. Fly ash resistivity.

Figure 3. SO₃ injection rates.

in particulate emission compliance, but an objectionable blue SO₃ plume was highly visible. Introduction of 4 ppmv of NH₃ with the SO₃ level reduced to 8 ppmv eliminated the blue plume and materially improved particulate collection.

CATALYST HANDLING

The catalyst for conversion of SO₂ to SO₃ may be chosen from any of the types developed for the manufacture of sulfuric acid and similar applications. Vanadium pentoxide is the active ingredient in most of these, and is classified as a hazardous material. It appears that catalyst life in this service is on the order of ten years so that frequent handling is not required, but prevention of dust dispersion and ingestion of or contact with the material, retention of the material in sealed containers, and disposal by qualified handlers are necessary. In spite of its hazardous classification, servicing of the catalyst bed is neither particularly difficult nor expensive, but it is nevertheless desirable to do it as infrequently as possible. To this end care should be taken to exclude dust and water from the air intake to the maximum extent possible, and to service the air intake filter on a regular basis. Dust entering the system will tend to plug the inflow end of the catalyst bed and decrease the available air flow, eventually causing overtemperature tripouts. Water has the effect of breaking down the physical structure of the catalyst pellets, so that interstices in the bed become plugged and air flow is restricted. Air intake locations which might be subject to overspray from cleaning hoses or windblown rain, for instance, should be suitably shielded or relocated to an absolutely dry position.

SO₃ DELIVERY TO FLUE GAS

The combustion air stream bearing the generated SO₃ will issue from the catalyst at temperatures from 400°C to about 540°C, depending on the rate of SO₃ production. It is essential that this stream be held above its acid dew point temperature all the way through the delivery manifold and injection probes until it actually issues into the flue gas. If the temperature goes below the dew point, the acid will condense out in the manifold or the injection probes. This is undesirable for two reasons. First, none of the acid will reach the flue gas to do the intended conditioning job, and secondly, the condensed acid will corrode the piping and nozzles. Since the SO₃ concentration is a few percent in this stream the acid dew point will be on the order of 240°C, but maintaining the delivery end of the system in a condensation-free state requires that the calculated gas temperature as it issues from the injection probe nozzles not be less than 260°C. For this reason the distribution manifolds are heavily insulated, and in addition the injection probes, if installed downstream of the air preheater, are thermally insulated from the flue gas. Also,

calculations of the expected temperatures at the most distant (or coldest) injection nozzle are made for every such installation.

It is quite obvious that avoidance of acid condensation in the manifold and probe areas requires preheating of the system with hot air when being started up from cold. It is not quite so obvious that a hot purge of the system during shutdown is required to remove sulfur products from the catalyst so that acid will not be present in the warm-up gases at the next startup. When proper startup, operating and shutdown procedures are observed as described here, long manifold and probe life is obtained. Some early systems are approaching 20 years on line with original probe and manifold parts still in service. Steel sheathing over the insulation of cold-side probes is subject to the same erosive fly ash attack as other internal parts of the ductwork, and requires similar periodic maintenance and repair.

MIXING REQUIREMENTS

The length of travel of the flue gas in the ductwork after the injection point required to provide essentially complete mixing with the SO_3 is often glibly cited as "one second mixing time" or "ten times the nozzle spacing". These rules of thumb are derived from experiments showing that in turbulent flue gas flow complete mixing with another gas injected through a bank of nozzles arrayed as a uniformly spaced grid occurred at a distance downstream of the grid equal to about eight to ten times the nozzle spacing. In FGC systems a nominal grid spacing of one meter has been found to be a reasonable compromise. Ten times this spacing gives a mixing distance of 10 meters, which at typical duct velocities of 20 m/s allows only one-half second mixing time, and this is adequate providing the duct is straight and unchanged in size over that length. Ordinarily that is not the case, hence the conservative quest for one second. Expansions, contractions and bends in the ductwork interfere with neat mixing patterns. If the ESP ductwork is being modeled for flow visualization it is desirable to include an examination of the mixing behavior which may be expected. Modification of the spacing, location and gas delivery rate of the nozzles are steps which may be taken to cope with less-than-optimum mixing situations.

HOT SIDE INJECTION VS. COLD SIDE

Because installation of injection probes is ordinarily more easily accomplished in the ESP-type ductwork downstream of the air preheater (cold side) than in the boiler-type construction on the hot side, most of the present FGC installations inject on the cold side. It should be noted, however, that hot side installation has advantages of lacking any close approach to acid condensation temperatures in the probes, and provides excellent mixing and contact between the SO_3 and the fly ash as it passes through the air preheater. Hence, cases where long manifold runs may make it difficult to maintain sufficiently high probe temperatures or where there is little cold side gas travel length for mixing of the injected SO_3 with the flue gas favor location of the injection probes on the hot side. In determining the desirability of putting the probes on the hot side possible SO_3 condensation in the cold side of the air preheater must be considered. This is not usually a problem because the injected SO_3 quantity establishes air preheater conditions roughly equivalent to those expected from an unconditioned boiler firing coal containing 1.5 percent sulfur. If the average cold end temperature and material of the air preheater are compatible with that assumption hot side injection would ordinarily be acceptable, providing adequate soot-blowing facilities are installed.

Probes for hot side installation are less expensive than cold side because no thermal insulation is required and the erosion-protective outer sheathing can usually be eliminated. The probe insertion point into the boiler on the hot side may move more than a cold side point when the boiler is started up and shut down, and this can add to the difficulty of design and the expense of the manifold system, possibly offsetting savings in probe costs. Every existing hot side installation operates as well as or better than equivalent cold side units.

Note that the foregoing applies to injection of SO_3 . Injection of ammonia, to be discussed later, is ordinarily not allowed on the hot side of the air preheater because of the tendency to plug the preheater with ammonium-sulfate compounds unless there is little or no SO_3 in the boiler gas.

ONE CONDITIONER FOR MULTIPLE BOILERS

On the face of it, it seems like a good idea, considering the relatively high cost of the SO_3 generators, to use a single such generator to feed conditioning gas to several boilers. The primary objection to such an arrangement is that, assuming operation of the FGC system is necessary for compliance with emission limits, all the boilers served by whatever portion of the system is common must be taken off line simultaneously before the common portion can be shut down for service. The high availability figures compiled by existing installations are based on periodic (at least, annual) boiler outages during which accumulated maintenance requirements of the conditioner system can be met.

If, however, measures can be taken to maintain emission compliance with the FGC system off line or if simultaneous removal from service of all boilers on the common system is not objectionable, then a portion or all of the SO_3 generator may be made common to more than one boiler. The most straightforward way to do this is by making the blower and air heating apparatus common and providing individual burners (if used), catalytic converters, manifolds and injection systems for each boiler. Control of such an arrangement is uncomplicated, and manifolding and injection requirements are identical to those for single boilers. The possible alternate arrangement where the burner and catalyst are also made common appears to offer cost savings, but is actually difficult to implement unless simplifying assumptions such as operating all common boilers at the same output level, etc., can be made. To retain full flexibility in boiler operation it is necessary to provide valving in the manifold system. Careful heat tracing of the valves and the portions of the piping which may become dead-ended while still exposed to SO_3 -containing gases is required to prevent acid condensation. Cold spots in valve bonnets are not easily avoided. Acid-resistant valves are expensive. Another less severe problem with this system concept is that fully flexible operation of the individual boilers requires a relatively complicated control system. In general, this approach is not recommended.

PATTERNED INJECTION

Ideally, the amount of conditioning gas delivered to any single injection nozzle in the flue gas stream should be proportioned to the amount of ash passing through that nozzle's treatment area and adjusted for the flue gas temperature at that point. It is entirely possible to make comprehensive sets of measurements which determine these values, at least for one set of operating conditions, and it is also possible to divide the delivery of conditioning gas among the injection nozzles in accordance with such measurements. In practice, a full scientific treatment of this type is never done, and is rarely even approximated. The reason, aside from the variability of the target conditions, is that ESP's have a considerable degree of built-in tolerance for random variations. Witness to this fact is provided by many existing installations where flue gas conditioning was neither needed nor used. It is common in these units to find that a wide spread of temperatures across the air preheater outlets is passed through to the ESP inlet along with non-uniform dust concentrations, in spite of which the ESP exhibits excellent operation. In general, inlet conditions which meet industry criteria for satisfactory ESP operation allow treatment of a flue gas conditioning system on the basis of uniform temperature and flow distribution. Another way to state this is that situations which could require special precautions for distribution of conditioning gases usually also require modifications to permit satisfactory ESP operation, and incorporation of the latter can be expected to eliminate the former in most cases.

LOAD CYCLING

The burner and catalyst chambers of FGC systems are lined with refractory materials which can be damaged by thermal shocks. Recommended procedures for starting a system from cold conditions require a gradual warm-up procedure over several hours. Some modern boilers are capable of cycling from stand-by to full load in as little as 45 minutes. To permit the FGC system to follow this type of load change, it is held in stand-by condition with internal temperatures maintained at operating levels by the startup heat source. For economy, air flow rates in stand-by may be reduced from normal operation, thereby reducing heat input. The FGC unit is capable of going from stand-by to full output in 30 minutes, and can therefore accommodate the requirements of fast boiler cycling. Because of the length of time required for a cold start it is normal practice to hold the FGC system in stand-by when the boiler is in a

stand-by or banked-fire condition, and not go to a cold shutdown unless the boiler will be off-line for at least a few days.

ESP POWER CONSUMPTION

During most of the history of ESP collection of fly ash it was considered that use of the full available output of the high voltage supplies indicated good operation and high efficiency collection, and this was highly desirable. In later years attempts to collect high resistivity dust without resort to flue gas conditioning led to the construction of ESP's of monumental size, complete with row on row of hoppers, high voltage power supplies and ash handling apparatus. Whether or not these passed their guarantee test requirements, quite a few were eventually fitted with FGC which, among other things, promptly caused all the power supplies to go to full rated output. What once had been considered good ESP operation was now rightly considered outrageous consumption of station auxiliary power. Fortunately there is a cure for this situation.

Control units for the high voltage power supplies are now available from most ESP manufacturers which provide a feature called "intermittent energization" or "skip-cycle control". Although the claim that this type of control materially improves collection of high resistivity dust has proven to be somewhat optimistic, there is a definite economic justification for its use in conjunction with FGC. Once the fly ash resistivity has been adjusted by FGC to an optimum value, high collection rates may be maintained while ESP power consumption is greatly reduced by use of the "skip-cycle" feature. Power reductions to levels on the order of 20 to 30 percent of the unmodified power input have been obtained without noticeable increases in emissions. Note that micro-second type pulsers are not economical power savers.

ALTERNATE APPARATUS

In an effort to reduce the cost of SO_3 conditioning an experimental system which converts a portion of the SO_2 in the flue gas to SO_3 is being investigated as a possible way to avoid the purchase of sulfur or liquid SO_2 feedstock, but questions yet to be thoroughly investigated include control of SO_3 quantities to proper levels when a variety of different coals are burned producing ashes with differing conditioning requirements. Also, variation of flue gas temperatures as boiler loads vary may lead to insufficient production of SO_3 at low loads, causing fouling of the ESP with high resistivity ash which may interfere with emission compliance upon return to full load operation. For economy of installation and simplicity of operation it is preferred that booster fans not be used, which means that the system relies on the relatively small pressure drop in the main system to provide the driving force for the side loop in which the catalytic conversion of SO_2 to SO_3 occurs. This leads to large injection probe sizes and difficulty in obtaining uniform distribution and mixing of SO_3 in the downstream gas. The expense of custom ductwork design and installation for such a system is not negligible. It is expected that a considerable amount of testing and demonstration work will be required to accurately assess the suitability of this system for commercial operation. Development of another system proposed earlier in which ammonium sulfate was to be decomposed in hot boiler flue gas and the resulting SO_3 used for ESP conditioning is said to have been abandoned.

DUAL CONDITIONING

Simultaneous injection of SO_3 and NH_3 , arbitrarily called dual conditioning, was mentioned earlier as assisting in obtaining attachment of SO_3 to fly ash at temperatures above the inflection point of the injection rate curve. Dual conditioning has been found to have other uses as well. It has been demonstrated that it may be used to control rapping and reentrainment losses from ESP's. It appears that the process can be crudely visualized as reacting the two conditioning gases to form ammonium bisulfate which has a melting point close to typical ESP operating temperatures. This is thought to act as a binding agent (liquid glue?), increasing the cohesivity of the ash particles so that they adhere to each other and fall into the hopper with reduced dispersion into the gas stream. A striking demonstration of this effect occurred at the Monroe Station of Detroit Edison where SO_3 alone permitted operation only up to 450 Mw before the compliance limit on particulate emission was reached, but dual conditioning allowed the full 750

Mw unit rating to be attained. In tests conducted by Ontario Hydro it was found that dual conditioning obtained significant reduction of losses to the stack caused by high unburned carbon levels in the ash.

Some experimenters in the past found that the injection of NH_3 into flue gas streams containing appreciable quantities of SO_3 caused the ash to become "sticky" enough to cause problems in ash handling systems. Experience with dual conditioning to date indicates that this problem arises when relatively large quantities of NH_3 and SO_3 are present as compared to the amount of ash. The quantities required to provide effective prevention of excessive rapping and reentrainment losses are controlled to much lower values. None of the dual conditioning installations thus far (15,250 Mw) have had problems with ash handling from increased ash cohesivity.

TABLE 2

Dual Flue Gas Conditioning Installations

Location	Number of Boilers	Total Mw	Fuel
U.S.A.	21	6,350	Bituminous
	2	610	Sub-Bituminous
	2	1,190	Lignite
Canada	14	6,600	Bituminous
Taiwan	1	500	Bituminous
Total	40	15, 250	

WHEN IS DUAL CONDITIONING NEEDED?

From the preceding description of the inflection point which appears in the injection-rate-versus-temperature curves it is clear that one criterion for needing dual conditioning is flue gas temperature exceeding the inflection point temperature. Criteria for advance determination of a need for dual conditioning to suppress excess rapping and reentrainment losses by means of fuel and ESP data have not yet been developed. In part this is because the factors affecting ash cohesivity in the ESP have not been explored or defined, and partly because the mechanical and fluid dynamic characteristics of the ESP which affect the magnitude of rapping and reentrainment losses may differ radically from one installation to the next. Investigative procedures capable of developing applicable loss factors on a sound engineering basis are not available. It seems odd that such a significant ESP loss mechanism should be so poorly characterized. It is expected that continued research will help to clarify this situation in the future. In the meantime the only recourse is making field trials with fuel, SO_3 and ESP conditions as nearly as possible the same as expected in service. Then, observation of the difference between recordings of flue gas opacity with and without rapping will immediately indicate, if the difference is more than a few percent and large rapping spikes appear on the instantaneous trace, that dual conditioning should be considered.

CONDITIONING OF FABRIC FILTERS

It has been observed that introduction of SO_3 and NH_3 into gas streams containing fly ash significantly affects the physical composition of collected layers of the material, whether the collection is by mechanical or electrostatic methods. It is not surprising then, that dual conditioning has been found to have marked effects on the operation of fabric filters. Pilot scale tests conducted at the University of North Dakota Energy and Environmental Research Center and field tests at the Monticello Station of TU Electric have shown that for a number of different coals with several different fabrics and several different cleaning modes that fine particulate emissions and baghouse pressure drop are greatly reduced by use of dual conditioning. In the Monticello tests the filter drag without conditioning was more than twice as

great as that with conditioning. Inasmuch as the initial Monticello results confirmed laboratory data, it is expected that the pilot plant investigations of other ashes are reliable predictors of short-term field performance. Longer-term data from Monticello and elsewhere is needed to make sure no objectionable side effects exist. If this proves to be the case, dual conditioning should take a place in the future as a useful technique for control of baghouse performance.

INCIDENTAL EFFECTS

The addition of SO_3 alone to boiler flue gas streams only occurs if the coal is low in sulfur, as otherwise the ash resistivity will not be high enough to require conditioning. Nearly all of the injected SO_3 is attached to the ash particles and is captured with them in the ESP. Without conditioning one to one-and-one-half percent sulfur content in the coal would typically give the same ash resistivity as that obtained by injection, meaning that the same amount of SO_3 is on the ash surface, but an additional amount would still be present in the gas stream and would be emitted from the stack. This latter amount, typically about one-half percent of the SO_2 content of the gas stream, is not present in the emissions from the conditioned unit unless operation at temperatures above the inflection point of the injection rate curve is attempted without the simultaneous injection of ammonia.

Fly ash from a conditioned system carrying acid on its surface in about the same concentration as that from unconditioned combustion of one-plus percent sulfur coal is not significantly different in handling requirements and environmental effects from the ashes dealt with in the past. Ash handling systems which sluice SO_3 -conditioned ash to a pond and recirculate the water may find that the pH of the pond will be depressed below acceptable levels for discharge to the environment, making neutralization treatment necessary.

Ammonia treatment of fly ash may cause release of objectionable odors from concrete made with cement in which the fly ash has been used as an additive. Determination of the maximum acceptable ammonia content for fly ash in this use is a trial-and-error process. The level has been found to be greater than zero in all cases to date, but the maximum appears to be influenced by cement and ash chemistry and ash handling conditions.

Ammonia and sulfur as used by conditioning systems are essentially pure chemicals which neither introduce nor generate any hazardous or toxic pollutants. Except for improved control of particulate emissions the overall impact of the boiler system on the environment is essentially unchanged by the use of flue gas conditioning.

FUTURE PROSPECTS

It is reasonable to suppose that dual conditioning of both ESP's and fabric filters will develop through trial and error and gradual accumulation of pilot and full scale data in much the same way that SO_3 progressed over the past several years. Pilot scale work is under way at the present time to find out whether the beneficial short-term effects of dual conditioning on the performance of reverse-air and shake-deflate fabric filters also apply to pulse-cleaned designs. Full-scale long-term trials remain to be performed to validate dual conditioning of fabric filters as a commercial option. The demonstrated capability of conditioning to greatly improve baghouse collection of fine particles will likely become more important with increasingly severe restrictions on fine-particle emission.

There is a need for a great deal of basic work to establish a sound technical basis for the estimation and control of rapping and reentrainment losses from ESP's. Methods of measurement of dust cohesivity in the ESP environment, determination of the combination of dust cohesivity, rapping impact and plate height to attain minimum losses and design of ESP structures and operating schedules which best provide optimum cost and performance all need to be explored. ESP research, fueled in large part by EPA and EPRI, has made major progress during the past 20 years in substituting engineering for art. It appears that a complete understanding of the rapping/reentrainment process is the only significant remaining grey area.

Over the long run dual conditioning will progress to a position of predictability and acceptance now enjoyed by sulfur trioxide conditioning for adjustment of fly ash resistivity in electrostatic precipitators. In connection with flue gas conditioning at Monroe Station of the Detroit Edison Company mentioned earlier in this article it was found possible to develop specifications for fuel procurement taking advantage of the ability of the generating units to compensate for variations in coal and ash analysis. This was expected to simplify obtaining and evaluating fuel bids, and to avoid compliance problems by use of relatively precise knowledge of equipment and fuel limits. It would appear that there is a future possibility of using on-line coal and ash analysis capability in combination with economic analysis to optimize both fuel allocation to units and generation costs. A utility using a combination of generating units having flue gas conditioning without scrubbing, other units with scrubbing, and some purchased emission allowances, for instance, could very well be in position where optimum allocation of both fuel and load would make an appreciable difference in costs and emissions.

CONCLUSIONS

In ESP operation dust collecting performance is often adversely affected by resistivity effects or by rapping and reentrainment. Problems of this type reduce the performance level of the equipment compared to that which it is capable of attaining if the dust to be collected is treated to permit optimum operation of the collecting mechanisms. In many cases maximum economy may be attained by application of flue gas conditioning to an appropriately sized dust collector having fewer hoppers, less acreage, less power and much less maintenance than conventional units handicapped by being required to collect dusts which have not been properly prepared for efficient collection. Your automobile won't run well if you put crude oil in the tank - your ESP won't run well on high resistivity dust. Advantages obtainable by use of flue gas conditioning will permit better emissions control with smaller, more reliable, less expensive ESP installations. There is a possibility, yet to be fully confirmed, that fabric filter performance may be similarly subject to improvement in certain cases.

NO_x CONTROLS FOR COAL-FIRED UTILITY BOILERS IN EAST CENTRAL EUROPE

David Eskinazi, Manager, Government and International Projects

Electric Power Research Institute
Washington, DC, USA

E. Stratos Tavoulareas

Energy Technologies Enterprises Corporation
McLean, Virginia, USA

INTRODUCTION

Increasing environmental pressures worldwide, including East Central Europe are placing greater emphasis on NO_x emission controls in utility power plants. Western Europe, Japan and the U.S. have significant experience in applying NO_x controls, especially in boilers firing hard coal.¹ Some countries in Europe (i.e., Germany and Austria), have gained experience in applying NO_x controls in boilers firing low-rank coal.² This experience can be applied to East Central European countries in providing the basis for planning NO_x control projects, suggesting cost-effective solutions, and providing lessons learned. However, while the experience is generally applicable to East Central European countries, differences in boiler design, operation and coal characteristics also need to be considered.

This paper begins with a comparison of the NO_x regulations, identifies the key NO_x control technologies and the worldwide experience with them, and discusses the achievable NO_x reduction, O&M impacts, and retrofit costs for each technology. Emphasis is placed on retrofit applications for existing boilers, because new coal-fired power plants are not expected to be built for the next 5-10 years. This paper also focuses on technologies with relatively low cost and operational simplicity: combustion system tuning/optimization, low-NO_x burners (LNB), overfire air (OFA), selective non-catalytic reduction (SNCR), and reburning.

COMPARISON OF NO_x EMISSION REGULATIONS

Over the last ten years, there have been significant developments in NO_x emission regulations for existing power plants. Table 1 compares the NO_x regulations for existing coal-fired power plants in the East Central European countries, with these in the European Union (EU) and U.S. East Central European countries have adapted both "point source" standards for utility boilers and annual NO_x emission ceilings. Point source standards in East Central Europe are appearing closer to EU countries with some areas already having more stringent requirements. As signatories of the Sofia Protocol, East Central European countries are also required to freeze NO_x emissions to 1987 levels before 1995. However, it is uncertain whether compliance with this deadline will be practical.

EU has set the maximum NO_x level for power plants above 50 MWth at 650 mg/m³, as well as NO_x emission ceilings (Ktons/year) for each country. Due to this ceiling, Belgium, Denmark, Germany, France, Luxembourg, Netherlands and the United Kingdom are required to achieve 35-40% NO_x emissions from 1980 levels by 1998. Many EU countries have NO_x regulations significantly lower than the 650 mg/m³

¹ Hard coals, as discussed in this paper, have gross calorific value above 5,700 Kcal/kg (23.86 MJ/Kg or 10,260 Btu/lb) on ash-free basis and include bituminous coals and anthracite.

² Low rank coals, as discussed in this paper, have gross calorific value less than 5,700 Kcal/kg on ash-free basis and include subbituminous, lignites and brown coals.

level. For example, Germany and Austria require that all coal-fired power plants above 300 MWth reduce NO_x emissions below 200 mg/m³.

NO_x regulations in the U.S. are addressed in the Clean Air Act Amendment (CAAA) of 1990 under the acid rain (Title IV) and ozone attainment (Title I) articles. Under Title IV, approximately 180 boilers will be required to meet these NO_x levels by Jan. 1995. The remaining boilers will be required to meet these or potentially more stringent limits by year 2000. Considering that NO_x emissions from tangentially- and wall-fired boilers typically range from 800 to 1600 mg/m³ (0.6-1.2 lbs/MBtu), 30-60% NO_x reduction is needed in most cases to comply with the 1995 CAAA regulations.

Title I requires that Reasonable Available Control Technology (RACT) is used in all ozone non-attainment regions by May 1995. Each state is responsible for specifying RACT. Individual states are also required to develop and implement compliance plans to achieve ozone attainment between 1996 and 2010, depending on the classification of each area (Marginal, Moderate, Serious, Severe and Extreme).

In response to the NO_x regulations, East Central European countries have started installing low NO_x burners. In Poland, where most of the 32,000 MW installed capacity is coal-fired (60% hard coal and 36% low-rank coal), 4,000 MWs are expected to be retrofitted with low NO_x burners by year 2000 and 8,600 MW thereafter³. In the Czech and Slovak Republics, where most of the coal-fired plants utilize low-rank coal, about 30% of the existing 48 plants are expected to be decommissioned. The remaining plants will be retrofitted with NO_x controls or repowered with fluidized-bed combustors. Hungary has similar plans for its 2100 MW coal-fired capacity (60% hard coal and 40% low-rank coal); again, while some will be decommissioned, the remaining plants will be retrofitted with low NO_x burners or repowered with atmospheric fluidized-bed combustion.

NO_x CONTROL TECHNOLOGIES AND EXPERIENCE BASE

NO_x control technologies are broadly classified into three groups: combustion system optimization, combustion modifications and post-combustion technologies. Of the combustion modification options, low NO_x burners, overfire air and perhaps reburning appear to be most applicable to East Central Europe. Post-combustion technologies include SNCR and SCR with SNCR likely more suitable for East Central European applications. The alternative NO_x control technologies are shown in Figure 1.

Combustion System Optimization

Combustion system optimization for NO_x emissions involves changes in the settings of operating variables to minimize NO_x emissions without adverse impacts on unit operation. No equipment modifications are required making it the lowest cost option. Operating variables which are changed include auxiliary/secondary air dampers, primary air-to-fuel ratio and excess oxygen. Also, coal flow biasing to achieve higher coal flow rate through the bottom burners and lower flow through the top burners may be used, provided that the pulverizers have the excess capacity needed.

In addition to the above operating changes, optimization may also include minor refurbishments to the combustion system and auxiliary equipment. These may include re-orificing of coal pipes to improve air and coal flow distribution, restoring damper operation, and refurbishment of pulverizers to improve coal fineness which allows the boiler to operate at lower excess oxygen level and achieve lower NO_x emissions and satisfactory combustion efficiency.

Combustion system optimization typically is achieved through parametric testing, changing one variable at a time. Also, specialized software is available to facilitate the optimization process. While a digital control system is not required, it makes optimization easier and has the potential of achieving higher NO_x reduction.

³ Daly and Sondreal (Prague 1994)

Optimization can be applied to all types of boilers. However, some types of units (e.g., cyclones) have less flexibility in terms of operating adjustments and are expected to achieve lower NO_x emission reduction.

Combustion system optimization has been applied successfully in many wall- and tangentially-fired boilers, especially in the U.S. and Germany. Although most of the optimization experience is with boilers burning hard coal, there are at least five boilers firing low-rank coal which have demonstrated the effectiveness of this NO_x control option; these include four RWE boilers in Germany and Otter Tail's Hoot Lake #2 (a 55 MW tangentially-fired boiler burning North Dakota lignite) in the U.S.

Low- NO_x Burners⁴ and Overfire Air

With OFA, a portion of the secondary air is diverted to injection ports or compartments located above the primary combustion zone, thereby creating a fuel-rich primary combustion zone. Tangentially-fired units may have close-coupled overfire air (CCOFA) at the top of the existing windbox and/or separated overfire air (SOFA) above the windbox. Wall-fired boilers have OFA above the existing windbox. The amount of air introduced through the OFA system varies from 10 to 30% of the total combustion air.

As of January 1994, approximately 35 tangentially-fired and 55 wall-fired boilers, ranging in size up to 880 MW, were retrofitted with LNB and/or OFA systems in the U.S. The number of retrofits is expected to double at the end of 1994. The majority of these plants are burning bituminous coal. Five boilers (one tangentially-fired and four wall-fired) burning subbituminous coal have been retrofitted with LNBs and OFA.

The experience with lignite-fired boilers retrofitted with LNB or OFA in North America is limited to the following two units: 1) a 150 MW tangentially-fired power plant in Saskatchewan, Canada was equipped with ABB/CE's LNCFS I (concentric firing with CCOFA), and 2) a 55 MW tangentially-fired boiler burning North Dakota lignite (Otter Tail's Hoot Lake #2) which was tested in "simulated" overfire air mode.

In Europe, Germany and Austria have retrofitted most of their wall- and tangentially-fired units with LNBs and OFA. Among these units, 37 boilers in Germany and 5 in Austria burn brown coal. Other EU countries such as the United Kingdom, France and Denmark have also retrofitted boilers with LNBs and OFA.

For boilers burning low-rank coal, one issue which needs to be addressed is the possibility of limited air flow rate for the OFA system due to the high amount of primary air used for coal drying, especially at low loads.

Reburning

Reburning is accomplished by injecting coal, oil or natural gas above the primary combustion zone within the furnace to create a reducing zone (reburn zone). Figure 1 shows the location of the reburn injectors relative to the burners. Combustion is completed above the reburn zone, where burnout air is usually introduced. Reburn fuel typically accounts for 10-20% of the total heat input of the boiler. Because reburning performance depends on accurately controlling the stoichiometry in each combustion zone, accurate measurement and control of fuel and air flows is essential. For optimum performance, boiler instrumentation and controls upgrades may be required.

However, for units that can employ LNBs and/or OFA, reburning would generally be considered only as an add-on technology because it is a more complex and costly system to retrofit and operate. Reburning is ideally suited--albeit more costly--for units which can not utilize low NO_x burners (e.g., cyclones), and units requiring additional NO_x reduction beyond the level achieved by low NO_x burners.

⁴ The term LNB, as used in this paper, denotes both low- NO_x burners for wall-fired boilers and coal/air nozzle modifications such as concentric firing for tangentially fired boilers.

Experience with reburning technology is growing. As Table 2 shows, there are six demonstration projects, either under way or completed in the U.S. Two applications are on wall-fired boilers, one on tangentially-fired and three on cyclones. Four out of the six reburning systems use natural gas. The other two use coal (pulverized or micronized) as reburn fuel. The largest boiler retrofitted with reburning is 180 MW. An issue remaining for large boilers, above 300 MW is whether adequate mixing can be achieved without compromising potential NO_x reduction.

Post-Combustion Technologies

Post-combustion options include non-catalytic reduction (SNCR) and selective (SCR). Because of its relatively lower capital and operating costs, only SNCR is included in this paper.

SNCR

SNCR removes NO_x from the flue gas by injecting one of a number of nitrogen-based reagents which combine with NO_x to form elemental nitrogen and water vapor. No catalyst is employed. The most common reagents are urea (CH_2CONH_2), and anhydrous or aqueous ammonia (NH_3). The SNCR reagent injectors are placed either in the upper furnace or the backpass cavity, where the flue gas temperature is in the 870-1200°C (1600-2000°F) range to maximize the NO_x removal efficiency. Multiple injection locations may be required, especially in case of cycling and intermediate load units.

There are two primary types of SNCR systems: "low energy" and high energy" systems. Low energy systems utilize mechanical atomizers or dual fluid atomizers and nominal amount of atomizing air. High-energy systems use sonic injectors with air flow rate ranging from 0.5 to 2.5% of the total flue gas flow rate.

SNCR has been used in about 15 coal-fired utility applications in the U.S., Germany and Austria (see Table 3). Five of these (representing 735 MW) are demonstration projects. Ten projects (1230 MW) are commercial. Five out of the fifteen boilers burn low-rank coal. The remaining burn U.S. bituminous (hard coal) or subbituminous (low-rank) coal. In addition to the utility boilers, there are more than 150 industrial boilers burning various fuels which have been retrofitted with SNCR. From these, two 12 MW district heating boilers burning low-rank coal are at Strakonice of the Czech Republic have been retrofitted with Nalco's Fuel Tech's (NFT) NO_x OUT process. So far, SNCR experience is limited to boilers up to 330 MW. An issue remaining for large boilers from above 400 MW, is whether adequate mixing can be achieved without compromising potential NO_x reduction. Because reagent costs can be significant, SNCR is especially favored for smaller boilers and those with a low utilization factor.

KEY RETROFIT CONSIDERATIONS

Assessment of NO_x control technologies requires consideration of five key factors as shown in Table 4:

- boiler design,
- boiler operation,
- coal properties,
- auxiliary system design and operation, and
- condition of existing equipment.

In general, the overall goal in selecting optimum NO_x control technologies is to maximize NO_x reduction without adverse O&M impacts while minimizing costs and unit outage requirements. Industry experience suggests that important trade-offs among these elements will need to be considered.

For example, O&M impacts can occur even if precautions are taken to integrate the NO_x control technology into the existing power plant. In general, the higher the NO_x emission reduction sought, the higher the potential for O&M impacts.

Also, matching NO_x control system design with the actual capability and operating condition of the auxiliary systems is important. For example, Pennsylvania Electric's Homer City #2, a 600 MW opposed wall-fired boiler retrofitted with LNBs, experienced burner plugging and overheating. The primary cause of this problem was that the LNB system was designed to operate at a different primary air flow rate than the pulverizer actually could deliver. While LNBs are designed with some degree of operating flexibility, they can not overcome significant mismatches. At Homer City, redesign and replacement of all the burners was needed to correct the operating problems.

Pulverizer upgrading and coal pipe re-orificing may be needed to maximize the NO_x reduction and minimize O&M impacts. Operating experience indicates that NO_x control systems are more sensitive than conventional burners to changes in air and coal flow distribution in the coal pipes, as well as to coal fineness. In some retrofits, coal pipe re-orificing and mill refurbishment improved coal flow distribution and coal fineness, which resulted in lower excess air and NO_x emissions.

Although digital control systems are not required for NO_x control technologies, they can make it easier to operate such systems, achieve higher level of NO_x reductions and minimize adverse O&M impacts.

NO_x REDUCTION POTENTIAL

NO_x reduction potential with combustion optimization, combustion modifications and SNCR ranges from 5 to 70%. A summary of the utility retrofit experience is provided in Table 5.

Combustion System Optimization:

NO_x reduction potential with combustion system optimization depends on the degree to which the boiler has already been tuned and the operating flexibility of the existing combustion system. In the U.S., optimization of wall- and tangentially-fired boilers achieved up to 35% NO_x emission reduction without significant impacts on unit operation. When boiler auxiliary equipment are in disrepair, minor refurbishment may improve NO_x reduction.

Most of the optimization experience is with boilers firing hard coal. However, test results from four RWE boilers in Germany (60-600 MW firing brown coal) and Otter Tail's Hoot Lake #2 unit (55 MW tangentially-fired boiler burning North Dakota lignite) in the U.S. show that similar results can be achieved for low rank coals. The RWE units achieved approximately 10% NO_x reduction by optimizing just the excess air level. Hoot Lake #2 achieved 15-20% with optimization of excess air and air flow distribution in the windbox.

Low NO_x Burners and Overfire Air

NO_x reduction of 15-30% has been achieved at high loads with OFA in wall-fired boilers and close-coupled OFA in tangentially-fired boilers. NO_x reduction of 30-60% have been achieved with LNBs and 40-70% with LNB + OFA. In tangentially-fired boilers these NO_x reductions diminished at reduced load (below 70%).

An example of this is shown in Figure 2. The data is based on Gulf Power's Smith #2, a 180 MW tangentially-fired boiler retrofitted in a step-wise fashion with ABB/CE's LNCFS I (concentric firing + CCOFA), LNCFS II (concentric firing + SOFA) and LNCFS III (concentric firing + CCOFA + SOFA).

Figure 3 is an example for wall-fired boilers showing the NO_x emissions from Georgia Power's Hammond #4, a 500 MW wall-fired boiler retrofitted in a step-wise fashion with Foster Wheeler's OFA, LNB and LNB + OFA systems.

While most of the NO_x reduction experience is based on boilers firing bituminous and subbituminous coals, it is expected that similar reductions can be achieved when firing lignite and brown coals. In fact, the direct experience with low-rank coal, although limited to OFA applications in the U.S. and LNB in Germany supports these conclusions. In a 300 MW application in the RWE system in

Germany, 10-25% NO_x reduction was achieved with an OFA system. A combination of combustion system optimization, LNB and OFA has achieved 50-70% NO_x reduction in some RWE boilers. Also, Otter Tail Power's Hoot Lake #2, a 54 MW tangentially-fired unit firing North Dakota lignite, achieved 20-30% NO_x reduction through with "simulated" OFA

Reburning

With reburning, NO_x reduction of 40-60% is achievable at high load (80-100%), but it diminishes below 70% load. Figure 4 illustrates this for Ohio Edison's Niles #1, a 108 MW cyclone boiler firing eastern bituminous coal. The NO_x reduction experience with reburning is based largely on the projects shown in Table 2.

Similar NO_x reduction would be expected for both dry- and wet-bottom boilers in East Central European countries. For boilers firing low-rank coal, similar NO_x reduction is expected based on pilot scale (Babcock & Wilcox' 5 MBtu/hr facility) and limited full scale testing.

SNCR

Most coal-fired units are expected to achieve 30 to 60% NO_x reduction with SNCR. However, up to 80% NO_x reduction has been observed in some units, such as Mainz' Weisbaden, Germany (30 MW), which achieved 70-80% NO_x reduction, and Wisconsin Electric Power Company's Valley #4 (70 MW), which achieved 60-70% NO_x reduction. Five boilers, firing low-rank coals and ranging from 75 to 330 MW in size, have successfully used SNCR in Germany and Austria. All these plants demonstrated NO_x reduction in the 30-60% range. Boilers firing low-rank coal may achieve NO_x reduction at the upper end of this range, because they generally have a more suitable temperature window in the upper furnace.

OPERATING & MAINTENANCE (O&M) IMPACTS

O&M impacts due to NO_x control technologies are generally expected to be modest (up to 1% reduction in boiler efficiency). They are usually lower for LNB than OFA and expected to be higher for reburning and SNCR, which affect more boiler operation. Also, for a given technology, the potential O&M impacts increase with increasing NO_x reduction.

Combustion System Optimization

O&M impacts due to combustion system optimization are generally minimal, because in most cases simultaneous optimization of the combustion process and NO_x reduction are sought.

Low NO_x Burners and Overfire Air

Boiler retrofits with low NO_x burners and/or overfire air can lead to increases in excess O₂ and LOI (Loss on Ignition, which is an indication of unburned carbon in the flyash), changes in furnace slagging patterns, steam outlet temperatures and operating flexibility, and increases in waterwall corrosion. The most common impacts are increased LOI and excess O₂ which might reduce boiler efficiency by up to 1%.

For LNB, LOI increase depends on coal reactivity, coal fineness and the condition of the combustion and auxiliary systems. For overfire air systems, additional factors are the degree of staging and the furnace height. Generally, 3-5 percentage points LOI increase has been observed in boilers firing hard coal in the US. Higher LOI increase, 5-10 percentage points, has been observed in boilers firing low reactivity coals. Potential LOI increases can be controlled by increasing coal fineness and/or excess O₂. If it is practical, improvement in coal fineness is preferable, because increasing excess O₂ will result in higher NO_x emissions.

Figure 5 illustrates the increase in LOI across the load range due to the installation of LNB and OFA at Georgia Power's Hammond #4, a 500 MW opposed wall-fired boiler firing eastern bituminous (hard) coal; LOI increased from 5% during pre-retrofit (baseline) to 8% with LNB and 9-10% with OFA.

Excess O₂ increases of 1-2 percentage points have been observed in some retrofits, especially when OFA is utilized. This excess O₂ increase is mainly to avoid LOI and CO emission increases, and to maintain a stable flame.

Consistent changes in furnace slagging have not been observed, but in several cases furnace slagging was reduced due to LNB and OFA retrofits.

A decrease of up to 30°F in reheat temperature has been experienced by some tangentially-fired boilers, especially at low loads (below 70%). This has been observed in sites such as at Gulf Power's Smith #2 unit. In this instance, the impact on reheat temperature could be eliminated by increasing burner tilt and/or excess O₂, but NO_x emissions would increase.

There have been no reports of increased corrosion of boiler pressure parts due to LNB and/or OFA retrofits. However, because of the difficulty of obtaining accurate long-term data, few retrofit applications have sought to document changes in boiler tube thickness. In general, where corrosion problems existed before a NO_x control retrofit, waterwall corrosion should be monitored after the retrofit.

Impacts on boiler operation have varied. Where retrofits resulted in replacement of worn or damaged equipment, boiler operation improved. Also, the new burners resulted in improved boiler turndown. However, in some cases increased attention was needed by plant operators, especially where operation of LNB, and/or OFA was not fully automated.

Instances of reliability problems have been reported, including burner plugging, overheating and cracking. In some cases these problems have been corrected through minor design changes and modifications in pulverizer and burner operating practices. In other cases, burner re-design and replacement was required. In general, most of the problems have been corrected through burner design modification by the vendors.

To avoid or reduce O&M impacts systematic testing before and after the retrofit is advised. Where high incidence of prior O&M problems has occurred (e.g., tube failures and high attemperation rates), they should be communicated to the vendors through the design specifications. Careful integration of the NO_x control system with the boiler design and operating characteristics is also essential to minimize potential adverse impacts. Integration should consider not only the boiler, but key auxiliary equipment such as the pulverizers and air supply system.

Reburning

Potential O&M impacts in considering a reburning system retrofit include changes in boiler efficiency, heat absorption patterns, steam outlet temperatures and waterwall corrosion.

Boiler efficiency decrease will occur with utilization of reburn fuels with higher hydrocarbon content such as natural gas and oil. For gas reburn, boiler efficiency decrease of 0.5 to 1.0 percentage points should be expected. In fact, Niles #1 and Hennepin #1 retrofits experienced 0.7 and 0.9% decrease in boiler efficiency, respectively. For coal reburning, if sufficient residence time exists, no impacts on boiler efficiency are expected.

Changes may occur in heat absorption patterns, because of changes in heat release patterns in furnace slagging. This may impact steam outlet temperatures and heating surface metal temperatures. A small increase in furnace outlet temperature was observed in some applications in the U.S., but, attemperation spray was adequate to control steam outlet temperatures to pre-retrofit levels. The smaller the distance between the top burner and the furnace outlet plane, the greater the possibility for changes in furnace outlet and steam temperatures.

While the reducing atmosphere created in the reburn zone has the potential to accelerate waterwall corrosion, no significant problem has been observed. Again, long-term monitoring is advised.

SNCR

Key O&M impacts due to SNCR retrofits are focused on potential operating problems with the air heater and flyash handling resulting from ammonia slip. As a target, ammonia slip should be kept below approximately 5 ppm to avoid operating problems due to the formation and deposition of ammonium bisulfate in the air heater and below 2 ppm for flyash handling. Ammonium bisulfate formation increases with increasing sulfur in the coal, so ammonia slip requirements may need to be lower than 5 ppm for high sulfur coals.

Unit heat rate is not expected to be impacted significantly by heat losses due to the latent heat from injected liquids. However, heat rate will increase, with high-energy systems which require auxiliary power to operate.

RETROFIT COSTS

This section focuses primarily on the key factors affecting retrofit costs--rather than the costs themselves--because costs are country-specific (i.e., affected by local labor and material costs).

Combustion Optimization

Combustion system optimization takes 2-6 weeks to be completed and requires two to three engineers on a full-time basis. Parametric testing (changing of one variable at a time) typically takes 4-6 weeks for testing and data analysis. Utilization of specialized software may reduce the testing time required to 2-4 weeks. In the U.S., typical costs for boiler optimization are \$50,000-200,000.

Costs of hardware modifications, such as mill refurbishment (adjustment of classifier or installation of dynamic classifier) and coal pipe re-orificing should also be considered. Such costs vary widely with the type of modification and condition of existing equipment.

Combustion system optimization does not require unit outage, but the unit may need to be taken off load dispatch and operate at conditions dictated by the optimization test matrix.

Low NO_x Burners and Overfire Air Systems

Capital costs of NO_x control retrofits depend on the desired level of NO_x reduction and, subsequently, the NO_x control technology selected--especially if OFA is used. Differences in control system design and engineering approaches vary from supplier to supplier, as does the extent to which potential O&M impacts need to be considered. A variety of boiler design factors (e.g., boiler type), the condition of boiler key combustion system components (windbox and the waterwalls), the potential structural interferences and the required waterwall penetrations may also affect the retrofit costs.

In the U.S., capital costs for retrofitting tangentially-and wall-fired boilers with LNB and OFA have ranged from 5 to 30 \$/kW. (see Table 6) These costs include direct and indirect costs for the key NO_x control components (e.g., the burners, overfire air ports and ducts) but do not include any needed upgrades to auxiliary equipment (e.g., installation of mill classifiers) and digital controls. The latter may equal or exceed the cost of the NO_x control equipment.

Reburning

Capital and operating costs for reburn systems depend on the reburn fuel selected, natural gas, oil or coal, the reburn fuel required as a percentage of the total boiler heat input and the fuel prices. The main components of the reburn system are reburn burners, burnout ports, piping and ductwork, reburn combustion control system, tie-in with existing boiler controls, and burner secondary air monitors. However, in the case of cyclone boilers, a new pulverizer may be needed.

In the U.S., capital costs usually range from 20 to 50 \$/kW, with natural gas and oil reburning at the lower end of this range (20-30 \$/kW) and coal reburning at the upper end (30-50 \$/kW). A 10-year levelized busbar cost of electricity is expected to increase by 2.5 to 5 mills/kWh for natural gas and oil reburning (assuming 2.5-4.0 \$/MBtu for oil and gas prices) or by 1.0-2.0 mills/kWh for coal reburning (assuming 1.7 \$/MBtu for coal price).

SNCR

SNCR capital costs are affected mainly by the required NO_x reduction, the degree of load variations anticipated, and the type of SNCR. The SNCR capital costs range from 5 to 20 \$/kW. The key factors affecting SNCR O&M costs are the required NO_x reduction and the cost of reagent. In the U.S., the SNCR system adds 0.5 to 2.0 mills/kWh to the levelized operating costs.

CONCLUSIONS

There is significant experience with NO_x control technologies applied to boilers firing hard-coal in the Western Europe and the U.S. The experience with NO_x controls for low-rank coal applications is less extensive and primarily based on applications in Germany, Austria and the U.S. This experience can be used by East Central European utilities to provide a basis for planning NO_x control projects, suggest cost-effective solutions and build on a range of lessons learned. More detailed assessment of the applicability of Western experience for East Central European countries will require further evaluation of the differences in boiler design and operating practices of the specific power plants, as well as variations in coal properties.

Systematic planning is critical for successful NO_x compliance and NO_x control projects. This should consist of assessing of regulatory requirements, characterizing each affected unit in terms of baseline NO_x emissions and the potential for NO_x reduction through combustion system optimization, assessing commercially available NO_x control options, including experience base, NO_x reduction potential, O&M impacts, costs and unit outage requirements, evaluating system-wide considerations, and implementing NO_x control projects through development of design specifications, evaluation of commercial bids, retrofit, testing and operation.

Generally, retrofitting low NO_x burners and overfire air are likely to be the most cost-effective options for hard and low-rank coals to meet the NO_x regulations in East Central Europe, which range from 300 to 600 mg/m³. Low-NO_x burners in tangentially- and wall-fired boilers are expected to achieve 30-60% NO_x reduction. Overfire air is expected to achieve 15-30% NO_x reduction. A combination of low NO_x burners and overfire air can achieve 40-70% NO_x reduction in tangentially- and wall-fired boilers.

Potential O&M impacts with these technologies include changes in LOI, O₂ and steam outlet temperatures, which may reduce boiler efficiency and increase unit heat rate by up to 1 percentage point. In general, O&M impacts can be minimized with proper design of the NO_x control system and matching with the design and operating condition of the boiler and auxiliary equipment. Also, O&M impacts can be mitigated through operating changes after the NO_x control retrofit, but NO_x emissions may increase as a result.

Capital costs of NO_x control retrofit projects in East Central Europe are expected to be affected by local market factors, such as labor rates, cost of materials and manufacturing, and level of competition among NO_x control suppliers. In the U.S., the retrofit costs have been in the following range: low NO_x burners, 7-25 \$/kW; overfire air, 5-10 \$/kW; low NO_x burners + overfire air, 10-30 \$/kW.

Combustion system optimization without equipment modifications may reduce NO_x emissions by 5-35%. The high end of the range applies to boilers which have not tuned the combustion system recently, and may include coal flow biasing and mill modifications (e.g., coal pipe re-orificing and mill refurbishment to improve coal fireness). Utilities should explore the potential for NO_x reduction through optimization as application costs will be lower than for low NO_x burners or overfire air and may, in some instances, achieve NO_x compliance requirements. The latter may be the case for tangentially- and wall-fired boilers firing low-rank coals, which generate relatively low NO_x emissions.

For some applications, SNCR and reburning should also be considered. These technologies may be particularly important for boilers which can not use low NO_x burners or overfire air (e.g., cyclones) and in the case NO_x regulations are or become tighter. Reburning can achieve 40-70% NO_x reduction (50-70% with gas and 45-55% with coal reburning). SNCR can achieve 30-70% NO_x reduction while keeping ammonia below 20 ppm.

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TABLE 1

NO_x Regulations for Existing Coal-fired Power Plants
in East Central Europe, EU and U.S.

Country	NO _x Regs (mg/m ³) ¹	Notes
◦ East Central Europe ² :		
- Czech Republic	650	Over 5 MWth size
- Hungary	300	
- Poland	460	- For hard coal by 1997
	405	- For low-rank coal by 1997
European Union ³	650	Over 50 MWth size; individual country limits vary
USA	619-680	- For tangentially- and wall-fired boilers - NO _x limits for cyclones and others to be established in '97 - Individual states may require more stringent NO _x limits, with some having limits as low as 200 mg/m ³ - Lower national limits are under review

¹ These are based on 6% O₂ at 0°C, 1.013 bar—the most commonly used units in Europe

² Daly and Sondreal (Prague, 1994)

³ IEA, NO_x Control Technologies for Coal Combustion (1990)

TABLE 2

Reburning Demonstration Projects on Coal-Fired Boilers in the United States

Unit	Utility	Size ¹ (MW)	Unit Type	Reburn Fuel	Demo Status
Cherokee 4	Public Service Company of Colorado	180	Wall-Fired	Gas	Startup testing
Dewey 2	Wisconsin Power & Light	100	Cyclone	Coal	Operational
Hennepin 1	Illinois Power	70	Tangential- Fired	Gas	Operational
Lakeside 7	City Light & Power	40	Cyclone	Gas	Under construction
Niles 1	Ohio Edison	108	Cyclone	Gas	Decommissioned
Shawnee 3	Tennessee Valley Authority	175	Wall-Fired	Micronized Coal	Planned

¹ Approximate nameplate rating

TABLE 3

SNCR Experience in Coal-fired Utility Boilers

Utility, Country	Plant Name #	Size (MW)	Coal Type	Project Type	SNCR Supplier	SNCR Chemical
BKB, Germany	Offleben C	325	Brown	Comm (1989)	NOELL	Urea
Mainz, Germany	Weisbaden	30	Hard	Comm (1985)	Exxon	Anh. Ammonia
New England Power, US	Salem Harbor 1, 2 and 3	85, 85 & 185	Hard	Demo & Comm (1993)	Nalco	Urea
NEPO	NEPO 1	135	Hard	Comm (1991)	ACI	Anh. Ammonia
No. Am. Chemical, US	Trona 1 & 2	75 75	Hard	Comm (1989/91)	Nalco	Urea
ODK, Austria	St. Andra #2	110 (tangentially- fired)	Brown	Comm (1989)	OEDK	Aqueous NH3
ODK, Austria	Voitsberg #3	330 (tangentially- fired)	Brown	Demo (1990)	OEDK	Aq. & Anh. NH3 & Urea
ODK, Austria	Zeltweg	137	Hard	Comm (1988)	OEDK	Aq. Ammonia
PS of Colorado, US	Arapahoe #4	100	Hard	Demo (1993)	Noell	Urea & Aq. Ammonia
RWE, Germany	D	150 (tangentially- fired)	Brown	Demo (1987)	Nalco	Urea
RWE, Germany	C2	75 (tangentially- fired)	Brown	Comm (1988)	Nalco	Urea
WEPCo, US	Valley #4	70	Hard	Demo (1992)	Nalco	Urea

TABLE 4

Key Factors Affecting Combustion NO_x Control Retrofits

Key Factor	Specific Components
Boiler Design	- Boiler type (tangential, wall, etc.) - Size (MW) - Burner zone heat release rate - Physical dimensions (height, depth, width and distance between top burner and furnace outlet plane) - Windbox design - Possible structural interferences (for OFA and reburning)
Boiler Operation	- Dispatching (cycling, intermediate or baseloaded) - Excess air level - Burner settings (e.g., registers and/or tilts)
Coal Properties	- Reactivity - Nitrogen content - Moisture content - Propensity for slagging, fouling or corrosion
Auxiliary System Design and Operation	- Coal and air flow distribution in coal pipes - Primary air-to-coal ratio - Secondary air supply (pressure drop) - Instrumentation & controls
Condition of Existing Equipment	- Boiler (e.g., waterwalls) - Windbox (e.g., dampers) - Pulverizers (e.g., coal fineness)

TABLE 5

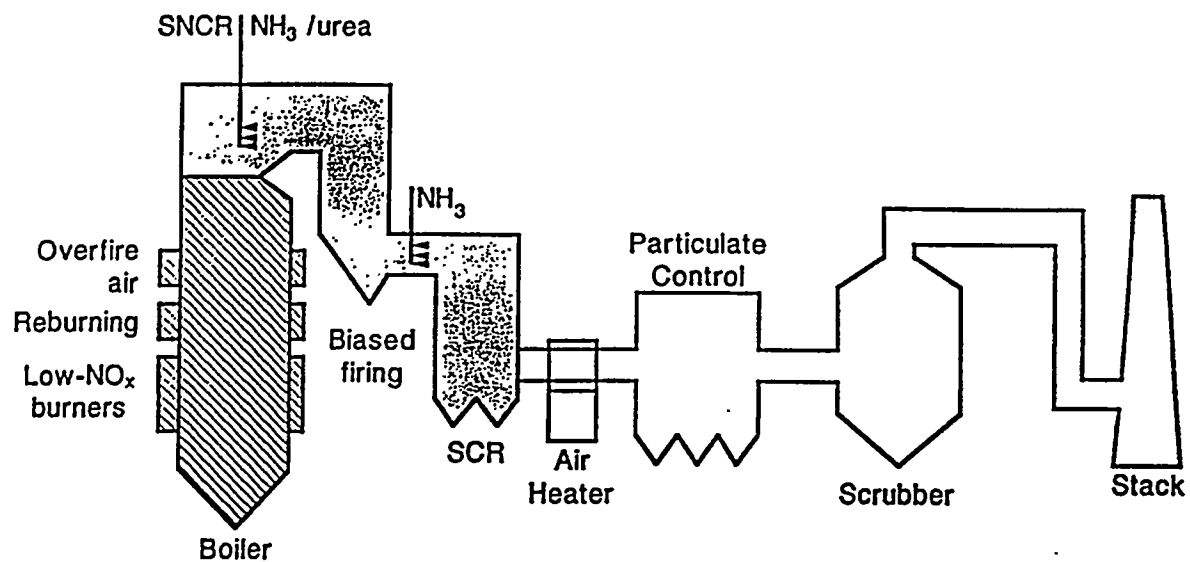
Summary of NO_x Reduction Experience

Technology	% NO _x Reduction	Comments
Combustion Optimization	5-35	5-15%: for recently retrofitted & tuned dry-bottom boilers 10-30%: for dry-bottom boilers, not recently tuned 20-35% with equipment refurbishment
OFA	15-30	OFA for wall and CCOFA for tangentially-fired
LNB	30-60	
LNB + OFA	40-70	
Reburning	40-60	For both dry- and wet-bottom boilers
SNCR	30-60	For both dry- and wet-bottom boilers

TABLE 6

Capital Costs of LNB and OFA Systems in the U.S.

NO _x Control Technology	Retrofit Capital Costs (\$/kW)
LNB	7-25
OFA	5-10
LNB + OFA	10-30

Figure 1. Power Plant NO_x Control

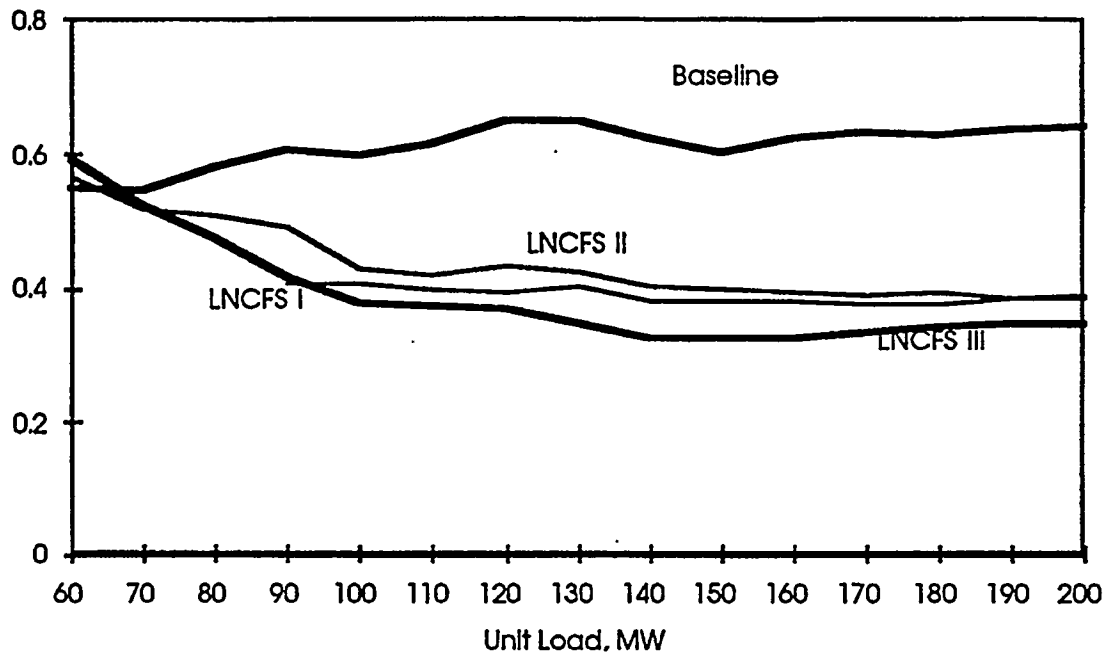


Figure 2. NO_x Reduction vs. Load with ABBA/CE's LNCFS Levels I, II, and III for Gulf Power's Smith #2 (180 MW tangentially-fired boiler).

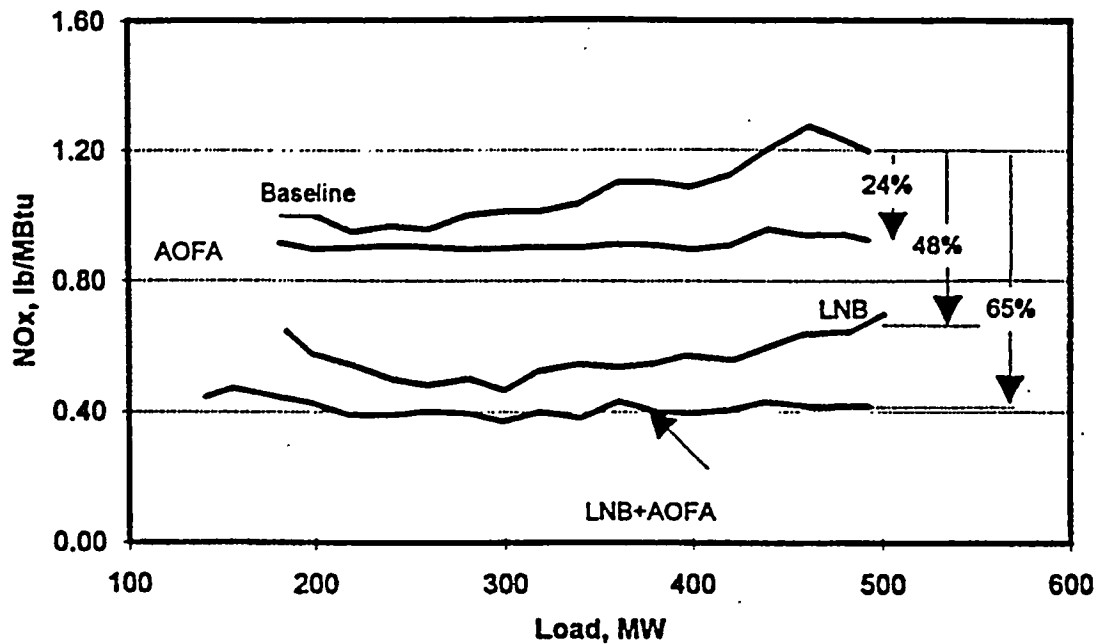


Figure 3. NO_x Emissions vs. Load – Georgia Power's Hammond #4, 500 MW Wall-Fired Boiler.

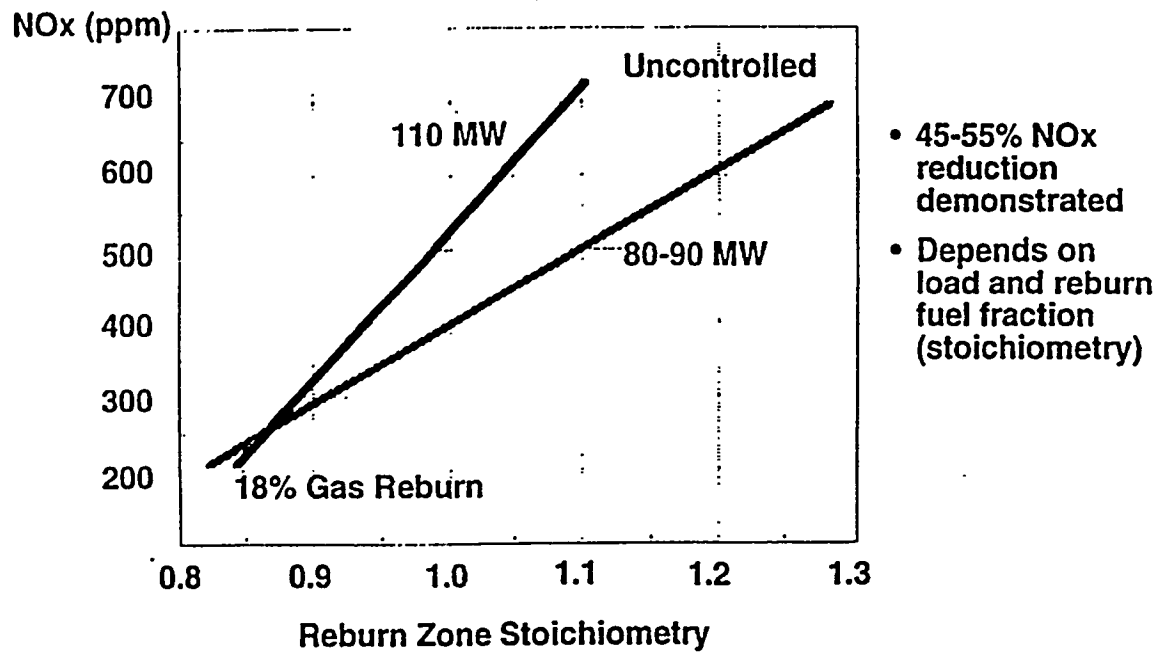


Figure 4. Cyclone Gas Reburn – Ohio Edison's Niles #1.

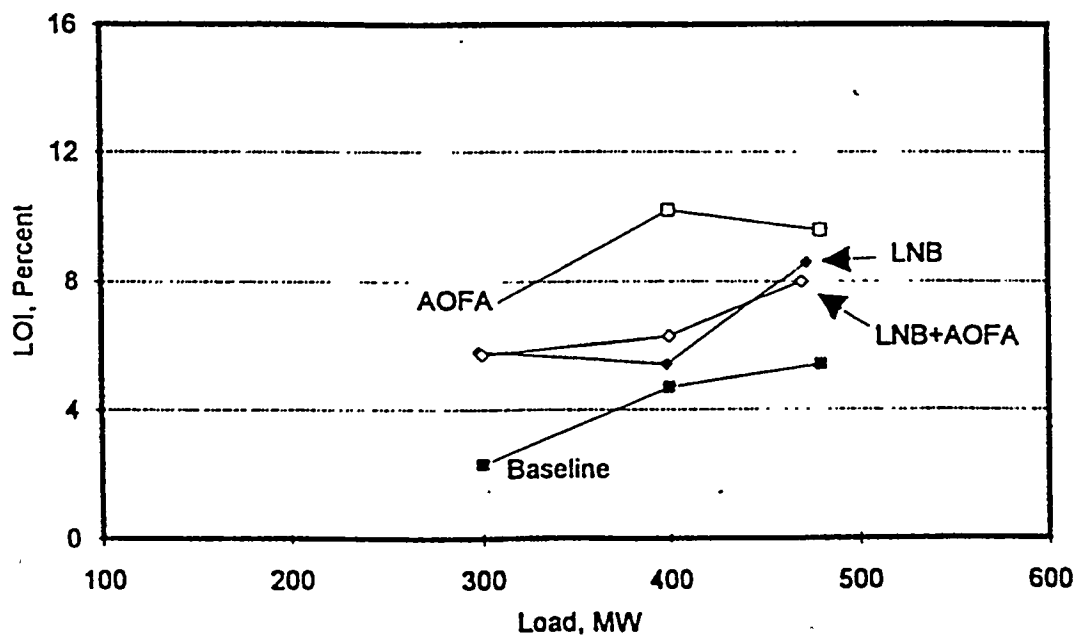


Figure 5. LOI vs. Load – Georgia Power's Hammond #4, 500 MW Wall-Fired Boiler.

Conventional Energy Systems III – Retrofitting and Repowering

Session A3

SESSION CHAIR:

*Richard Dunn, Assistant Chief Engineer
Stone & Webster Engineering Corporation
Boston, Massachusetts, USA*

A MINIMUM-COST SO₂ SCRUBBER CASE STUDY

Ing. Josef Kašparů, Director, ČEZ
Ing. Ladislav Ullmann

Power Plant Počerady
Počerady, Czech Republic

ABSTRACT

The role of Czech Power Company in the environment improvement process and its program to meet new legislation environment requirements.

SULPHUR DIOXIDE CONTROL

Since the early 1960's there has been an increasing awareness that industrial growth and energy production from fossil fuels are accompanied by the release of potentially harmful pollutants into the environment. Disregard for air protection under the socialist regime in the former Czechoslovakia caused a catastrophic situation especially in the Northern region of Bohemia with an extremely high concentration of power production.

Only at the beginning of the 1990's the legislation process setting new environmental requirements for air and water control has been completed. Total electric power production by fuel type in 1993 and installed generation capacity in Czech power sector are shown in Table 1. Czech Power Company (ČEZ) as the major power producer in the Czech Republic of 9 325 MW has started the air and water pollution control program. The underlying role of ČEZ's environmental activities is to meet its environmental

TABLE 1

Power Production in Czech Republic in 1993		
	Power Production (GWh)	
	Czech Republic	ČEZ
Coal	44,760 (76.02%)	32,661 (70.32%)
Hydro	1,495 (2.54%)	1,157 (2.49%)
Nuclear	12,627 (21.44%)	12,627 (27.19%)
Total	58,882 (100.0%)	46,445 (100.0%)
Installed Capacity (MW)		
Coal	9,261 (74.73%)	
Hydro	1,371 (11.06%)	
Nuclear	1,760 (14.24%)	
Total	12,392 (100.00%)	
(Czech Power Sector)		
- ČEZ	10,655	
- Independent	1,427	
- Plant Power Stations	1,893	
- Distribution Companies	311	
Czech Republic Total	14,286	

responsibilities including strict protection of the Czech Republic's population health. ČEZ will have to generate power in a way, that has a minimal impact on the environment. The ČEZ's Program for Environmental Improvements will fully meet the Clear Air Act in force. The indivisible part of this program is closing down of coal fired units with the total installed capacity higher than 2000 MW by the year 2000. ČEZ will have to install SO₂ removal equipment in all coal fired units remaining in operation. In power plants operating by ČEZ mostly low-grade quality domestic coal with high ash and sulfur content is used. The program itself is very extensive, requiring implementation in a very short period. At the same time, it is very capital intensive.

Table 2 illustrates a decommissioning program within ČEZ company beginning in 1990 to the year 1999.

Table 3 provides more detailed information about time scheduling of particular projects, method used and suppliers.

Table 4 shows the FGD program of substitution of old units by new fluidized bed boilers.

CLEAR AIR ACT REQUIREMENTS

The Clear Air Act signed into the law in 1992 represents a significant contribution to the air quality. The primary objective of the act is to protect and improve the quality of environment so as to promote the public health. The Act established strict SO₂ emission control requirements on all new and most existing coal, liquid fuel and gas fired units. Limits of SO₂ emissions set to the Clear Air Act are as follows:

INSTALLED CAPACITY (MW Thermal)	SO ₂ Limit mg/Nm ³)
Over 300	
- Coal	500
- Liquid	500
- Gas	35
50-300	
- Coal	1,700
- Liquid	1,700
- Gas	35

Required reductions in SO₂ emissions are:

Over 300 MW (thermal) - more than 85%
50 - 300 MW (thermal) - more than 70%

BIDDING AND EVALUATION PROCEDURES

ČEZ is faced with legislative pressure to reduce emissions of air pollutants in a relatively short time. As shown in a Table 3, most of SO₂ removal technologies should be in operation by the year 1998.

Usually an independent buyer's committee has been appointed to coordinate initial stages of project management and procurement. Such a committee (consisting of power plants and ČEZ technical and financial experts, design specialists, bankers and consulting engineers) is responsible for accurate specification of buyer's needs as well as for bids evaluation.

TABLE 2

ČEZ's Decommissioning Program

Name - Initial installed capacity (MW)	Decommissioning units No.- capacity - date	Operating capacity after decommissioning (MW)
Prunéřov II 5 x 210	—	1050
Prunéřov I 6 x 110	Unit 2 - 110 - 12/1990 Unit 1 - 110 - 12/1991	440
Počerady 6 x 200	Unit 1 - 200 - 12/1993	1000
Chvaletice 4 x 100	Unit 2 - 200 - 12/1997	600
Tušimice I 6 x 100	Unit 6 - 100 - 12/1990 Unit 1 - 110 - 03/1992 Unit 2 - 100 - 05/1993 Unit 3 - 100 - 06/1994 Unit 4 - 100 - 03/1997 Unit 5 - 100 - 03/1997	0
Tušimice II 4 x 200	—	800
Mělník III 1 x 500	—	500
Mělník II 4 x 110 1 x 12	Unit 7 - 100 - 12/1998 Unit 8 - 100 - 12/1998	220
Dětmárovice 4 x 200	—	800
Ledvice 1 x 200 4 x 110	Unit 5 - 110 - 12/1993 Unit 4 - 100 - 03/1994 Unit 1 - 200 - 04/1997	220
Tisová I 2 x 50 2 x 55 2 x 12	Unit 4 - 55 - 12/1998	167
Tisová II 3 x 110	Unit 7 - 110 - 12/1990 Unit 8 - 110 - 12/1991	110
Poříčí 3 x 55	Boil.5,6 - 55 - 9/1996	110
Hudonín 2 x 50 2 x 55	Unit 3 - 55 - 1993 Unit 2 - 50 - 1995 Unit 1 - 50 - 1997	55 (+40 new unit)

TABLE 3

ČEZ's Program of Desulphurization Plants Installation

Power station Unit No./ Capacity (MW)	Date of contract placing	Expected commissioning date	Technology Supplier	Financing
Prunéřov II 21 - 210 22 - 210 23 - 210 24 - 210 25 - 210	02/1993	from 02/1996 to 08/1996	Wet limestone Mitsubishi Heavy Industries + ZVU Hradec Králové	45% World Bank credit 55% ČEZ
Prunéřov I 3 - 110 4 - 110 5 - 110 6 - 110	07/1992	01/1996	Wet limestone Consortium Gottfried Bishoff + Brown & Root Škoda	ČSOB & KfW bank credit Czech & German government Grant
Počerady 5 - 200 6 - 200	04/1989 01/1992	08/1994 09/1994	Wet limestone Consortium OTES+Škoda	ČEZ
2 - 200 3 - 200 4 - 200	04/1994	11/1996 10/1996 11/1996	Hoogovens Group	ČEZ + banking credit
Chvaletice 3 - 200 4 - 200 1 - 200	01/1995	12/1997 12/1997 12/1997	Depends on tendering conclusion	ČEZ or by credit, if convenient conditions will be offered
Tušimice II 21 - 200 22 - 200 23 - 200 23 - 200	05/1994	05/1997	Jet bubbling reactor consortium Chiods Co & Marubeni Co & Burmeister & Wain Energi	ČEZ
Mělník 9 - 110 10 - 110 11 - 500	10/1995	12/1998	Wet limestone depends on tendering	?
Dětmárovice 1 - 200 2 - 200 3 - 200 4 - 200	03/1995	1997-1998	depends on tendering process	financing offer by supplier required
Ledvice 2 - 110 3 - 110	04/1994	05/1994	Semi-dry method Consortium Austrian Energy & Environment + Vítkovice a.s.	domestic part- ČEZ 80% of foreign & delivery by banking credit
Tisová 6 - 110	—	09/1997	has not been chosen yet	ČEZ + banking credit

TABLE 4

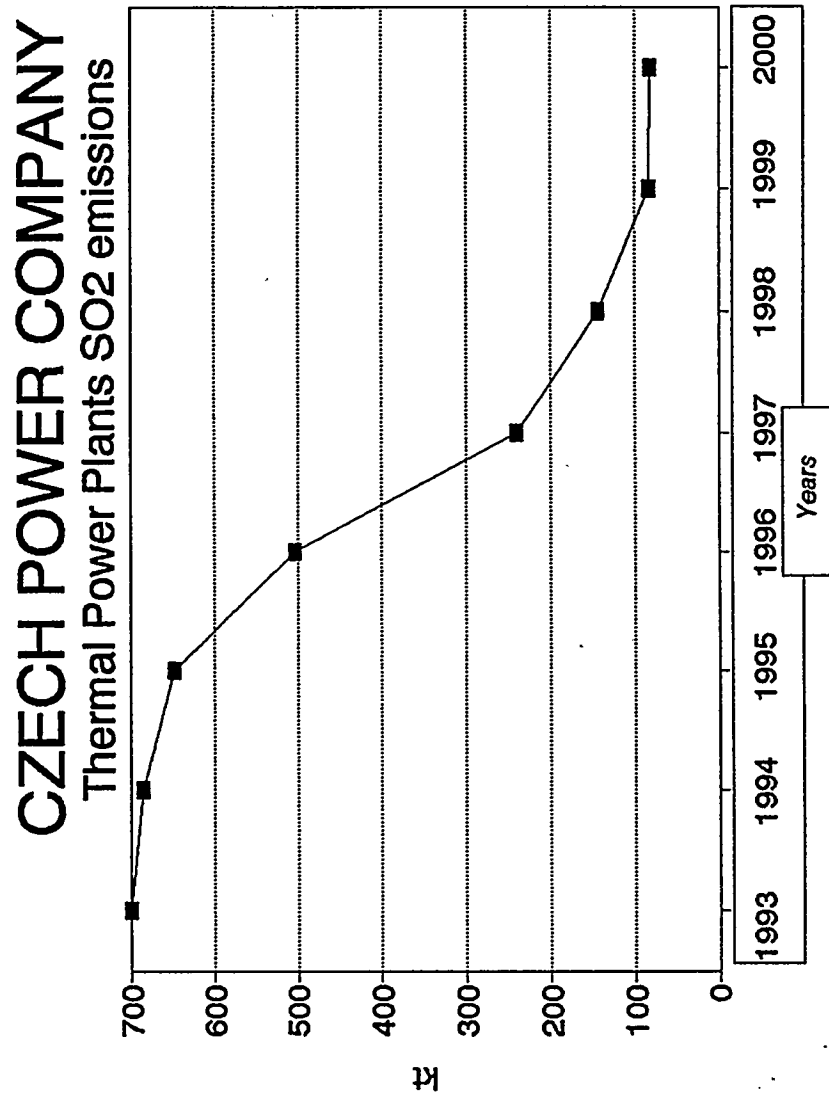
ČEZ'S Program of Fluidized Bed Boilers Installation

Power station Unit no./ Capacity (MW)	Date of contract placing	Date of commission	Technology - Supplier	Financing
Tušimice 2 x 50	—	—	feasibility study	
Mělník 7 - 110 8 - 110	—	after 2000	feasibility study	
Ledvice 4 - 110	—	9/1997	depends on tendering	
Tisová 1 350 t/h 2 350 t/h	09/1993 07/1995	10/1995 10/1997	circulating fluidized bed -Vítkovice -has not been decided yet	ČEZ + credit
Poříčí FK1 - 170 t/h FK2 - 170 t/h	06/1994 06/1994	11/1996 09/1996	Ahlstrom Pyroflow AEE	ČEZ + credit fo foreign delivery (85%)

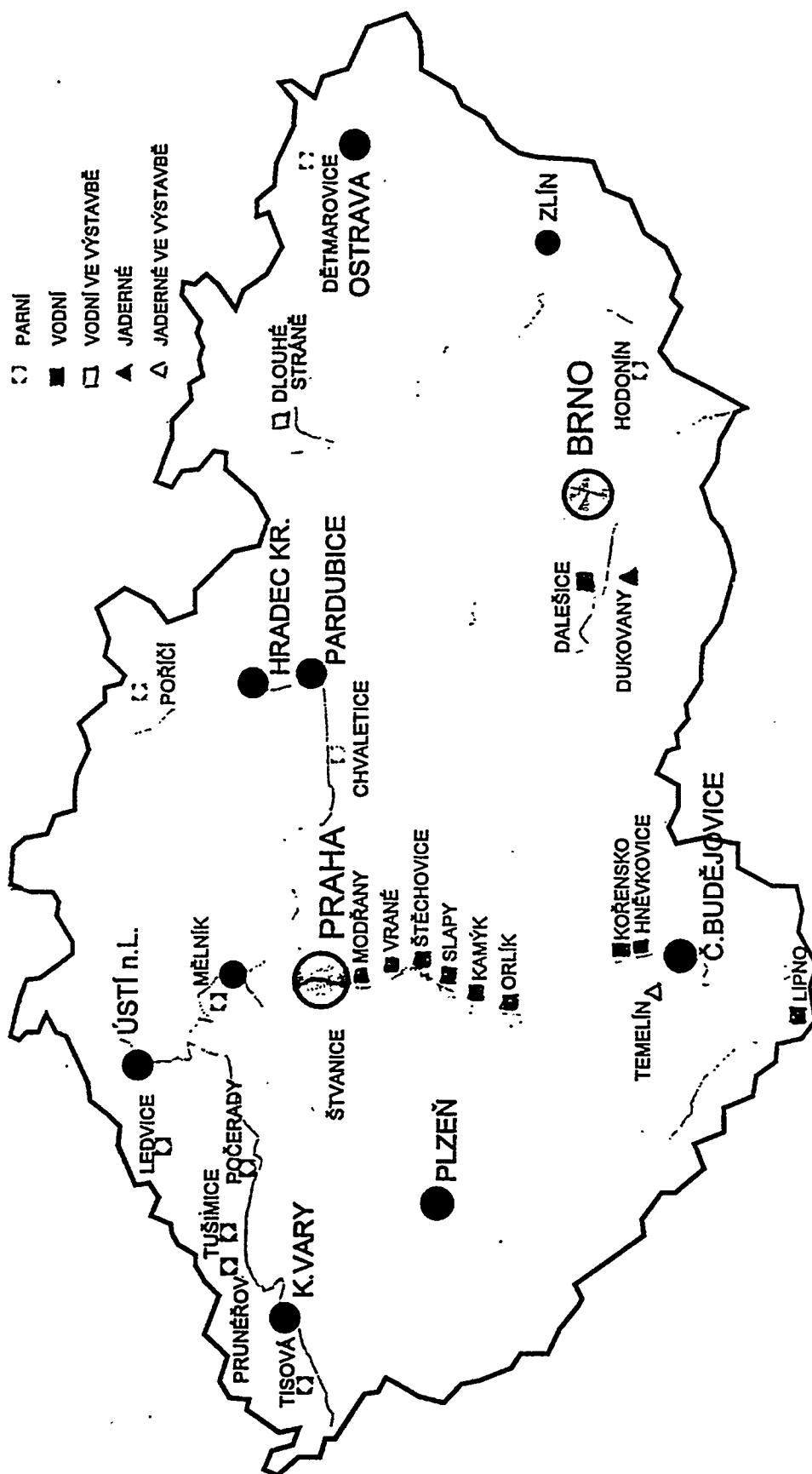
Bids evaluation includes a review of the scope, operation ease, maintenance and operation costs, service, design and construction features, time schedule, experience, terms and price. Efficiency and availability are the two most critical factors.

In most cases a complete turnkey project system is used, when the supplier is fully responsible for a performance liability outlined in guarantees. Normally ČEZ uses an open tender process in accordance with recommendations of the World Bank.

The proportion of Czech subcontractors' participation in the air pollution control projects ranges from 40% to 90%. There is no priority for domestic suppliers in a tender process, but the domestic participation is very important for the price level of bids.



ELEKTRÁRNY ČEZ



PERFORMANCE ANALYSIS AND PILOT PLANT TEST RESULTS FOR THE KOMORANY FLUIDIZED BED RETROFIT PROJECT

Gerry C. Snow, Project Development Manager

POWER International, Inc.
Coeur d'Alene, Idaho, USA

ABSTRACT

Detailed heat and mass balance calculations and emission performance projections are presented for an atmospheric fluidized bed boiler bottom retrofit at the 927 MWt (steam output) Komorany power station and district heating plant in the Czech Republic. Each of the ten existing boilers are traveling grate stoker units firing a local, low-rank brown coal. This fuel, considered to be representative of much of the coal deposits in Central Europe, is characterized by an average gross calorific value of 10.5 MJ/kg (4,530 Btu/lb), an average dry basis ash content of 47 %, and a maximum dry basis sulfur content of 1.8 % (3.4 % on a dry, ash free basis). The same fuel supply, together with limestone supplied from the region will be utilized in the retrofit fluidized bed boilers.

The primary objectives of this retrofit program are, 1) reduce emissions to a level at or below the new Czech Clean Air Act, and 2) restore plant capacity to the original specification. As a result of the AFBC retrofit and plant upgrade, the particulate matter emissions will be reduced by over 98 percent, SO₂ emissions will be reduced by 88 percent, and NO_x emissions will be reduced by 38 percent compared to the present grate-fired configuration. The decrease in SO₂ emissions resulting from the fluidized bed retrofit was initially predicted based on fuel sulfur content, including the distribution among organic, pyritic, and sulfate forms; the ash alkalinity; and the estimated limestone calcium utilization efficiency. The methodology and the results of this prediction were confirmed and extended by pilot scale combustion trials at a 1.0 MWt (fuel input), variable configuration test facility in France.

INTRODUCTION

Beginning in September of 1991, POWER began a series of comprehensive feasibility studies to identify the best technical and economic solution to upgrade power plants and minimize environmental emissions in North Bohemia, Czech Republic. One of the sites studied is a large power station and district heating plant located at Komorany near the city of Most. This power station, known as the First Northwest Power and Heating Plant (1.SZT) was one of the first firms to be privatized during the restructuring of the political and economic system in Czechoslovakia. The feasibility studies resulted in the conclusion that atmospheric fluidized bed combustion (AFBC) represented the best technical solution for the utilization of the local supplies of brown coal while meeting the strict emission limits under the new Czech Clean Air Act, Law No. 309 (1).

As a result of the initial feasibility studies, 1.SZT contracted with POWER for the design and engineering of an AFBC system suitable for the Komorany Power Station. The basis of design report, representing the final concept of the AFBC application to Komorany, was completed in December of 1992. This document identified bubbling fluidized bed bottom retrofits to each of the ten boilers as the most cost effective means to achieve the plant upgrade and emission reduction goals.

Reconstruction of the first of ten boilers is currently underway. This unit is scheduled for startup in the fourth quarter of 1994. The remaining nine retrofits at the Komorany station will be completed in phases, with the final unit scheduled to be on-line in December 1998.

AFBC RETROFIT DESCRIPTION

Details of the 1.SZT AFBC basis of design and engineering approach have been presented elsewhere (2). Each of the ten boilers at Komorany will be retrofit using the same design and overall approach. Combustion Power Company of Menlo Park, California provided the detailed design of the fluidized bed combustion system and boiler interface. The new fluid bed combustor is bottom supported and will interface with the existing furnace walls through a flexible seal.

Approach

The existing combustion chamber is about 13 m in height from the highest point of the traveling grate to the convective section inlet. The plan area of each grate bottom is 6.5 m by 10.5 m. The basic approach to the retrofit is to remove the existing traveling grate bottom and the lower portion of the existing furnace walls to an elevation of approximately 3 m above the highest point of the grate (about 13 m above the building floor level).

A unique feature of this retrofit project is the retention of the existing electrostatic precipitators in their present locations supplemented by new baghouses located on the roof of the boiler house. The precipitators will serve primarily as a pre-collector to each baghouse and as a source for material to be re-injected into the fluid bed. The expected ESP collection efficiency following the AFBC retrofit is between 80 and 90 percent. Between 50 and 60 percent of the ESP ash will be re-injected into the fluid bed together with ash collected from the superheater and air heater hoppers. The total re-injected ash represents a recycle ratio (ash to fuel) of about 0.4. This recycled ash will improve both carbon burnout and limestone calcium utilization so that the SO₂ capture requirements can be met without excessive limestone usage.

Fuel and Sorbent

The brown coal currently fired at Komorany, and to be used in the AFBC retrofit, has the following characteristics:

Lower Heating Value (As Fired):	8.0 - 11.0 MJ/kg (3,440 - 4,728 Btu/lb)
Higher Heating Value (As Fired):	8.9 - 12.1 MJ/kg (3,841 - 5,214 Btu/lb)
Higher Heating Value (Moisture Free):	12.1 - 17.1 MJ/kg (5,210 - 7,344 Btu/lb)
Moisture (As Fired):	23 - 29 %
Ash (Moisture Free):	40 - 54 %
Sulfur (Moisture Free):	1.0 - 1.8 %

The nominal size of the current stoker fuel is 0 to 40 mm with 15 percent greater than 40 mm. For use in the AFBC retrofit, this fuel will be crushed and screened to a nominal size of 0 to 20 mm with 10 percent greater than 20 mm.

The limestone specified for the AFBC retrofit has the following properties (dry basis):

CaCO ₃	75%
MgCO ₃	3%
SiO ₂	17%
Al ₂ O ₃	4%
Fe ₂ O ₃	1%
Moisture	4–6%
Nominal Grain Size	0.1–3.0 mm

Process Design

The main operating parameters for the AFBC retrofit (for each boiler) are as follows:

Steam output:	125 tonnes per hour
Minimum steam output:	50 tonnes per hour
Maximum superheat temperature:	500°C
Nominal superheater pressure:	7.5 MPa
Maximum superheater pressure:	7.7 MPa
Maximum drum pressure:	8.24 MPa
Feed water temperature:	170°C

PREDICTED PERFORMANCE

Heat and mass balance calculations were performed at three design point conditions to determine the range of fuel and limestone flow requirements, the ash flows, steam conditions, and flows, and boiler efficiency. The design point conditions were defined at the low, intermediate, and maximum points for the coal heating value. The three coal heating values analyzed were 8.0, 10.2, and 11.0 MJ/kg on a lower heating value (LHV or net), as fired (23–29 % moisture) basis. The other design conditions are 816° bed temperature (812° at the low range LHV of 8.0 MJ/kg), and a steam flow of 125 tonne/hr. The heat and mass balance calculations are summarized in Table 1.

Fluidizing Velocity

The initial size specification of the feed limestone was developed from an evaluation of the minimum fluidization velocity, the maximum elutriable size, and experience with other bubbling bed FBC installations. The feed limestone top size was determined using a simplified Kunii-Levenspiel correlation for minimum fluidization velocity (3, 4).

$$U_{mf} = \frac{\mu}{\rho D_p} [(25.25)^2 + (0.65) Ar]^{0.5} - 25.25$$

where:

μ = gas dynamic viscosity at operating conditions

ρ = gas density at operating conditions

Ar = Archimedes number for the particle relating gravitational forces against viscosity forces.

TABLE 1

Summary Of Process Conditions For The Komorany AFBC Retrofit (Each Boiler)

Coal LHV As Fired, MJ/kg	Fuel Flow, kg/hr	Steam Flow, tonne/hr	FBC Bed Temp., °C	Boiler LHV Thermal Efficiency, %	Limestone Addition To Meet Emission Limit, kg/hr	Total Bottom Ash and Fly Ash for Removal, kg/hr
11.0	35,200	125	816	85.0	3,520 ^a 3,168 ^b	15,720 ^a 15,380 ^b
10.2	38,200	125	816	85.0	3,820 ^a 3,438 ^b	17,060 ^a 16,690 ^b
8.0	48,700	125	812	84.2	4,870 ^a 4,383 ^b	21,750 ^a 21,280 ^b

^a Without ash re-injection.^b With ash re-injection at 0.5 recycle ratio.

The design point superficial velocity for the AFBC retrofit is 2.5 m/s. Setting this velocity as the minimum fluidization velocity results in a maximum particle diameter of 2.4 mm. A calculation of terminal velocity was used to estimate the maximum elutriable (carryover) size. By setting the terminal velocity to 2.5 m/s, the resulting maximum elutriable size is 0.34 mm.

These calculations indicated that a limestone nominal size range of between 0.1 and 3.0 mm, with a mean diameter of 0.7 to 1.0 mm, would give good fluidization behavior. The final AFBC system design incorporates ash reinjection to recirculate limestone fines carried over. Pilot plant test data (discussed below) confirms that these size ranges and the reinjection system provide good operating performance.

Emissions

The SO₂ emissions from the retrofit AFBC boilers will be limited to 500 mg/Nm³ (0°C, 101.32 kPa, 6% O₂, dry) under the Czech Clean Air Act (equivalent to about 0.4 lb/10⁶ Btu). Sorbent capture performance and subsequent emissions of SO₂ depend upon many variables, including coal sulfur content, percent pyritic and sulfate sulfur, ash alkalinity, firing temperature and combustion efficiency, mixing and time-temperature profile in the reaction zone, Ca/S ratio, limestone effective surface area, calcium availability, and limestone impurities.

From the heat and mass balance calculations, 1 tonne (1000 kg) of the specification coal combusts to produce 4,453 Nm³ of dry combustion products corrected to 6 percent oxygen content at 0°C and 101.32 kPa. Therefore the total potential SO₂ concentration in the product gas can be estimated by:

$$\begin{aligned} \frac{\text{mg}}{\text{Nm}^3} &= \left(\frac{\% \text{ S}}{100} \right) \left(1 - \frac{\% \text{ retention}}{100} \right) \left(\frac{64}{32} \right) \left(\frac{1 \text{ tonne coal}}{4453 \text{ Nm}^3} \right) \left(10^9 \frac{\text{mg}}{\text{tonne}} \right) \\ &= \left(\frac{\% \text{ S}}{100} \right) \left(1 - \frac{\% \text{ retention}}{100} \right) (449,135) \end{aligned}$$

At zero inherent retention (100 percent sulfur release), the uncontrolled SO₂ emissions and the required overall capture efficiencies to meet the 500 mg/Nm³ emission limit for the specification coal is shown in Table 2.

TABLE 2

Projected Maximum Uncontrolled SO ₂ Emissions		
% Sulfur (moisture free)	Uncontrolled SO ₂ Emissions, mg/Nm ³	Required Overall Capture To Meet Emission Limit, %
1.0	4490	88.9
1.2	5390	90.7
1.4	6290	92.0
1.6	7190	93.0
1.8	8080	93.8

The added limestone Ca/S requirement depends on the actual percentage of sulfur released during combustion of the coal. Somewhat less than 100 percent of the coal sulfur will be released as gaseous SO₂. From the detailed coal analysis data, approximately 39 percent of the total coal sulfur is pyritic and another 5 percent is bound as sulfate.

During FBC combustion, about 20 percent of the pyritic sulfur and essentially all of the sulfate sulfur will remain in the ash. This means that the potential for total coal sulfur release during combustion will be about:

$$[1 - (0.39)(0.2) - (0.05)] \times 100 = 87.2\%$$

This is equivalent to a retention of 12.8 percent.

Additional sulfur will be captured by the sodium and calcium in the coal ash. The specification coal ash contains about 0.21 percent sodium as Na₂O and 2.1 percent calcium as CaO. The average ash content is 47 percent. At an average coal sulfur content of 1.3 percent, the effective inherent sodium to sulfur ratio is therefore:

$$\begin{aligned} \text{Na}_2 &= \frac{(0.0021)(0.47) \left(\frac{1 \text{ kg - mole Na}_2}{62 \text{ kg - mole Na}_2\text{O}} \right)}{(0.0013) \left(\frac{1 \text{ kg - mole S}}{32 \text{ kgS}} \right)} \\ &= 0.038 \end{aligned}$$

The effective inherent calcium to sulfur ratio is:

$$\begin{aligned} \frac{\text{Ca}}{\text{S}} &= \frac{(0.021)(0.47) \left(\frac{1 \text{ kg - mole Ca}}{56 \text{ kgCaO}} \right)}{(0.013) \left(\frac{1 \text{ kg - mole S}}{32 \text{ kgS}} \right)} \\ &= 0.43 \end{aligned}$$

The total inherent alkali to sulfur ratio for the specification brown coal is therefore $0.038 + 0.43 = 0.47$. The inherent alkali compounds in the coal will capture sulfur and retain it as a solid sulfate (Na₂SO₄ or CaSO₄). At inherent alkali to sulfur ratios of 0.4 to 0.5, the effectiveness of the retention mechanism, measured as utilization efficiency of the ash alkali, can range from 40 to 80 percent or higher (5). Using an average utilization efficiency of 60 percent, additional sulfur retention by the specification coal ash of about $(0.47)(0.60)(100) = 28$ percent was projected.

Therefore, as a result of how the sulfur is bound, and allowing for additional retention by the alkali compounds in the ash, it was predicted that about 40 percent of the total sulfur would be retained in the coal ash for AFBC combustion of the specification coal. Until actual AFBC pilot plant testing was conducted to verify this performance, an average estimated sulfur retention rate of 34 percent (66 percent release) was used for process engineering calculations and initial for equipment sizing. The estimated SO₂ emissions considering all mechanisms of inherent retention, and the required additional capture by the added limestone to meet the emission limit was estimated as shown in Table 3.

At an average coal sulfur content of 1.3 percent, the required sulfur capture by the added limestone will be about 87 percent. Sulfur capture as a function of Ca/S ratio from added limestone has been widely reported and published in the literature. Zhang, et al. presented test data for several coals and AFBC combustors (6). To predict the performance of the Komorany AFBC retrofit, an average correlation was developed from their data of 18 test runs on five coal types in a bubbling fluidized bed combustor. This correlation is given in the following expression:

$$SC = 1 - 0.715 \exp \left(-0.50 \frac{Ca}{S} \right)$$

where:

SC = sulfur capture

$\frac{Ca}{S}$ = calcium to sulfur molar ratio

From the above correlation a sulfur capture of 87 percent of by the added limestone would require a Ca/S molar ratio of about 3.4.

By recycling or re-injecting flyash collected from the boiler ash hoppers and the electrostatic precipitator back into the combustor, the sulfur capture effectiveness of the calcium, expressed as calcium utilization efficiency, can be improved (5, 7, 8, 9). The recycle ratio is defined as the ratio of re-injected flyash to fresh coal feed. Published data for low-rank lignitic coals (5), indicate that at a recycle ratio of

TABLE 3

Projected Maximum SO ₂ Emissions Considering Effects Of Inherent Retention		
% Sulfur (moisture free)	Uncontrolled SO ₂ Emissions, mg/Nm ³	Required Additional Limestone Capture Efficiency, %
1.0	2964	83.1
1.2	3557	86.0
1.4	4150	88.0
1.6	4743	89.5
1.8	5336	90.6

0.5 to 1 (the maximum ratio considered feasible for the Komorany AFBC retrofit and the specification coal) the calcium utilization efficiency can increase by 1.9 percent (relative). This would allow the added limestone Ca/S molar ratio to be decreased from 3.4 to 3.3.

PILOT PLANT TESTING

Pilot plant combustion trials were completed in June 1993 on the specification coal and limestone. Testing was conducted at CERCHAR, Research Centre of Charbonnages de France in Mazingarbe (10). The CERCHAR pilot plant combustor is capable of operating in both circulating and bubbling fluidized bed configurations. The combustor thermal input is approximately 500 kW in the bubbling bed configuration, and 1000 kW in the circulating bed configuration.

The combustor is cylindrical in shape, and is 7 m in height. The lower section is 600 mm in diameter, and the upper section is 800 in diameter. The inner wall of the combustor is lined with refractory and mounted with heat transfer surfaces. Fuel, sorbent, and bed material are fed through two screw conveyors, one at an elevation of 0.55 m above the distributor plate for sorbent and bed material, and the one at 1.55 m for fuel. Flue gas leaving the combustor passes through a cyclone separator and then to a fabric filter. To provide ash recycle at up to a 0.5 to 1 ratio, a pneumatic transport system was installed to re-inject a portion of the collected material back to the combustor.

Ten water cooled heat transfer coils were installed along the vertical walls of the furnace to control combustor temperature and to measure heat transfer coefficients in the bed and freeboard area. The two lower coils were immersed in the dense bed. The uppermost coil was 5.7 m above the distributor plate.

A computerized data recording and processing system was used to log temperatures, pressures, and flow rates. A state-of-the-art continuous emission monitoring system was used to record flue gas concentrations of CO, CO₂, SO₂, and CH₄. Solid samples were collected at the bottom of the combustor, cyclone, hopper, and fabric filter hopper.

A test matrix was developed to investigate the main parameters of combustor temperature, ash recycle ratio, and Ca/S ratio on the combustion and emission performance of the coal and limestone in the fluidized bed. To simulate the full-scale process design, the fluidizing velocity was set at approximately 2.5 m/s, with a nominal 1 m bed depth (expanded), and 28 percent average excess air. The basic test matrix is shown in Table 4.

TABLE 4

Test Matrix	
Fixed Parameters	Variable Parameters
Effect of Ca/S Ratio	
Recycle = 0.4	Ca/S = 2 - 5
Bed Temp = 790°C	(4 Steps)
Recycle = 0.4	Ca/S = 2 - 5
Bed Temp = 815°C	(4 Steps)
Effect of Bed Temperature	
Recycle = 0	Bed Temp = 790 - 850°C
Best Ca/S	(3 Steps)
Recycle = 0.4	Bed Temp = 790 - 850°C
Best Ca/S	(3 Steps)
Validation of Optimized Conditions	
Best Recycle	All Parameters Constant
Best Bed Temperature	
Best Ca/S	

For all test runs with the range of specified parameters shown in Table 4, the combustion efficiency as measured by carbon in the ash and CO in the flue gas was above 98 percent. Since the pilot unit was shut down and restarted each day, the effects of thermal inertia tended to produce elevated CO emissions, and lower combustion efficiencies early in the test period, or for shorter runs. The final validation run of the optimized conditions (818°C bed temperature, 0.4 ash recycle ration, and 2.7 Ca/S

ratio) was 4.5 hours long and demonstrated an average combustion efficiency of 99.1 percent, and an average CO emission of 155 mg/Nm³.

The test data indicated that the effect of ash recycle on limestone calcium utilization and resulting SO₂ emissions was much more significant than the performance prediction estimates. At a fixed Ca/S ratio of 3.4, an increase in recycle ratio from 0 to 0.4 resulted in a reduction of SO₂ emissions from 523 to 131 mg/Nm³ at a nominal bed temperature of 790°C, and from 565 to 224 mg/Nm³ at a nominal bed temperature of 840°C.

The test data also show that both SO₂ and NO_x emissions are impacted by temperature and Ca/S ratio. Ash recycle also affects limestone calcium utilization and SO₂ emissions as expected, but showed little effect on NO_x emissions. Figure 1 shows that without ash recycle, measured SO₂ emissions remained essentially constant between 790°C and 840°C. NO_x emissions showed an increase of about 10 percent over the same temperature range. The data at 788°C represent a limited number of sample points over a short (10 minute) test duration, and are probably statistically insignificant compared with the other measurements.

Figure 2 shows that for an ash recycle ratio of 0.4, and for the same Ca/S ratio of 3.4, an increase in temperature from 760°C to 840°C causes essentially a linear increase in SO₂ emissions from 100 to 250 mg/Nm³. Above 850°C, SO₂ emissions show a steep increase. The NO_x emissions show a very similar trend as without ash recycle.

Figure 3 shows a plot of SO₂ emissions versus Ca/S ratio for two different bed temperature ranges, at a constant ash recycle ratio of 0.4. The two upper data points at the Ca/S ratio of 2.7 were considered to be non-representative and were therefore not included in the curve fits. These two points represent data collected early in the test period, prior to the turnover of the inert sand startup bed material and the subsequent stabilization of bed chemistry. The lower data point at the Ca/S ratio of 2.7 is the 4.5 hour validation run at the optimized conditions with the bed material essentially at steady state.

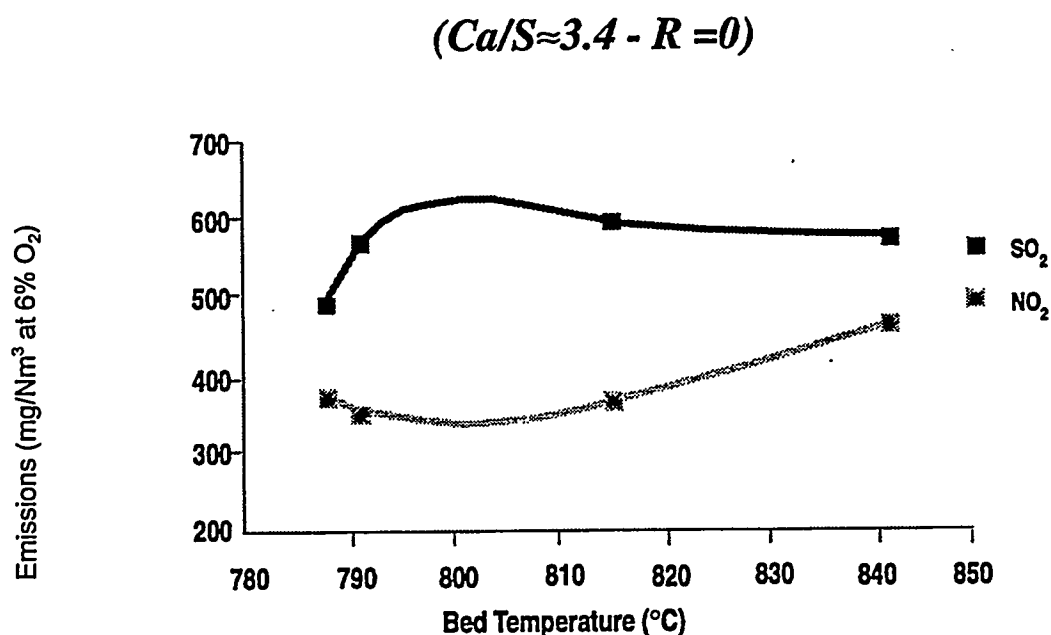


Figure 1. Effect of bed temperature on SO₂ and NO_x emissions without ash recycle.

$(Ca/S \approx 3.4 - R = 0.4)$

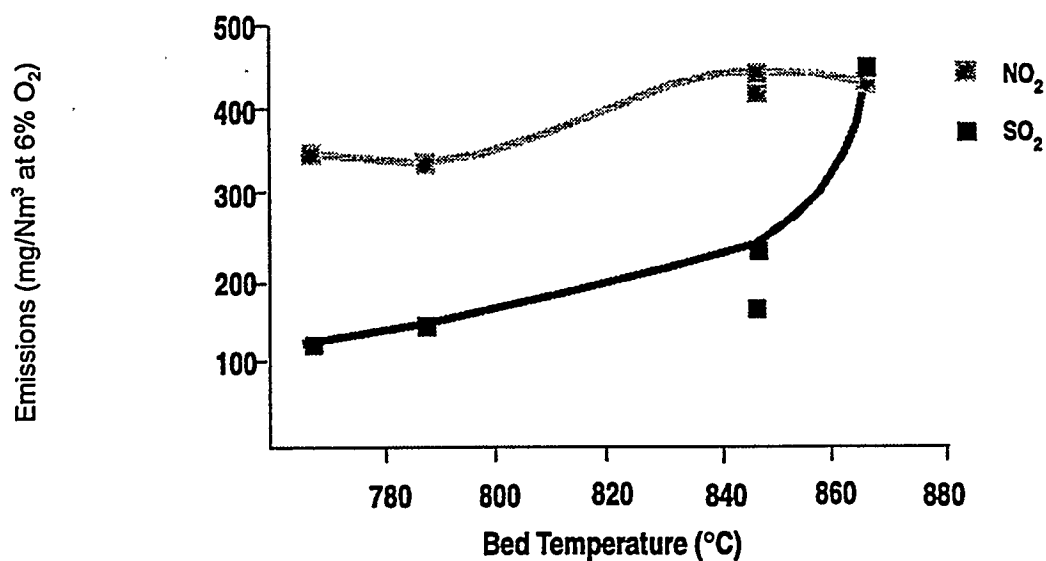


Figure 2. Effect of bed temperature on SO₂ and NO_x emissions with ash recycle.

(recirculation ratio: 0.4)

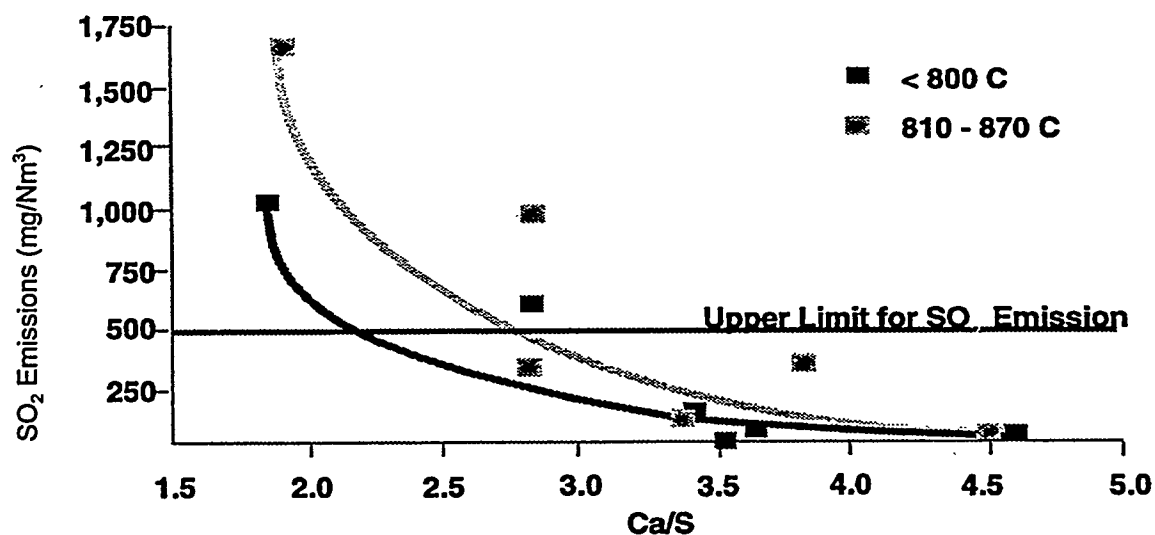


Figure 3. Emissions of SO₂ with respect to Ca/S ratio.

Emissions of NO_x (measured as NO₂) ranged from approximately 320 to 420 mg/Nm³. Figure 4 shows that both nominal bed temperature and Ca/S ratio affected NO_x emissions. The test data show that NO_x emissions remained below the limit of 400 mg/Nm³ when the nominal bed temperature is 820°C or less, and the Ca/S ratio is below 4.

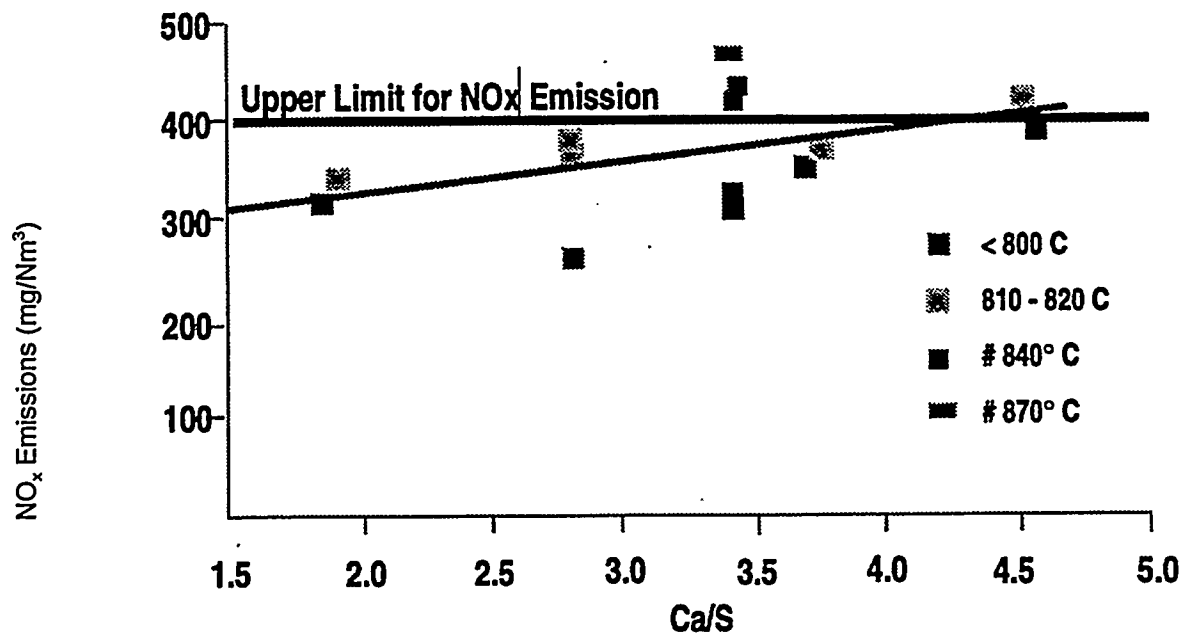


Figure 4. Emissions of No_x with respect to Ca/S ratio.

Table 5 summarizes the Czech Clean Air Act emission limits applicable to the Komorany AFBC retrofit boilers, the current emissions from the traveling grate boilers, and the final projected emissions

TABLE 5

Stack Emissions Summary

Emission	Emission Limit Vol. 84/1992 Clean Air Act No. 309/1991 mg/Nm ^{3a}	Current Emissions From Komorany Traveling Grate Boilers		Estimated Emissions Following Komorany Fbc Retrofit		
		mg/Nm ^{3a}	t/d ^c	mg/Nm ^{3a}	t/d ^d	t/d ^e
SO ₂	500	3330	137.3	399	10.4	14.4
NO _x	400	589	24.3	362	9.43	13.1
CO	250	100	3.99	155	4.05	5.61
Particulate Matter	50	2080	85.9	23	0.60	0.83

^a 0°C, 101.32 kPa, 6% O₂, dry.

^b 1991 Data

^c Total potential emissions for 10 traveling grate boilers operating at rated capacity of 90 t/h each.

^d Total potential emissions for 10 FBC retrofit boilers operating at 90 t/h each.

^e Total potential emissions for 10 FBC retrofit boilers operating at rated capacity of 125 t/h each.

from the full-scale retrofit based on the pilot plant combustion trials. The estimated particulate matter emissions are based on the vendor guarantee for the new fabric filter.

The heat transfer coefficients calculated from the water cooled heat transfer coil data in the test facility, were used to verify the full-scale design of in-bed and freeboard heat transfer surfaces. Figure 5 shows the heat transfer coefficients along the height of the combustor. The average heat transfer coefficient within the dense bed was calculated to be $251 \text{ W/m}^2 \text{ C}$. Above the splash zone, at the top of the freeboard area, the average coefficient ranged from 38 to $46 \text{ W/m}^2 \text{ C}$.

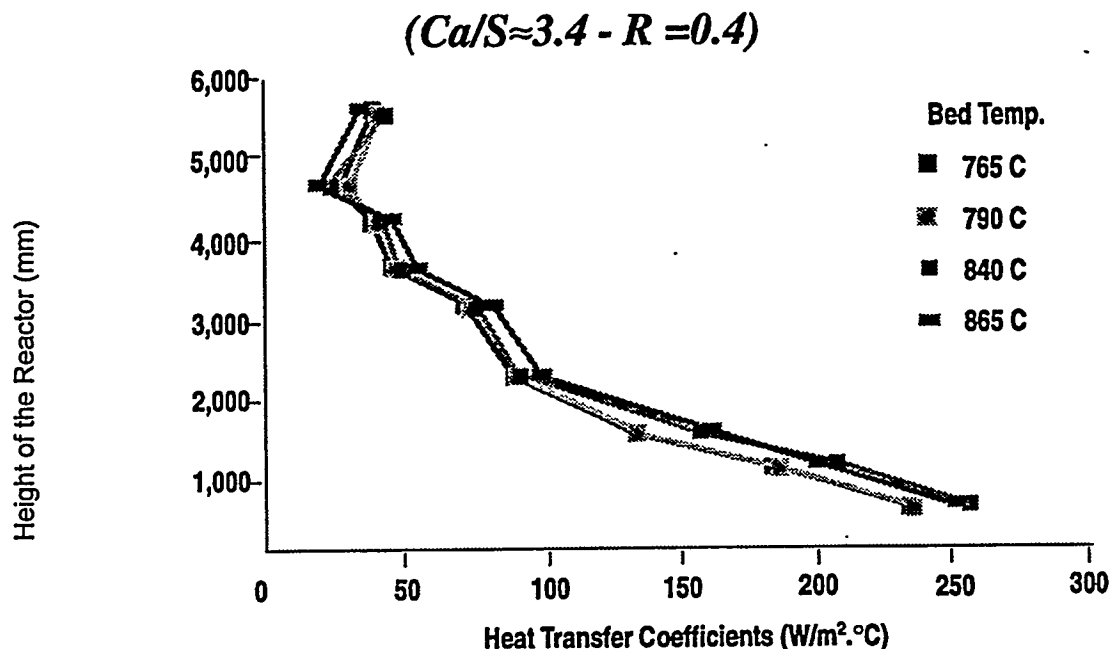


Figure 5. Heat transfer coefficients along the height of the combustor.

SUMMARY

This project shows that AFBC retrofits can be applied to existing traveling grate boilers at Central and Eastern European power stations for continued utilization of local low-rank and brown coals. Through such a retrofit approach, plant upgrades and emission reductions can be achieved with a substantial reduction in investment capital as compared with new, greenfield installations.

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VOJANY STATION RECONSTRUCTION, REPOWERING AND EXPANSION ASSESSMENT

OPTIONS, ISSUES AND OPPORTUNITIES

William F. Coe, Project Manager

Southern Electric International, Inc.
Atlanta, Georgia, USA

George H. Griswold, Project Engineering Manager
Joe C. Peyton, Special Projects Engineer

Southern Company Services, Inc.
Birmingham, Alabama, USA

ABSTRACT

Recent European community and state specific environmental guideline, legislative, and regulatory activities have led power producers to assess their currently installed generation technologies with regard to clean air compliance strategies. For the application to older generation facilities, the prudence of linking facility rehabilitation with the addition of environmental control systems to repowering options is warranted. Similarly, ongoing privatization efforts emphasize the necessity for sound economic decisions of site specific technological applications that consider maintaining or enhancing thermal efficiencies.

Southern Electric International (SEI) has conducted such a feasibility study assessment evaluating the reconstruction, repowering and possible expansion of the Slovensky Energeticky Podnik (SEP) 1320 MWe Vojany Station in the Republic of Slovakia. Alternatives included such technologies as atmospheric fluid bed combustion, furnace and duct sorbent injection, low NO_x burners, gas re-burn, selective catalytic reduction, selective non-catalytic reduction, state of the art precipitators and baghouses, wet and dry flue gas desulfurization systems and repowering technologies. In addition, new, turn of the century environmentally plausible and efficient electric power technologies were addressed.

INTRODUCTION

The Vojany Power Station is owned and operated by the Slovak Power Enterprise (Slovensky Energeticky Podnik-SEP).

EVO (Vojany Power Station), the major fossil fuel station of SEP, is located in Vojany, Slovakia, on the Laborec River near the Ukraine border approximately 80 km east of the city of Kosice. The station has two groups of generating blocks, EVO I and EVO II, each having six blocks of 110 MWe each. EVO I is fueled with anthracite T-coal from the Don-Bass region of Ukraine and Russia, and EVO II is fired with either natural gas or heavy oil.

The EVO I blocks were completed in 1967. EVO I emission control devices were originally installed as 84 percent efficient mechanical separators only, with no SO_x or NO_x abatement. Blocks 1 and 2 of EVO I were recently upgraded (1991 and 1992), respectively, to include electrostatic precipitators rated at 98.5 percent efficiency. In the current configuration, only Blocks 1 and 2 are able to operate near compliance with dust emission standards and none of the EVO I blocks will meet the end of 1997 standards for NO_x and SO_x. Each of the six EVO I boilers are supported in a structure 27.0 meters wide and 45.0 meters deep.

EVO II was completed in 1973. The six 110 MWe blocks were originally designed to hard burn coal but were reconstructed to burn oil. Both coal and oil became unavailable and finally the blocks were

redesigned and reconstructed to burn gas. The boiler can now burn either gas or oil. As the turbines were designed for 565°C-535°C superheat-reheat and the boilers as reconfigured achieve 535°C-535°C, the resultant generation capability is therefore 95 MWe per block. No emission controls exist and compliance with the end of 1997 regulations will require NO_x abatement and possibly gas clean-up if sour gas is used for fuel. If the option to burn oil continues, particulate collection equipment could also be required as well as SO_x treatment. The blocks have approximately 50,000 operating hours with an estimated remaining life of approximately 150,000 - 200,000 operating hours before major repairs can be anticipated. Each of the EVO II boilers are supported in a structure and space approximately equal to EVO I. Space is available for addition of gas turbines and boiler/duct modifications on the ground level base slab.

DISCUSSION

The feasibility study conducted by Southern Electric International (SEI) for Slovensky Energeticky Podnik (SEP) evaluated the reconstruction, repowering, and possible expansion of SEP's Vojany Station (EVO). The study was conducted by SEI personnel in conjunction with EVO staff, SEP personnel, and selected consultants knowledgeable about SEP, the Slovak Republic, and the range of technical issues addressed herein. Previous SEP evaluations, studies, station records, and technical data were reviewed and utilized as part of the feasibility analysis.

The premise for determining feasibility of:

- Reconstruction of EVO is to enable the blocks (units) to meet current and future emission standards with the most feasible and economical technology;
- Repowering portions of EVO is to meet emissions standards and concurrently maintain or attain additional more efficient generation;
- Expansion of EVO by adding EVO III is to enable SEP and Slovakia to reduce the import of electric power, to become a reliable exporter of power to neighboring utilities and countries, and to investigate potential equity participation in EVO III by SEI.

The general intent of the study, as applicable to EVO I and II, was to review immediate requirements for EVO to meet the targeted emissions deadline of 1997 to evaluate solutions to meet the new emissions limits through equipment modifications, and to develop benefit/cost parameters associated with installing the necessary retrofitting equipment. Additional generation as a result of modifications to EVO I and II and possible greenfield construction of EVO III was reviewed for applicable technology in the time frame outlined by SEP.

The study results recommend a time-phased implementation for the recommended solutions as shown by appropriate project schedules. Specific recommendations are compiled in the following categories.

1. EVO I - Blocks 1 and 2

Reconstruct with a "dry/semi-dry" scrubber, baghouse, and NO_x control devices.

2. EVO I - Blocks 3 through 6

Reconstruct/repower with circulating fluid bed boilers and electrostatic precipitators.

3. EVO II - Blocks 7 through 12

Add low NO_x burners only; provide pre combustion gas scrubbing if sulfur (SO_x) in gas or oil is proven excessive. Provide baghouse filters if solids in oil are proven excessive.

4. EVO - General Reconstruction

Rebuild support systems in the infrastructure of station as required to support the above modifications.

5. EVO III - Options

A. Secure cost competitive contracts of tenure for fuel (including coal, gas, and oil).

B. Add generation expansion as required by existing and forecasted load demand with technology dependent on long-term/spot fuel prices.

Feasibility discussions were initiated by visit of SEI personnel with SEP personnel both in Bratislava and Vojany, (Eastern) Slovakia. Study scope was discussed and modified as required, data was provided, and station walkdowns ensued. The study began with a review of SEP's Basic Technological and Economical Parameters of Production and Maintenance as well as maintenance schedules, and reconstruction plans for the EVO I and II stations. These reviews included discussions with EVO management and technical staff on technology options, existing station limitations, emerging emissions laws and critical path scenarios toward resolutions. The review included EVO's position in the SEP system; variables of concern such as electric load demand, fuel price, stability of all fuel supplies, raw water supply; and construction programs planned and currently underway.

As noted in the scope and reconstruction plans, it was determined and confirmed that EVO cannot meet the future requirements for controlled emissions from either EVO I Blocks 1 and 2 with (recently) new electrostatic precipitators, Blocks 3 - 6, with mechanical separators, or from EVO II as it is currently configured.

The then proposed CSFR law (No. 309.91 Zb, July 1991) established limits for emissions which were not totally concurrent with EVO design requirements or ensuing EEC guidelines. As these were both emerging in implementation and interpretation the assumption was made by the SEI/SEP study team that more stringent requirements would eventually be issued and technology assessments should therefore include prudent considerations for greater removal capability by the components controlling SO_x , NO_x , dust, opacity, particulates, and CO . That is, monies should be allocated for present technologies to ensure compliance but not to the mutual exclusion of expanded compliance.

In addition:

- Each EVO blocks' design thermal capacity rating is very close to a mandated step function decrease in emissions allowable at 300 MW thermal by guideline standards. Therefore, any increase in generation or decrease in efficiency of individual blocks would result in a second category of more stringent emission limits.
- EVO I is currently designed for assisted condensing cooling at low water occurrence on the Laborec River. Additional water usage for ash disposal of sludge or limestone/ash waste, power augmentation of combustion turbines, addition of EVO III, or other water intensive technologies imposes strict water conservation on the EVO site for full capacity generation or a new source of long term, continuous raw water must be secured.
- The main gas supply line, pressure reducing station, and possibly source supply pressure is presently sized for only four blocks of EVO II. If added generation capacity is gas dependent (combustion turbines, gas duct burners, gas reburn, etc.) additional gas pipelines or possibly boosted supply pressure must be installed to meet projected expansion plans.
- Fire protection, stacks, rail facilities, ash ponds, cooling tower fill, limestone handling facilities, crane facilities, industrial water, condensate polishers, boiler acid cleaning, coal/gas/oil contracts improvement, warehousing of major spares, ash marketing, and scrap disposal are items which were assessed for changes or enhancements to support SEP/EVO goals.

- Numerous other existing conditions, normal to any electric generating station of the age and important geographic locale of Vojany, have been identified which will need upgrading for EVO and SEP to meet 1997 emission limit standards and growth projections.

As EVO represents a range of 25-30 percent of SEP's electric production capability and as it is located at the eastern end of the SEP system, it is necessary that EVO be prudently reconstructed and maintained as a valuable asset to SEP.

Factors affecting justification for reconstruction are: Recovery of load demand, assumptions that imports of power can be reversed to export without violation of existing contracts, and production costs lowered or maintained in relation to power sales agreements. Expansion by construction of EVO III, if necessary, can be justified on the same basis as reconstruction or repowering.

Upgrading the functional support systems for all EVO blocks is cost justified based on outages, reduced operating costs, and projected increased revenues.

Assumptions

- Recommendations are based upon industry accepted, mature technology, guaranteed by suppliers.
- Forecasted reliability of existing EVO blocks will continue to be maintained by equipment replacement and maintenance according to Vojany supplied equipment/material condition assessment checklists.
- All future solids rejects are assumed to be acceptable from an ecological standpoint (sulfites, sulfates, ash).
- All fuels, water, reducing agents, catalyzers, lime, limestone, etc., and, in general, all products and services, necessary for the reliable and efficient operation of the modified/new blocks shall be deemed available for SEP procurement.
- Preferred solutions shall be those which target maximum local supplies, having in view that a portion of U.S.A. supply is to be considered in order to adhere to the U.S. Trade and Development Program (presently TDA) guidelines.

Bases for the recommendations are: EVO is a vital component of SEP's generation mix and will remain 25-35 additional years. In order for EVO to remain as such, it was recommended:

- First, that emission standards be met by modification of equipment with some capability of margin at minimal evaluated expense in anticipation of future more stringent standards.
- Secondly, it was recommended that SEP/EVO efforts be directed to alternative less expensive fuel sources including imported and domestic coal, oil, and gas obtained on competitive bid bases.
- Third, it was recommended that as enhanced retrofit systems are added, production costs and staff be reduced and/or reassigned to drive down fixed costs.

Specific recommendations were:

EVO I Blocks 1 and 2

SO_x - A spray dryer dry scrubber should be added to control SO_x. A single vessel to handle gas from Blocks 1 and 2 (220 MWeg total) would be added to accommodate space restrictions. Sizing of the components would be for full gas flow at 91 percent removal. Vessel location would require demolition of the existing concrete ducts and induced draft fan changes.

NO_x - A phased approach (targeting economy) should be initiated immediately to test various NO_x control technologies. Due to the design of the existing boilers (double lower arch with fines/overfire air combination) and the "low volatile" anthracite fuel, the resultant boiler configuration is a high (thermal) NO_x producing device without significant turndown control below 85 percent rating.

Following detailed boiler stoichiometry balancing and tuning, a first test would be planned following completion of the NH₃ injection. Gas reburn by installation of gas guns (ignitors) strategically located downstream of the combustion zone would be extensively investigated. Extension of the existing startup gas piping would supply the gas reburn ignitors. Up to 18 percent thermal input would be from the new gas guns. Note: This would increase generation cost.

A second test should begin immediately to evaluate urea/ammonia injection for NO_x reduction via spray pipe into the post combustion zones (SNCR). An adequate supply of NH₃ would have to be secured and tests would have to be sufficiently extensive to determine long range effects on components, ash, operations, etc. One block only should be tested before committing the second block to this scenario.

A third battery of tests should be planned which would be a combination of Tests 1 and 2.

Although these technologies have previously been proven on specific blocks elsewhere, each case is a "customized" application. In addition, these technologies have limited experience with anthracite fuel and the Vojany boiler design.

Following an analysis of the test results, a determination of effectiveness would be evident and a future course of action would be planned.

Should neither test system prove sufficiently effective for NO_x reduction, bidders would be invited to address application of low NO_x burners. Should there be no manufacturers willing to guarantee against liquidated damages, flame stability on the present low volatile anthracite, excessive slagging, and increased carbon carryover (unburned coal in the ash), then bidders would be invited to bid on the application of SCR (selective catalytic reduction) systems for each boiler.

Dust - In conjunction with the new dry SO_x system, NO_x abatement equipment, and existing electrostatic precipitator, it would be necessary to add a baghouse to collect particulate not captured in the precipitator. The action of unreacted limestone on the filter bags would enhance sulfur capture.

Support Systems

Systems necessary to support the above recommended equipment would be required.

- Lime system complete with storage, handling, compressed air, ash loading dust control system, cyclone filters, switchgear, controls, pumps, pipe, delivery rail facilities.
- Waste disposal system for the baghouse including all of the above plus disposal equipment.
- CEMS (Continuous Emissions Monitoring System)
- NH₃ injection system complete with storage, vaporizer, etc.
- Gas duct replacement
- Gas duct heaters for reheat to avoid acid dew point condensation
- Natural gas supply system expansion
- Controls additions

It was further recommended that the existing mills be retained for cost savings but that the mill exhausters fans be reworked or replaced for enhanced control and containment of fugitive dust.

EVO I Blocks 3 through 6

It was recommended that the pulverized coal boilers be replaced with circulating fluidized bed (CFB) boilers designed specifically for multi-fuel application with the existing anthracite as the primary fuel. Replacement would be staged, starting with Block 6. It was recommended that the boilers be purchased from a single vendor also contracted to work within the existing structures as much as possible. The CFB technology would be sufficient to comply with emission regulations for NO_x and SO_x and CO to avoid future compliance issues. The CFB's would also be sufficiently versatile to handle a variety of fuels - anthracite, lignite, brown coal. A dust collection electrostatic-precipitator would be required to replace the existing mechanical separators.

Support systems would include:

- Structural Modifications
- Limestone Handling System
- Ash Handling System
- New ID Fans
- New Pulverizers
- Controls System
- CEMS
- Reassessment and/or Reconstruction of Existing Electrical Components (switchgear, motor starters, termination cabinets, etc.)

It was recommended that incentives for co-manufacturing by vendors be considered for some major component parts of the boiler and duct. Fabrication at Skoda, Brno, Kosice, or closer would be practical.

EVO II Blocks 21 through 26 (7 through 12)

It was recommended that boiler emissions tests be performed on two separate blocks of EVO II to specifically determine emissions of NO_x, SO_x, CO, and particulate. It was further recommended that the tests be performed while burning gas on one block and oil on the other block to establish baseline data for emission abatement equipment design. Initial analytical assessment anticipated that only NO_x related equipment would be required for burning gas.

EVO General Reconstruction

The following systems were recommended to be reconstructed on a phased basis to support reconstruction of EVO I and II.

- Rail Modifications
- Fire Protection Upgrade
- Gas Reducing Station Capacity Increase
- Condensate Polishing

- Station Air Compressors/Dryers
- Industrial Water Plant
- Penthouse Pressurization
- Cooling Tower Drift Eliminator Upgrade
- Full Conversion of New Ash Pond to Dry System
- Conversion of Cooling Tower Blowdown to Ash Disposal Area Dust Suppression Water
- Limestone Silo Erection
- EVO Roof Crane Permanency
- Water Recycle
- Additional Warehouse for Transformers
- Switchyard/Station Service
- Controls/Block (Unit) Performance Monitoring

EVO III Options

Power plant design is a complex process of engineering and economic optimization. The final design of a power system is at best a compromise based on prioritization of specific parameters and assumptions in the optimization process: capital cost, expected O&M costs, fixed and variable costs, space, operating life, environmental restrictions, efficiency, fuel costs, reliability, availability, schedule, risk assessment, credit rating, interest rates, insurability, locale, infrastructure, short and long term goals, and business purpose.

Environmental demands take precedence over efficiency but economics of competition demand efficiency. In the case of Vojany, fuel flexibility is a critical issue as well as driving production and maintenance costs to the lowest point. Competition between stations within SEP and blocks for economic dispatch and between generation or import of electricity drives efficiency at Vojany to a parallel priority with environmental concerns.

Recent technological advances in gas turbines in a combined cycle and circulating fluidized bed boilers have replaced the pulverized coal fired boiler/steam turbine cycle (especially where low fuel volatility is a possibility) as the primary choice for power generation in many applications. Technology of the future such as Pressurized Fluidized Bed Combustion Combined Cycle (PFBC-CC) and Integrated Gasification Combined Cycle (IGCC) are on the horizon as practical, reliable, and efficient methods of generation but at present are just past the test/prototype or demonstration phase.

Each power project is sufficiently different due to fuel, finance, locale, and demand such that designs for large combined stations like Vojany become a custom or specific design. The design must obviously comply with the anticipated end of 1997 standards but be sufficiently flexible to meet emerging standards not yet legislated (CO, VOC's, opacity). The entire electric generation production thus becomes an integrated mechanical/power/chemical facility producing kV, MWe, MWth clean gas, and inert ash, economically on demand of dispatch.

Thus, EVO III station options included at the time of the assessment were:

- Simple cycle combustion turbine
- Combined cycle plant (GT-CC)

- Pulverized coal conventional plant
- Pulverized coal supercritical plant
- Circulating fluidized bed conventional plant
- Pressurized fluidized bed plant (PFBC-CC)
- IGCC plant
- ALWR Nuclear plant

A construction schedule for EVO III was not finalized during 1992 due to load demand/growth, reconstruction schedule of EVO I and II, fuel costs, and investigations to secure/assure long term load/debt. Therefore, it was recommended the choice of technology to be applied be postponed to a schedule point, 48 months prior to evaluated need, as dictated by load demand, cost of fuel, and the cost of imported power.

CONCLUSION

In conclusion, we previously have stated some of the critical issues and options, technological and otherwise, that transform perceived short term problems with upcoming environmental regulatory guidelines into challenges which, if executed with due diligence, will lead to long term opportunities in the European community.

Feasibility studies, such as the SEI/SEP Vojany assessment, are a major actor in an intricate cast of "foundation entities." These entities are required to effectively secure adequate financing along with the present trend of equity participation and financial investment guarantees which allow power producers in the sector to meet environmental concerns. If necessary and if evaluated technically possible, the power facilities' thermal efficiencies can concurrently be improved (or maintained) as part of the total rehabilitation investment undertaken. Thus, such feasibility studies become more than a technological screening tool - they become a foundation cornerstone in the eventual realization of the power producers goals and the infrastructure they serve and are part of.

Waste Management: Utilization

Session A4

SESSION COCHAIRS:

*Oscar Manz, Consultant
Alvarado, Minnesota, USA*

*Jan Bubeník, Consultant
Venners & Co., Ltd
Prague, Czech, Republic*

LEACHING TESTS AS A TOOL IN WASTE MANAGEMENT TO EVALUATE THE POTENTIAL FOR UTILIZATION OF WASTE MATERIALS

H.A. van der Sloot

Soil & Waste Research
Netherlands Energy Research Foundation (ECN)
Petten, The Netherlands

D.S. Kosson

Department of Chemical and Biochemical Engineering
Rutgers University
Piscataway, New Jersey, USA

ABSTRACT

Several waste materials from large scale industrial processes possess technical properties that would allow their use in certain construction applications, e.g. coal fly ash, slags from large scale industrial melting and ore processing, and incinerator residues. The disposal of such materials requires space and controlled landfills to minimize long term environmental risks. The beneficial use of such bulk materials is an attractive alternative, if it can be shown that such applications are environmentally acceptable.

For this management of wastes and the decision to either dispose or use, information on the environmental properties of materials is needed. Leaching tests have been developed to assess such properties. These have been designed typically in relation to regulatory tools, not as instruments to guide the management of wastes and the possibilities to improve material properties. New methods have been designed to address this aspect, in which maximum benefit can be derived from knowledge of the systematic behaviour of materials and the already existing knowledge in other countries producing similar residues.

After initial detailed characterization, concise procedures can be used for control purposes focused on the typical aspects of a certain residue stream. Examples of existing knowledge in this field will be presented.

INTRODUCTION

In different countries around the world, large differences exist in the degree to which waste materials from energy generation and other industrial activities are utilized beneficially [1,2]. Particularly in densely populated countries and provinces, where landfill space is scarce and natural aggregate is not easy to obtain, the use of secondary materials is being promoted [3,4]. If a material is no longer regarded as a waste material but instead has a positive value, the reduction of disposal cost becomes an economically attractive side effect. Due to the improved understanding of the leachability of residues, the quality of the treated product will be improved and the environmental impact from the treated product will generally be considerably less than that of the original waste. In this paper we will highlight relevant fundamental aspects of leaching to be able to lead into the necessary testing of waste prior to utilization. The paper gives an overview of current developments and references to more detailed descriptions of methodologies are provided. A distinction will be made between granular and monolithic materials as the release controlling mechanisms are different for these categories of materials. Estimates of long term release can be made based on the leaching parameters derived in the testing and by taking into account factors modifying the release as measured in the laboratory. Finally, concise testing for quality control purposes is addressed.

FUNDAMENTAL ASPECTS OF LEACHING

Factors influencing release

Several factors influence the release of contaminants from both granular and monolithic materials. An important factor governing release is the major element chemistry because the major elements dictate the pore water composition, which in turn controls the trace element leachability to a large extent. The pH of the solution has been shown to be a crucial parameter in determining the solubility of contaminants [1,2]. In addition, the redox status of the system and the presence of complexants, either inorganic, such as Cl^- or organic, humic substances, or other dissolved organic compounds capable of complexing metals [5,6]. The liquid to solid ratio is important because it relates to the time scale through the rate of infiltration [7]. The role of biological activity should not be forgotten as it has an impact on the generation of dissolved organic substances as well as the potential to turn a system anoxic and reducing. The changes brought about by any of these factors may lead to order of magnitude changes in leachability.

Classification of leaching tests

From a technical point of view, tests can be classified as tests aimed at equilibrium conditions during leaching or tests aimed at the dynamic aspect of leaching e.g. time-dependence [8]. The first type is generally performed in the form of batch type leaching tests. Tests with controlled pH also fall in this category. Dynamic tests are typically tests in which time is an important variable. Examples of dynamic tests are diffusion tests for monolithic materials and column leaching tests for granular materials.

Another type of classification is the distinction in tests in relation to practice. In that context, tests can be classified as characterization tests aimed at understanding the leaching behaviour of materials, compliance tests, which are generally of much shorter duration and are aimed at a direct comparison with regulatory thresholds, and finally on-site verification tests, which are aimed at verifying a previous evaluation of a charge or batch arriving at a processing plant. The latter distinction has been adopted in CEN, the European Standardization Organisation, as basis for leach test development [9,10].

Mechanisms controlling release

Mechanisms controlling release can be distinguished in control by the release potential, which the fraction ultimately available for leaching, in control by solubility and control by mass transfer limitations. Diffusion control is an example of the latter.

LEACHING OF GRANULAR MATERIALS

Characterization tests

Characterization tests for leaching are summarized in Table I. In the Table the test conditions are specified. For further details the standards [11,12,13] provide more background information. The tests

TABLE I

Characterization tests for granular materials

Method	Conditions
Static pH test	$4 < \text{pH} < 13$; $\text{LS} = 5$; $d_p < 4 \text{ mm}$
Availability test	$\text{pH} = 7$, 3 hours, $\text{LS} = 50$ $\text{pH} = 4$, 3 hours, $\text{LS} = 50$ $d_p < 125 \mu\text{m}$
Column test	$0.1 < \text{LS} < 10$; $d_p < 4 \text{ mm}$
Reducing capacity test	(under development)

specified cover release as a function of liquid to solid ratio (LS in l/kg), the leaching potential and the influence of pH. The only aspect not covered in this Table is the effect of redox conditions. This aspect is being addressed now and will lead to recommendations how to proceed, when redox conditions have a strong influence on the release rate [6]. In Figures 1, 2 and 3 the equipment used for the the column test, availability test, and the pH-stat test is shown. The results obtained from column tests will generally fall in one of the categories shown in Figure 4, which indicates the release of contaminants with a low affinity for the matrix (e.g. salts), a moderate retention in the matrix and a high retention in the matrix.

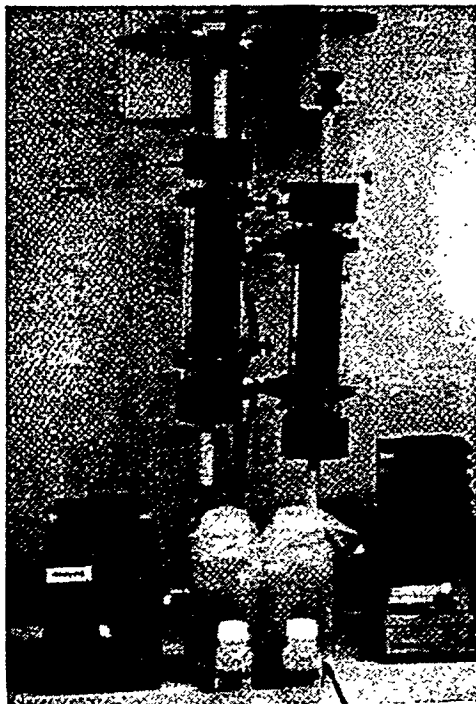


Figure 1. Equipment for the column test (NEN 7343) operated in up-flow and covering a Liquid to Solid (L/S) ratio of 0.1 to 10 L/kg.



Figure 2. Equipment used for the availability test according to NEN 7341. The acid-base addition is controlled by a computer reading the pH of the well stirred solutions.

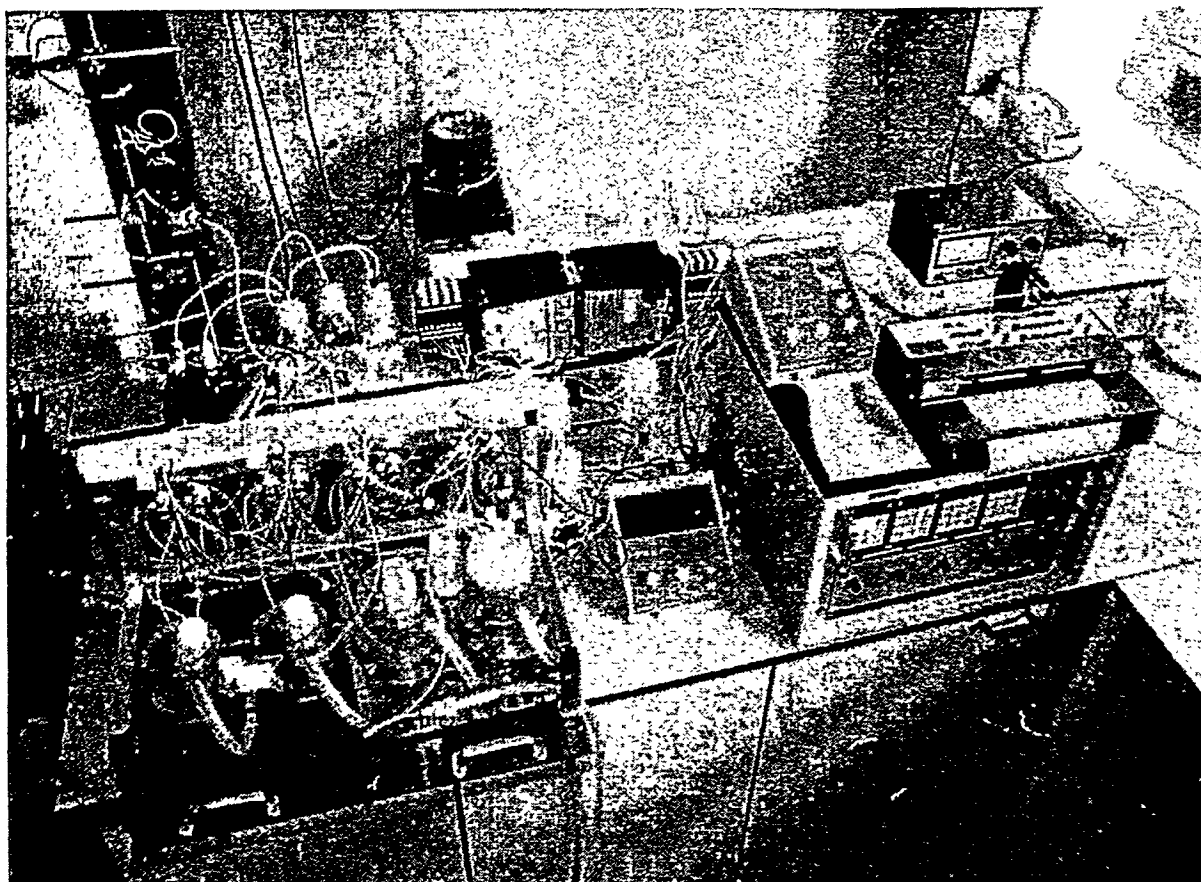


Figure 3. Equipment for the pH static test with 8 pH controlled positions.

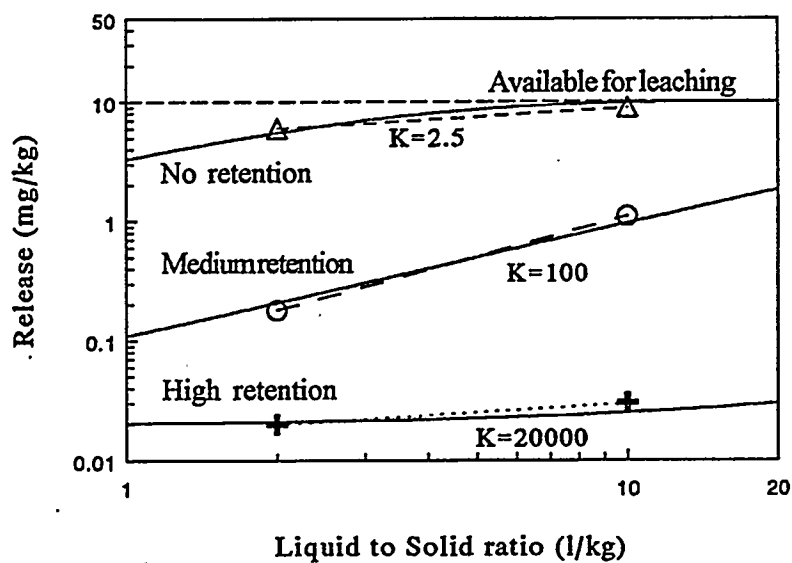


Figure 4. Release patterns observed in column experiments showing fast, intermediate and slow release relative to the availability for leaching as obtained from NEN 7341.

It should be realized that in field conditions an LS higher than 10 is seldom reached [7]. In Figure 5 actual data are given the leaching behaviour of Ca, Ba, Cr, Pb, Mo, Cu, V and Zn from coal fly ash [14]. In the graph the total concentration in the ash is indicated by the horizontal, solid line and the availability by the dotted line. The K values relate to modelling the retention in the matrix using a simple CSTR (continuous stirred tank reactor) model. A high K value indicates a high retention. From the release

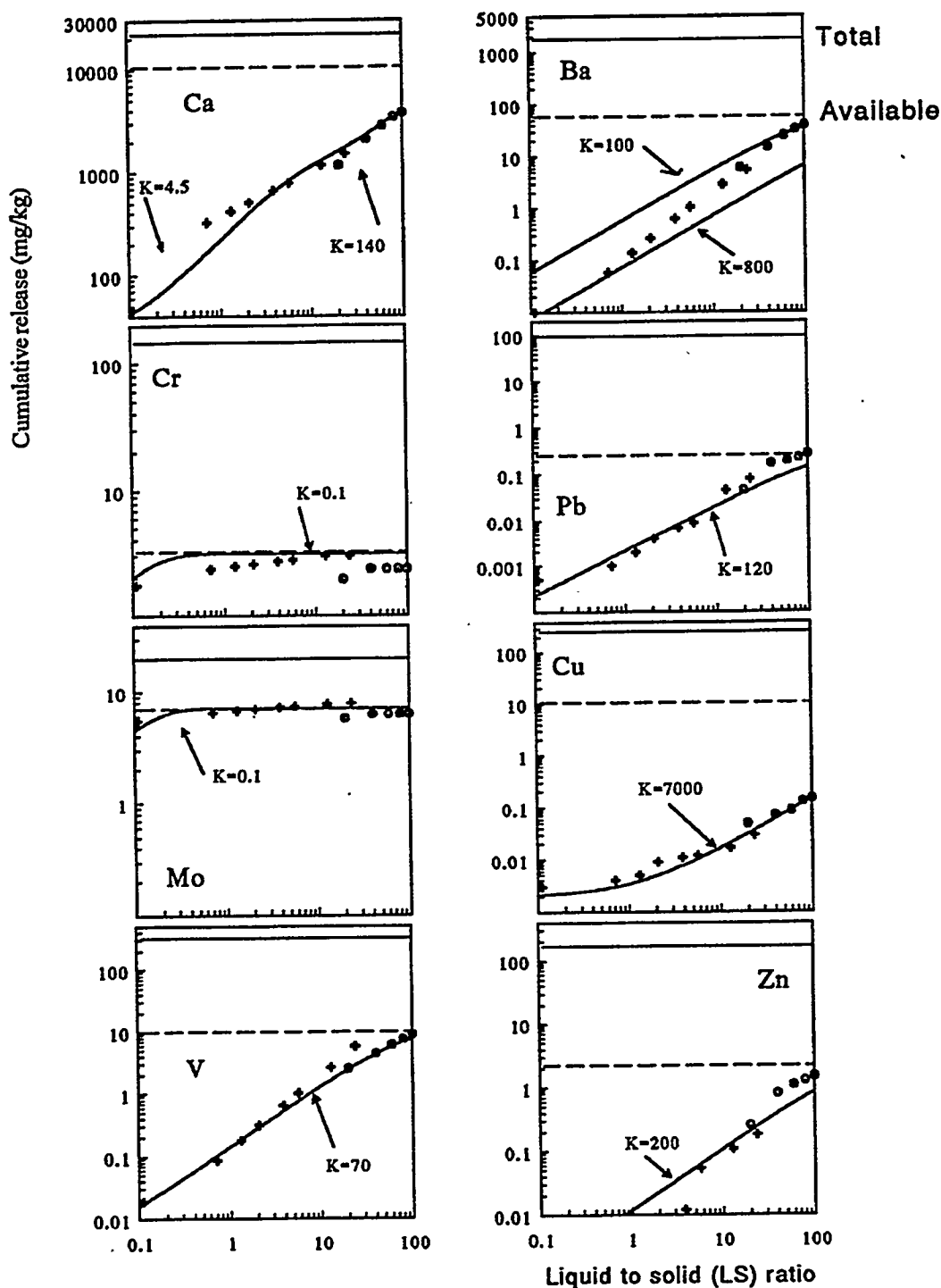


Figure 5. Column data on Ca, Ba, Cr, Cu, Mo, V, Pb and Zn from coal fly ash showing actual release as a function of LS, the total concentration (solid line) and the availability for leaching (dotted line). The retention values (K) were derived from a simple CSTR model [16].

pattern useful information can be derived for the prediction of the long term behaviour and about the chemical speciation of some particular constituents (e.g. Cr as chromate).

Unified approach of leaching

Two main aspects affecting release from granular materials have been combined in the Unified Approach of Leaching as indicated in Figure 6. Here the release as a function of LS is presented together with the release as a function of pH [15]. From the combination of the graphs conclusions can be drawn for conditions other than those tested. In the graph data are shown for other regulatory tests applied in Europe and in the US and Canada. The data obtained fall on the pH stat curve, which points at solubility control over a large pH range. The existing tests all tell a small part of the leaching story but really the combination of the tests provides the insight in how factors influence release and can be used to control release.

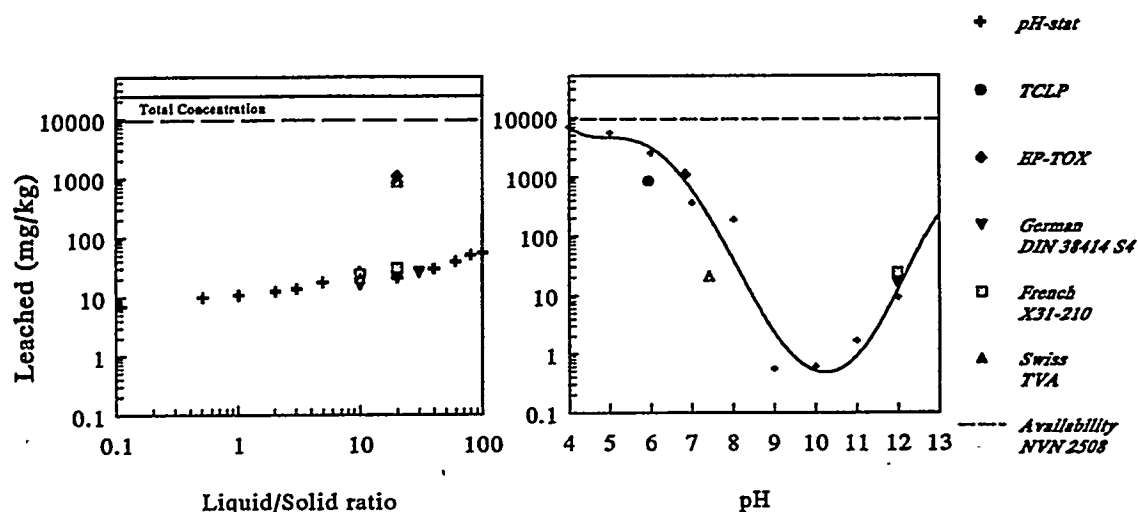


Figure 6. Unified approach of leaching for lead from Municipal Solid Waste Incinerator bottom ash. The release as a function of LS and release as a function of pH are given. A comparison with current regulatory tests is included [10].

Concise testing

Based on the knowledge gained and keeping in mind that there is a certain level of background information, concise tests have been derived covering several factors controlling extracts. In Table II the specifications are given [14]. In this combination an option is provided to identify whether a material has reducing properties.

TABLE II

Concise Test protocol for granular materials

2-Step serial batch test

LS = 2 : 6 hours
 LS = 2 - 10 : 18 hours
 Size reduction : 95 % < 4 mm
 Closed vessels

Measure:

pH, E_h , TDS, DOC, Conductivity
 Major and minor elements

2-Step pH static test

LS = 50 : pH = 8 for 4 hours
 LS = 50 - 100 : pH = 4 for 3 hours
 Size reduction : 95 % < 300 μ m

Measure:

Acid or base consumption
 Major and minor elements

LEACHING OF MONOLITHIC MATERIALS

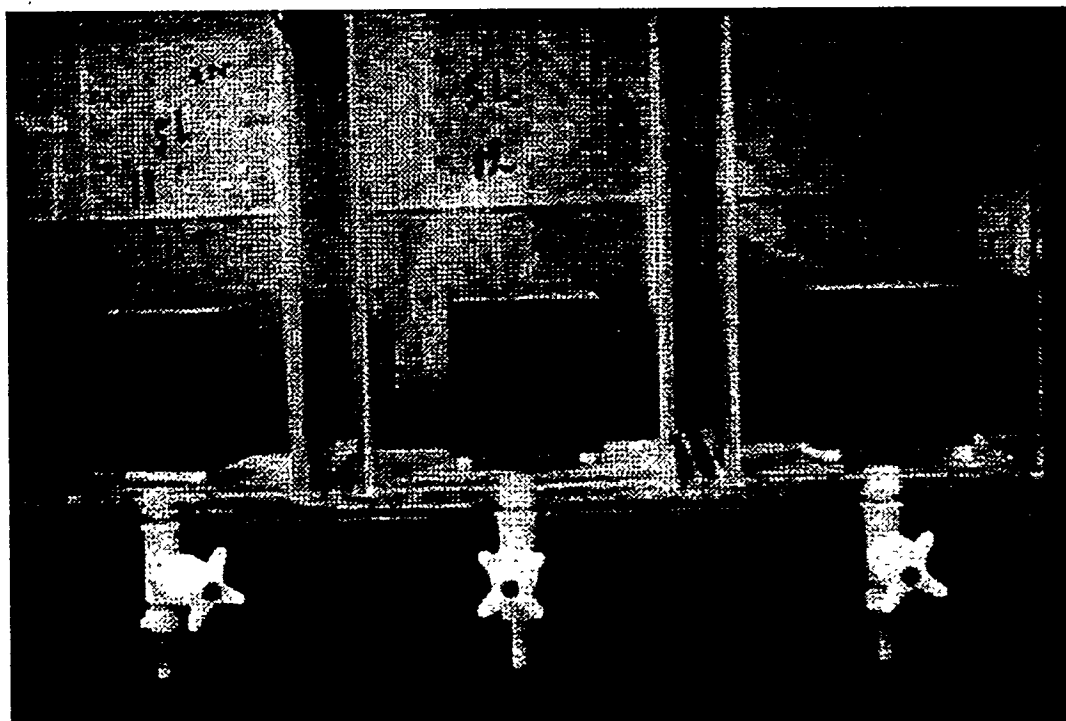
Characterization tests for monolithic materials

Similarly as for granular materials characterization tests for monolithic materials can be specified. In Table III the characterization tests for monolithic materials are given with the specified conditions. For further details the standard procedures give detailed information [12,13]. In Figure 7 the experimental set-up of the tests is shown. the basic principle of the tests is very simple and easy to perform. The data reduction is more sophisticated as diffusion modelling forms the basis of the data processing. When an

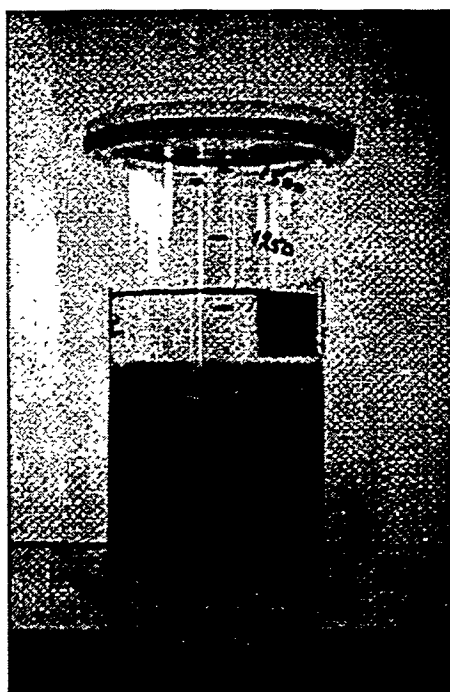
TABLE III

Characterization tests for monolithic materials.

Method	Conditions
Availability test	pH = 7, 3 hours, LS=50 pH = 4, 3 hours, LS=50 $d_p < 125 \mu\text{m}$
Tank leach test	Leachant renewal 8 cycles: 6 hrs to 64 days LV=5; $d_{\min} > 40\text{mm}$
Reducing capacity test	(under development)



(a)



(b)

Figure 7. Equipment for leaching of monolithic materials according to NEN 7345. The leachant is renewed at regular intervals (a). Equipment for the compacted granular leach test to assess diffusional release from granular materials. The data processing is similar to that of data obtained in the tank leaching test for monolithic materials (b).

inert species such as Na, K or Cl is measured, it is possible to derive information on physical aspects of leaching from monoliths. Since the inert species do not react with the matrix, they reflect the tortuous path an ion has to travel to the the surface of the monolith before being released to the surrounding. Taking this tortuosity measure as a basis of reference, the release of other contaminants can be related to that of the inert species, which allows a retention value to be derived [16]. In Table IV the tortuosities derived from the test for a wide range of materials are given. Note the high tortuosity for bituminous products. This is related to the hydrophobic properties of this material limiting the exchange with the surrounding leachant.

TABLE IV

Tortuosities for different materials	
Material	Physical retardation (tortuosity)
Unconsolidated granular material	2 - 5
Stabilized coal fly ash	10 - 30
Stabilized MSWI bottom ash	30 - 40
Calcium silicate brick	70 - 100
Light weight concrete	200 - 240
Concrete	300 - 400
Coal fly ash concrete	400 - 900
Bituminous concrete	2000 - 10000

Release curves obtained with this test are given in Figure 8. These data are for a cement-stabilized Municipal Solid Waste Incinerator Fly Ash. Samples were tested after 30 days curing and after 9 months curing [17]. The effect of further hardening of the cement-paste on release is significant. The leaching behaviour of some constituents changes substantially. The results obtained with a short test match those obtained in the longer procedure quite well. This observation has been the basis for the development of a concise test for monolithic materials [18].

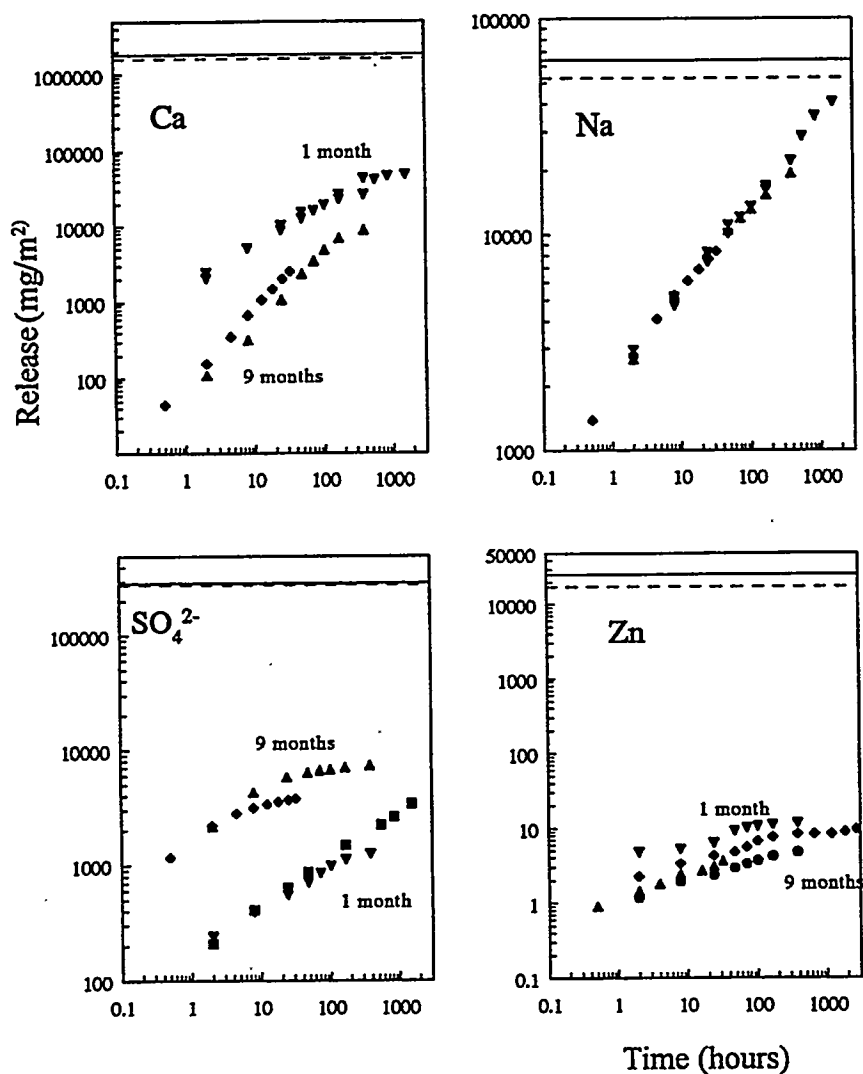


Figure 8. Release patterns as observed in the tank leach test carried out on a stabilized MSWI fly ash. data are given for testing after 30 days curing and 9 months hardening. A comparison of a short (32 hr) test and the standard procedure (64 days) is given for the samples cured for 9 months [19].

Modelling release

Using the parameters derived from the test modelling of release using simple 1-D and complex 3-D models can be performed to assess release for different specimen sizes at different time scales [7,16,19].

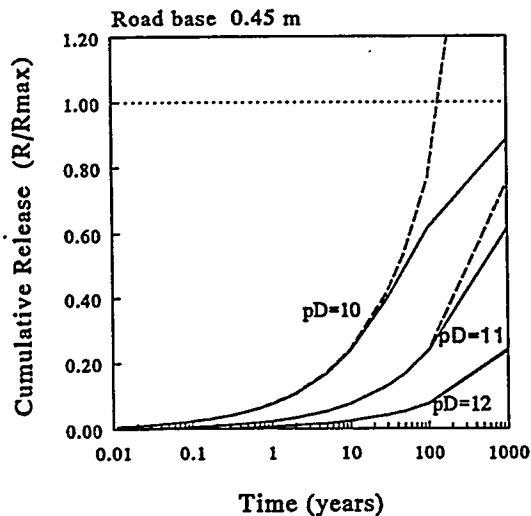


Figure 9. Comparison of 1-D and 3-D release modelling of a road base application showing that for a 100 year life-time the agreement between the models is good from pDe values larger than 11.

From Figure 9 it is concluded that for not too small applications release predicted by a 1-D model will accurately predict release for pDe values larger than 11, as the 1-D and 3-D data overlap up to 100 years of exposure [20].

This now forms the basis for a data evaluation which has been proven very helpful in comparing different materials and in deciding what measures would be needed to improve the performance of a product. In Figure 10 such a nomograph is given for Pb [4,10]. In the plot the pDe derived from the tank leach test is plotted against the availability for leaching. In the graph the iso-release lines corresponding

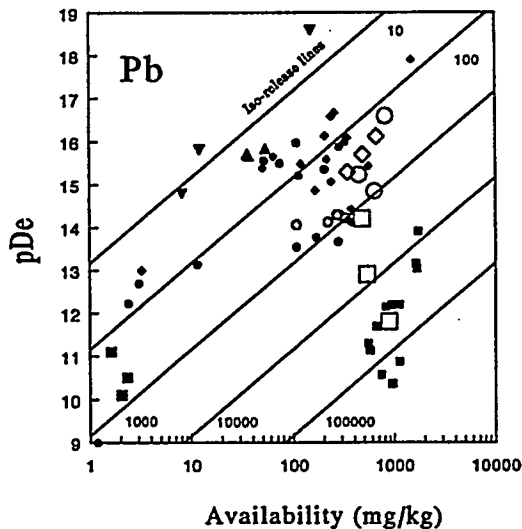


Figure 10. Release nomograph for lead for a wide variety of construction materials with and without secondary materials and stabilized waste materials. Iso-release lines are given for the different pDe's at an exposure time of 100 years (saturated conditions). Open symbols : untreated Municipal Solid Waste Incinerator (MSWI) residues; squares: treated MSWI fly ash; diamonds: treated MSWI bottom ash; circles: treated MSWI combined ash; triangles: asphalt products with MSWI fly ash and bottom ash [23].

with release of Pb for a timespan of 100 years at a given pDe are shown as diagonal lines in the plot. Instead of these lines regulatory thresholds can be plotted in a similar way thus providing a regulatory tool. As indicated in Figure 11 the same graph can be used as a waste management tool. The measures that can be taken to change the release properties of a material are indicated. It is clear that the desired direction is to the upper left hand corner [21].

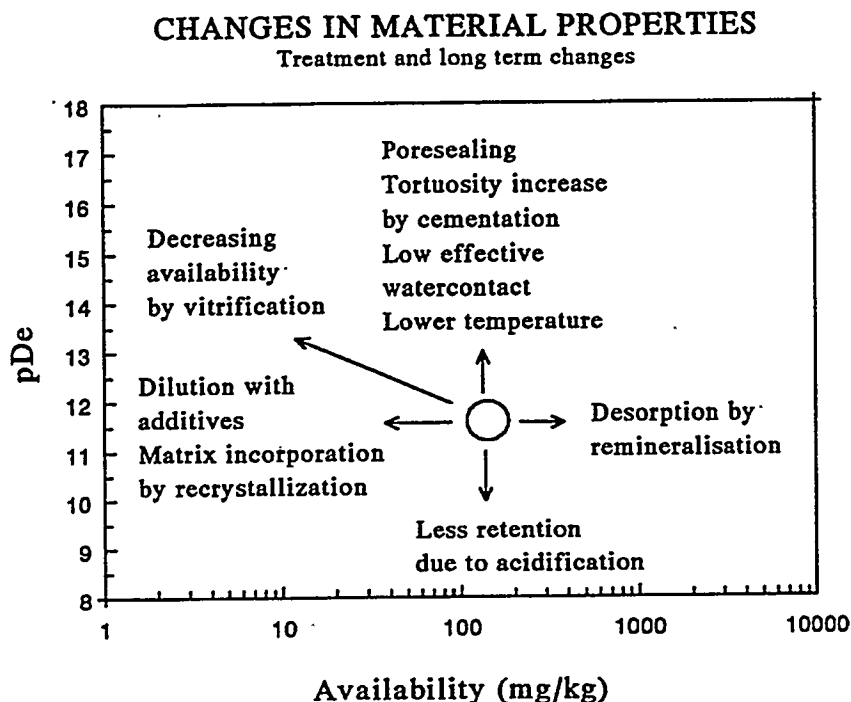


Figure 11. Material modifications based on the release nomograph indicating changes resulting from certain control measures and indicating possibilities for improvement of product quality [24].

Product durability

All the above testing of monoliths has been based on the assumption that the product is sufficiently durable. If a material does not withstand the leach test (too high loss of solid matter) or is insufficiently durable to avoid degradation in the field, it should not be tested as a monolith but evaluated as a granular material. Several test for structural integrity are available [21,22].

Concise testing of monolithic materials

As discussed for granular materials, the aim is to develop concise tests for monolithic materials as well. Some recent work has shown the potential for such an approach to be feasible.

In Figure 12 a comparison of a short and a longer tests procedure are given [18]. This shows that the agreement between both tests, even where it does not concern diffusion controlled release matches quite well with the long procedure. This has formed the basis for the development of a concise tests of which some preliminary conditions are specified in Table V. The long procedure needs to be carried out first to identify the general leaching characteristics of the material category and to establish that the short procedure properly reflects the long term behaviour, which is not always the case [6].

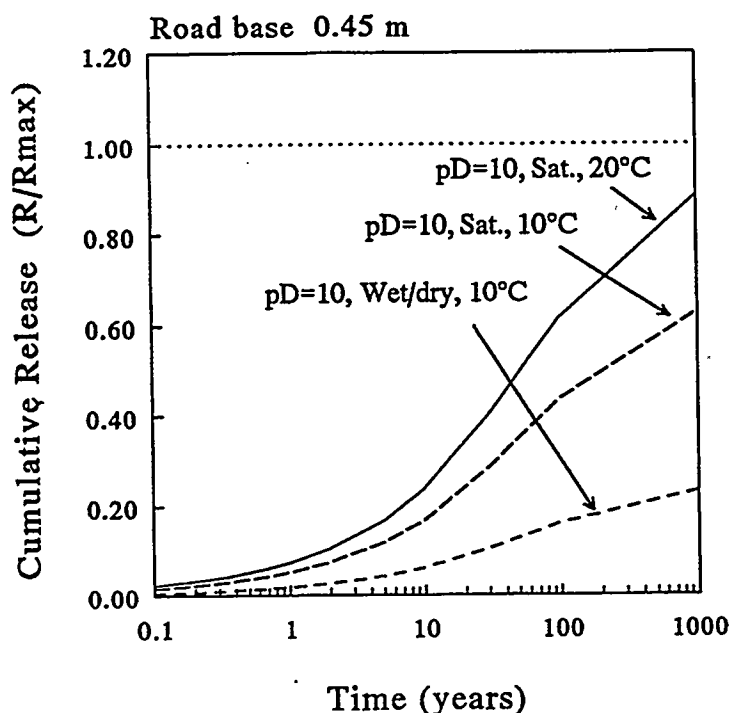


Figure 12. Effects of intermittent wetting and of temperature under field conditions on the release predicted from release models [22].

TABLE V

Concise Test protocol for monolithic materials

3-Step tank leach test Liquid to Volume ratio = 1.5 - 2 Vacuum saturation $t_1 = 0.5$ hours; $t_{2-4} = 8$ hours; $t_{5-7} = 25$ hours Minimum diameter : 40 mm Closed vessels	2-Step pH static test LS = 50 : pH = 8 for 4 hours LS = 50 - 100 : pH = 4 for 3 hours Size reduction : 95 % < 300 μ m
Measure: pH, Eh, TDS, DOC, Conductivity Major and minor elements	Measure: Acid or base consumption Major and minor elements

It shows many similarities with the concise test for granular materials. The choice has been a 25 hour test with 7 leachant renewal cycles, later on combined to 3 samples for analysis. A low liquid to surface area ratio is used to facilitate chemical analysis and vacuum saturation of the specimen is used to minimize surface effects and delayed release effects.

EVALUATION OF LAB-FIELD RELATIONS AND PREDICTION OF LONG TERM RELEASE

The situation on which a decision on acceptability has to be taken is an actual application or utilization scenario. The laboratory testing will not give a one to one relation between lab and field as there are several factors that affect the release under field conditions that are not or not easily assessed in the laboratory. In the laboratory the trends can be established. An interpretation of the test results is needed

to give a prediction of release under field conditions. A number of factors that need to be taken into account in this interpretation will be addressed below:

Factors in the translation of laboratory test data to release under field conditions

Time - The projected life-time of the application is a factor in assessing release. Based on a model description of the release controlling mechanism(s) the release as a function of time is modelled.

Temperature - Temperature has an effect on diffusion as the free mobility of constituents is affected by temperature. The difference in between testing in the laboratory and conditions in the field can be substantial. Especially, for decisions on release in different climates (arctic, temperate or tropical) this factor needs to be taken into account [7,19].

pH - The pH conditions in the laboratory and in the field may differ substantially due to carbonation or self-neutralization effects. Since the difference in release as a function of pH may change over orders of magnitude over relatively small pH ranges [5,9,23], this factor is not to be neglected. Generally, the pH measured in the laboratory is higher than that encountered in the field. Particularly for metals, which show a higher leachability at high pH (e.g. Pb, Zn) this may lead to an overestimation of release.

Redox - The material tested in the laboratory may be reducing and be tested as such. If such a material becomes oxidized in a field scenario the data obtained in the laboratory no longer reflect conditions encountered in the field and should thus be adjusted. A normally oxidized material may become exposed to reducing conditions in the field and therefore not reflect the conditions to be assessed [6].

Geometry - The shape and dimensions of a material affect the rate of release. A very thin slab of material may become depleted in a relatively short time scale. Whereas a very large scale application can be treated as a 1-D problem.

Water-to solid contact frequency - The degree of contact with water is a factor of importance as the testing is generally carried out under fully saturated conditions. In the field the exposure may occur only part of the time. For instance by means of the average rainfall rate in the country or province. In case it rains about 14 % of the time each year, this leads to about a correction of a factor of 3. In Figure 12 the effect of wet/dry cycles and the temperature effect on release are shown [20].

Surface reactions - In several cases surface effects have been shown to occur as a result of changes in the chemistry of the product in a thin surface section. Since this is the surface exposed to the leachant, it is likely to dictate release. Even surface sealing effects have been noted [24] as a result of such interface reactions.

CONCLUSIONS

The leaching parameters derived from leaching tests in combination with mass transfer models can be used to provide long-term release estimates under a variety of exposure scenarios.

Data may be used to select waste management options and design waste facilities to minimize the environmental impact of constituent release by taking into account a variety of crucial release controlling parameters.

Estimation of constituent release through leaching can be achieved using a combination of laboratory leaching procedures, laboratory to field translations and field verification. Protocols for evaluation of leaching should be specific to the anticipated scenario.

Concise protocols for testing of granular and for testing of monolithic materials are proposed based on a fundamental understanding of leaching behaviour. The concise protocols provide information with respect to time, pH, redox, retention, availability, acid neutralization capacity and chemical speciation. Both protocols can be completed within 2 days, which makes them suitable for quality control purposes.

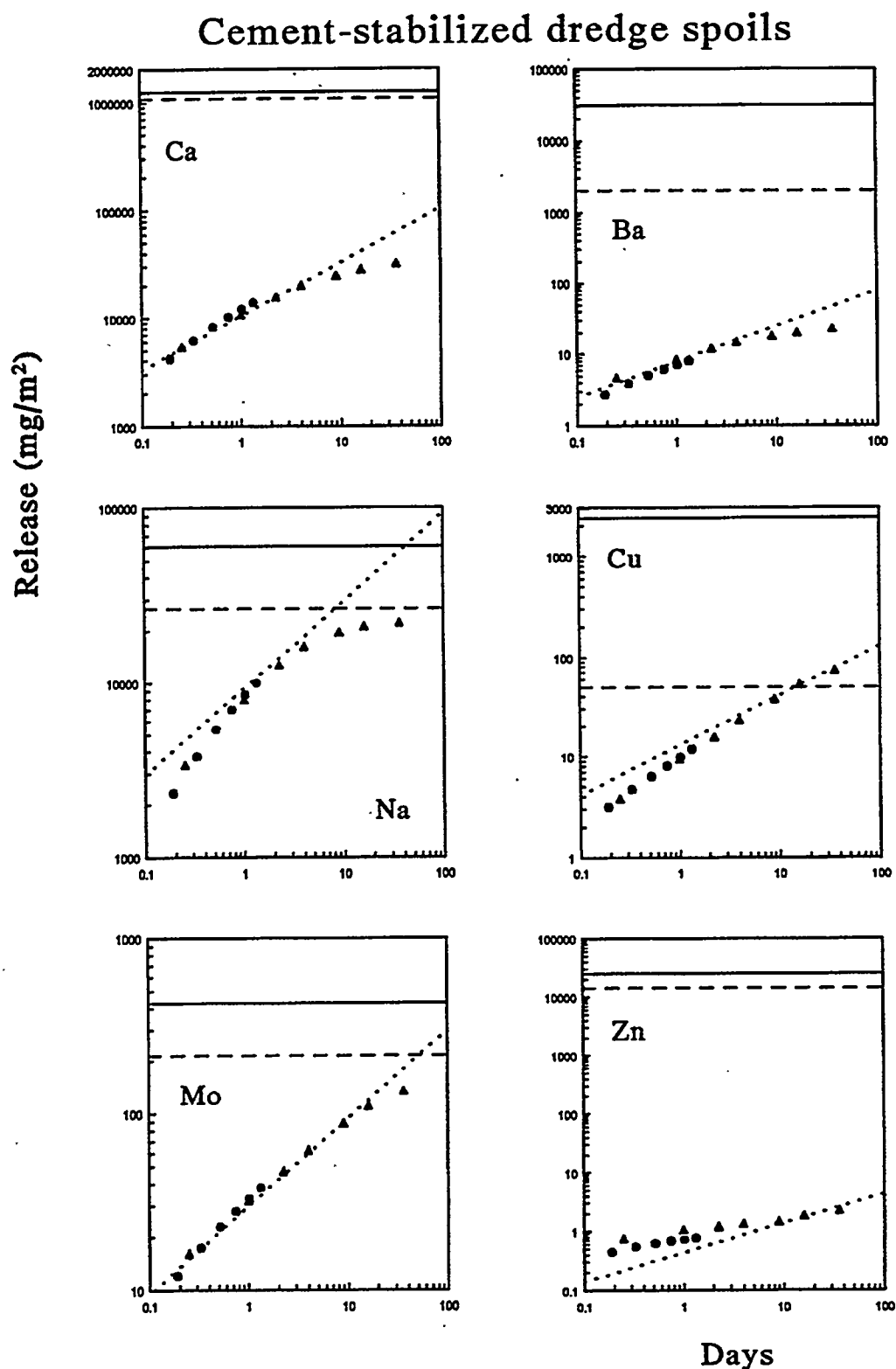


Figure 13. Comparison of short (25 hours) and long (64 days) test procedure for monolithic materials. Cumulative release data on Ca, Ba, Na, S, V and Mo obtained for cement stabilized dredge-spoil are given [20]. The availability and total composition are included for comparison based on the specimen size tested and converted to mg/m².

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FLY ASH QUALITY AND UTILIZATION

L.E. Barta, Scientific Advisor
L. Lachner
G.B. Wenzel

Institute for Energy
Budapest, Hungary

M.J. Beér

Massachusetts Institute of Technology
Cambridge, Massachusetts, USA

ABSTRACT

The quality of fly ash is of considerable importance to fly ash utilizers. The fly ash puzzolanic activity is one of the most important properties that determines the role of fly ash as a binding agent in the cementing process. The puzzolanic activity, however is a function of fly ash particle size and chemical composition. These parameters are closely related to the process of fly ash formation in pulverized coal fired furnaces. In turn, it is essential to understand the transformation of mineral matter during coal combustion.

Due to the particle-to-particle variation of coal properties and the random coalescence of mineral particles, the properties of fly ash particles e.g. size, SiO_2 content, viscosity can change considerably from particle to particle. These variations can be described by the use of the probability theory. Since the mean values of these randomly changing parameters are not sufficient to describe the behavior of individual fly ash particles during the formation of concrete, therefore it is necessary to investigate the distribution of these variables.

Examples of these variations were examined by the Computer Controlled Scanning Electron Microscopy (CCSEM) for particle size and chemical composition for Texas lignite and Eagle Butte mineral matter and fly ash. The effect of combustion on the variations of these properties for both the fly ash and mineral matter were studied by using a laminar flow reactor.

It is shown in our paper, that there are significant variations (about 40-50% around the mean values) of the above-listed properties for both coal samples. By comparing the particle size and chemical composition distributions of the mineral matter and fly ash, it was possible to conclude that for the Texas lignite mineral matter, the combustion did not effect significantly the distribution of these properties, however, for the Eagle Butte coal the combustion had a major impact on these mineral matter parameters

INTRODUCTION

The characteristics of fly ash generated in pulverized coal fired boilers are of considerable interest among designers of pulverized coal combustion boilers and fly ash utilizers. Bulk analyses of fly ash - such as average chemical composition - are not sufficient for the assessment of fly ash behavior in boilers and in material structures, such as in concretes.

In fly ash utilization, it is usual to rely on ASTM bulk chemical analyses. The reason, however, of the poor correlation between the bulk chemical composition of fly ash and its binding propensity (puzzolanic activity) may lay in the variation of chemical composition from particle to particle.

Previous studies [1] have indicated that the chemical composition of fly ash particle changes from particle to particle due to similar variations of the mineral matter properties in the parent coal and the random coalescence of mineral particles during coal particle burnout.

The development of combined scanning electron microscopy (SEM) with automated image analyses (AIA) and energy dispersive X-ray spectroscopy (abbreviated as CCSEM) makes it possible to analyze statistically significant number (several thousands) of mineral and fly ash particles to determine the distribution of particle size and chemical composition in the mineral matter and fly ash [1].

In this paper we describe an adaptation of the CCSEM technique to investigate the effect of char burnout on mineral matter properties and to characterize the distribution of particle size and chemical composition of fly ash. Applications of CCSEM technique are reported for mineral matter and fly ash of a TEXAS lignite and an Eagle Butte bituminous coal.

EXPERIMENTAL PROCEDURE

Samples of mineral matter and fly ash were examined under Scanning Electron Microscope of the Jeol 733 Super Probe. The instrument was equipped with a Tracor Northern TN 5500 minicomputer as a controller. For the measurement, a dry sample of 0.9 g weight was mixed with epoxy resin to which, 0.3 g of hardener was added. Then the mixture was placed into a 3/8 inch diameter plastic mold. After a few hours, the solidified pellet was removed from the mold. The pellet was then cut into two pieces, which were embedded in an aluminum mold of 1.5 inches diameter with the same epoxy resin and hardener. The prepared sample was polished with four different abrasive papers and polishing sludges containing 5, 1 and 0.3 μm diameter diamond particles. Before microscopic analysis the surface was carbon coated.

The analysis began with running the Particle Recognition and Characterization Program (PRC) on the Tracor Northern computer. Different number of random fields were set up at different magnifications to obtain significant number of particles analyzed for each size class. Back-scattered electron detector was used to provide the best contrast between inorganic particles and the epoxy resin. The beam, operated at 15 KeV and controlled by the PRC code, scanned the surface of the sample until a particle was found, and providing that its brightness was between a preset minimum and maximum threshold, then its area, perimeter, minimum and maximum diameter were determined. The shape factor and average diameter were also calculated. From the center of the inorganic particle, an energy dispersive X-ray spectrum was acquired for 10 seconds.

Total counts of 13 elements (Na, Mg, Al, Si, P, Cr, S, Cl, Ca, K, Ba, Ti, Fe) were then normalized to 100 %. The information acquired by the minicomputer was sent to a computer. To evaluate the raw data, a computer code was written to convert the fractional X-ray counts into oxide concentrations by using calibration curves developed with standard materials. The particles were classified into mineral groups (such as quartz, or illite) by using criteria published in the literature [1].

APPLICATIONS OF THE CCSEM TECHNIQUE

Mineral Matter and Fly Ash of Size Classified (65-74 μm) TEXAS Lignite

A size classified coal sample was burned in a laminar flow reactor at 1750 K temperature and 20 vol% O_2 concentration. Fly ash samples were collected at the end of the reactor tube. Our primary interest was to investigate the effects of char burnout on the distribution of particle size and chemical composition of mineral matter.

The results for mean chemical composition of mineral matter and fly ash are reported in Table 1.

The results show that most of the mineral matter and fly ash are made of SiO_2 and Al_2O_3 indicating high amount quartz and clay constituents. As expected, the change of mean chemical composition of mineral matter was negligible during coal burnout. It can be seen from Table 1, that the confidence

TABLE 1

Mean Chemical Composition of Mineral Matter and Fly Ash (Texas Lignite)

Oxides	Minerals (%)	Confidence Limits (95%)	Fly Ash (%)	Confidence Limits (95%)
Na ₂ O	0.69	3.7	1.26	3.9
MgO	0.19	4.3	0.13	16.2
Al ₂ O ₃	15.22	1.3	17.21	2
SiO ₂	76.6	1.1	73.01	1.7
K ₂ O	1.64	1.7	1.99	2.8
CaO	2.01	2.1	3.2	2.9
FeO	0.83	2.9	1.62	8

intervals were different for the compounds due to analyzing different number of particles for different compounds.

In Figure 1, the mass based distribution functions of SiO₂ content of the mineral and fly ash particles are plotted. For both samples these distributions are bimodal most likely because the SiO₂ compound may be shared by two main mineral types (quartz and clay). The higher concentration peak may be related to quartz whereas the lower to a clay material. The distributions of mineral matter and fly ash are very similar indicating minimal effect of random coalescence of mineral particles.

In Figure 2, the mass based distribution functions for the ratio of SiO₂/Al₂O₃ in the mineral and fly ash samples are shown. The two peaks in SiO₂/Al₂O₃ ratio supports also the conclusion that both materials are made up by a physical mixture of two homogeneous mineral fractions. The higher peak of SiO₂/Al₂O₃ ratio (~7) indicates that this mineral class is probably a mixture of pure quartz and clay with higher quartz content, however the lower peak (~2.5) suggests a pure clay mineral matter. The similarity between the two curves indicates negligible mineral matter coalescence during combustion.

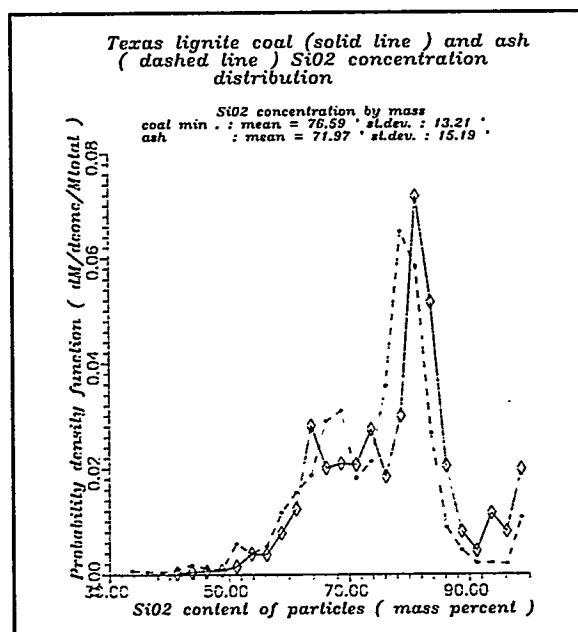


Figure 1. Distribution of SiO₂ Content, Texas Lignite

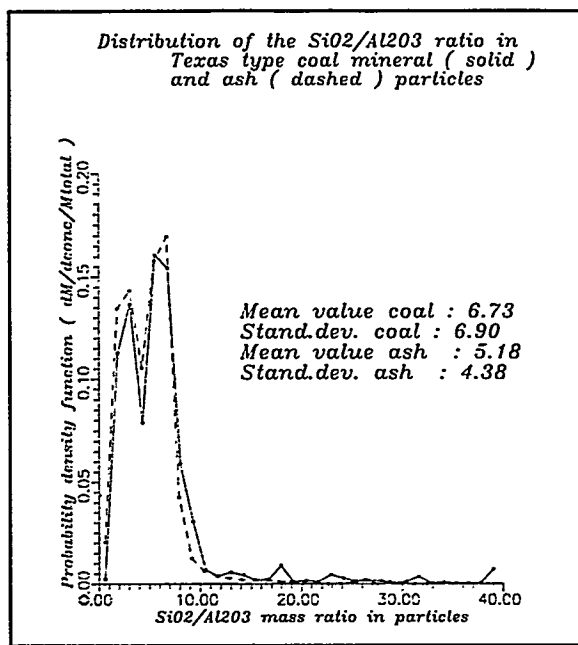


Figure 2. Distribution of SiO₂/Al₂O₃ Ratio, Texas Lignite

The number based size distributions of the mineral and fly ash samples are presented in Figure 3. Also included in this Figure, the theoretical size distribution of an imaginary fly ash (shown by diamond signs) which would have been generated assuming total inclusion coalescence during char combustion. The results show, however that the size distribution of the fly ash lays closer to that of the mineral matter.

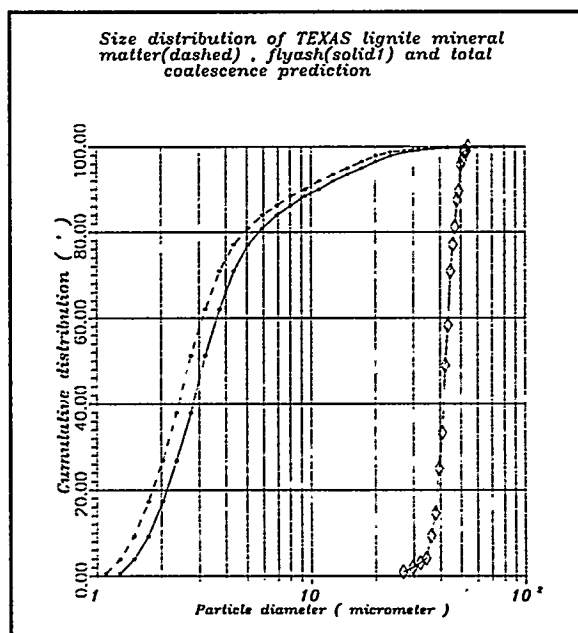


Figure 3. Size Distribution of Mineral Matter and Fly Ash, Texas Lignite

Chemical composition of individual particles can be used to set up mineral groups such as quartz and illite. It is then possible to determine the size distribution of particles of these mineral groups. Such results for quartz and illite are plotted in Figure 4. It can be seen that the quartz component in the fly ash was of coarser size distribution than that for the illite glass. This information is important for predicting the pozzolanic activity of fly ash. It has been shown that the illite type glass material plays an active role in the cementing process of pozzolans, whereas the quartz acts like an inert material [7].

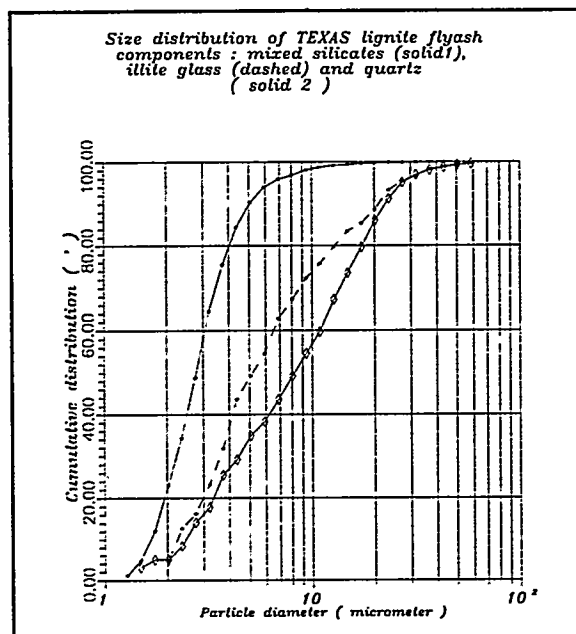


Figure 4. Size Distribution of Mineral Groups, Texas Lignite

Mineral Matter and Fly Ash of Eagle Butte Bituminous Coal

The Eagle Butte coal was burned in a pilot scale furnace of 2 MW thermal capacity and fly ash samples were collected from the flue gas at the exit of the combustion chamber. Mineral matter and fly ash samples were prepared for CCSEM measurements as described in section 2.

Results for the mean chemical composition of mineral matter and fly ash can be seen in Table 2.

TABLE 2

Mean Chemical Composition of Mineral Matter and Fly Ash (Eagle Butte)

Oxides	Minerals (%)	Confidence Limits (95%)	Fly Ash (%)	Confidence Limits (95%)
Na ₂ O	1.4	6.7	2.44	3.5
MgO	2.5	4.3	5.99	2.7
Al ₂ O ₃	29.6	2.3	22.4	2.3
SiO ₂	49.1	2.9	26.8	2.3
K ₂ O	0.67	7.7	0.87	3.6
CaO	5.2	2.1	30.6	2.2
FeO	5.9	2.9	6.73	2.5

The results indicate that there was a major difference between the mean mineral matter chemical composition and that of the fly ash. The cause of discrepancy was found by analyzing the ion-exchangeable mineral matter content of the coal. It was concluded that a major portion (about 32%) of mineral matter containing high amount of CaO was in an ion-exchangeable form in the coal, which could not be detected by CCSEM. This portion of mineral matter was exposed to high temperature during coal combustion and coalescence occurred between the inclusions and ion-exchangeable mineral matter forming the fly ash particles.

The distribution of particle CaO content can be indicative for the process of ion-exchangeable mineral matter coalescence with inclusions during char burnout. The results can be seen in Figure 5. It shows that the CaO is randomly distributed. The lack of pure CaO particles (or even particles with CaO content higher than 50 %) indicates that the probability of finding a coal particle without inclusions is small. Similar conclusion can be drawn from the distribution of SiO₂ content. The results are shown in Figure 6.

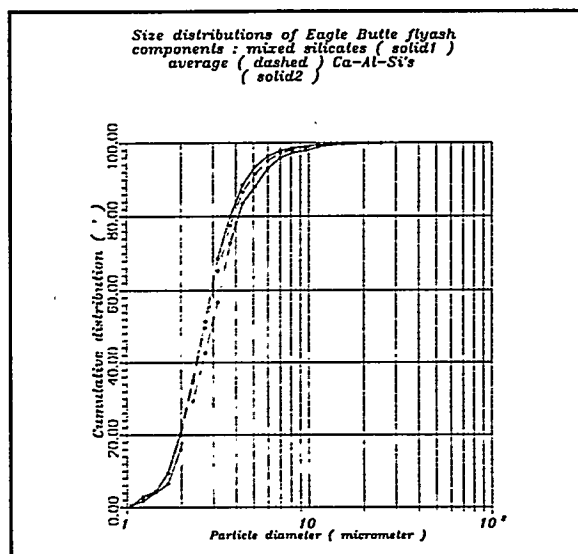


Figure 5. Size Distribution of Mineral Groups, Eagle Butte

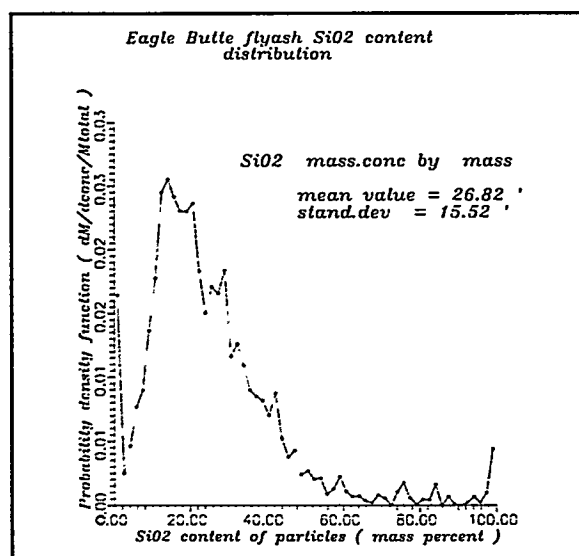


Figure 6. Distribution of SiO₂ Content, Eagle Butte

It has been found [8], that the presence of Ca-aluminosilicates in fly ash is one of the sources of the cementing process, therefore analyses of this component is of great importance to fly ash utilizers. The size distribution and chemical composition of this mineral type can determine whether the fly ash can be used in concretes without addition of cement. It has been also shown [8] that the ratio $\text{CaO}/(\text{SiO}_2 + \text{Al}_2\text{O}_3)$ is important to predict the cementing property of fly ash. In Figure 7, this ratio is plotted. It can be seen that the $\text{CaO}/(\text{SiO}_2 + \text{Al}_2\text{O}_3)$ ratio has also a distribution. Its mean value was found as 1.05. This ratio is similar to that of the mono-calcium- aluminosilicate-hydrates, an important product of the cementing process.

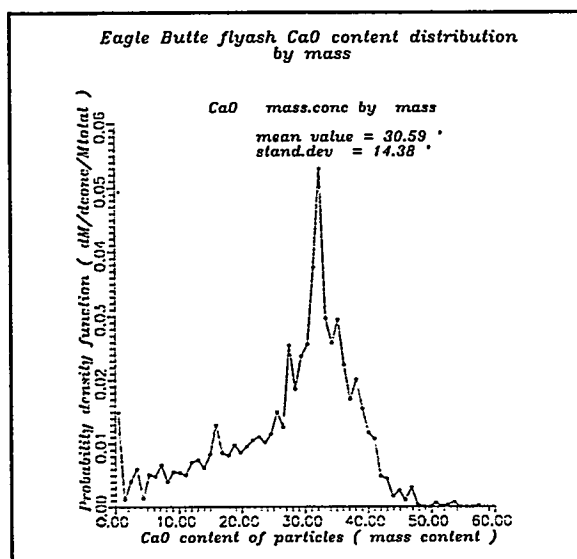


Figure 7. Distribution of CaO Content, Eagle Butte

The size distributions of calcium aluminosilicates and mixed silicates - obtained by particle classification based on chemical composition - and that of the fly ash are plotted in Figure 8. It can be seen that the three curves lay very close indicating similar random process of fly ash particle formation.

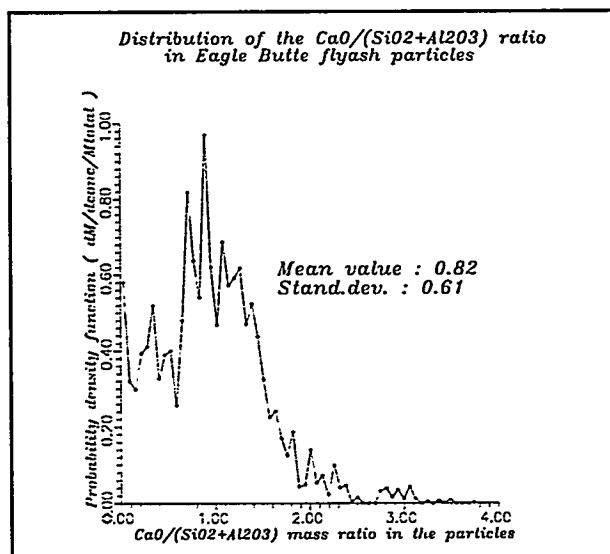


Figure 8. Distribution of $\text{CaO}/(\text{SiO}_2 + \text{Al}_2\text{O}_3)$ Ratio, Eagle Butte

CONCLUSIONS

Particle to particle variations of properties, such as SiO_2 content or diameter, for mineral matter and fly ash can be determined with high confidence by measuring statistically sufficient number of particles by CCSEM technique.

Two major mineral types were identified as quartz and clay in the Texas Lignite mineral matter. By comparing the distribution functions of particle size and SiO_2 content for mineral matter and fly ash, it was shown that the char burnout did not bring any significant change to the mineral matter properties.

In the case of the Eagle Butte bituminous coal, however a major change of chemical composition occurred during combustion due to the random coalescence between included and ion-exchangeable mineral matter in the coal. This process resulted in fly ash particles with chemical composition similar to that of the mono-calcium-aluminosilicates, an active component in the cementing process.

ACKNOWLEDGEMENTS

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CONSTRAINTS TO WASTE UTILIZATION AND DISPOSAL

Edward N. Steadman, Deputy Associate Director
Everett A. Sondreal, Principal Research Advisor
David J. Hassett, Senior Research Advisor
Kurt E. Eylands, Research Associate
Bruce A. Dockter, Manager, Physical Analysis

Energy & Environmental Research Center
University of North Dakota
Grand Forks, North Dakota, USA

ABSTRACT

The value of coal combustion by-products for various applications is well established by research and commercial practice worldwide. As engineering construction materials, these products can add value and enhance strength and durability while simultaneously reducing cost and providing the environmental benefit of reduced solid waste disposal. In agricultural applications, gypsum-rich products can provide plant nutrients and improve the tilth of depleted soils over large areas of the country. In waste stabilization, the cementitious and pozzolanic properties of these products can immobilize hazardous nuclear, organic, and metal wastes for safe and effective environmental disposal. Public benefits of coal combustion by-product utilization are substantial, including conservation of land, energy, and natural resources; reduction in CO₂ emissions generated in the production of competing materials; improvements in the balance of trade (e.g., fewer cement imports); and prevention of solid waste pollution. The increasing environmental and economic costs associated with the disposal of coal by-products are making the utilization of coal by-products a more desirable option.

Although the value of coal combustion by-products for various applications is well established, the full utilization of coal combustion by-products has not been realized in most countries. The reasons for the underutilization of these materials include attitudes that make people reluctant to use waste materials, lack of engineering standards for high-volume uses beyond eminent replacement, and uncertainty about the environmental safety of coal ash utilization. More research and education are needed to increase the utilization of these materials. Standardization of technical specifications should be pursued through established standards organizations. Adoption of uniform specifications by government agencies and user trade associations should be encouraged. Specifications should address real-world application properties, such as air entrainment in concrete, rather than empirical parameters (e.g., loss on ignition). The extensive environmental assessment data already demonstrating the environmental safety of coal ash by-products in many applications should be more widely used, and data should be developed to include new applications. The ultimate goal of research, standardization, and specification programs should be the development of practical design manuals for safe application of by-products as engineering materials.

INTRODUCTION

The nearly 90 million tons of coal combustion by-products produced annually in the United States is a valuable national resource that is vastly underutilized. Current applications use about 30% of the coal ash and only 2% of the flue gas desulfurization (FGD) products, representing only a fraction of the utilization potential in the United States, while nearly complete utilization has already been achieved in some western European countries. Increased utilization could offer substantial benefits to the nation's electric generation, construction, and manufacturing industries, to agriculture, and to the environment, whereas failure to act will create, literally, mountains of solid waste, an unnecessary legacy of future energy production.

An interlocking network of institutional, legal, and regulatory barriers is preventing the forward movement needed to achieve full economic utilization of coal combustion by-products in the foreseeable future. The key to reducing or eliminating these barriers lies in the entirely different attitudes and reactions engendered by considering these materials as products as opposed to wastes. The regulatory classification of a material as a solid waste, even though the material is nonhazardous (as in the case of coal combustion by-products) raises a caution flag and triggers case-by-case approval and permitting procedures that discourage beneficial use because of unreasonable cost and delay. The environmental safety of coal combustion products is a valid concern that, for the most part, has already been addressed. The overwhelming weight of evidence indicates that these products are not hazardous by legal or regulatory definitions and that they pose no greater cause for concern than a host of other common solid materials, including cement, rock, and soil. Nevertheless, current regulatory practice in the U.S. treats coal combustion products as solid waste, requiring further environmental validation before allowing substantially unrestricted use of these products.

The following discussion has been derived from work at the Energy & Environmental Research Center (EERC) to determine the primary reasons for the underutilization of coal by-products in the United States. The increased utilization of coal combustion by-products will provide numerous environmental and economic benefits to the United States. The utilization of coal by-products has many positive environmental effects related to 1) the reduction of solid waste, 2) the conservation of natural resources, and 3) reduced energy consumption and CO₂ emissions (e.g., from the reduced production of cements). The economic benefits of increased coal combustion by-product utilization can play a significant role in rebuilding the U.S. infrastructure. The economic benefits of by-product utilization include 1) reduced construction costs (including highways, bridges, airports, buildings, etc.) at equal or improved quality, 2) savings in energy prices through the reduction of ash handling and disposal costs to utility companies, and 3) the creation of new jobs through marketing opportunities provided by product sales.

BACKGROUND

Solid residues inevitably result from the conversion of coal for energy production. These residues can vary greatly in character depending on the coal conversion process, the coal used, and the environmental control systems (1-3). The quantity of coal by-products produced is in direct proportion to the amount of coal burned, the ash content of the coal, and the product of flue gas desulfurization. The average ash content of coal used by U.S. electric power utilities is approximately 10%, and the ash content has decreased significantly since 1975 (4). This reduction resulted from a nominal increase in coal cleaning, and a large increase in the use of low-sulfur, low-ash western coals to meet the sulfur dioxide emission requirements of the Clean Air Act (CAA). U.S. coal consumption for electric power generation has doubled since 1975 and is projected to increase by an additional 25% by 2010 (5). Approximately 22% of U.S. coal-fired generating capacity is currently equipped with FGD controls, and additional retrofit installations are projected to increase FGD coverage to about one third of generating capacity by the year 2000, when the sulfur control provisions of the 1990 Clean Air Act Amendments (CAAA) are fully implemented (5, 6).

Many coal by-products have properties advantageous for engineering, construction, and manufacturing applications (7-9). The first university research study on coal fly ash was reported in the Proceedings of the American Concrete Institute (ACI) in 1937, where the term "fly ash" first appeared in the literature. In 1946, the Chicago Fly Ash Company was formed to market coal fly ash as a construction material for manufacturing concrete pipe (10). The first large-scale use of coal fly ash was by the U.S. Bureau of Reclamation in the construction of the Hungry Horse Dam in Montana in 1949 (10). Six other dams were constructed during the 1950s using coal fly ash concrete. Initial markets opened up by the Chicago Fly Ash Co. were as a cement replacement and as an enhancer of concrete qualities to meet the new postwar demands. The technology used to establish these markets came from the experience of the U.S. Bureau of Reclamation and Army Corps of Engineers in using natural pozzolans in concrete for dam construction. Pozzolanic technology dates back to Roman times, some 2000 years ago, in the building of the aqueducts and the coliseums.

Historically, the principal use of coal by-products has been in concrete, and this still holds true today. However, many other utilization applications are discussed in the literature, including controlled

low-strength materials, highway road base and subgrade, soil amendments for agricultural uses, waste stabilization, extenders in plastics and paints, and the manufacture of products such as cement, insulating materials, lightweight building block, brick, and other construction materials.

Currently, coal by-products are an underutilized industrial by-product in the United States. Approximately 25% of all U.S. by-products produced in 1991, including FGD material, were recycled into other applications (11). Large potential markets for these by-products have not yet been exploited. Many of the applications referred to above are in the initial stages of commercial development. Although extensive research, development, and promotional effort has been expended, much more work is needed to achieve full commercial potential. Research, development, and demonstrations to address technical issues are continuing under the auspices of numerous institutions across the United States. The American Coal Ash Association, Edison Electric Institute and the Utility Solid Waste Activities Group, the Electric Power Research Institute (EPRI), and many individual utilities and marketing organizations are devoting their best efforts to promote coal by-product use. Yet all evidence indicates that full commercialization will not be realized in the foreseeable future unless the barriers hindering increased utilization can be substantially reduced or removed.

TECHNICAL OBSTACLES TO WASTE UTILIZATION

Numerous coal ash utilization applications are fully commercial in the United States. Most of these commercial applications would be considered traditional engineering and construction applications such as use as a cement replacement or admixture, various fill applications, and roadbuilding applications. Other new or advanced utilization applications are currently being investigated at the research, development, and demonstration levels at institutions in the United States and worldwide. These applications include the use of coal ash as fillers in ceramics, plastics, and metals, as a stabilization/solidification agent, for agricultural soil amendment, and others. Technical obstacles exist for both traditional and new coal ash utilization applications, and much of the ongoing research is focused on the removal or reduction of these technical obstacles. Changes in ash and FGD materials are occurring in response to new regulatory requirements such as those in the CAAA. The most common example is the increase of calcium and sulfur resulting from lime in limestone-based sulfur control methods. These new materials will need to be tested for chemical, mineralogical, physical, and leaching characteristics as well as for trace element mobility for each type of application to be considered. In order to maintain current commercial coal ash markets in the U.S., the technical feasibility, quality control, and product performance related to coal ash use must constantly be reaffirmed through research, development, and demonstration. These requirements, usually demanded by end users of coal ash, reduce coal ash industry resources available to advance current and open new markets.

The U.S. coal ash industry has participated in research, development, and demonstration activities since its beginning. Numerous government agencies have been instrumental in developing technical information on coal ash use, especially in building dams, roads, and other public works. As a result of this historical effort, the industry has developed a good working relationship with numerous research institutions and developed a good communication network to relay technical information within the industry. The means to address technical obstacles identified by the coal ash industry has been well developed, however, several obstacles related to technical issues need to be resolved. Almost all of the socioeconomic obstacles discussed in further detail later in this document have some relationship to technical information that either needs further development or better dissemination. Most frequently, the resolution of socioeconomic obstacles depends on the development of additional technical information. These areas are linked and must be addressed in tandem to make progress toward removing barriers to coal ash utilization.

SOCIOECONOMIC OBSTACLES TO WASTE UTILIZATION

Regulatory Obstacles to Increased Use

The Resource Conservation and Recovery Act (RCRA) of 1976 and the 1980 Solid Waste Disposal Act Amendments, provide for comprehensive cradle-to-grave regulation of solid waste generation,

collection, transportation, separation, recovery, and disposal (12-14). Subtitle C of RCRA and its implementing regulations impose specific federal requirements on materials deemed to be "hazardous," either because of being listed by the U.S. Environmental Protection Agency (EPA) as hazardous or by reason of having hazardous or toxic characteristics. Subtitle D of RCRA delegates regulation of nonhazardous solid wastes to the individual states. In its original form, RCRA did not specify whether coal ash fell under Subtitle C or D. The 1980 amendments temporarily excluded coal combustion by-products from Subtitle C regulation pending an EPA study report addressing appropriate classification. In the interim, coal by-products were subject to regulation under state laws pertaining to solid wastes.

On August 2, 1993, the EPA presented their final regulatory decision on fly ash, bottom ash, boiler slag, and flue gas emission control waste (40 CFR Part 261) stating that, effective September 2, 1993, these materials are not regulated as hazardous wastes under Subtitle C and officially placing them under Subtitle D as solid wastes under the jurisdiction of individual states (15). Further evaluation will be made by the EPA of hazardous or toxic properties of industrial solid wastes, but at this time coal by-products are expected to remain under state regulation where little positive change is expected regarding beneficial use.

An important barrier issue originating in RCRA legislation is the indiscriminate designation of coal by-products as solid wastes, whether they are recovered for use or disposed of in a landfill. In the absence of special state exemptions from solid waste regulations for beneficial use, which exist in only a few states, the "waste" designation can trigger case-by-case approval and permitting procedures that discourage coal by-product use because of unreasonable cost and delay. Suggested remedies for this problem include both the elimination of the "waste" designation and the creation of appropriate exemptions from regulation based on environmentally sound regulatory classifications for various classes of by-product use.

While RCRA is the principal federal law affecting the regulation of coal by-products, a larger statutory framework of federal laws, more or less integrated with state and local statutes, may ultimately have to be considered. Other federal statutes that potentially apply to coal ash use or disposal in particular circumstances, as well as to virgin raw materials and derived products, include the Clean Water Act of 1972; the Safe Drinking Water Act of 1974; the Toxic Substances Control Act of 1976; and the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (CERCLA). All of these statutes deal with the control of toxic substances and ultimately rely on environmental testing and risk assessment to establish regulatory criteria. Therefore, it appears that the answer to regulatory questions constituting barriers to beneficial use lies in obtaining adequate environmental data to demonstrate environmental safety, a process that is well-advanced for coal by-products but requires systematic compilation and refinement to provide the basis for regulatory classification.

Legal Obstacles to Increased Use

The key legal barrier to coal by-product utilization is the potential for environmental liability. Other issues involving commercial law and patents pose limited constraints of much less significance. The most serious environmental issue centers on the wide divergence in the legal and regulatory treatment of the beneficial use of coal by-products under state laws. Whereas the EPA confirmed in a ruling on August 2, 1993, that coal ash and FGD products are not hazardous materials under RCRA Subtitle C, the delegation of regulatory authority under RCRA Subtitle D for solid waste allows various states to regulate the use and disposal of coal ash by very different standards. Some states restrictively control coal ash as a de facto hazardous material, while other states treat recycled ash as an unregulated construction material (12). Some states regulate coal ash on a case-by-case basis. In recent years, several states have adopted statutes prohibiting the importation of solid wastes. Although these statutes have been regularly overruled as restraint of trade, their temporary status has impeded ash sales in some instances.

RCRA is the principal federal statute affecting the regulation of solid waste and, therefore, related beneficial use (discussed under regulatory barriers in Section 2.5.2.) Other federal environmental statutes that may affect barriers to coal by-product utilization are the Clean Water Act and CERCLA, also known as the "Superfund Act." A 1988 summary of state statutes compiled by the Utility Solid Waste Activities Group (USWAG) identified forty-three states that exempt coal ash from hazardous waste regulations; seven states—including Kentucky, Tennessee, Oklahoma, Washington, New Jersey, Maine, and

California—that require testing to determine if the ash would be regulated as a solid waste or a hazardous material; and one state, Ohio, which exempts coal ash from both solid and hazardous waste regulations (16).

As a general consideration, statutory liability under environmental law is not based on fault and imposes strict responsibility without regard to negligence. Tort law, on the other hand, applies where a dangerous condition can be traced back to the point of manufacture of a product, which is not a condition that commonly applies to coal ash utilization. The commonly held opinion that semantic reclassification of coal ash as a product rather than a solid waste would, by itself, simplify regulatory liability appears to have little legal validity since the intent of the statutes would not change, and their wording could be readily adapted. Also, compliance with one statute would not remove jeopardy from others, and therefore, compliance with state regulations under delegated RCRA authority does not prevent liability under the Clean Water Act or CERCLA. The CERCLA statute appears to be the broadest statute covering hazardous materials that present "substantial danger to public health or welfare or the environment," and it incorporates by reference any substance designated as hazardous or toxic in the Clean Water Act or RCRA (13). CERCLA places strict liability for remediation and restitution on the party responsible for the hazardous material without regard to negligence. However, it is very significant to note that petroleum and natural gas are specifically exempted from liability under CERCLA. This type of exemption from liability establishes a precedent that could appropriately be considered in legislation for coal ash, owing to its importance as the largest-volume, recyclable material in the U.S. and the record of environmental testing that indicates coal ash is not a hazardous substance, pollutant, or contaminant.

Other legally recognized remedies for environmental liability, apart from statutory exemption, involve demonstration of compliance with a regulatory authority based on recognized technical specifications and environmental criteria. Improved regulatory classification of coal by-products for use in various classes of applications would help to reduce environmental liability by providing background and specificity for legally defending particular utilization practices. By controlling the end use of coal by-products, utilities and marketers can limit their liability by providing material only for those uses that are demonstrated to be environmentally safe (17). Exemption from regulatory control as solid wastes under RCRA could be provided for pre-approved classes of by-product use. Although such federal deregulation of preapproved products may be difficult to accomplish, it would permit approved coal combustion products to move into unrestricted interstate commerce. Federal regulatory clarification and improved specifications would, at a minimum, provide direction for state regulators.

Some difficulties may exist in applying commercial or contract law to the sale of coal by-products because of the current lack of both technical specifications and environmental criteria applying to some uses. Suggestions have been advanced for developing a uniform commercial code for by-product transactions that would incorporate specifications to assist buyers and sellers in writing clear and enforceable contracts. Legal research is needed to establish the usefulness of this approach. As better specifications are incorporated, quality control in the production of coal by-products becomes a more significant factor in meeting legal responsibility (17).

Patents held on various processes, materials, and practices involved in coal by-product utilization appear to involve broad claims that are difficult to distinguish from common practices normally considered public domain. For example, certain patents involving controlled, low-strength materials would not appear to necessarily represent unique or novel practices, and no known information indicates these patents are being enforced. No judgment is intended here on the validity or enforceability of such patents, but patent searches and legal opinions in selected areas may be useful to remove uncertainties that may constitute de facto legal barriers. Such patent reviews could appropriately be sponsored by trade organizations representing utilities and marketers.

Economic Obstacles to Increased Use

The primary interests of power companies are the generation and sale of electricity. However, utilization or disposal of the by-product has become more of an issue because of increased disposal costs and the large amount of material produced. To avoid disposal costs, utilities are actively promoting by-product use.

As previously discussed, the chemical and physical properties of an individual coal by-product depend on the type of combustion technology used, the type of coal burned, the pulverizing equipment used, the make and type of the boiler, the rate of burning, the air-to-fuel ratio, and the pollution control devices used. Each different by-product produced has slightly different properties that may make it more or less suitable for a specific type of application.

The local demand for different by-products can be quite variable (18). Road or dam projects may provide large demand for coal by-products that tapers off once the project is completed. Most marketers have no provision for stockpiling these materials in anticipation of high demand. Establishing a consistent pricing policy is difficult whenever diverse markets are considered. A high-quality ash sold for \$25/ton in the cement replacement market cannot compete in the structural fill market where competing natural soils may be available for \$2/ton. Unless all ash can be sold for cement replacement or for a use of equal value, some ash will remain unsold.

A study by EPRI (19) surveyed nine different ash marketers to identify their major constraints in marketing ash. Two constraints were identified more frequently than were any others: 1) unfamiliarity with ash and its potential benefits and 2) the regulatory designation of fly ash as a waste material rather than a beneficial resource. These constraints were identified on many levels, including construction personnel, design professionals, and regulatory personnel.

Environmental Obstacles to Increased Use

Regulatory agencies, the coal-mining industry, the utility industry, and the coal by-product utilization industry all agree that environmental protection of clean air and clean water is of the highest priority when considering utilization or disposal of coal conversion solid residues and other by-products. However, it is also agreed within the by-product utilization industry that disposal regulations should not be generically applied to materials in use applications. The American Society for Testing and Materials (ASTM) E50 committee, formed to deal with this issue, has begun to address the definition of coal by-product as wastes versus resources. Although regulatory approaches must be adequate to safeguard the environment, it is important that appropriate and comprehensive scientific information be used to make the necessary decisions regarding the disposal or utilization of these highly complex solid materials. The environmental impact of coal by-product disposal and utilization has recently been studied, but discussion was limited to soil amendment applications (20). Technical aspects of environmental characterization of coal by-products and studies of environmental impact of utilization in various applications are summarized below.

Numerous works in the literature evaluate the potential of coal by-products to adversely impact the environment, however, the tests generally used have been designed for wastes codisposed in sanitary landfills. The most commonly used tests are the EPA-approved toxicity characteristics leaching procedure (TCLP) (21), the ASTM D3987 leaching procedure (22), the EPA-EP (23), and the synthetic precipitation leaching procedure (SPLP) (24). The TCLP is the EPA regulatory leaching procedure, through the RCRA, for the identification of wastes as hazardous when codisposed in a sanitary landfill. These tests are all short-term tests (generally 18 to 24 hours in duration) and do not allow adequate time for secondary mineralization to occur and the subsequent change in the material controlling long-term behavior (25). The scientific validity of these short-term tests as generally applied to utilized materials or to evaluate materials disposed of in a monofill has been questioned (26, 27). Land disposal of materials identified as hazardous by this leaching procedure is prohibited by the EPA. The TCLP has also been adopted by many state regulatory agencies to provide leaching information on solid wastes (not hazardous) that are not federally regulated.

Only a few procedures in the literature are appropriate to assess the environmental impact of utilized (as opposed to disposed) coal by-products. In utilization applications, the coal by-product is commonly combined with other materials. Leaching tests for coal by-products are generally performed on the coal by-product alone rather than on the final product. For example, coal fly ash is commonly combined with fine aggregate (sand) and cement to produce a controlled, low-strength material for a broad range of construction applications. While a leaching test may be required on the coal ash prior to use, the final product may not be tested, even though the leachability of the trace elements in the by-products may change because of the new matrix. As a result of inappropriate environmental

evaluation procedures, misleading or incorrect information on coal by-products prevents proper evaluation of coal by-product suitability for other applications.

As noted in above, the study on the impact of coal by-product utilization focused primarily on agricultural and mine soil amendment applications (20). Results in the literature indicate the presence of numerous trace elements in coal ash, and enrichment of some trace elements in coal by-products is also documented (24, 28). Although a majority of these studies reported in the literature indicate very low concentrations of trace elements in leachate (26, 28, 29), concern for trace element contamination from placement of products containing coal by-products has been raised by numerous state environmental and health agencies as well as by the public. In a few cases, high concentrations of RCRA trace elements (arsenic, barium, cadmium, chromium, lead, mercury, selenium, and silver) have been reported in leachates from coal by-products, but these reports are the exception rather than the rule (28). Numerous recent reports indicate low toxic leachate concentrations under diverse conditions in applications that involve marine construction (30–35), agricultural amendments (36–38), and waste stabilization (38–45). Studies have also investigated the impact of coal by-product use on ground and surface water (46, 47). These reports indicate limited-to-negligible impact on groundwater quality as a result of coal by-product use in various applications, including paving, embankments, and road base. A recent overview of the environmental impact of coal by-product use (40CFR Part 261) found no justification for the inclusion of coal by-products as hazardous wastes. In effect, environmental concern may be based on a perception of a potential problem and not on factual information. The prohibition of coal by-product use based on perception is unwarranted.

Educational and Attitudinal Obstacles to Increased Use

Education is central to any program aimed at reducing or removing attitudinal barriers, continuing from initial design to troubleshooting during construction and long-term assessment. Familiarity with potential uses, correct environmental data, physical and engineering data, and information on the quantity or quality of coal by-products are absolutely necessary at all levels of the coal by-product industry. Users of coal by-products need access to technical assistance from a variety of sources. Little written documentation is readily available to interested parties unfamiliar with by-product properties. Documentation should include commonly accepted mix designs and construction practices. Suggested sources of technology assistance would include federally or privately owned technical assistance centers, trade associations, and universities. Individuals who would benefit from continuing education include designers, engineers, specification writers, owners, contractors, regulators, educators, and legislators. The following approaches have been recommended for removing barriers (19):

- Increase educational programs, including college-level instruction, continuing education courses, workshops, and seminars.
- Continue demonstration projects and publication of results, concentrating on joint projects involving federal and state agency cooperation, with an emphasis on cost and quality benefits and environmental compliance.
- Collect, distribute, and publish data on environmental effects, particularly on the mobility of leachate.
- Develop beneficial fly ash use programs and guidelines.

The attitude of related industries and organizations can also affect coal by-product use. The term "related industries" as used herein covers a broad range of commercial concerns including those thought to be competing industries. Their inclusion is because coal by-products may replace other natural or manufactured raw material, as in the case of fly ash as a replacement for cement, or by-product gypsum as a replacement for natural gypsum. Other related industry groups include engineers and architects, cement and concrete producers, manufacturers, coal companies, and others. The diversity of this group reflects the fact that coal by-products can be used in so many different applications. It is important to emphasize that a limited number of contacts were made from this large group and that the information on barriers presented here has been summarized to best reflect general barriers throughout these related

industries. A wide range of opinion exists on how coal by-product utilization is viewed by this diverse group, even within a single industry.

The key issues for coal by-product utilization indicated by related industries are related to profitability and good business operation. The issues noted to be of greatest importance were quality control and performance of products, cost of raw materials and manufacturing, availability and quality of raw materials, customer satisfaction, as well as safety and health concerns. It was noted that the cost savings of coal by-product use must be balanced with product quality and customer satisfaction. Even when a related industry is strongly motivated to utilize coal by-products, that industry must be responsive to its own customers.

As stated above, competition between traditional raw materials and coal by-products can be very important. A specific case of competition is that of portland cement with coal fly ash. Coal fly ash has long been used as a mineral admixture in concrete and has often been termed as a cement replacement. Use of fly ash, either pozzolanic or cementitious in nature, in concrete has been shown to be very advantageous, and it is obvious that the replacement of cement with fly ash reduces the amount of cement in a concrete mix. Cement producers and the Portland Cement Association promote cement use but also have participated in research, development, and commercialization of blended cement containing fly ash, by-product use in cement manufacturing, and use of fly ash as a mineral admixture in concrete. In recent years, the cement industry has come to accept coal by-products in the marketplace. Several cement companies sell coal ash and products containing coal ash, such as blended cements. It has been speculated that more concrete will be sold because of the economic advantage gained with the addition of fly ash and that the cement market may increase because of this. Many cement manufacturers now market coal by-products in addition to cement. In some concrete markets, the superior performance of fly ash concrete is required to meet specifications. An example is high-strength concrete used in construction of high-rise buildings. The strengths required for these applications are above 10,000 psi. It is not technically feasible to achieve strengths beyond 10,000 psi using standard portland cement concrete, but strengths in this range are regularly reached using a combination of cement, fly ash, and super plasticizer. This high-strength concrete is a key example of a specialized product being produced with inclusion of coal by-products as a raw material.

While the cement industry is an example of material competition for coal by-products that appears to be approaching a mutually beneficial resolution in the marketplace, some barriers still exist to coal by-product use in some applications where cement is well-accepted. An example of this barrier is in the production of controlled, low-strength material, where environmental testing may be required on coal fly ash used in this application whereas testing may not be required for cement.

The perception of coal by-products as wastes is of itself a barrier to coal by-product utilization. In some instances, coal by-products are automatically considered hazardous wastes, reflecting a lack of information on and understanding of these materials. This perception of these materials as generally hazardous in nature may come from an association of the term solid waste with the terms of hazardous solid wastes; it has been noted in the coal by-products industry that this is sometimes an automatic, albeit erroneous, association. General acceptance of coal by-products as risk-neutral raw materials for manufacturing in place of competing raw materials will be realized only when their nonhazardous characteristics are recognized.

Traditionally, coal by-products have been used to reduce the cost of a project or product. From the results of numerous research projects, demonstrations, and commercial and public projects, coal by-products have also been shown to improve the quality of products. The best example is fly ash concrete, which typically has higher long-term strength, improved sulfate resistance, reduced permeability, and decreased alkali-silica reactions as compared to portland cement concrete. Cost savings and end product quality were of key importance to most individuals interviewed, and anything that would improve or at least maintain product quality while maintaining or reducing the cost would be favorably considered. It was widely indicated that products containing coal by-products are often viewed as being of low quality because of lack of familiarity with their demonstrated prospects, and that this erroneous perception is responsible for the slow commercialization of coal by-products in many industries. The economics of coal by-product utilization are influenced by the cost and availability of competing materials, transportation charges, and the need for new or modified facilities.

RECOMMENDATIONS FOR REMOVAL OF OBSTACLES TO INCREASED UTILIZATION OF COAL BY-PRODUCTS

The primary recommendation to remove barriers to increased utilization of coal by-products is to educate the related industrial groups and the public on the benefits of using coal by-products. Education of engineers, architects, and other professionals at the college level is highly recommended to provide a baseline level of competence in utilizing coal by-products. Developing additional federal procurement guidelines and standards and performing more demonstration projects, particularly in public works projects, are also widely recommended. Additionally, design manuals addressing utilization practices in construction and engineering projects would be beneficial.

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Advanced Clean Coal Technologies for East Central Europe

Session A5

SESSION COCHAIRS:

*Lowell Miller, Director of Clean Coal Technology
U.S. Department of Energy
Washington, DC, USA*

*Josef Vavroušek, Chairman
Society of Sustainable Living
Prague, Czech Republic*

IMPACT OF FUEL PROPERTIES ON ADVANCED POWER SYSTEMS

Everett A. Sondreal, Principal Research Advisor
Michael L. Jones, Associate Director, Industrial Relations and Technology Commercialization
John P. Hurley, Senior Research Manager
Steven A. Benson, Deputy Associate Director
Warrack G. Willson, Senior Research Advisor

Energy & Environmental Research Center
University of North Dakota
Grand Forks, North Dakota, USA

ABSTRACT

Advanced coal-fired combined-cycle power systems currently in development and demonstration have the goal of increasing generating efficiency to a level approaching 50% while reducing the cost of electricity from new plants by 20% and meeting stringent standards on emissions of SO_x , NO_x , fine particulates, and air toxic metals. Achieving these benefits requires that clean hot gas be delivered to a gas turbine at a temperature approaching 1350°C , while minimizing energy losses in the gasification, combustion, heat transfer, and/or gas cleaning equipment used to generate the hot gas. Minimizing capital cost also requires that the different stages of the system be integrated as simply and compactly as possible. Second-generation technologies including integrated gasification combined cycle (IGCC), pressurized fluidized-bed combustion (PFBC), externally fired combined cycle (EFCC), and other advanced combustion systems rely on different high-temperature combinations of heat exchange, gas filtration, and sulfur capture to meet these requirements.

The choice of an optimum advanced system and the level of success that can be achieved depends on the quality of the design coal, including the levels of moisture, sulfur, and ash and the high-temperature properties of the ash. The diversity of coals found in East Central Europe, which range from high-quality bituminous coal to low-quality lignite, can make optimum design selection somewhat difficult. No advanced power system has been demonstrated in the range of the more extreme coal properties found in this region, which can involve 60% moisture as mined, 40% ash (dry basis), and 6% sulfur (moisture- and ash-free). Preliminary assessments can, however, be made of the limits of applicability of various gasification and combustion technologies in relation to these properties. At very high levels of coal moisture, slurry feed to a gasifier becomes impractical, and feeding even the coal moisture itself without predrying can increase oxygen requirements by one-half and reduce the calorific value of the product gas by up to 70%. Without predrying, gasifying high-moisture coal with either air or oxygen while retaining the moisture in the product gas through use of hot-gas cleaning may not meet the minimum heating value of about 100 Btu/scf for fuel gas used in a gas turbine. The highest operable level of coal moisture that can be fed to a moving-bed gasifier is estimated to be about 40%. High ash content in coal fed to an entrained-flow gasifier can account for up to 3% direct heat loss in slag, and the high bed drain and related increase in carbon loss associated with high ash content in a fluidized-bed gasifier can represent even greater losses. At 6% coal sulfur (dry basis), up to 10% of the heating value in the raw fuel gas from the gasifier can occur as H_2S , which is removed. In a PFBC, high ash can account for up to 2% heat loss in the absence of heat recovery from the bed drain, and high moisture can reduce in-bed heat transfer to 10% of total heat release. However, in a PFBC, high moisture also increases the percentage of power generated in the gas turbine, which thereby may compensate for increased stack losses and help to maintain system efficiency. In general, high moisture and ash contents will change the approach designers use to optimize both the efficiency of the gas turbine and the quality of the steam delivered to the steam turbine. High-temperature properties of ash that are important in various systems include the ash fusion temperature, the slag viscosity-temperature relationship, slag deposition and corrosion characteristics, and levels of corrosive alkalies and chlorides that critically damage ceramic filters and alloy turbine blades.

Adverse impacts of coal properties can be minimized by precleaning, drying, and/or hydrothermally processing the feed coal, but not without adding substantial cost. Integrated pretreatment methods are available to meet the feed requirements of certain combustion and gasification systems. Designers of baseload coal-fired power plants in East Central Europe will need to take into consideration the widest possible range of coal research data and vendor-supplied technical information in order to achieve optimum advanced systems for the region's diverse coal resources.

INTRODUCTION

The utilization of lignite and brown coal in East Central Europe has been optimized over several decades in steam power plants to account for variably adverse properties applying to some local coal reserves. Given the diversity of properties represented, further optimization is likely required in designing future advanced power systems for these coals. The Energy & Environmental Research Center (EERC) is currently participating in assessment of applicable advanced technologies along with organizations planning future coal-based power projects in the Czech Republic, Poland, and Bulgaria under the sponsorship of the U.S. Department of Energy and the U.S. Agency for International Development. The information presented in this paper addresses in a general way the issues and limitations that will need to be addressed in depth when coals containing very high levels of moisture, sulfur, and ash are used in combined cycle systems (PFBC and IGCC). Our starting point is a comparison of the properties of low-rank coals from the United States and East Central Europe. The assessment of technology that is presented is generic and is not intended to address the merits or shortcomings of particular vendor designs. However, understanding the underlying principles covered in this paper will be essential in selecting optimum technologies for the subject coals.

FUEL UTILIZATION PROPERTIES

Variability in Analysis of Low-Rank Coals

Various advanced power technologies are applicable over different ranges of coal analyses, but none has been developed specifically for low-rank coals in general or for the properties of East Central European coals in particular. In the United States, low-rank coals are classified under ASTM standards as lignites below 8300 Btu/lb (4610 kcal/kg) and as subbituminous coals between 8300 and 11500 Btu/lb (6390 kcal/kg), where the higher heating value is expressed on a moist, mineral matter-free (mmf) basis. Representative ranges in analysis for major U.S. low-rank coal regions are compared in Table 1 with ranges for East Central European brown coals and lignites. Chlorine content, which was not available for most of the coal represented, is low in most U.S. low-rank coals, typically ranging below 100 ppm in North Dakota and Texas lignites and Wyoming subbituminous coal. While the ranges of variation in properties for U.S. and East Central European coals in Table 1 overlap, the latter include higher levels of moisture, sulfur, and ash and lower heating values (LHV) than those observed in the United States. The difference represented by these factors of quality is greater than can be noted from the ranges shown since the predominant U.S. low-rank coal reserves of the Powder River Basin in Montana and Wyoming average below 1% sulfur and 10% ash, dry basis. Significant reserves of East Central European low-rank coals appear to exhibit properties near the high end of variation in moisture, sulfur, and ash. The ranges of variation in ash oxide analysis are generally similar for Czech, Bulgarian, and U.S. coals, but U.S. lignite ashes more commonly contain high concentrations of sodium, calcium, and magnesium. A more acidic ash composition is usually found in high ash coal since silica and aluminosilicates make up most of the added inorganic burden. The generally higher alkali and alkaline earth concentrations in U.S. low-rank coal ashes can result in ash and slag properties differing from those of acidic ashes higher in silica and alumina. Fusion temperatures are typically lower for moderately basic coal ashes.

Low-Rank Coal Structure and Chemical Functionality

The authors of this paper did not have access to chemical formation ability data for East Central European coals, but in general they would be expected to resemble U.S. coals of similar rank.

TABLE 1

Variability in Properties of Low-Rank Coals by Country							
	Czech Republic	Poland	Hungary	Bulgaria	Spain	Germany	U.S.
Location	Bilina Melnik Nastup Most Sokolov	Belchatow Konin Turow Adamow Rybnik	Oroszlany Matraalja Borsod	Maritsa East Sofia Bobov Dol Pernik	Teruel	Cologne Leipzig	Wyoming Montana New Mexico Texas North Dakota
Moisture, % as mined	6-55	9-55	19-48	14-62	13-24	48-63	10-42
Ash, % db	7-44	8-40	18-40	28-58	14-70	4-40	3-30
Sulfur, % daf	0.7-9	0.5-7	0.8-5	3-11	3-12	0.4-3	0.3-4
Lower Heating Value, MJ/kg	9-19	7-22	6-15	5-14	12-17	7-12	8-25
Ash Analysis, % Oxides							
SiO ₂	35-50			15-65			18-63
Al ₂ O ₃	11-25			4-32			13-25
Fe ₂ O ₃	9-15			5-20			4-20
CaO	7-8			1-60			5-39
MgO	3-4			1-5			2-13
Na ₂ O	0.6-1.6			0.2-0.4			0.1-12
K ₂ O	0.4-1.1			0.2-0.6			0.1-2

Sources of data include papers by Brix, Couch, and Zakrzewski from the April 1992 Energy and Environment Conference in Prague; case study reports submitted by East Central European participants at the Least Cost Power Course at the EERC in 1992; coal analyses obtained from Bulgaria, Poland, and the Czech Republic for EERC studies performed in 1994; papers by Franke (1977), Stefanski (1981), and Hein (1986) from EERC Lignite Symposia; and U.S. analyses compiled by Selle in his 1986 Review of Slagging and Fouling from Low-Rank Coal.

The molecular structure of U.S. low-rank coals has been summarized by several investigators based on interpretation of a broad range of analytical data, including elemental analysis, pyrolysis, extraction, controlled oxidation, instrumental Fourier transform infrared analysis (FT-IR) and nuclear magnetic resonance spectroscopy (NMR), and calorimetry (Schobert, 1990; Knudson, 1986; Kube and others, 1984; Benson and Schobert, 1982). Highly simplified molecular models, such as the one illustrated in Figure 1, indicate small one- to three-ring aromatic clusters, a greater abundance of aliphatic and hydroaromatic carbon chains than in bituminous coal, and a much higher oxygen content. The atomic H/C ratio for maf low-rank coals is in the range of 0.75 to 0.9, which is comparable to hvA bituminous coal, but only about half the value of petroleum. Between 50% and 75% of the carbon occurs in aromatic rings, compared to typically 85% for bituminous coal and nearly 100% for highly graphitized anthracite. The most important bridging groups between aromatic ring systems consist of polyethylene chains (-CH₂-) and ethers (R-O-R). Methylene chains can exceed ten carbon atoms in length. In laboratory calorimetry, the aliphatic and hydroaromatic carbon burns off at a lower temperature than the clustered aromatic structure, paralleling similar differential burnoff in combustion and gasification processes.

Physical structure has been suggested to be related to molecular structure in terms of the effect of oxygen functional groups on hydrogen bonding and structural order and the role of moisture as a structural component (Schobert, 1990). Phenolic groups may provide a framework for hydrogen bonding of coal macromolecules of the type illustrated in Figure 1 into chain and cyclic structures, whereas carboxyl groups may hinder this structuring. Moisture in low-rank coal is both loosely held on surfaces and in large pores and tightly bound in the coal by hydrogen bonding, and it may also occur in micropores or other intermediate states of bonding. The 20% of total moisture believed to be tightly held by hydrogen bonding may contribute to structural rigidity in low-rank coal in the same manner as in wood, which would account for the friability, dustiness, and loss of strength of low-rank coal when it is dried to low moisture levels.

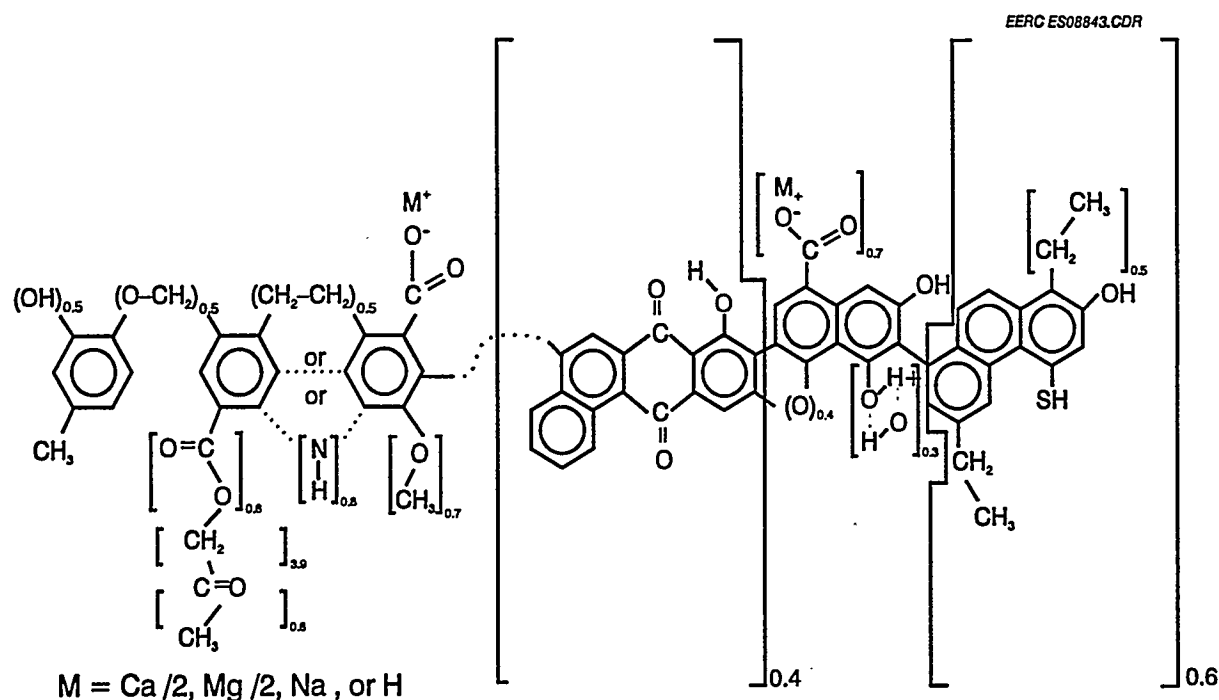


Figure 1. A molecular model for Wyodak subbituminous coal (Knudson, 1986).

High oxygen content in U.S. low-rank coal, up to 22% maf, consists of carboxyl ($-\text{COOH}$), phenolic (Ar-OH), ether and methoxyl (R-O-R and R-O-CH_3), and carbonyl ($-\text{C=O}-$) type groups. Carboxyl groups, accounting for one-quarter to one-half of the total maf oxygen, provide functionally important ion-exchange sites for alkali, alkaline earth, and trace element constituents that uniquely occur in association with the organic structure of low-rank coals. Thermal decomposition of alkali carboxylate starting at relatively low temperatures, well under 500°C , is believed to be an important part of the mechanism causing substantial release of sodium from low-rank coals in combustion and gasification processes, leading to adverse ash deposition and corrosion effects in boilers and gas turbine power systems.

Sulfur and nitrogen in U.S. low-rank coal are not well characterized in terms of molecular form. Analysis of pyrolysis products indicates that these elements occur in both aliphatic and aromatic structures, with aliphatic sulfur, in particular, being high (60%-80%) in lignite and decreasing as rank increases (Calkins, 1987). Average distributions of ASTM sulfur forms in North Dakota lignite (Sondreal and others, 1968) and Wyoming subbituminous coal (Glass, 1975) indicate about 50%-60% organic, 40% pyritic, and 5% sulfatic. The greatest variability occurs in the pyritic sulfur. These ASTM sulfur forms have only limited utility in understanding sulfur process chemistry, recalling that the pyritic sulfur is calculated from iron measurements and the organic assigned by difference. Studies at the EERC using supercritical fluid extraction (SFE) to separate and analyze the true sulfur forms have shown that as much as 36% of the ASTM "organic" sulfur is, in fact, elemental sulfur (Louie and others, 1993). The amount of elemental sulfur detected correlates well with total inorganic sulfur, suggesting possible geochemical equilibrium. Organic sulfur fractions can also be separated by SFE, but their molecular forms have not been reported. Heteroatom distributions in various thermal processes suggest that some organic forms of both sulfur and nitrogen are tightly bound in clustered ring structures and some are more labile and subject to early release in combustion and gasification systems, a significant distinction in pollutant formation.

Surface area and porosity measurements on U.S. lignite appear to indicate a surface area on the order of $1 \text{ m}^2/\text{g}$ in the macropores larger than 20 nanometers (nm) determined by nitrogen adsorption at 77 K and about a 200-fold larger area in micropores smaller than 2 nm determined by CO_2 adsorption at near ambient temperatures (Smith and others, 1993; Sharkey and McCartney, 1981). Subbituminous coals have a somewhat higher N_2 surface area and a slightly lower CO_2 area, which is consistent with the

general trend moving toward higher rank. Pore volume increases with devolatilization, causing the predominant micropore structure in low-rank coal to enlarge and the area to increase during char formation. The interpretation of measurements is complicated by questions as to possible multilayer absorption of polar CO₂ molecules on oxygen-rich low-rank coal surfaces and possible changes in surface structure at very low measurement temperatures.

High reactivities are observed for U.S. low-rank coals at elevated temperatures in both oxidizing (Smith and others, 1993) and reducing (Timpe and others, 1989) atmospheres, but this reactivity does not correlate with surface area measurements. However, increased reactivity leading to onset of spontaneous heating at lower temperature does correlate with both particle size reduction and drying (Sondreal and Ellman, 1974). The high reactivity of low-rank coal in thermal processes can be attributed to the abundance of free radicals formed from the oxygen functionalities in low-rank coals during thermal transformations such as decarboxylation. These free radicals either react rapidly with gaseous agents, or they mutually coalesce to form the highly cross-linked solid char (noncaking) that is characteristic of low-rank coal. The lack of softening upon heating allows free flow, mixing, and reaction at high temperatures. Differences in reactivity among low-rank coals are attributed to catalytic activity of minerals and ion-exchangeable cations, and the addition of alkalis or alkaline earths to low-rank coals serves to catalyze their reactions. Alkali gasification catalysts are believed to interact with char by means of a redox mechanism, whereby carbon reduces the alkali to metal, the metal reacts with water to release hydrogen, and the resulting metal hydroxide combines with CO₂ to form carbonate that can reenter the catalyst cycle (Wood and Sancier, 1984).

Inorganic Forms and Associations

Inorganic constituents in U.S. low-rank coal occur primarily as either ions associated with coal carboxylate (20%-60%) or discrete mineral grains (40%-80%).

Advanced analytical methods are being used at the EERC to characterize inorganic forms and their transformations by wet chemical fractionation and electron microscopy. Chemical fractionation (Benson and Holm, 1985) based on sequential solubilities in water, 1 M ammonium acetate, and 1 M HCl serves to quantitatively distinguish between 1) soluble salts and ion-exchangeable cations; 2) acid-soluble hydroxides, oxides, and carbonates; and 3) insoluble minerals such as clays, quartz, and pyrite. Automated scanning electron microscopy/microprobe techniques and image analysis are used to characterize unaltered coal samples to determine the spatial distribution of minerals by type, size, and association. Primary modes of occurrence of major elements are given in Table 2 and the most common mineral species in Table 3.

TABLE 2

Principal Association of Major Elements in U.S. Low-Rank Coals (Adapted from Benson, 1992)

Silicon, Si	Clay minerals, quartz
Aluminum, Al	Clay minerals, possible hydroxide or coordinated
Iron, Fe	Oxides, hydroxides, sulfides, sulfates, possible coordinated
Titanium, Ti	Rutile, associated with quartz and clay, oxides, organically bound
Phosphorus, P	Organically bound, phosphates
Calcium, Ca	Organically bound, carbonates, sulfates (gypsum)
Magnesium, Mg	Organically bound, carbonates
Barium, Ba	Organically bound, sulfides, barite, crandallites
Strontium, Sr	Organically bound
Sodium, Na	Organically bound, some Na montmorillonite and zeolite, sodium sulfate
Potassium, K	Associated with illite and other clays, organically bound
Sulfur, S	Sulfides, sulfates, elemental sulfur, organically bound

TABLE 3

Common Minerals Found in U.S. Low-Rank Coals	
Mineral Name	Formula
Silica and Silicates	
Quartz	SiO_2
Kaolinite	$\text{Al}_2\text{O}_3 \cdot 2\text{SiO}_2 \cdot 2\text{H}_2\text{O}$
Illite	Hydrated micalike minerals
Montmorillonite	$(1-x)\text{Al}_2\text{O}_3 \cdot x(\text{MgO}, \text{Na}_2\text{O}) \cdot 4\text{SiO}_2 \cdot \text{H}_2\text{O}$
Sulfides	
Pyrite	FeS_2
Oxides	
Hematite	Fe_2O_3
Rutile	TiO_2
Sulfates	
Gypsum	$\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$
Barite	BaSO_4
Carbonates	
Calcite	CaCO_3
Dolomite	$\text{CaCO}_3 \cdot \text{MgCO}_3$
Phosphate	
Apatite	$\text{Ca}_5(\text{PO}_4)_3(\text{F}, \text{Cl}, \text{OH})$

Major classes of minerals in U.S. low-rank coals, in a very approximate order of decreasing abundance, are silicate and aluminosilicate, sulfide as pyrite, oxides of iron and titanium, sulfates including gypsum and barite, carbonates chiefly as calcite, and phosphate as apatite (Table 3, Benson and others, 1993; Zygarlicke and others, 1990; Benson and others, 1984; Edgar and Kaiser, 1984; Paulson and others, 1972). A typical mass mean diameter for liberated mineral grains in pulverized (80% through 200 mesh) western U.S. low-rank coal is on the order of 20 microns. However, grain sizes range down to the scale of nanometers, causing a substantial fraction (normatively 30%–70%) of the discrete mineral content to remain locked within pulverized coal particles, in association with other mineral grains and the organically bound elements. The degree of association or segregation of inorganic constituents in the coal fed to a gasifier or combustor is an important determinant of inorganic thermal transformations and process impacts.

Organic associations measured by sequential solubility in water and ammonium acetate solution account for most of the alkali and alkaline earth elements in U.S. low-rank coals, typically including 80%–90% of Na, 70%–80% of Mg, 60%–70% of calcium, and 30%–40% of K for coals shown in Table 4. The percentage for potassium is lower because of its occurrence in clay minerals. In Figure 2, the total concentration of these organically associated elements is shown to be well correlated with the carboxylate content of the coal. Organic association is substantially less in bituminous coals.

TABLE 4

Organic Associations of Major Cations in U.S. Low-Rank Coals
(Benson and others, 1993; Sondreal and others, 1985)

	Subbituminous Coals			Lignites	
	New Mexico	Wyoming	Montana	Texas	North Dakota
Number of Analyses	1	3	7	4	16
Averages by Element					
Sodium	82	87	90	90	94
Magnesium	31	74	82	76	88
Calcium	72	65	76	65	72
Potassium	6	37	39	42	34

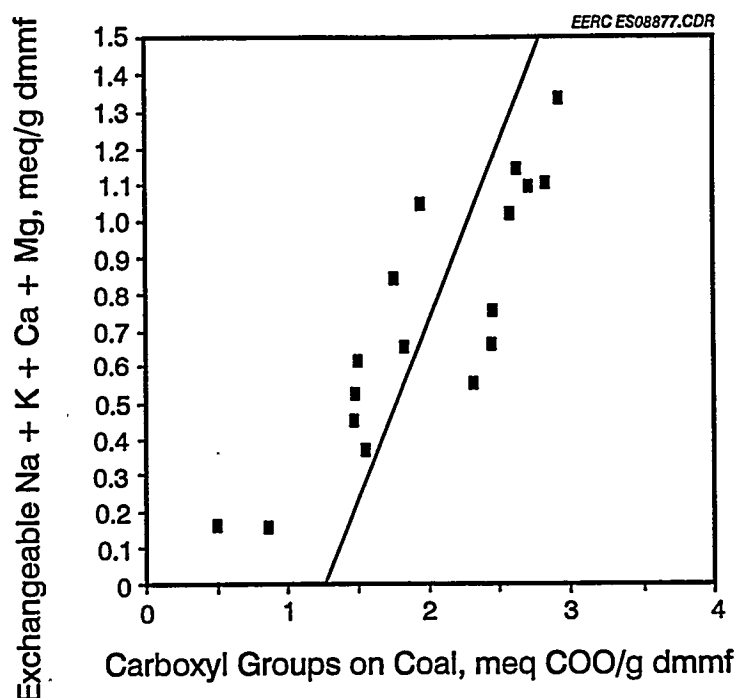


Figure 2. Correlation of exchangeable alkaline cations with carboxylate (Adapted from Sondreal and others, 1985).

THERMAL AND CHEMICAL TRANSFORMATIONS IN COMBUSTION AND GASIFICATION

Coal devolatilization and char reaction (oxidation or gasification) are governed by the chemical and structural properties of the organic portion of the coal and the catalytic activity of inorganics. The inorganic constituents in low-rank coal, consisting of organically associated cations, mineral grains included within coal particles, and excluded grains, undergo extremely complex and varied transformations depending on the composition of the coal, the reactor configuration, and the reaction conditions. Studies on ash transformations are being performed at the EERC in a pressurized drop-tube furnace capable of operating under either oxidizing or reducing conditions using carefully controlled time, temperature, and gas atmosphere conditions. The brief summary that follows identifies some of the key processes and properties affecting the behavior of inorganics in advanced power systems.

Devolatilization and Char Reactions

The principal effects of coal rank on reactions of coal organics in advanced power systems are briefly summarized based on a recent review of combustion fundamentals (Smith and others, 1993) and a literature survey on pyrolysis (Willson and others, 1988). Generalization is rendered difficult by diversity among particular coals, irrespective of rank. However, most significantly for low-rank coals, oxygen structures decompose early in the devolatilization process, generating free radicals that rapidly coalesce to form a cross-linked solid char. This early char formation, and the absence of melting to form the "metaplast" of coal liquid components produced by heating bituminous coals, causes relatively fewer tar precursors to form and evolve and accounts for the nonagglomerating behavior of low-rank coals. Tar yields obtained by indirectly heating low-rank coals are typically less than half those for hvA bituminous coal (e.g., 5%–12% vs. 20%–30%). Even lower condensable yields are obtained by either pyrolysis involving internal combustion or by fluidized-bed gasification using a bed of limestone or dolomite, wherein fractional percentage tar yields minimize downstream effects in combined cycle applications. The lower tar yields from low-rank coals are offset by higher gas yields from the decomposition of oxygen functional groups and from cracking reactions. Correlations based on Fischer assay data for bituminous coals do not, even remotely, fit the entirely different product spectrum of low-rank coals. The yield properties that distinguish low-rank coals include much higher percentages of CO₂, CO, and water in the gas; generally

higher phenolic, light aromatic (benzene), and aliphatic concentrations in the liquids; and scarcity of heavy tar. High phenolic content favors repolymerization reactions leading to char formation under certain conditions, as in catalyzed cracking. Repolymerization may be increased at elevated pressure or inhibited in a hydrogen atmosphere. Use of rapid heating to produce higher yields of lighter condensable products would be expected to be less effective for low-rank coals.

The review of char combustion processes emphasizes the effect of physical structure on pore diffusion and the relationship of intrinsic surface reactivity to molecular order and inorganic catalysis. Char morphology and pore structure develop as devolatilization and surface carbon reactions progress. Differences due to swelling in bituminous coals and early char formation in low-rank coals, as key elements in pore development, have not been adequately described. The typically microporous structure of low-rank coals is enlarged as carbon is consumed to increase diffusional access to a more open macropore structure. Large differences in intrinsic surface reactivities in the lower-temperature kinetic regime are less well understood, where low-rank coals evidence high reaction rates that can be orders of magnitude higher than bituminous coals—or equivalent rates at up to 200°C lower temperatures. Higher intrinsic reactivity is influenced by a relative lack of molecular order and the catalytic effect of organically associated cations. The positive effects of high reactivity have been widely demonstrated in using low-rank coals in processes involving lower reaction temperatures, such as in dry ash or catalytic gasification, or at short residence times, such as those experienced in direct coal-fired turbines or diesel engines.

Physical Transformations of Inorganics

Physical transformations involved in high-temperature suspension- or entrainment-type combustion and gasification systems are illustrated in Figure 3 to include 1) selective elemental vaporization and subsequent reaction/condensation to form surface coatings or homogeneous fine particulates, 2) coalescence of mineral grains within hot reactive char particles, 3) char fragmentation and partial coalescence of included minerals, 4) shedding of particles from the char surface, 5) fragmentation or fusion of liberated mineral grains, 6) convective transport of volatile species within and between char/mineral particles, and 7) formation of thin-walled ash spheres known as cenospheres. The typical result of these interactions is an ash having a bimodal size distribution, including larger particles that resemble the inorganic constituents in the parent coal and a very fine submicron fractionate resulting from condensation and fragmentation. A trimodal size distribution has been observed in some low-rank coals which have high levels of organically associated calcium that is shed from the char surface during combustion. The additional mode is in the 1- to 3- μm size range (Zygarlicke and others, 1990). Some liberated minerals with high melting temperatures, such as quartz (SiO_2), are carried through a reactor in their original angular form. However, at high temperatures, the bulk of the total inorganic content, made up of silicate and aluminosilicate particles, in dynamic association with other condensed or fused phases, will tend to form molten glassy spheres.

Different reactor configurations used in advanced power systems will cause this basic set of physical transformations to be modified somewhat as follows:

- In a dry ash fixed-bed gasifier or grate-type combustor, bed temperatures are maintained below the fusion temperature of the ash, and the bulk of the ash along with a substantial part of the coalesced vapor species are consolidated in the grate discharge.
- In a fluidized-bed gasifier or combustor (bubbling or circulating), physical transformations are again limited by bed temperature, but the fractionation and discharge of ash can be controlled by adjusting the temperature and fluid dynamic on reactor configuration. In a fixed-bed slagging reactor (e.g., the BGL gasifier), regimen to accomplish various degrees of ash agglomeration, dry ash bed drain, or fly ash carryover/separation/reinjection as may be desired.
- In very high-temperature slagging gasifiers and combustors, all of the physical transformations described are operative, but the consolidation of ash and slag depends on reactor configuration. In a fixed-bed slagging reactor (e.g., the BGL gasifier), virtually all of the inorganic reaction

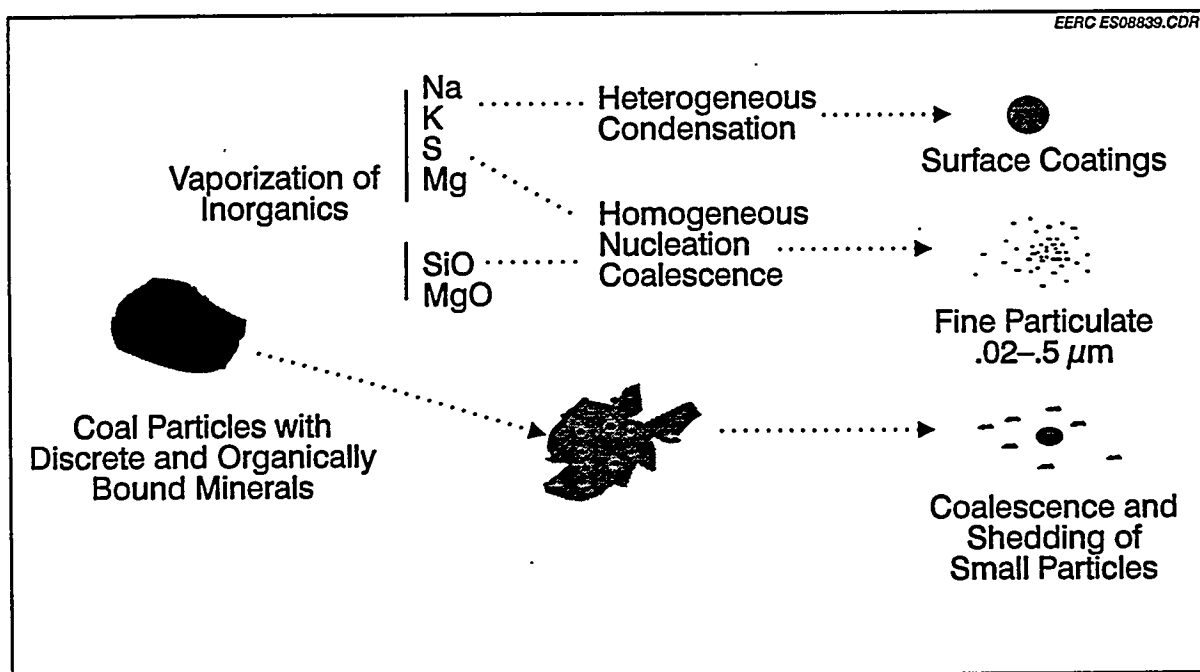
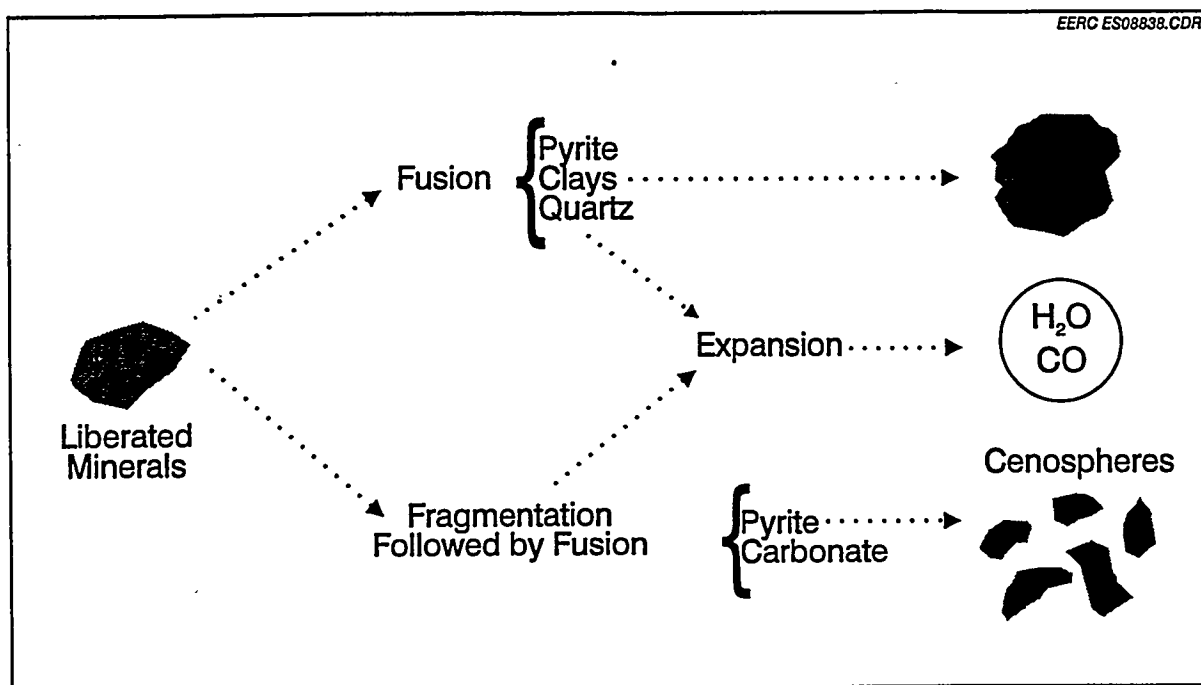


Figure 3. Schematic diagram of the transformations of inorganic constituents during coal combustion and gasification.

products are recaptured in the relatively cool descending fuel bed and consolidated into the slag discharge. In an entrained-flow reactor (e.g., Texaco, Dow, and Shell gasifiers or cyclone-type combustors), slag is partially separated by impingement or cyclonic action while a (potentially small) fraction is carried forward with the hot gas.

Ash Volatility

The extent to which different elements initially vaporize and subsequently remain in the vapor state depends on their original association in the coal, the process temperature, and the gas composition (e.g., oxidizing or reducing, water vapor concentration, HCl concentration). In general, alkaline earth elements (Ca, Mg) will tend to remain primarily in a condensed form. Silica and alumina can only be volatilized as suboxides in a reducing atmosphere, causing their vapor or submicron fume to play a very minor role in combustion systems, but possibly a significant role in gasification. The fraction of potassium originally present in illite-type clays tends to be retained in the bulk aluminosilicate ash, as evidenced by the high temperatures (up to 1350°C) required to revolatilize potassium from combustion fly ash (Sondreal and others, 1985). All available evidence indicates that the sodium in low-rank coal (along with the organically associated potassium) is substantially vaporized and subsequently distributed throughout a reactor system, primarily as a surface coating on ash particles or as discrete particles (with enrichment in finer particle-size fractions), but also as a persistent vapor under certain conditions of concern in advanced power systems.

Organically Associated Inorganics

Reactions of organically associated alkalis are initiated by the decomposition of carboxylates to form carbonates between 400° and 600°C (Stewart and others, 1982). At higher temperatures, the carbonates are believed to decompose to metal oxides that are subsequently reduced to metal vapor by carbon monoxide or char. In a quadrupole mass spectrometry profile of a laboratory pulverized lignite-air flame, vapor-phase sodium atoms appeared first, followed by vapor-phase sodium hydroxide (Greene and O'Donnell, 1987). Quenched sampling of an entrained flow combustion reactor operated on Montana lignite indicated that up to 80% of the coal sodium was vaporized and converted to a submicron fume at 1900 K (1627°C, 2961°F) (Neville and Sarofim, 1985). Up to 20% of the magnesium and a small percentage of the calcium were vaporized (Quann and Sarofim, 1986).

Thermodynamics of Alkali Behavior

The thermodynamics of alkali behavior in coal-derived gas (Scandrett and Clift, 1984) predict the saturation concentrations at 900°C (1652°F), shown in Table 5. Comparison of these concentrations indicates that alkalis present as chloride or hydroxide will occur in the vapor state, whereas sulfates will occur predominantly in the condensed phase. In a combustion environment where the presence of sulfur oxides (SO₂ and SO₃) converts alkalis to sulfates at temperatures below about 1000°C (1800° to 1900°F), the alkalis will either condense on ash or form aerosol, and their removal is primarily a problem of particulate and aerosol removal. However, in the reducing environment of a gasifier, with sulfur present as H₂S, the alkali will persist in volatile chloride, hydroxide, or sulfide forms unless removed by an aluminosilicate alkali "getter."

TABLE 5

Alkali Saturation in Coal-Derived Gas
(Scandrett and Clift, 1984)

Species	Saturation Vapor Pressure, atm	Concentration of Na or K in ppm (wt) at 10 atm
Na ₂ SO ₄	2.9 x 10 ⁻⁸	0.004
K ₂ SO ₄	2.3 x 10 ⁻⁷	0.06
NaCl	2.1 x 10 ⁻³	160
KCl	4.8 x 10 ⁻³	620
NaOH	1.4 x 10 ⁻²	1000
KOH	2.3 x 10 ⁻²	3000

Reactions of Discrete Mineral Matter

Thermal reaction products from discrete mineral matter in U.S. low-rank coals have been studied by XRD and TGA (O'Gorman and Walker, 1973; Falcone and Schobert, 1986; Falcone and others, 1984). With heating in air, clays first lose their absorbed interlayer water between 50° and 150°C. Gypsum ($\text{CaSO}_4 \cdot \text{H}_2\text{O}$) dehydrates in this same temperature range, first to bassanite ($\text{CaSO}_4 \cdot \frac{1}{2}\text{H}_2\text{O}$) and then to anhydrite (CaSO_4) at 180°C. Clay structures are further dehydrated and collapsed by loss of hydroxyl water between about 350° and 600°C, with attending substitution of cations into their structure from decomposition of carboxylates, carbonates, and sulfates. The oxidation of pyrite (FeS) to produce iron oxides occurs between 325° and 620°C.

Calcite (CaCO_3) decomposes to calcium oxide between 700° and 830°C. Quartz is stable up to 1000°C. Various glassy and amorphous phases are observed at 1300°C. The amorphous glass and liquid phases have special importance as bonding agents in high-temperature sintered deposits.

Ash Deposition Mechanisms

Ash deposition mechanisms in combustion systems have been extensively investigated by the EERC under sponsorship of industry consortia (Benson and others, 1988, 1992; Hurley and others, 1992). At the microscopic level observable by scanning electron microscope point count (SEMP) techniques developed at the EERC, ash deposits in combustion systems are shown to be caused by sodium-rich glass/liquid cementing phases and recrystallized alkaline earth aluminosilicates at temperatures above about 1900°F (1038°C) and by low melting sulfate-rich phases that bond deposits at lower temperatures. Sodium enrichment of the aluminosilicate-based amorphous phase is the foremost cause of the low liquid-phase viscosity and sintering that characterize severe fouling at higher temperatures. This type of ash deposition has been successfully modeled by a viscous-flow sintering mechanism, where the growth and strength of the deposit are directly related to the amount of the liquid phase and inversely proportional to its viscosity.

At temperatures below 1900°F (1038°C), the thermodynamic equilibrium shifts to allow sulfation of alkali and alkaline earths, leading to several modes of ash deposition when high-calcium coals are burned in pc-fired boilers. Laboratory strength tests and SEM observations indicate that calcium sulfate crystals form an interlinked lattice that imparts strength over periods of 1 to 10 days, with more rapid strength development occurring at higher temperatures up to 1850°F (1010°C), at higher ratios of total alkali to silica ($[\text{Na}_2\text{O} + \text{K}_2\text{O} + \text{MgO} + \text{CaO}]/\text{SiO}_2$), and with more uniform diffusion of SO_2 through the deposit. Deposits formed on leading edge tube banks just below 1900°F rapidly become sulfated and hard. Tubes downstream of this screening action are coated with calcium-rich enamel-like deposits that are hard upon deposition, formed from particles smaller than about 3 μm . Loose powdery deposits formed on the downstream side of tubes by ash particles smaller than 10 μm being trapped in gas eddies behind the tubes are somewhat stronger at higher gas velocities and correspondingly smaller affected-particle sizes. A Low-temperature Engineering Algorithm of DEposition Risk (LEADER) has been developed at the EERC to predict low-temperature deposition.

Coal ash deposition in a gasification environment, which is currently under investigation at the EERC under support by an industrial consortium, occurs primarily by the action of volatile sulfide species that condense and react on coal ash surfaces to form low melting eutectics. Alkali-iron sulfide eutectics are chemically stable in a gasification environment below about 750°C, but decompose or vaporize above that temperature. CaS is stable at higher temperatures up to about 900°C and may form CaS-FeS solid solutions at lower temperatures where FeS is stable. Eutectics formed from Na_2S , FeS , Na_2O , and SiO_2 are believed to be the principal cause of sintering at temperatures below 700°C. Above 750°C, sulfided silicates may be the major cause of sintering. Gas transport processes that move volatile species from higher-temperature regions to lower-temperature zones promote sintering below about 700°C. Water vapor absorbed into fused silicate glass below 720°C may also contribute to mass transport in the liquid phase by reducing the viscosity of eutectic melts (Uchins and others, 1991).

Slag and Alkali Attack on Ceramic Materials

Candidate ceramic materials used in hot particulate filters and heat exchangers are subject to corrosive attack by molten slag and alkali vapor, augmented by other agents including sulfur oxides, sulfides, chlorides, hydrogen, steam, carbon monoxide, char, and ceramics impurities. Failures of ceramic filters in short-term tests conducted to date, up to about 1000 hours, are attributed primarily to mechanical flaws in design or manufacturing; long-term reliability over a desired service life of 10,000 hours will be largely determined by stability to chemical attack. Candidate materials include both oxides, such as mullite, alumina, and cordierite, and nonoxides, such as silicon carbide and silicon nitride, in various bonded matrices. Extensive research is continuing to understand the synergistic interaction of chemical, thermal, and mechanical failure mechanisms (Alvin and others, 1981; Vass and others, 1990). The corrosive mechanisms which have special relevance to low-rank coals are those involving alkali vapors and low-viscosity basic slags.

Alkali attack on aluminosilicates such as mullite occurs by formation of low melting alkali-silica glassy phases on surfaces and in grain boundaries, involving the same types of chemical reactions as occur in ash deposition; resistance to alkali attack is increased by increasing alumina content up to about 60%. Silicon carbide and silicon nitride materials suffer alkali attack when the protective surface layer of silica resulting from passive oxidation during manufacture and later use is converted to an alkali-silica glassy phase, exposing the unprotected SiC and Si₃N₄ surface to further oxidation and alkali attack. In other contributing mechanisms, hydrogen and steam can cause silica volatilization in reduced (SiO) or oxidized (H₂SiO₄) states, and the decomposition of carbon monoxide to carbon at 400° to 700°C can lead to the chemical reduction of iron oxide impurities in ceramics, triggering iron-based catalytic disintegration reactions. These various mechanisms are strongly temperature-dependent, but all are significant at or above the 1600°F (871°C) maximum operating temperature of first-generation ceramic filters and at the 2000°–2500°F (about 1100°–1400°C) temperatures of structural or insulating refractories used in direct coal-fired turbine combustors and heat exchangers for externally fired combined cycle systems. The phase changes resulting from chemical attack together with thermal cycling lead to volume expansion, cracking, spalling, viscous creep, loss of mechanical strength, and eventual structural disintegration. Susceptibility to progressive corrosive attack can be critically influenced by the viscosity of the melts and coal-ash slags on refractory surfaces. Chemically basic slags from some low-rank coals exhibit a rapid reduction in viscosity over a relatively narrow range of temperature increase. Early tests at Oak Ridge National Laboratory on heat-exchanger ceramics at temperatures up to 2260°F (1238°C) (Ferber and Tennery, 1981) indicated that the most corrosion-resistant (silicon carbide) material survived 500 hours of exposure without degradation under a dry acidic slag, but was severely attacked by a runny basic slag. However, differences in the reported corrosion resistance of various ceramics suggest that subtle differences in the slag composition may play an important role that is unexplained by currently available data or theory.

IMPACTS OF LOW-RANK COAL PROPERTIES IN ADVANCED POWER SYSTEMS

Background on Emerging Advanced Systems

The driving forces for development of advanced coal-fired power systems are cost, efficiency, and environmental compliance. Capital costs and sulfur removal efficiencies are compared for conventional pc-fired plants with flue gas desulfurization (PC-FGD) and PFBC and IGCC systems in Figure 4, adapted from a 1990 DOE study (Notestein and others, 1990). Efficiencies for these same systems, along with an externally fired combined cycle (EFCC, Combustion 2000) and an integrated gasification/fuel cell system (IGFC), are compared in Figure 5 from a 1992 DOE report (Salvador and Mahajan, 1992). Coal fired combined cycle efficiencies are projected to evolve toward a level of approximately 50%, based principally on various means for achieving higher gas turbine temperatures with hot-gas cleanup, but also on the use of supercritical steam generators in heat recovery. Beyond the next decade, the efficiency of integrated gasification fuel cell (IGFC) systems based on advanced catalytic gasification could approach 55%–60%. Various sources place the cost and efficiency of these systems in slightly different standings, but the information presented is sufficiently correct to provide background for the assessments that follow.

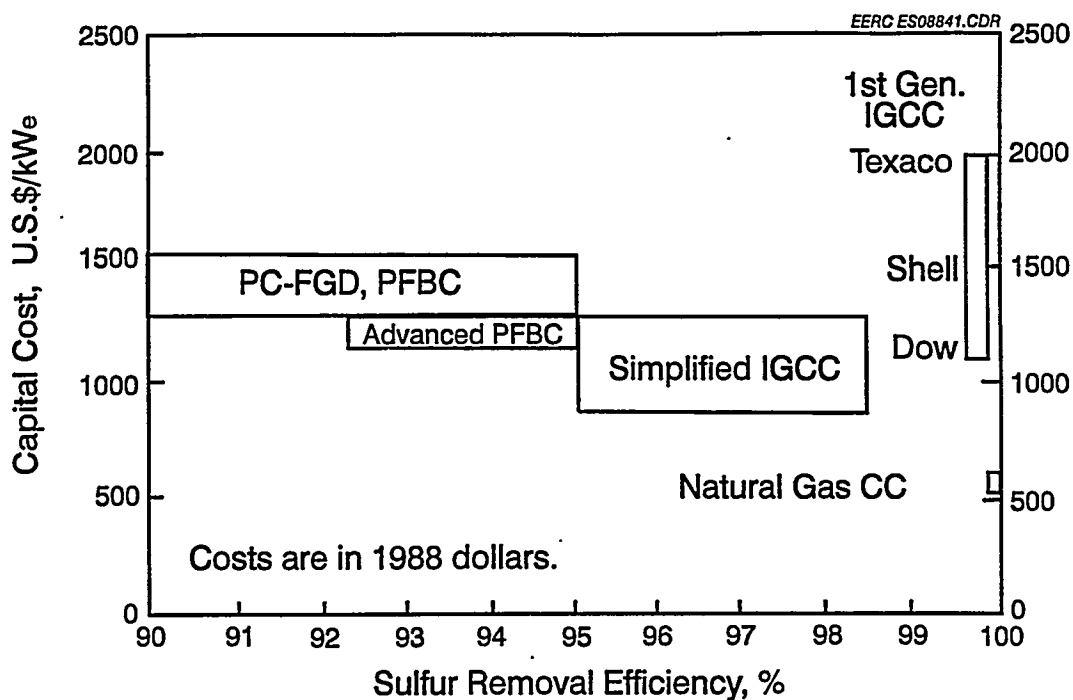


Figure 4. Capital cost versus SO₂ removal (adapted from Notestein and others, 1990).

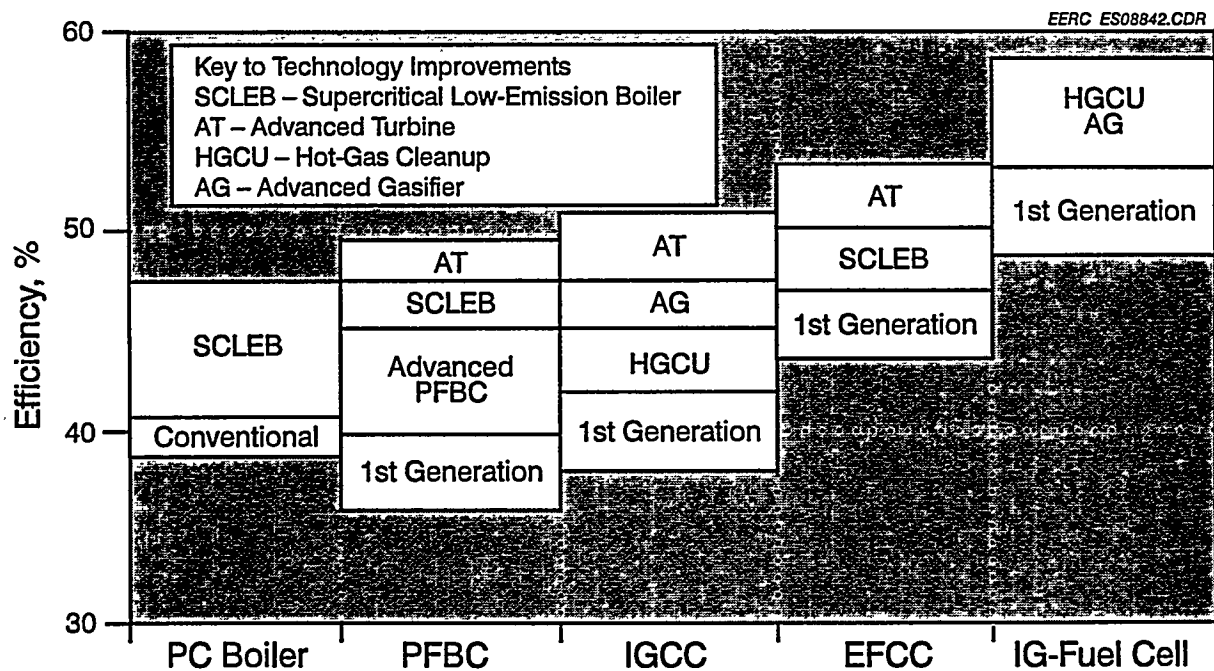


Figure 5. Projected efficiencies of coal-fired advanced power systems (adapted from Salvador and Mahajan, 1992).

These coal-based technologies face strong competition in the United States and many other countries from commercially available natural gas-fired combined cycle systems offering superior environmental performance at capital costs of US\$500-US\$600/kW and at efficiencies approaching 50%, but typically at more than double the fuel cost. One measure of the challenge faced by advanced coal-fired power systems is that their capital cost would have to be reduced to about US\$800/kW to be competitive with combined cycle units burning natural gas delivered for US\$3/MMBtu (Pitrolo and Bechtel, 1988).

First-Generation Advanced Power Systems

Advanced power systems that have used low-rank coals at or near commercial scale include ABB/CE PFBC in Spain; the Texaco, Dow, and Shell IGCC systems in the U.S.; and the HT-Winkler and Lurgi gasification systems in Germany. These first-generation systems offer efficiencies of 38%–41% at projected mature capital costs of US\$1200–US\$2000/kW. Comparable efficiencies can be achieved in advanced supercritical pc-fired boilers. Of the leading U.S. systems, only the Dow and Shell IGCC, using entrained-flow gasifiers equipped with cold-gas cleaning, offer substantial improvement in sulfur control (99+%) at projected capital costs comparable or lower than pc-firing. The system having the lowest reported cost (Dow) uses a two-stage slurry feed, which would not be expected to provide as much flexibility as the dry-feed Shell gasifier for burning high moisture lignites, although both systems are reported to be suitable for all ranks of coal. First-generation Texaco IGCC, which uses a single-stage slurry feed requiring higher oxygen and heat recovery duty, does not appear to be competitive for high-moisture coal applications. First-generation PFBC units are approximately equivalent to supercritical pc-fired boilers in cost, efficiency, and sulfur removal, but market acceptance requires improvements to offset the risk involved in using new technology.

Second-Generation Advanced Power Systems

Goals for future market-driven power systems used by DOE planners are listed in Table 6 (Notestein and others, 1990; Salvador and Mahajan, 1992). Capital costs under US\$1000/kW can be met only by highly simplified systems based on hot-gas cleanup, with minimum heat recovery and reheat duty. Combined cycle efficiencies of 45%–50% will require that pristine clean fuel or combustion gases be delivered to gas turbines operating at 1371°C (2500°F). These performance goals will have to be met under more stringent environmental requirements, including 95%–99% sulfur control achieved without gas cooling and NO_x standards as low as 0.1 lb/MMBtu (150 mg/scm). Air toxic emissions pose additional, but as yet unknown, requirements awaiting the completion of an EPA study mandated by the 1990 Clean Air Act Amendments. First-generation advanced systems cannot meet all of these requirements, and the future of coal-based advanced power generation depends, in some measure, on the success of emerging second- and third-generation systems.

TABLE 6

U.S. DOE Goals for Future Market-Driven Coal-Fired Power Systems	
Capital Cost	Under US\$1000/kW
Efficiency	45%–50%
Sulfur Control	95%–99%
NO _x Control	0.1–0.3 lb/MMBtu
Air Toxics	Meet 1990 CAAA regulations

The second-generation systems which are the principal subject of evaluation in this paper are IGCC and PFBC designs entering their demonstration phase of development. These are represented by the four PFBC and six IGCC demonstration projects listed in Table 7, which are part of the U.S. Clean Coal Technology Program (CCT Demonstration Program, 1994). Technical progress in PFBC involves moving beyond the use of high-efficiency cyclones and hardened turbines to incorporate ceramic barrier

TABLE 7

Advanced Power Projects in the U.S. Clean Coal Technology Program

Project	Primary Technology Providers	Unit Capacity, MWe	Important Features
<u>Pressurized Fluidized-Bed Combustion</u>			
Tidd	B&W	70	PFBC with high efficiency cyclones and hardened gas turbines
Appalachian Power	B&W	340	Compact scaleup of Tidd design with possible hot-gas filtration
DMEC-1	Pyropower	80	Circulating PFBC with ceramic barrier filter
Four Rivers	Foster Wheeler	95	Hybrid carbonizer/PFBC, ceramic barrier filter and topping combustor
<u>Integrated Gasification Combined Cycle</u>			
Springfield	ABB-CE	65	Air-blown entrained-flow gasifier with moving-bed hot-gas cleanup
Camden	British Gas/Lurgi	240	Oxygen-blown slagging fixed-bed gasifier with cold-gas cleanup and 2.5-MW fuel cell
Pinon Pine	Kellogg	102	Air-blown fluidized-gasifier with in-bed limestone, ceramic barrier filter, and metal oxide desulfurization
Toms Creek	TAMCO/IGT	190	Air-blown fluidized-bed gasifier with in-bed dolomite, zinc, titanate fluidized-bed hot gas desulfurization, ceramic candle filters
Tampa Electric	Texaco/GE	322	Oxygen-blown entrained-flow gasifier with parallel cold-gas cleanup and zinc-titanate fixed-bed hot-gas cleanup; advanced gas turbine with N ₂ injection for NO _x control
Wabash River	Destec	262	Oxygen-blown two-stage entrained-flow gasifier with heat exchanges for steam generation and fuel gas reheat after cold gas cleaning

filters and a topping combustor fueled on coal carbonization gas to raise the gas turbine operating temperature (Dellefield and Reed, 1992). The six IGCC demonstrations involve different combinations of air- or oxygen-blown gasification along with hot- or cold-gas cleanup for particulate and H₂S and gas turbine combustion control for NO_x. The gasifier types represented are entrained flow (Texaco, Destec, and ABB-CE), fluidized bed (Kellogg and TAMCO), and slagging fixed-bed (British Gas/Lurgi).

Process parameters for the above technologies and other designs under development are summarized in Table 8. The interactions of low-rank coal properties with all of these processes and issues are too numerous to be covered in detail, and discussion will deal only with the more important impacts in generic PFBC and IGCC systems. Coal property impacts on alkali gettering, hot particulate filtration, air toxic controls, and solid residuals management are common to all advanced systems, and these will be discussed separately.

PFBC Systems

Advances in PFBC as already stated are related to improvements in ceramic barrier filters and to the development of hybrid systems for increasing gas turbine temperatures and efficiencies. Conventional PFBC-combined cycle systems normally produce only 20%–25% of their power output from the gas turbine, which, along with low gas turbine temperature, limits efficiency and provides only a small increment of added capacity in repowering applications. Hybrid systems serve to overcome these limitations. It is of particular interest for East Central European coals that high coal moisture content may also serve to reduce these limitations in conventional PFBC, as discussed later in this report.

Hybrid PFBC systems (Figure 6) offer substantial improvement in efficiency through the use of afterburning with coal gas or natural gas to raise gas temperatures and efficiencies up to the limits imposed by the gas turbine (Dellefield and Reed, 1992). This decoupling of the gas turbine temperature allows flexibility for reducing PFBC temperatures when operating on high-alkali low-rank coals, thereby reducing the risk of both alkali vapor carryover to the turbine and agglomeration in the bed. The high reactivity of the low-rank coal would, in this case, maintain reasonable carbon burnout at the lower bed temperature. Alternatively, the bed temperature could be optimized for SO₂ removal and sorbent utilization.

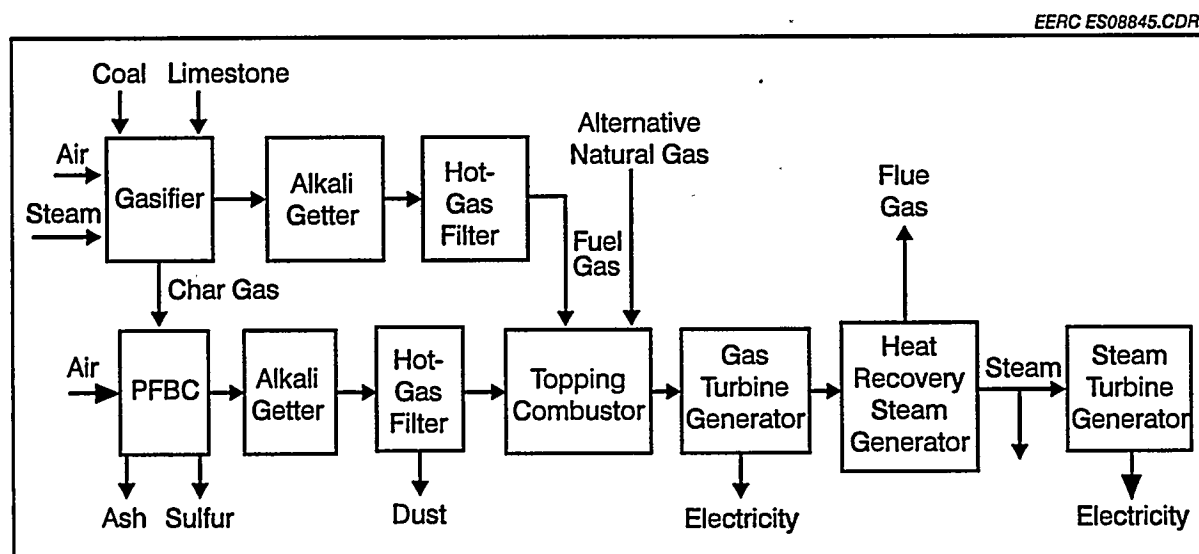


Figure 6. Hybrid PFBC combined cycle.

TABLE 8

Process Parameters for Second-Generation Advanced Power Systems*

	Combined Combustion Cycle			Gasification		
	Advanced PFBC	Direct-Fired Slagging	Externally Fired Comb. Cycle	Fixed-Bed Dry Ash	Fluidized Bed	Entrained Flow
Process Developers	Foster Wheeler Babcock & Wilcox ABB/Comb. Eng. Pyropower	AVCO/Westinghouse Solar Turbines	United Technologies Foster Wheeler Hague International	Lurgi	KRW TAMCO/IGT HT-Winkler Kellogg	Texaco (Oxygen) Dow (Oxygen) Shell (Oxygen) CE (Air)
Coal Conversion Conditions	10-20 800-900 800-900 Oxidizing	10-20 1500-1600 1000-1350 Reducing/oxidizing	1-20 1500-1600 1200-1400 Oxidizing	10-20 1100-1300 250-300 Reducing	10-20 800-900 800-900 Reducing	10-20 1300-1700 1000-1400 Reducing
Key Technical Issues	Bed agglomeration SO ₂ removal eff. Sorbent utilization Sulfide oxidation Alkali gettering Barrier filters NO _x control	Slag removal eff. Sulfur control method Alkali gettering Barrier filters Materials corrosion NO _x control	Slag control Ceramic ex. design Materials corrosion NO _x control	Coal fines High steam req. Tar separation Low offgas temp. Hot-gas cleanup High NH ₃ NO _x control	Carbon conv. Char recycle In-bed sul. cont. Alkali gettering Barrier filters	Coal feeding Air operation High offgas temp. Heat recovery Oxygen demand Alkali gettering Hot-gas cleanup
Priority Gas Contaminants In Hot-Gas Cleanup Tar Cracking Ceramic Barrier Filters Mixed Metal Oxide Desulfurization	Particulates Alkalies	Particulates Alkalies H ₂ S/SO ₂		Coal dust Tar H ₂ S	Char Tar H ₂ S Particulates Alkalies Chloride	H ₂ S Particulates Alkalies Chloride Trace elements
Auxiliary Emission Controls	CC or SCR In-bed limestone	CC or SCR Sorbent injection	CC or SCR Scrubber ESP or baghouse	TCC or SCR	TCC or SCR In-bed limestone	TCC or SCR
NO _x Sulfur Particulate Air Toxics	Char filter	Char filter	Char filter		Char filter	Char filter

* PFBC Pressurized fluidized-bed combustion.

IGCC Integrated gasification combined cycle.

IGFC Integrated gasification and fuel cells.

CC Combustion controls for NO_x reduction.TCC Turbine combustion control for NO_x reduction.SCR Selective catalytic reduction for NO_x control.

In a hybrid PFBC system, sulfur control in the fluidized-bed gasifier supplying fuel gas for afterburning is provided by adding limestone or dolomite to capture H_2S as calcium sulfide (CaS). Achieving high levels of sulfur capture (e.g., 90%) in the gasifier requires operation at temperatures above $900^\circ C$ to calcine $CaCO_3$ to CaO (Pitrolo and Bechtel, 1988). The reaction of calcined limestone/dolomite is rapid, and H_2S removals approach equilibrium (Abbasian and Rehmat, 1990). However, high gasification temperatures intensify concern over alkali release and bed agglomeration when high-alkali low-rank coals are used. Also, conversion of CaS to $CaSO_4$ in the PFBC, which is necessary for safe waste disposal, does not go to completion, and some of the oxidized sulfur is released as SO_2 in the offgas (Pham and Lawson, 1990).

IGCC Systems

Simplified IGCC systems designed to minimize capital cost, as depicted in Figure 7, consist of a gasifier, a hot-gas cleanup module, and the gas turbine/steam turbine power system.

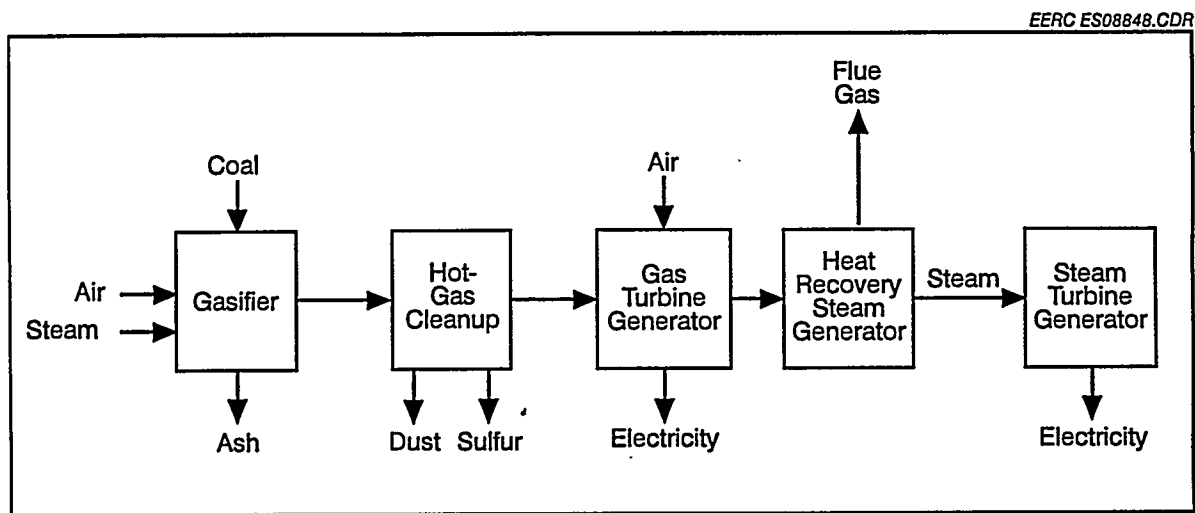


Figure 7. Simplified IGCC.

System configuration would be predicated on the type of gasifier used, which ideally would be air-blown and match the temperature requirement of the hot-gas cleanup module. Exit gas temperatures shown in Table 8 vary from as high as $1400^\circ C$ in the Texaco entrained-flow gasifier down to $250^\circ C$ in a dry ash fixed-bed gasifier operating on high-moisture lignite. IGCC can be an attractive repowering technology in some circumstances owing to the relatively larger amount of power generated in the gas turbine when compared to a PFBC combined cycle, thereby facilitating a larger capacity gain by repowering an existing steam turbine.

Commercial entrained-flow gasifiers offered by Texaco, Dow, and Shell are oxygen-blown and, therefore, not ideal for a highly simplified system. The planned CE air-blown entrained-flow gasifier to be used in the Springfield Project under the Clean Coal Technology Program is a two-stage gasification process that combines a tangentially fired slagging combustion section, operating on pulverized coal and recycle char, and an entrained-flow gasification section operating on pulverized coal only, with both sections incorporated into a waterwall steam generator design (Thibeault and others, 1992). Despite the cooling provided by the waterwall, the CE design is expected to have a somewhat costly gas cooling requirement ahead of the hot-sulfur cleanup module. Demonstrations of advanced IGCC systems based

on an entrained-flow gasifier with cold-gas cleanup include Tampa Electric (Texaco), Wabash River (Destec), and Buggenum in the Netherlands (Shell).

The advantages of a fluidized-bed gasifier design are its capability for incorporating in-bed sulfur capture using limestone and its reduced gas cooling requirements. A 90% sulfur removal potential is achievable at temperatures above 900°C where the limestone is substantially calcined. The use of precalcined limestone may reduce this temperature, but confirming data are needed. At best, in-bed sulfur control does not match the 99% removal capability of mixed metal oxide sorbents such as zinc ferrite or zinc titanate. Also, in-bed sulfur removal adds complexity by requiring a PFBC or other combustion unit to convert unstable calcium sulfide waste produced in the gasifier into calcium sulfate that is suitable for disposal, as well as to make use of unburned carbon in gasifier char. Operation of the gasifier above 900°C on high-alkali coals also raises concern over bed agglomeration and increased need for alkali gettering to reduce alkali vapor carryover into the gas turbine. High carbon conversions and low char recycle rates can be achieved at temperatures lower than 900°C when reactive low-rank coals are used, provided that a lower level of in-bed sulfur capture is acceptable. Demonstration of IGCC based on fluidized-bed gasifiers include Pinon Pine (Kellogg) and Toms Creek (TAMCO/IGT) in the U.S. and Kobra (High-Temperature Winkler) in Germany.

The creative use of fixed-bed gasifiers in minimum-cost IGCC systems was evaluated in a DOE study report (Notestein and others, 1990), which predicted process capital costs as low as US\$500/kW and a total capital requirement of about US\$700/kW for nth plant installation, presenting an optimistic prospect for halving the lowest costs reported for first-generation advanced power systems. The favored system in this study was configured to include 1) a dry ash fixed-bed gasifier operating on air pressurized to 150% of the gas turbine compressor discharge pressure; 2) a combined function fluidized bed for hot-gas cleanup, using zinc titanate for sulfur control and a zeolite catalyst for tar cracking; 3) a limestone PFBC consuming minimum fuel to serve both as a waste fuel burner and sulfur fixation reactor; and 4) a gas turbine/steam turbine combined cycle power system. The gas turbine would provide air to both the gasifier and the PFBC units and would accept hot flue gas from the PFBC. For low-moisture or predried feed coals, the exit gas temperature from a dry ash fixed-bed gasifier approximately matches the nominal 1000°F operating temperature of the sulfur control module. The most critical design aspects of the fixed-bed system are concerned with desulfurization and tar cracking, which are proposed to be combined in a single fluidized-bed absorber, with regeneration in either another fluidized bed or a riser-tube reactor. Replacement of the PFBC with a sulfur recovery process would not substantially increase the estimated plant cost, but it eliminates the capability for directly utilizing waste fuels, including coal fines.

The use of low-rank coals in minimum-cost fixed-bed IGCC systems appears to be an opportunity which deserves consideration in East Central Europe. Ten years of experience with oxygen-blown Lurgi gasifiers at the Dakota Gasification Great Plains Plant in the U.S. has demonstrated their suitability for U.S. lignites. Principal advantages of this technology match include 1) the noncaking property of the coal, allowing free flow through the reactor; 2) high throughput with essentially complete carbon conversion; 3) low gasifier exit temperatures that eliminate concern over alkali carryover to the turbine; and 4) inherently high heat recovery achieved through in-process use of steam generated in the jacketed gasifier shell. Technical issues related to the use of dry ash fixed-bed gasifiers include their limited ability to use friable coals or coal fines; tar separation and recycle; high ammonia yields that affect turbine NO_x emissions; and the need to tailor gas cleanup to the low gasifier exit temperature.

Some of the limitations of dry ash fixed-bed gasification are remedied in the British Gas/Lurgi (BGL) slagging fixed-bed gasifier. This design has not been advocated for use with low-rank coals, even though extensive tests showed that the method was applicable to North Dakota lignites. Tests at the EERC on a 25-tpd oxygen-blown slagging gasifier operated on high-moisture lignite yielded 250 Btu/scf gas at 350°F (Willson and others, 1981), which when corrected for the substitution of 1000°F air for oxygen is calculated to give 170 Btu/scf gas at about 600°F. The BGL gasifier has repeatedly been tested in an air-blown mode operating on a 1000°F air blast, reportedly producing 120–130 Btu/scf gas at an exit temperature higher than in a dry ash design (Notestein and others, 1990). The advantages of the BGL gasifier include the capability for using coal fines by injection into the high-temperature (3000°F) reaction zone, a fourfold reduction in steam consumption that improves system efficiency both at the gasifier and at the plant stack (by reducing the substantial energy loss due to water vapor leaving the stack), generation of a vitrified slag that is environmentally benign, and a lower yield of ammonia (NH₃). Handling

of tar in the product gas is an issue shared by dry/ash Lurgi gasifiers, whereas reliably maintaining slag flow is a problem unique to the slagging design. Demonstration of IGCC based on the BGL gasifier is planned for the Camden CCT Project in the United States using bituminous coal.

Hot Filtration of Particulates

High-efficiency cyclones can remove particulates down to 5–10 μm , but further reduction down to smaller particle sizes will require the use of either a barrier filter, a granular bed, an ESP, or a fabric filter. Fabric filters widely used at lower temperatures require substantial materials development before they can be applied in advanced power systems. Materials that can withstand significantly higher temperatures have been tested at atmospheric pressure and at temperatures up to about 800°F (Weber and others, 1990). The use of electrostatic precipitators is limited by sparkover and problems with maintenance of electrical insulation at high temperatures. Granular beds may be applicable where particulates need to be removed along with alkalis. Ceramic barrier filters are currently the preferred choice for augmenting high-efficiency cyclones. Ceramic candle filters supplied by Westinghouse are being tested at commercial scale on a slipstream at the Tidd PFBC plant, and various types of ceramic barrier filters will be included in the IGCC plants being designed under the CCT program. The filtering capabilities of pulse-cleaned candle filters have been proved at outlet dust loadings of 3 to 19 ppm, but surface blockage by fine ash particles remains a problem, and service life has not been demonstrated beyond about 1300 hours. Ceramic cross-flow filters, which offer higher filtration efficiency at lower pressure drop, are at an earlier stage of development and require improvements addressing delamination, long-term pressure drop, and service life. Certain low-rank coals that contain inorganic constituents primarily in organically associated form, which produce an extremely fine cohesive fly ash, will require special attention in designing hot-gas filtration systems.

Coal property impacts on ceramic barrier filters and other ceramic components such as refractories or heat exchangers are related to the presence of alkalis, chlorides, and iron and to slag fusion and viscosity behavior (Table 9). At lower temperature, starting at about 800°C, alkalis and chlorides accelerate corrosive reactions including oxidation of silicon carbide and silicon nitride and also promote the adhesion and caking of ash particle causing filter blinding. At low to intermediate temperature in a reducing atmosphere, silicate refractories can be reduced to volatile SiO. At temperatures involved with the onset of ash fusion (e.g., 1100°C), a fraction of the ash is converted to a liquid phase that can potentially cause corrosive pitting. At higher temperature, the corrosion and deposition properties of liquid slags depend importantly on slag viscosity, where low viscosity promotes ion mobility and corrosive attack.

TABLE 9

Coal Property Impacts on Ceramic Refractories, Filters, and Heat Exchangers

Temperatures	Low	Intermediate	High
	800°C (1500°F)	1100°C (2000°F)	1400°C (2500°F)
Properties	Alkali Chloride	Phase variability	Iron Slag viscosity
Effects	Ash adhesion Alkali/Cl corrosion Alkali-accelerated oxidation of SiC and SiN Partial reduction to volatile SiO	Slag pitting	Ion mobility Slag deposition Slag corrosion

Alkali-Gettering Technology

Alkalies, as previously noted, occur primarily as fine sulfate particulates (aerosols) or surface coatings in combustion systems below about 1900°F, but as volatile chloride, hydroxide, or sulfide species under reducing conditions in gasification systems. This suggests that alkali "gettering" will be more important in gasification than combustion, although alkali removal is important in both. Alkalies form stable silicates under both reducing and oxidizing conditions, which serve as the basis for alkali "gettering," but also lead to corrosion and deposition problems. Currently, no fully proven method for removing corrosive alkalies and chlorides from hot fuel or flue gases has been demonstrated, making this the key issue to be resolved in using high-alkali, high-chloride low-rank coals in advanced power systems.

Recent reviews on alkali gettering (Shadman and others, 1992; McLaughlin, 1990) indicate that alkali removals up to 99%, as required to meet gas turbine specifications, are possible using suitable aluminosilicate sorbents. Bauxite has proven effective, based on partially reversible physical adsorption, and also kaolinite and emathlite, based on irreversible chemical fixation. The product of alkali absorption on emathlite (albite) has a melting temperature of 1832°F; the favored high-temperature product formed on kaolinite, nephelite, melts at 2840°F; and bauxite melts at the highest temperature of 3600°F. Design data addressing removal kinetics and capacity are limited. Capacities in the range of 5% to 18% have been reported. For chemical fixation, alkali diffusion through a surface product is believed to be rate-limiting, based on the "shrinking core" behavior observed by depth profile SEM analysis on sorbent particles. Overall removal efficiencies have been shown to be increased at higher inlet alkali concentrations, at increased sorbent/alkali ratios, and with reduced sorbent particle size. Good removal performance as indicated by outlet alkali concentrations below 20 ppbw has been demonstrated in combustion tests at Argonne National Laboratory, New York University, and Westinghouse. In gasification, the direct reaction of alkali vapors with aluminosilicates has been suggested to be even more effective than alkali sulfate particulate removal from combustion gas, although HCl produced in the gasification of high-chlorine coal has been reported to seriously reduce the rate of alkali uptake (McLaughlin, 1990). Furthermore, the difficulties involved in accurately measuring very low alkali concentrations introduce some uncertainty. Sorbent agglomeration resulting from alkali adsorption remains a serious design and operating issue that must be addressed in selecting suitable sorbents and configuring reliable removal systems.

Fuel Gas Desulfurization

Leading processes for removing H₂S and other "acid gases" from fuel gases are categorized in Table 10 (Simbeck and others, 1993). Commercially available cold gas processes being considered for coal gasification application require cooling the gas to temperatures ranging from lower than -50°C to about 50°C. These processes have capabilities for reducing H₂S to low levels in the range of 1 to 50 ppm and may also remove components such as ammonia, hydrogen cyanide, chlorides, organics, and volatile metals (e.g., alkalies). The extensive heat exchanger capacity required to cool the gas and recover heat for gas reheat and steam generation adds significantly to capital cost and reduces system efficiency. Coal properties would be expected to have minimal impact on cold processes other than the added capacity required for high-sulfur coal.

Hot gas processes for removing H₂S are still under development. Use of in-bed limestone or dolomite, as already covered in discussing fluidized-bed gasifiers, has the potential for removing 80% to 95% of the H₂S at about 870°C (1600°F). The primary waste product from limestone addition is calcium sulfide, which must be oxidized to calcium sulfate for safe disposal. Regenerable mixed metal oxide systems (Cicero, 1994) operate well only below 540°C (1000°F), but can reduce H₂S to levels as low as 10 ppm. Metal oxides can either be used alone or as a secondary polishing step after in-bed limestone-based desulfurization. Metal oxide sorbents experience some deactivation and attrition in use and regeneration depending on their formulation and the design of the contacting reactor, which may be either a fixed-bed or fluidized-bed design. Regeneration with steam and air yields a concentrated stream of SO₂ which can be converted to elemental sulfur or sulfuric acid. Neither in-bed limestone or metal oxides provide significant removal of ammonia, chloride, or other trace contaminants. Coal chlorides can react with metal oxides to accelerate degradation. High usage of limestone or metal oxide could be a significant cost factor for high-sulfur coals.

TABLE 10

Fuel Gas Desulfurization

	Cold to High Ambient	Hot	
Method	Solvents and chemical reagents	Mixed metal oxides	In-bed sorbents
		ZnO-Fe ₂ O ₃ ZnO-TiO ₂ Zn-SORP® METC2/6	Limestone Dolomite
Temperature	<-50°C to 50°C (-60°F to 120°F)	540°C (1000°F)	870°C (1600°F)
Sulfur Removal	98% to 99.8%	99+%	80%-95%
Common Processes	Rectisol - Linde Selexol - Union Carbide Purisol - Lurgi MDEA - Dow Sulfinol - Shell	GE EnviroPower ABB-CE METC	TAMCO Kellogg
Problems	Extensive heat exchange	Sorbent stability Attrition Deactivation Regenerability Limited removal of NH ₃ , HCN, Cl ⁻ , and volatile alkalis	Lower H ₂ S removal Calcination of CaS
Coal Property Impacts	Minimal	Chloride degradation	Excessive waste at high sulfur levels

Solid Residuals – Reuse or Disposal

New technologies have no future if their residuals cannot be managed to present an acceptable level of risk to the public. New processes pose undefined requirements for reuse or disposal, where the most desirable option is to convert a disposal expense into residual value. Alternative management strategies involve a combination of source reduction and disposal. Fly ash currently accounts for almost all residuals utilization, including applications in road base stabilization; cement admixture; grouting around pipes, culverts, and oil well casings; and soil or waste stabilization. Potential new applications include a variety of manufactured structural products. Residuals from U.S. low-rank coals in the Fort Union Region have been extensively characterized at the EERC in studies on fly ash, bottom ash, slag, FGD waste, and gasifier ash (Pflughoeft-Hassett and others, 1992 [includes a compendium of key references]). In the United States, ASTM protocols are adequate for physically characterizing the engineering properties of traditional ash reuse materials, but more complete chemical and physical analyses are needed for new by-product materials. Environmental assessment includes leaching tests under conditions approximating the chemistry of the disposal setting. When leachates are generated, natural pH buffering and attenuation have been shown to provide protection against groundwater contamination in some disposal settings. Arsenic and selenium are effectively attenuated by pH buffering in clayey soils; other priority elements that are attenuated include lead and cadmium precipitated as carbonates and barium as sulfate. Molybdenum, which is not currently addressed by U.S. regulations, along with sodium and sulfate, remain mobile. Water flow through the disposal setting provides a transport and reaction medium, therefore favoring disposal that is above the groundwater table and protected from hydraulic recharge. Leachate mobility is of primary concern in a saturated setting. The

residual itself can contribute to good disposal design, where, for example, permeability is reduced by the cementitious properties of ash or FGD waste. The starting point in managing a new type of residual from low-rank coal-fired power systems is to be able to predict, in advance, what its behavior will be in reuse or disposal settings, based on a fundamental scientific understanding of the material, the setting, and their interactions.

COMPUTED EFFECTS OF EAST CENTRAL EUROPEAN COAL PROPERTIES

The EERC is currently participating in preliminary studies to evaluate the applicability of U.S. clean coal technologies for retrofitting and repowering coal-fired boilers in the Czech Republic, Poland, and Bulgaria. As a part of that study, material and energy balance calculations have been performed by the EERC to determine the sensitivity of PFBC and gasifier performance to changes in coal moisture, ash, and sulfur contents. These calculations are for generic designs, such as fluidized-bed gasifiers as a class, and they should not be interpreted to represent particular vendor technologies. Some of the conditions calculated may be outside of the range of feasible or economic operation. In the course of the overall study program, the computed results will be compared with information obtained from vendors to determine the limits of applicability of various technologies. The selected calculations presented here represent an interim assessment that will need to be confirmed both in the current study and in future design activities focused on particular coal reserves.

Effects of coal moisture, ash, and sulfur were calculated for both PFBC and several gasifiers, including fixed-bed, fluidized-bed, and entrained-flow designs. All calculations except those for the fixed-bed gasifier were made by varying the coal analysis in reference to a baseline case analysis containing 57% moisture, 35% ash db, and 5.9% sulfur maf. The fixed-bed cases run were computed in reference to the design coal analysis for the Dakota Gasification Great Plains Gasification Plant using North Dakota lignite containing 34.3% moisture, 9.5% ash, and 1.3% sulfur. Base case gasifier operating conditions and product gas compositions were adapted from literature sources (Simbeck and others, 1993; Miller and Lang, 1985) and EERC equilibrium calculations, and these base conditions were subsequently adjusted for changes in coal analysis to satisfy the energy, total mass, and elemental balances. Hydrogen, carbon, oxygen, nitrogen, sulfur, and ash were balanced in all calculations along with calcium sorbent and waste products in the case of PFBC. Operating conditions for PFBC were adapted from the TIDD Clean Coal Technology project (Hafer and others, 1993), using a gas turbine inlet of 860°C (1580°F) and steam conditions of 538°C (1000°F) and 175 psia (11.9 atm).

The Effect of High Coal Moisture, Ash, and Sulfur in a PFBC

In Figure 8, the calculated effect of increasing coal moisture over a range from 5% to 64% (including pasting water for slurry feed where indicated) was to increase the percentage of system power generated by the gas turbine from 27% to 59%, reducing in-bed heat transfer from 62% to 21% of coal LHV, and lowering total steam generation both in the PFBC and HRSG from 75% to 38% of coal LHV. Generating efficiency (LHV) drops from 38.7% at 5% moisture to 34.5% at 64%, indicating that higher stack losses due to excess moisture partially compensated by the beneficial shift in energy flow to the gas turbine. At high coal moisture, the generating efficiency based on gas turbine power alone approaches 20% while still providing 38% of the coal LHV as steam that can be used for heat or process applications. This result suggests that the use of high moisture coal in a PFBC system operating with a gas turbine alone (no steam turbine) could be a low capital cost approach for Industrial Power Plants (IPP) or Combined Heat and Power (CHP) projects.

Heat loss in the PFBC bed drain increases nearly linearly with coal ash content to about 2.2% of coal LHV at 45% db ash content. Bed drain loss was only slightly affected by coal sulfur content owing to the nearly neutral enthalpy balance for limestone addition under conditions of a high partial pressure of CO₂, where the unreacted reagent remains in the form of calcium carbonate rather than calcium oxide. In a PFBC, nearly full benefit is obtained from the heating value in coal sulfur, whereas in IGCC, where hydrogen sulfide is removed, most of this heating value is either lost or recovered as low-grade heat. These calculations support the use of PFBC for East Central European coal, even at extremely high levels of moisture, ash, and sulfur contents. The practicability of operating at these extreme concentration levels

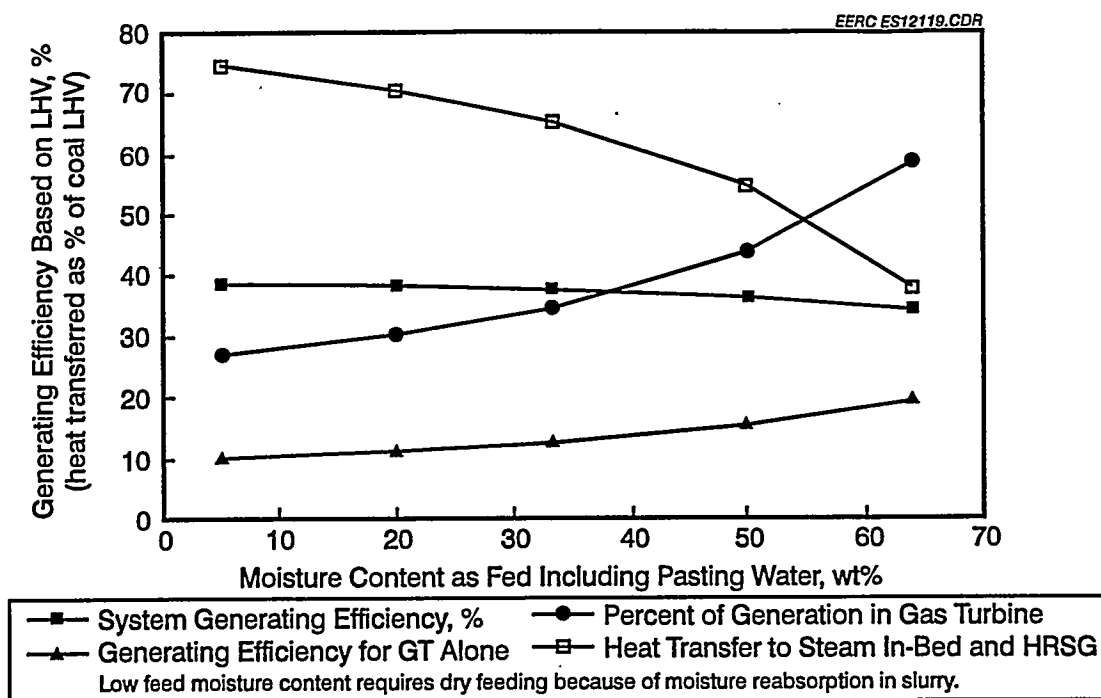


Figure 8. Effect of coal moisture on PFBC performance.

needs to be evaluated by vendors of PFBC systems. Also turndown capabilities will need to be evaluated in reference to the extreme property conditions discussed here.

SO₂ Removals Required to Meet East Central European Emission Standards

SO₂ removals required to meet applicable emission standards for large new power plants are shown in Figure 9. At the more stringent 400 mg/scm level applying in the Czech Republic and Hungary, SO₂ removals are required to range from 83% to 97% for between 1% and 6% daf coal sulfur. For the 650 mg/scm standard applying in Bulgaria, removals range from 72% to 95% over this same range of coal sulfur. Requirements in Poland fall between these sets of values.

Impact of High Coal Moisture, Ash, and Sulfur on IGCC

The limits of applicability for IGCC technology to East Central European coals are determined primarily in the gasifier. Criteria that determine the applicability of different types of gasifiers may variously concern 1) achieving a minimum calorific value in the gas of approximately 100 Btu/scf, 2) minimizing oxygen demand to limit the cost of the oxygen plant, and 3) maintaining operable temperature levels in the gasifier or in the exiting gas.

Moisture

In a dry feed oxygen-blown entrained-flow gasifier, calculations on the effect of coal moisture (Figure 10) indicate that the lower heating value (LHV) of the raw product gas without H₂S is reduced below 100 Btu/scf at moisture levels above 45%. Oxygen demand is increased by about 50%, from 0.43 to 0.66 moles O₂/mole C, for between 0% and 45% coal moisture. Since it is expected to be more economical to dry coal using low-grade heat outside of the gasifier than to supply additional oxygen, the economic limit on coal moisture may be closer to 10%.

In an oxygen-blown fluidized-bed gasifier, the sensitivity to coal moisture content (Figure 11) is slightly reduced compared to the entrained-flow case, and the gas LHV is reduced below 100 Btu/scf at

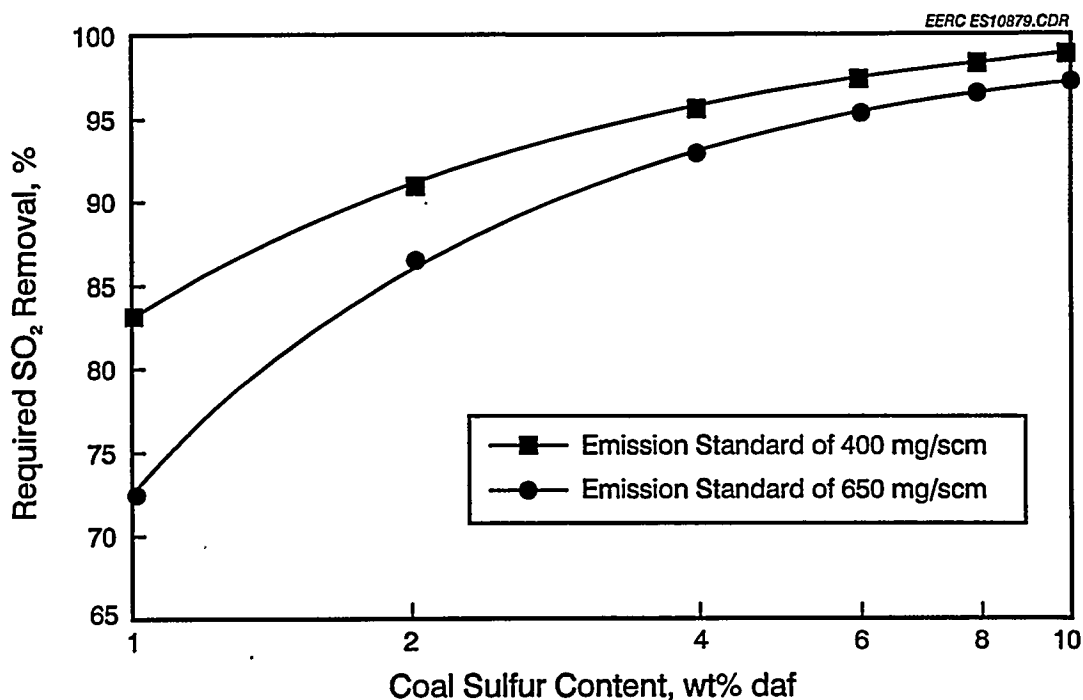


Figure 9. SO₂ removals meeting East Central European standards for new plants.

coal moisture contents above 50%. Oxygen demand, which is lower overall than for the entrained-flow case, is increased from 0.32 to 0.36 between 0% and 20% coal moisture, which may represent the economic limit for this technology. The steam requirement of the gasifier is theoretically reduced to zero

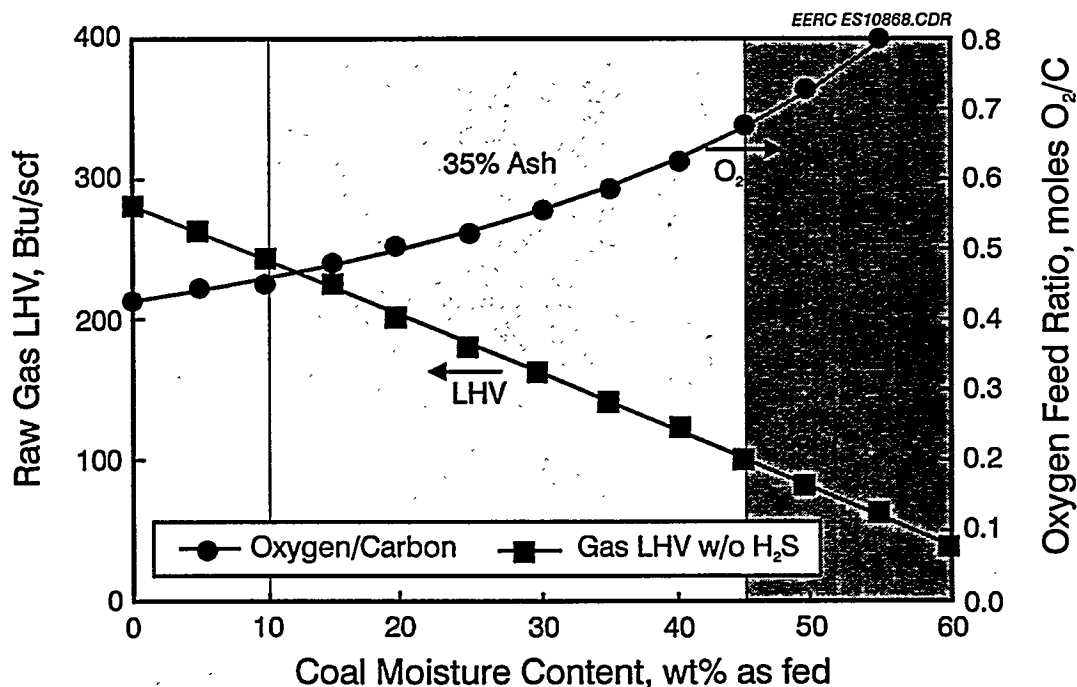


Figure 10. Effect of coal moisture in an oxygen-blown entrained-flow gasifier (dry feed gasifier with exit temperature at 1371°C [2500°F]).

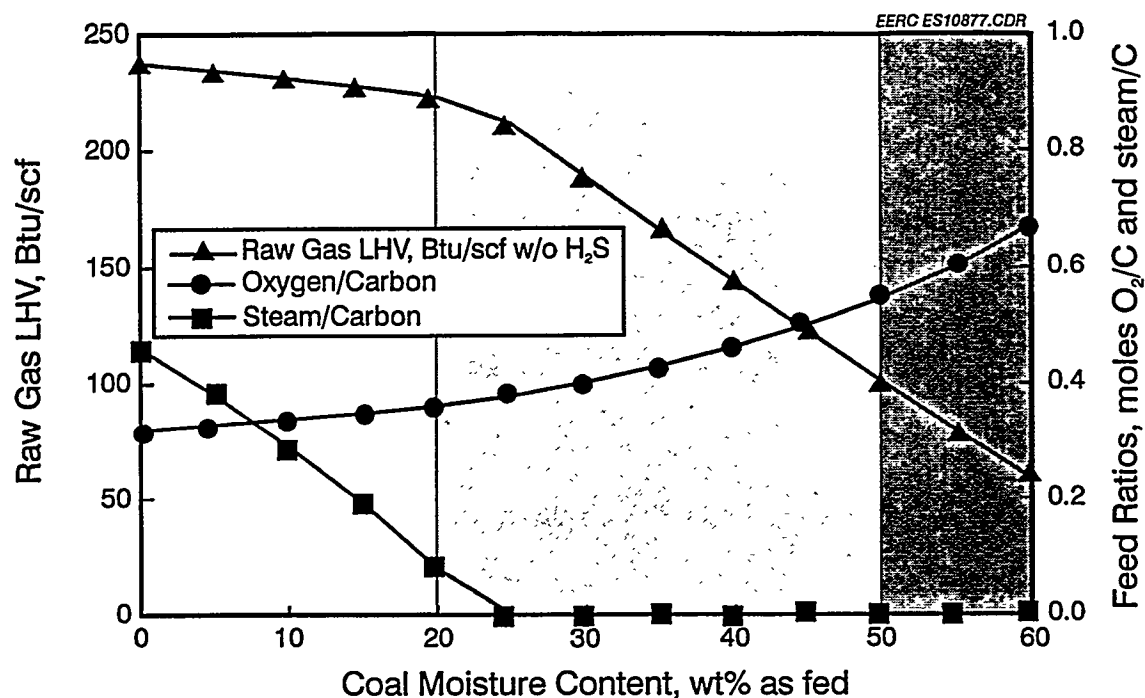


Figure 11. Computed effect of coal moisture in an oxygen-blown fluidized-bed gasifier (gasifier temperature is constant at 927°C [1700°F]).

at 25% coal moisture. In an air-blown fluidized-bed gasifier (Figure 12), coal moisture is limited to 20% by the minimum acceptable gas LHV.

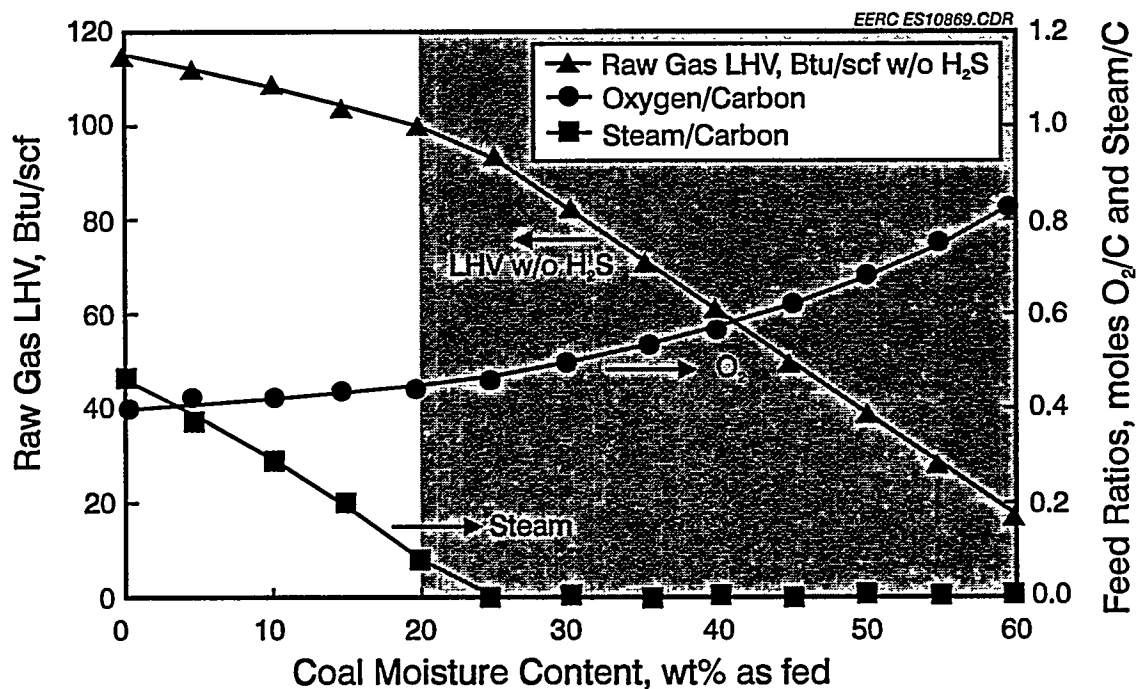


Figure 12. Computed effect of coal moisture in an air-blown fluidized-bed gasifier (gasifier temperature is constant at 927°C [1700°F]).

The limiting effect of coal moisture in a dry ash fixed-bed gasifier is determined by its influence on the exit gas temperature (Figure 13). The calculation indicates that this temperature drops below 200°C at approximately 39% coal moisture, which is estimated to be a practical limit below which condensation problems would hinder operation. The Dakota Gasification Great Plains Plant was designed for 34% moisture coal, and it likely experiences operating excursions to levels between 34% and 39%. Over the entire range of calculation for coal moisture, oxygen and steam requirements remain fixed and the gas heating value is reduced only by the diluting effect of the moisture in the raw product gas. This stability suggests that a fixed-bed gasifier may be more forgiving of variations in coal quality and less sensitive to turndown operation.

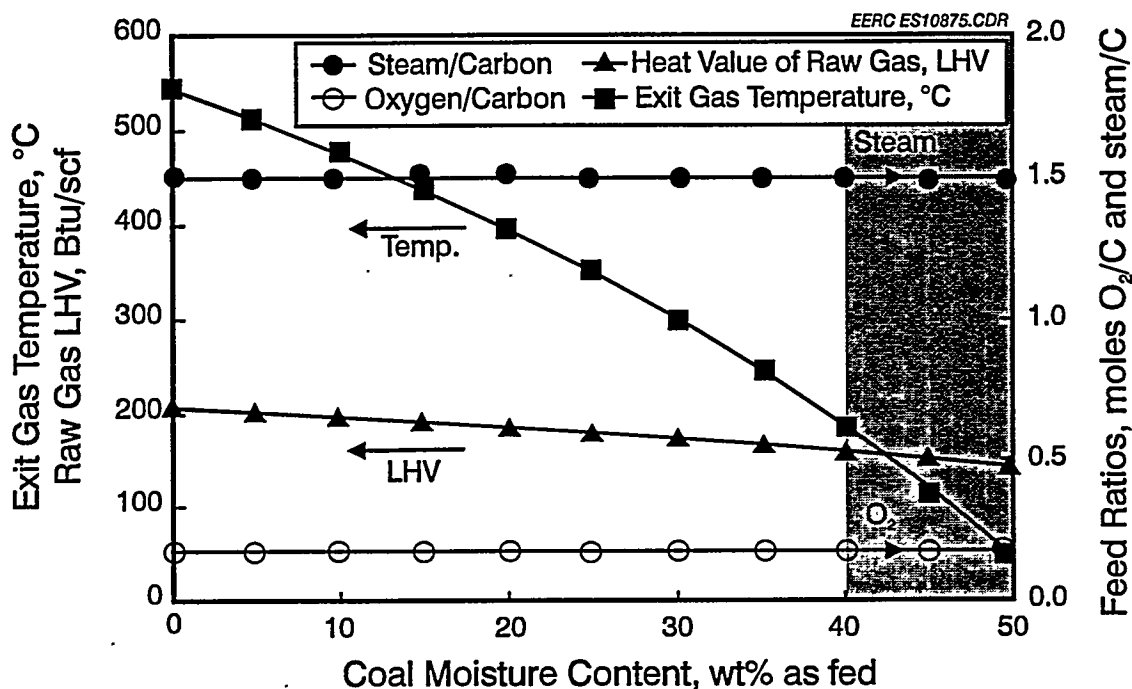


Figure 13. Computed effect of coal moisture content in a dry ash fixed-bed gasifier (calculated in reference to data from GPGP gasification of ND lignite).

Ash

Sensitivity to coal ash content based on heat loss in ash alone is somewhat less critical than that for coal moisture. In Figure 14, the heat loss in ash or slag at 40% ash content is calculated to be 1.1%, 2.3%, and 3.2% for fixed-bed, fluidized-bed, and entrained-flow gasifiers, respectively, reflecting differences in ash/slag discharge temperatures. However, the overall impact of ash content also depends on the associated moisture content, as shown in Figure 15, for entrained-flow gasification. At 57% coal moisture, the gas heating value is reduced from 102 Btu/scf to 43 Btu/scf over the range of 0% to 40% ash, while the oxygen requirement is increased by 31%. Much of this adverse impact of ash at high moisture levels can be attributed to the moisture associated with the added ash, as can be visualized by considering the gasification of fixed amounts of coal carbon and ash along with similar percentages of moisture accompanying both. By comparison, the effect of ash at 0% moisture is slight; the gas heating value is reduced from 291 to 279 Btu/scf and oxygen demand increased by only 7% over the range of 0% to 40% ash.

A far more serious impact of high ash content may be experienced in a fluidized-bed gasifier if the gasification carbon loss increases along with ash content, as reported by Gavor and others (1992). Based on reported experimental data for five Czech coals, the percentage of unburned carbon in the ash solids

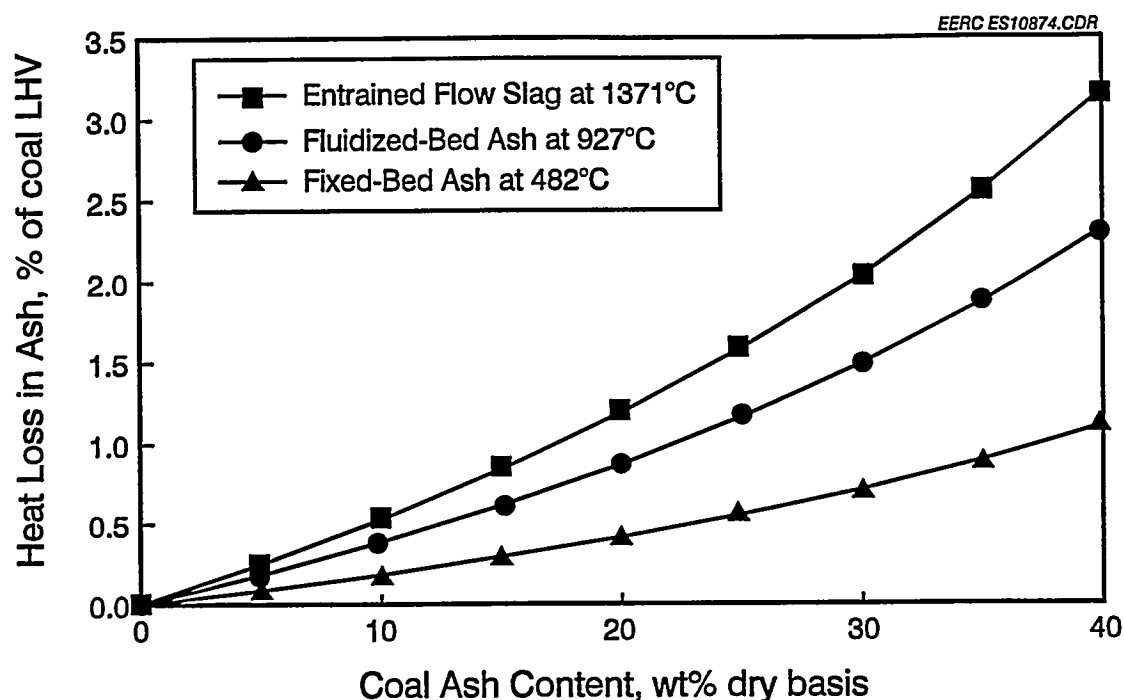


Figure 14. Gasifier heat loss in ash.

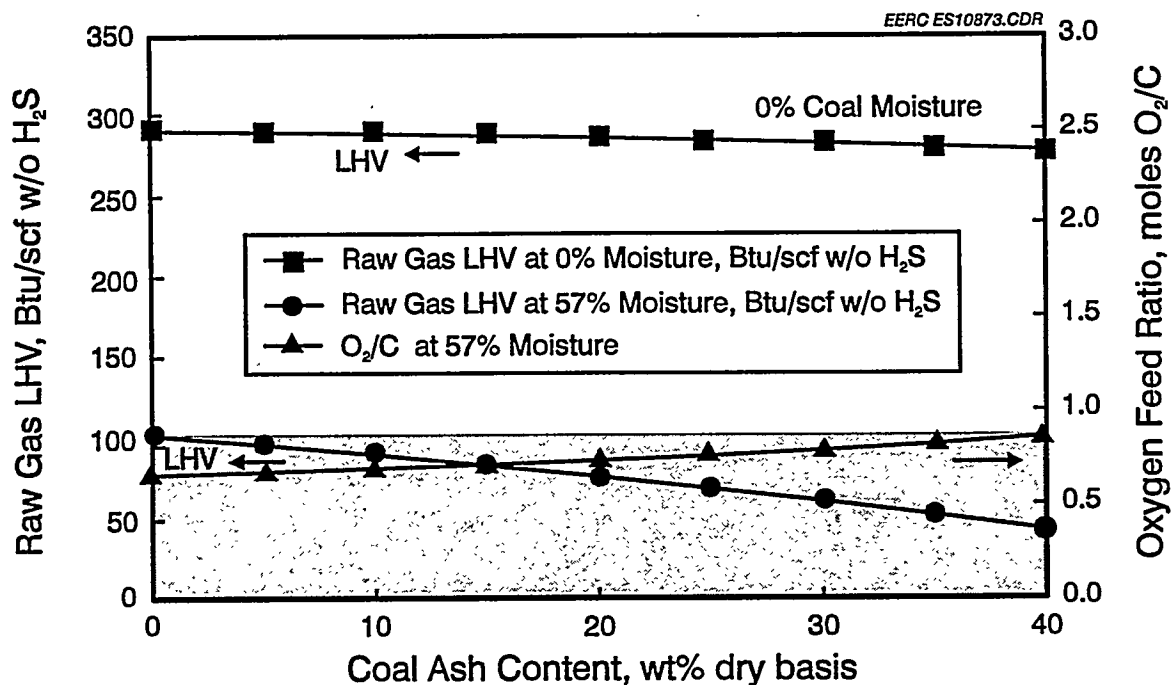


Figure 15. Effects of coal ash content at high- and low-moisture levels in an entrained-flow gasifier (dry feed gasifier with exit temperature at 1371°C [2500°F]).

increased linearly along with coal ash contents, as shown in Figure 16, from 10% carbon-in-ash solids at 5% ash to 30% carbon in ash solids at 23% ash. Using this linear correlation, the heat loss in ash plus carbon (including the heating value in the lost carbon) was computed to increase from zero to 44% of the coal LHV between 0% and 35% coal ash content for the conditions of the present calculation. Gavor

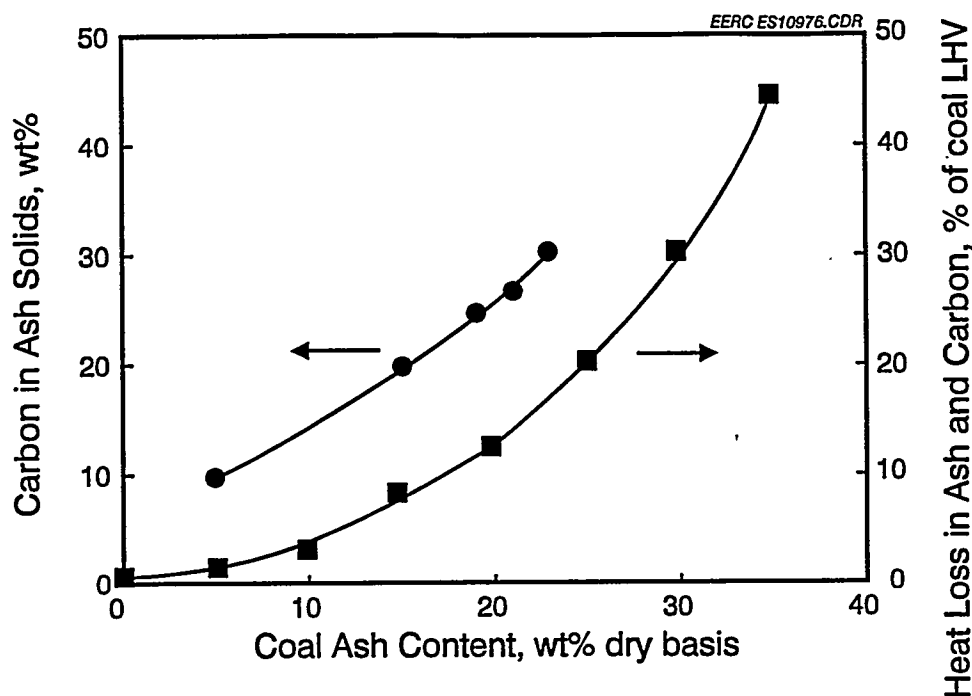


Figure 16. Heat loss in ash and carbon in a fluidized-bed gasifier based on correlation of carbon loss with ash (Gavor, 1992).

reported a 36% heat loss at 23% coal ash content calculated for a slightly different set of conditions (Gavor and others, 1992). The gasification of high-ash coal would not be feasible under these circumstances. Compensating operational changes such as increasing gasification temperatures may be capable of offsetting these unacceptably high carbon losses.

Sulfur

Worst-case impacts of coal sulfur content on gas heating values are shown in Figure 17. The calculated concentration of H_2S in the moist raw product gas increases from 0 to 15,000 ppmv between 0% and 10% daf sulfur. The heating value of this H_2S , which is substantially lost in gas cleaning, is indicated to range upward to 17% of the raw gas LHV for an entrained-flow gasifier operated on as-received lignite at 57% moisture and 35% ash. Lower percentages of gas LHV are indicated for H_2S in a fluidized-bed gasifier owing to the higher heating value of the gas produced (where the higher sensible heat of product gas from the entrained-flow gasifier is offset by a high heating value in gas from the fluidized bed). It should be noted that operation on a feed coal containing the extreme levels of moisture and ash shown would not be practical, and the percentage heating values attributed to H_2S will in practice be somewhat lower, but still very significant.

SUMMARY AND CONCLUSIONS

Abundant low-rank coal resources in East Central Europe can supply a significant portion of future need for electricity at reasonable cost if challenges are met. Success in designing new power systems demands that advanced technologies be tailored to the properties of the fuel. The highly reactive and nonagglomerating properties of low-rank coals provide some unique opportunities in applying advanced systems. However, difficult choices must also be made in selecting technologies for those coals containing very high levels of moisture, ash, and sulfur. PFBC and IGCC based on dry ash fixed-bed gasification may provide the greatest flexibility for using these coals with minimum pretreatment. Entrained-flow and fluidized-bed gasifiers will likely require predrying to low moisture levels and possibly cleaning to reduce ash. The characteristics of the inorganic portion of the coal, involving organically

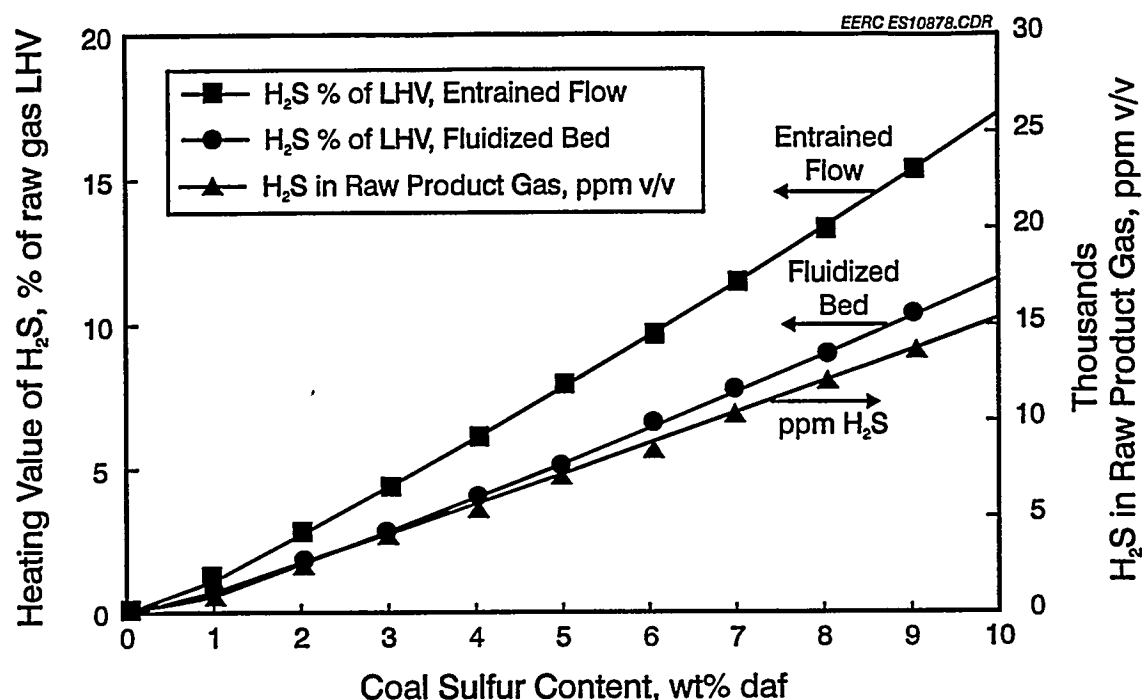


Figure 17. Worst-case effect of coal sulfur on gas heating values (raw lignite feed at 57% moisture and 35% ash).

associated elements, volatile alkalis, and low-viscosity slags, pose special ash deposition and materials corrosion problems that must be overcome.

For high-alkali low-rank coals, problems of ash deposition, bed agglomeration, and alkali-slag corrosion can be addressed by designing for low conversion temperatures and developing effective alkali getters. Corrosion of high-temperature ceramic filters and heat exchangers by vapor-phase alkali and slag will require further research.

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THE SHELL COAL GASIFICATION PROCESS

Ir. L.O.M. Koenders, Coal Gasification Business Development
Dr. Ir. P.L. Zuideveld

Shell Internationale Petroleum Maatschappij B.V.
The Hague, The Netherlands

ABSTRACT

Future Integrated Coal Gasification Combined Cycle (ICGCC) power plants will have superior environmental performance and efficiency.

The Shell Coal Gasification Process (SCGP) is a clean coal technology, which can convert a wide range of coals into clean syngas for high efficiency electricity generation in an ICGCC plant. SCGP flexibility has been demonstrated for high-rank bituminous coals to low rank lignites and petroleum coke, and the process is well suited for combined cycle power generation, resulting in efficiencies of 42 to 46% (LHV), depending on choice of coal and gas turbine efficiency.

In the Netherlands, a 250 MWe coal gasification combined cycle plant based on Shell technology has been built by Demkolec, a development partnership of the Dutch Electricity Generating Board (N.V. Sep). The construction of the unit was completed end 1993 and is now followed by start-up and a 3 year demonstration period, after that the plant will be part of the Dutch electricity generating system.

INTRODUCTION

Basic Concept

Shell's experience with gasification dates back to the 1950's, when the first Shell Gasification Process was commissioned with oil as feedstock. The experience gained on oil gasification provided a firm theoretical and practical base for the start of coal gasification process development in 1972.

Coal gasification (making carbon monoxide and hydrogen by the partial oxidation of coal) can be considered for a variety of applications, since the synthesis gas (syngas) produced can be used as:

- a chemical feedstock for making transportation fuels and chemicals.
- a source of hydrogen (making use of the water gas shift reaction) for upgrading petroleum products.
- a fuel for heating process streams and/or generating electricity.

It was against this background of potential applications world-wide that an analysis was made of different options for configuring a coal gasification process.

The basic concepts selected for the Shell Coal Gasification Process are:

- Pressurized (compact equipment)
- Entrained flow (compact gasifier)
- Oxygen blown (compact equipment, high gasification efficiency)
- Membrane wall, slagging gasifier (high temperature, insulation by slag layer)
- Opposed burners (good mixing, high conversion)
- Dry feed of pulverized coal (size range of as-received coal not an issue)

In order to avoid problems with molten or sticky fly slag particles entrained in the raw syngas, a gas quench concept was selected. After quenching the raw syngas down to approx. 900°C with recycled dust-free syngas, further cooling is done by raising steam in a syngas cooler.

After cooling, the clean up of the syngas can be achieved by combining and improving technology used throughout the process industries for removing solids and acid gas, recovering sulphur and treating process effluent.

Shell's operational experience with coal gasification started with a 6 t/d pilot plant in Amsterdam, followed by a 150 t/d unit in Harburg, Germany and a third unit in Houston with a capacity of 250-400 t/d. This experience has been the basis for the design of the coal gasification unit of the Demkolec plant.

A DESCRIPTION OF THE PROCESS (see attached flow scheme)

The process can handle a wide variety of coals, ranging from bituminous to lignite, in an environmentally acceptable way and produces a high purity, medium-Btu gas as a fuel for power generation.

Raw coal is crushed and fed to a pulverizer, a conventional bowl mill, similar to those used in a pulverized coal boiler. This mill grinds the coal to a size range suitable for efficient gasification (90% wt less than 100 microns). As the coal is being ground, it is simultaneously dried utilizing a heated inert gas stream that carries the evaporated water from the system as it sweeps the pulverized coal through an internal classifier to collection in a baghouse.

The oxygen required in the SCGP gasification step (95% pure) is supplied by an air separation plant. Other oxygen purities can be used, depending on project premises. Nitrogen from the air separation unit is compressed to provide low-pressure and high-pressure nitrogen for use in the gasification plant, e.g. for transporting coal in the feed system.

Milled and dried coal from the coal milling and drying area is pneumatically transported to the coal pressurization and feeding system. Pressurized coal, oxygen and, if necessary, steam enter the gasifier through pairs of opposed burners.

The gasifier operates in the range 20 to 30 bar. The gasifier consists of a pressure vessel with a gasification chamber inside. The inner gasifier wall temperature is controlled by circulating water through the membrane wall to generate saturated steam. The membrane wall encloses the gasification zone from which two outlets are provided.

One opening at the bottom of the gasifier is used for the removal of slag. The other outlet allows hot raw gas and fly slag to exit from the top of the gasifier.

Most of the mineral content of the feed coal leaves the gasification zone in the form of molten slag. The high gasifier temperature (over 1500°C) ensures that the molten slag flows freely down the membrane wall into a water-filled compartment at the bottom of the gasifier. High carbon conversions (above 99%) are obtained, and the high temperature ensures that no organic components heavier than methane are in the raw syngas. The insulation provided by the slag layer in the gasifier minimizes heat losses, such that cold gas efficiencies are high and CO₂ levels in the syngas are low. The recycle of fly slag enhances gasification efficiency.

Flux may be added to the coal feed to promote the appropriate slag flow from the gasifier at the preferred operating temperature. As the molten slag contacts the water bath, the slag solidifies into dense, glassy granules. The slag is washed, depressurized and then fed to intermediate storage.

The hot raw product gas leaving the gasification zone is quenched with cooled, recycled product gas to convert any entrained molten slag to a hardened solid material prior to entering the syngas cooler. The syngas cooler recovers high-level heat from the quenched raw gas by generating high-pressure steam.

The bulk of the fly slag contained in the raw gas leaving the syngas cooler is removed from the gas using commercially demonstrated equipment such as filters or cyclones. The recovered fly slag can be recycled back to the gasifier via the coal feeding system. The syngas then goes to a scrubbing system, where the remaining traces of solids and water soluble contaminants are removed, and thereafter to an acid gas removal system, where an amine-based solvent, such as Sulfinol, removes typically 98 to 99% of the sulphur species.

A bleed from the scrubbing system is sent to a sour slurry stripper. The water is then clarified and can be recycled to minimize the volume of effluent to be biotreated and discharged or evaporated. The acid gas from the acid gas removal system and from the sour slurry stripper is fed to a Claus plant, where saleable elemental sulphur is produced. For maximum sulphur recovery and minimal sulphur emissions, the Shell Claus Off-gas Treating process (SCOT) is used.

PROCESS FEATURES

Of the energy in the coal being fed to the gasifier, approximately 83% is converted into raw synthesis gas. Over 99% of the carbon in the coal is converted. With a further 14% to 15% of the heating value of the coal being recovered as steam, the overall thermal efficiency of the Shell Coal Gasification Process is very high.

The composition of the syngas is similar for most coals processed, with CO and H₂ accounting for over 90% of the syngas on a molar basis.

Sixteen different coals as well as petroleum coke were successfully run at SCGP-1 in Houston (see Table 1) during some 15,000 operating hours.

TABLE 1

Coals Run at Shell's Demonstration Plant, SCGP-1

Name	Rank	Country (Basin)
Turris Illinois No. 5	Bituminous	USA (Illinois)
Drayton	Bituminous	Australia
Blacksville No. 2	Bituminous	USA (N. Appalachia)
Maple Creek	Bituminous	USA (N. Appalachia)
Buckskin	Sub-bituminous	USA (Powder River)
Pyro No. 9	Bituminous	USA (Illinois)
Pike County	Bituminous	USA (C. Appalachia)
Dotiki	Bituminous	USA (Illinois)
Sufco	Bituminous	USA (Utah)
Newlands	Bituminous	Australia
El Cerrejon	Bituminous	Colombia
Alcoa Lignite	Lignite	USA (Wilcox trend)
Skyline	Bituminous	USA (C. Appalachia)
Robinson Creek	Bituminous	USA (C. Appalachia)
R&F	Bituminous	USA (N. Appalachia)
Pocahontas No. 3	Bituminous	USA (C. Appalachia)
Petroleum Coke	-	-

Coals can be switched "on the fly", with gasifier operating conditions being adjusted as the new coal "breaks through". With a slagging process such as SCGP, there is a transition from fully molten slag in the gasifier at some 1500°C to when the slag and fly slag leave the process as solids at ambient temperatures. The process can handle this transition for a broad range of the relevant coal

quality parameters, and remove heat efficiently at the same time. The use of automatic process control makes it possible to maintain optimal operating conditions even with variable coal quality; for example, an unwashed blend of two seams with significantly different ash contents.

To accommodate changing power demand from the grid, load-following was thoroughly tested at SCGP-1, including steady-state operation at 50% plant capacity. In response to small disturbances in the grid, the control system is able to accommodate ramp changes in syngas demand at a rate of 3% per minute between 100% and 50% plant capacity.

ENVIRONMENTAL

Integrated gasification combined cycle power generation based on SCGP has excellent environmental performance. A priority throughout the development and commercialization of the process has been the establishment of an environmental data base and also a number of design options for treating and handling effluents.

Gaseous Effluents

Sulphur Compounds

A key advantage of using coal gasification for power generation is that the gasification step converts the sulphur in the coal into hydrogen sulphide and some carbonyl sulphide, both of which can be removed down to extremely low levels. The resulting sulphur-rich acid gas is normally sent to a Claus unit for conversion into sulphur, a readily saleable product.

Nitrogen Compounds

The nitrogen in the coal is converted to molecular nitrogen, except for small amounts of ammonia and hydrogen cyanide which are completely removed in the syngas clean-up sections.

Tests in full-scale gas turbine combustors with a SCGP type simulated syngas have shown that NO_x levels can be controlled well within regulatory limits while still maintaining complete combustion.

Trace Organics

SCGP operates at high temperatures which eliminate the potential for tars and other heavy hydro-carbons. No organics have been detected in the slag or fly slag while a few ppb wt of formaldehyde were occasionally detected in the process water. Only a few combustible trace constituents were detectable at ppb wt levels in the syngas. No aromatic or polynuclear aromatic hydrocarbons were detected in the syngas.

Carbon Dioxide

The clean gas produced by SCGP consists primarily of CO and H₂. Combustion of the syngas in gas turbines converts virtually all of the CO to CO₂. The high efficiency of SCGP/ICGCC electricity generation means less CO₂ per unit of electricity produced compared with less efficient technologies.

Particulates

Particulate removal is done in a dry solids removal section comprising cyclones and filters to produce a syngas that meets particulate specifications of typically 1-5 ppm wt. This is further reduced in subsequent scrubbing and treating steps.

Trace Elements

The majority of the metals present in the coal ash are captured in the slag. Only a very low percentage is entrained in the raw syngas and this is further reduced in the gas cooling and gas treating sections. Halides are concentrated in the scrubbing water where they are easily neutralized and removed as salts. The concentrations of species covered by Title III of the 1990 Clean Air Act (USA) for 'air toxics' are present only in the parts per billion range in the syngas.

Gasification of petroleum coke at SCGP-1 confirmed that nickel and vanadium concentrations in the purified syngas were below detection levels (7 and 2 ppb wt, respectively) and that gasification of petroleum coke presents no new environmental issues.

Aqueous Effluent

Process water from SCGP has no detectable amounts of volatile or semi-volatile organics. Biological treatment of the stripped and clarified process water provides oxidation for the small amounts of inorganic nitrogen and sulphur species that remain. Biotreated effluent contains fully oxidized products and very low concentrations of trace metals. Stripped sour water and treated scrubber water can be recycled.

Toxicity tests have been carried out on samples of biotreated effluent. The results showed no acute toxicity in the undiluted SCGP effluent and no chronic toxicity effects at a modest 3 to 1 dilution of the effluent.

A "zero water discharge" configuration is also an option.

Solid By-Products

Depending on the coal and the gasifier operating mode, more than 90% of the ash in the coal ultimately leaves the process as bottom slag. Both bottom slag and fly slag are non-hazardous according to RCRA (Resource Conservation and Recovery Act, USA) requirements.

Environmental characterization of SCGP-1 slag, fly slag and clarifier solids was performed for several coals using the EP (Extraction Procedure) test. Toxic trace metal concentrations in the leachate were well below RCRA requirements, and many of the elements were even below the detection limits.

As part of a solids utilization program, SCGP slag has been used as a major component in concrete mixtures to make roads, pads and storage bins. Other applications of SCGP slag and fly slag that have been demonstrated are asphalt aggregate, portland cement kiln feed and light weight aggregate.

INTEGRATED GASIFICATION COMBINED CYCLE

The application of oil and gas-fired combustion turbine combined cycle systems has grown rapidly in the industry due to the lower cost, higher efficiency and demonstrated reliability of gas turbine equipment. In recent years, the perception of supply limitations and increasing costs of conventional clean fuels, such as oil and gas, has renewed interest in the use of coal in combined cycles for electrical and thermal energy production.

Combined cycle power generation presents electric power producers with the potential for major improvements in efficiency and cost effectiveness. Gas fired combined cycle power plants with overall efficiencies above 50% LHV are now in operation. Developments in gas turbines and steam cycles point in the direction of 55 to 60% LHV efficiency for such plants in the late nineties.

Modern coal gasification technologies present a unique opportunity to combine the advantages of high efficiency combined cycle power generation with an environmentally friendly coal based

process. The Shell Coal Gasification Process (SCGP) is especially well-suited to produce clean turbine fuel gas efficiently and it can be coupled with a combined cycle system in either an integrated or a non-integrated arrangement. This allows considerable flexibility in configuring the gasification plant.

There are numerous possibilities for optimizing the use of energy in SCGP/CC designs, depending on the specifics of the gas and steam turbine selected and the site specifics (elevation, temperature).

Recent studies show that optimal integration of the three main building blocks of an ICGCC plant (air separation unit, gasification block and the combined cycle) could give an overall efficiency (LHV) of at least 46%. Optimal integration should also consider operability criteria.

In such cases the air separation unit receives part of its air from a dedicated air compressor, with the remainder coming from the air compressor of the gas turbine. The nitrogen not required in the gasification unit is used for dilution of the clean syngas fired in the gas turbine to reduce NO_x emissions and increase electrical output.

The efficiency is dependent on the coal properties. Low-rank coals, with high moisture contents, require more energy for drying. High sulphur coals give lower efficiencies because the sulphur is removed as H_2S and COS , two syngas components which have calorific value.

In a non-integrated arrangement, the gasification plant would operate as a stand-alone unit providing syngas 'over the fence' to a separate combined cycle power generation plant. This makes SCGP suitable for repowering natural gas-based combined cycle systems and for phased gasification projects. However, compared with a highly integrated design, a non-integrated arrangement would have an efficiency which is 1.5 to 2.0 percentage points lower.

Competitive Position of ICGCC

Present gas prices for most countries will result in a lowest cost for "clean" electricity when produced in a modern gas-fired combined cycle power station and consequently a lot of new gas based capacity, with attractive short building times, is starting up or under construction. Fuel diversification, oil-, gas- and coal reserves, price stability and supply logistics are the main reasons to limit dependency on gas, and considering the nuclear debate in many countries, coal will remain a major fuel for power generation. The prime competitors for ICGCC are therefore other coal technologies, able to meet the increasingly stringent environmental requirements.

The cost of power comprises three elements, capital cost, fuel cost and operating and maintenance cost, the last element includes sorbent injection cost and by products value or disposal cost. The high fuel efficiency of ICGCC and the anticipated cost for maintenance and operation are placing ICGCC in a good competitive position. The capital investment, expressed in USD/KWe, for commercial sized ICGCC projects in start-up or construction phase are some 20-35% higher compared with PC-boilers with FGD. With increased size (economy of scale), high(er) efficiency of available and future gas turbines, and equipment cost improvement, ICGCC will be able to close the capital cost gap with PC-boilers. The latter may be forced to include catalytic denoxing to meet more severe NO_x -emissions standards. A recent conceptual design for a two-string 800 MW-output ICGCC has confirmed ICGCC-competitiveness. Most power companies are willing to utilize clean coal technology, ICGCC and PFBC, when the technologies are economically competitive and adequately demonstrated, with respect to reliability, availability and load-following characteristics. Prove of these aspects are main objectives for the Demkolec demonstration period.

CONCLUSION

In many countries, concerns about nuclear power and uncertainty about oil prices in the long term are expected to lead to an increase in the proportion of electricity generated by gas and coal. Concerns about the environment are also growing. Natural gas is the cleanest of the fossil fuels.

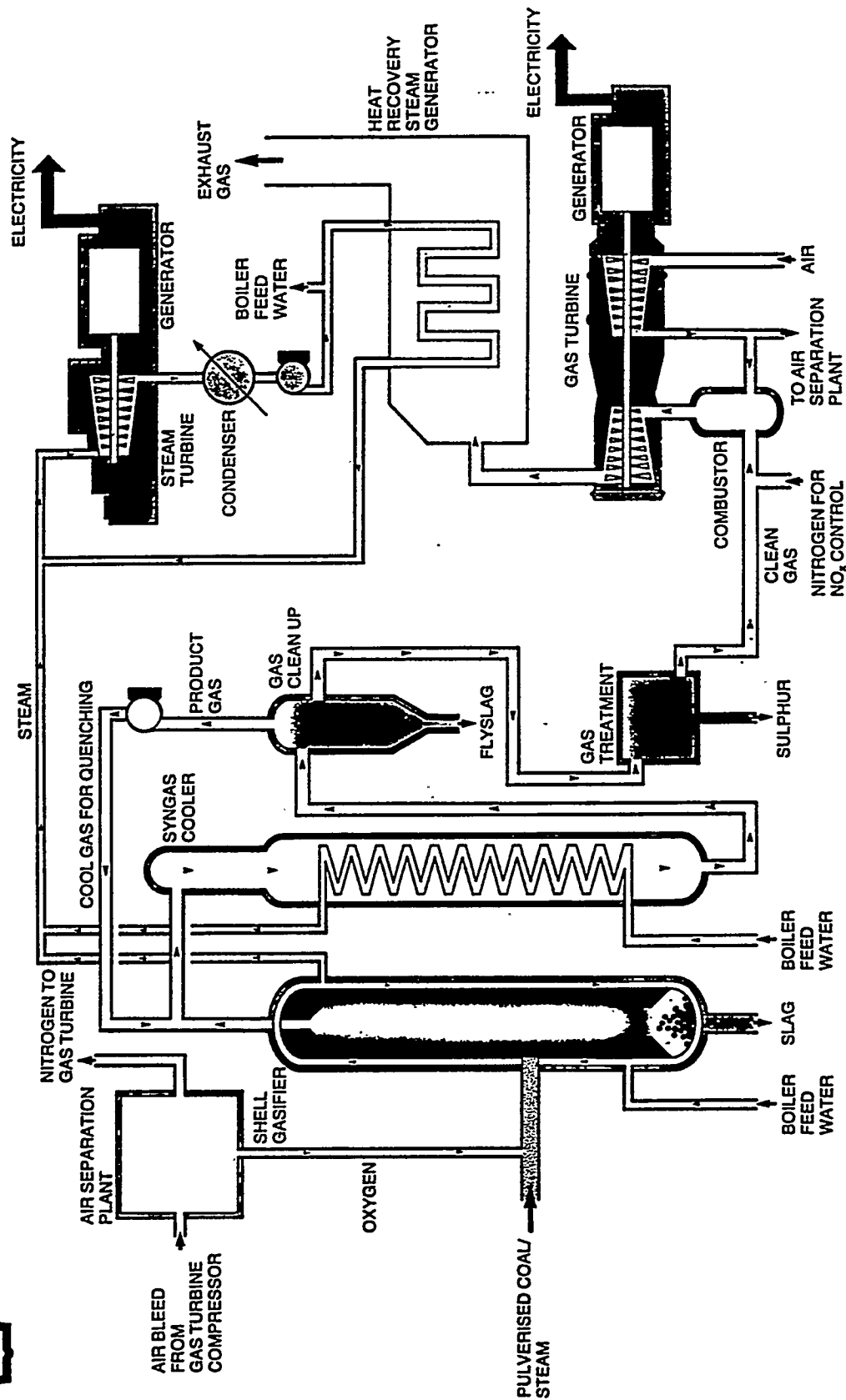
Maintaining fuel diversity and flexibility, however, implies a continuing need for new coal based capacity. Countries with large coal reserves can be expected to continue to use their indigenous resources. New coal burning power stations must be cost effective and flexible, for instance by being able to burn the range of coals likely to be traded internationally. In countries with exacting environmental standards, they must also address environmental concerns about acid rain (NO_x and SO_2 emissions), waste solids and water, and global warming (CO_2 emissions).

IGCC power stations are a major step forward in producing electricity at competitive prices while significantly reducing acid rain emissions, by advances in low- NO_x gas turbine combustion technology and by very deep desulphurization.

The waste solids from slagging gasifiers are non-leachable and are readily utilized. Cooling water needs are reduced, since less than half of the power from an IGCC unit is generated by a steam turbine.

Given adequate, operational experience from commercial size units, presently starting up or being constructed, the production of competitive power from integrated coal gasification combined cycle will be an important technology to meet future power demand with stringent environmental specifications.

THE SHELL COAL GASIFICATION PROCESS COMBINED CYCLE ELECTRICITY GENERATION



A CASE STUDY ON PFBC FOR LOW RANK COALS

Sven A. Jansson

ABB Carbon AB
Finspong, Sweden

ABSTRACT

Pressurized Fluidized Combined-Cycle (PFBC) technology allows the efficient and environmentally friendly utilization of solid fuels for power and combined heat and power generation. With current PFBC technology, thermal efficiencies near 46%, on an LHV basis and with low condenser pressures, can be reached in condensing power plants. Further efficiency improvements to 50% or more are possible.

PFBC plants are characterized by high thermal efficiency, compactness, and extremely good environmental performance. The PFBC plants which are now in operation in Sweden, the U.S. and Japan burn medium-ash, bituminous coal with sulfur contents ranging from 0.7 to 4%. A sub-bituminous "black lignite" with high levels of sulfur, ash and humidity, is used as fuel in a demonstration PFBC plant in Spain.

Project discussions are underway, among others in Central and Eastern Europe, for the construction of PFBC plants which will burn lignite, oil-shale and also mixtures of coal and biomass with high efficiency and extremely low emissions. This paper will provide information about the performance data for PFBC plants when operating on a range of low grade coals and other solid fuels, and will summarize other advantages of this leading new clean coal technology.

Paper unavailable at time of publication.

DEVELOPMENT OF SECOND-GENERATION PRESSURIZED FLUIDIZED BED COMBUSTION PROCESS

Walter Wolowodiuk, Senior Vice President
Archibald Robertson, Department Manager

Foster Wheeler Development Corporation
Livingston, New Jersey, USA

Donald Bonk, Project Manager

Morgantown Energy Technology Center
U. S. Department of Energy
Morgantown, West Virginia, USA

ABSTRACT

Under the sponsorship of the United States Department of Energy, Foster Wheeler Development Corporation, and its team members, Westinghouse, Gilbert/Commonwealth, and the Institute of Gas Technology are developing second-generation pressurized fluidized bed combustion technology capable of achieving net plant efficiency in excess of 45 percent based on the higher heating value of the coal. A three-phase program entails design and costing of a 500 MWe power plant and identification of developments needed to commercialize this technology (Phase 1), testing of individual components (Phase 2), and finally testing these components in an integrated mode (Phase 3).

This paper briefly describes the results of the first two phases as well as the progress on the third phase. Since other projects which use the same technology are in construction or in negotiation stages—namely, the Power System Development Facility and the Four Rivers Energy Modernization Projects—brief descriptions of these are also included.

INTRODUCTION

As we approach the 21st Century, we begin to reassess our global energy needs more realistically. We are vigorously studying more efficient technologies. We are already in the beginning stages of commercialization of the first generation coal gasification combined cycles, and pressurized fluidized bed combustion (PFBC) power plants. Both of these technologies yield net plant efficiencies, based on higher heating values of the coals, of approximately 40 percent. This represents a 4-point jump over those of pulverized coal and atmospheric fluidized bed combustion power plants. New and improved technologies, presently under development, promise efficiencies in excess of 40 percent. One of these new technologies is the second-generation pressurized fluidized bed combustion plant, which is capable of achieving efficiency in the 45- to 47-percent range. This paper presents a summary of the second-generation PFBC developmental efforts performed by a team headed by Foster Wheeler Development Corporation (FWDC). The program is funded by the U.S. Department of Energy (DOE) and cost-shared by FWDC and the participating team members (Westinghouse, Institute of Gas Technology and Gilbert/Commonwealth). The program entails three phases:

- Phase 1 – Design and cost estimating of a 500-MWe power plant and identification of developments needed in support of commercialization of this technology
- Phase 2 – Pilot plant testing of individual components presently not under development
- Phase 3 – Pilot plant testing of components in an integrated mode and update of the commercial plant based on test results obtained in Phases 2 and 3.

Second-Generation PFBC Concept

Schematically, the second-generation PFBC plant is shown in Figure 1. In this concept, all coal and sorbent are fed under pressure into a carbonizer/partial gasifier where a portion of the coal energy is converted into low-Btu fuel gas, and a major portion of the released sulfur is captured by the sorbent. The char-sorbent residue from the carbonizer is then fed into a circulating pressurized fluidized bed combustor (CPFBC) where the balance of the coal energy is extracted. Part of this energy is used to preheat gas turbine air to 871°C (1600°F), while the balance of energy generates steam. The flue gas from the CPFBC and the fuel gas from the carbonizer are cleaned of particulates by cyclones and ceramic barrier filters, and both proceed to the gas turbine combustor. There the temperature of the flue gas from the CPFBC is raised by combustion of the fuel gas from the carbonizer, and then expanded in the gas turbine. Additional steam is generated in the heat recovery steam generator (HRSG) which is located downstream of the gas turbine. The high-pressure/high-temperature steam for the HRSG and CPFBC is fed to a steam turbine which, together with the gas turbine, generate the plant electrical output.

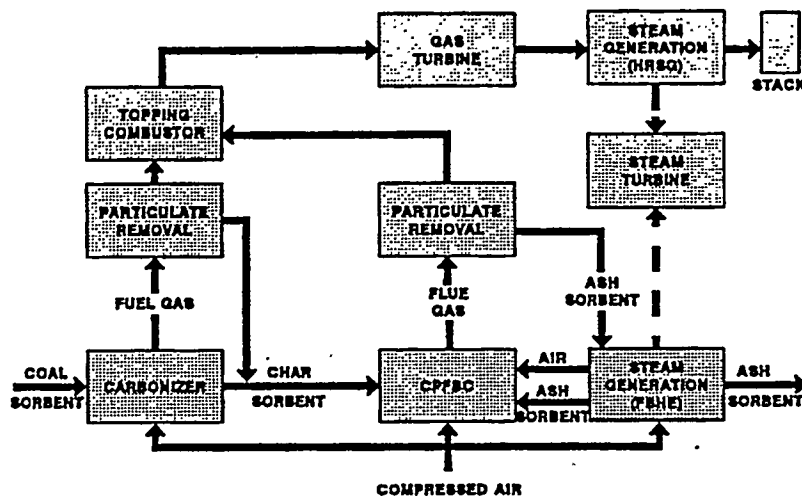


Figure 1. Simplified process block diagram of the second-generation PFBC plant.

As mentioned previously, Phase 1 of the program addressed the design and costing of a 500-MWe net electric power plant as well as identified its R&D needs.

The requirements of the plant are stated below:

- Net plant efficiency of 45 percent
- Cost of electricity 20 percent below that of pulverized coal-fired plant with scrubber
- Flexibility in burning different coals.

The plant burned Pittsburgh No. 8 coal with sulfur content of 3 percent and higher heating value of 7175 kcal/kg (12,916 Btu/lb) (as received). The sorbent was Plum Run dolomite. The cost estimate was in accordance with Electric Power Research Institute (EPRI) Technical Assessment Guide [1].

Design of a Commercial Plant

The first step in the design predicted the performance of the carbonizer. Based on limited and scattered published data [2-6], a heat and material balance of the carbonizer (shown in Figure 2) was generated. Using this as a basis, heat and material balance for a 500-MWe CPFBC plant was prepared (Figure 3). It is based on Westinghouse's 501F gas turbine with combustor outlet temperature of 1288°C (2350°F) and steam turbine conditions of 16.55 MPa/538°C/538°C/63.5 mm

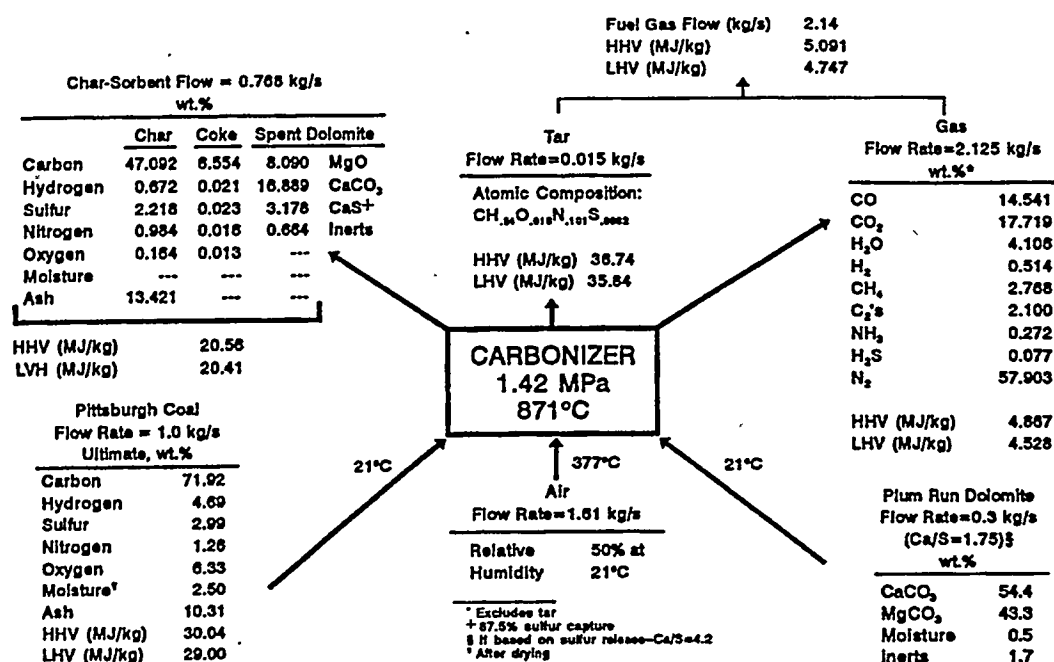


Figure 2. 871°C carbonizer heat and material balance.

Hg (2400 psig/1000°F/1000°F/2.5 in. Hg). The plant [7] is comprised of two identical carbonizer-CPFBC-gas turbine trains, each rated at approximately 250 MWe and a single steam turbine. Table 1 shows the cost and performance comparison between the second-generation CPFBC plant and a conventional pulverized coal-fired plant with scrubber, as estimated in 1987.

The sensitivity study revealed that the second-generation CPFBC plant performs satisfactorily with a variety of coals and sorbents provided that the solids handling equipment is properly sized. The R&D needs are summarized in Table 2. Since the high-temperature/high-pressure particulate filtration system is pursued under different DOE contracts, its development will not be directly addressed in this program.

COMPONENT TESTING

Carbonizer

A pilot plant was constructed at Foster Wheeler Development Corporation to test a carbonizer and a CPFBC. The carbonizer was tested in two modes of operation: a jetting, bubbling fluidized bed and a circulating fluidized bed. The bubbling bed tests were conducted in a jetting fluidized bed reactor of 254 mm (10-in. I.D.) (bottom section) by 9.144 m (30 ft) high, as shown in Figure 4. Coal and sorbent, crushed to 3.2 mm x 0 (1/8 in. x 0) and dried, were pneumatically fed into the carbonizer through a centrally located nozzle. Testing was conducted with and without steam addition. Table 3 shows the range of variables investigated during this portion of the testing. Typical analysis of feedstocks and sorbents are shown in Tables 4 and 5, respectively. In the jetting mode, the pilot plant operated for a total of 533 hours, during which 37 steady-state conditions were evaluated [8, 9]. The effects of temperature on fuel gas composition and on carbon and energy conversion are shown in Figure 5 and Table 6, respectively.

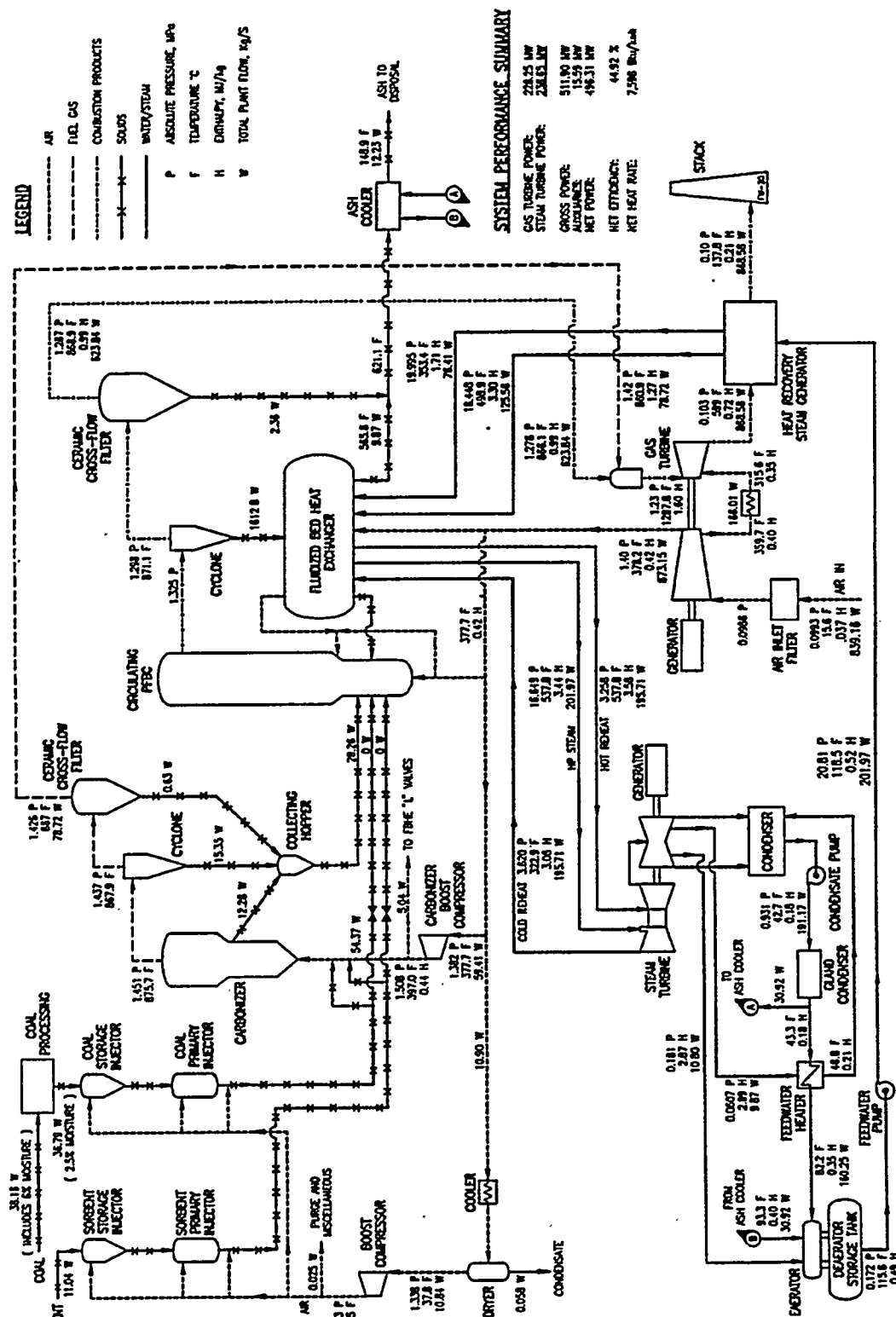


Figure 3. Heat and material balance for a 500-MW(e) second-generation PFBC plant.

TABLE 1

Phase 1 Plant Comparisons (Pittsburgh No. 8)

Summary	1.418-MPa Second-Generation PFB at Best Eff. Point 871°C Carbonizer	Conventional PC-Fired Plant with Scrubber
Net Capacity, MWe	496.3	500.9
Net Plant Efficiency, % (HHV)	44.9	35.9
Topping Combustor, °C	1288	---
GT/ST Power Split, %	45/55	0/100
TCR, 1987 \$/kW	1002	1375
COE, mills/kWh*	72.9	93.2
COE Advantage, %	21.8	---
Pittsburgh No. 8 Coal, kg/s	38.16	48.25
Sorbent Flow, kg/s		
Dolomite	11.04	---
Limestone	---	5.49
Ash Production, kg/s	12.23	0.96
Ash & Spent Sorbent	---	8.91
Fixed Sludge	22.00	42.47
Water Consumption, 10 ³ m ³ /day	0.220	0.27
SO ₂ , kg/s	0.144	0.360
NO _x , kg/s	0.000251	0.01802
Particulate, kg/s		

* 65% capacity factor

TABLE 2

Second-Generation PFBC Plant R&D Needs

Component	Areas of Concern
Ceramic Barrier Filters	■ Particulate Collection Efficiency with Time ■ Material Degradation ■ Effective Sealing of Filter Elements to Headers/Tubesheets ■ Effects of Thermal Shocks
G.T. Topping Combustor	■ Flame Stability with Low-Caloric Fuel Gas ■ Effective Cooling of Burner Components ■ Maximum Conversion of NH₃ in Fuel Gas to N₂ ■ Low Generation of Thermal NO_x
Carbonizer	■ Tar Destruction ■ Formation of Agglomerates ■ Sulfur Capture ■ Fuel Gas Composition and Heating Value
CPFBC	■ Char Combustion ■ Conversion of CaS to CaSO₄ ■ Sulfur Capture ■ NO_x Generation
Integrated System	■ Char Transfer between Carbonizer and CPFBC ■ Load Following Capability ■ Total Environmental Emissions

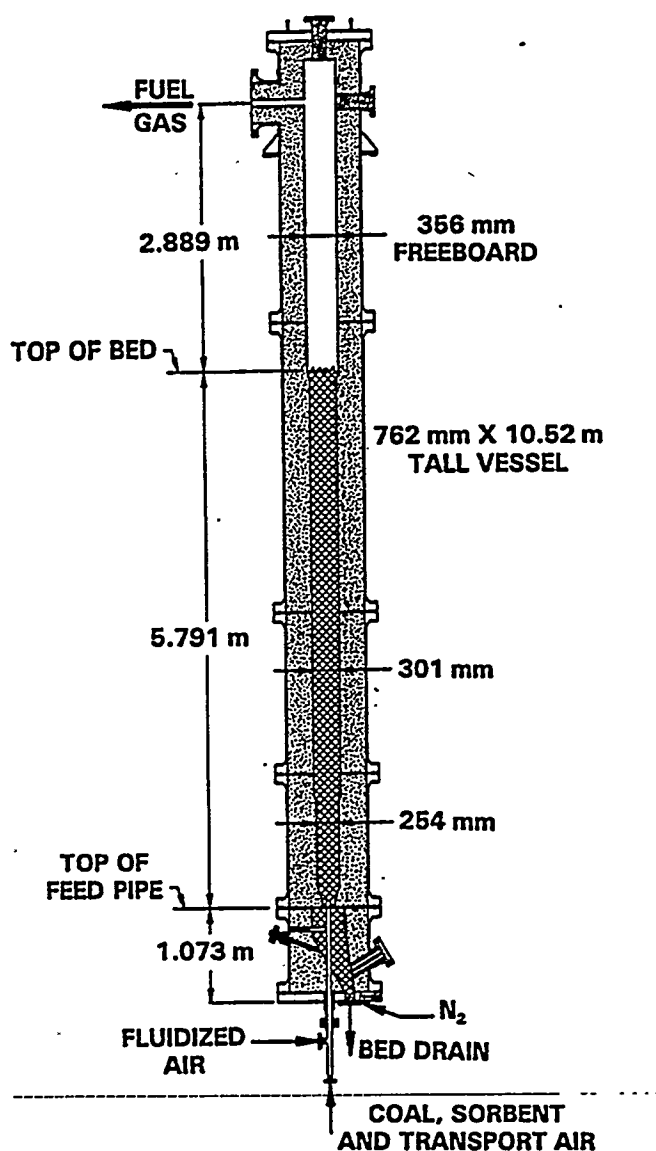


TABLE 3

Carbonizer Range of Variables Investigated

Pressures (MPa)	1.013 to 1.418	
Temperature (°C)	816 to 922	
Velocity (m/s)	0.91 and 1.1	
Steam Injection	Up to 0.4 kg/kg bituminous coal	
Fuels	Bituminous	Subbituminous
	■ Pittsburgh No. 8 ■ Illinois No. 6	■ Eagle Butte, Wyoming Petroleum Coke
Sorbents	Dolomite	Limestone
	■ Plum Run, Ohio ■ Longview, Alabama	

* In 254-mm I.D. section

TABLE 4

Typical Carbonizer Feedstock Analysis

Description	Petroleum Coke	Coal		
		Pittsburgh No. 8	Illinois No. 6	Eagle Butte
Feed Size	-3.2 mm	-3.2/4.8 mm	-3.2 mm	-3.2 mm
Free Swelling Index	—	6.5	4	0
Proximate, wt%				
Fixed Carbon	83.96	51.06	45.06	36.16
Volatile Matter	14.97	34.23	33.49	31.39
Ash	0.94	12.61	10.59	5.58
Moisture	0.13	2.10	10.87	26.87
Ultimate, wt%				
C	89.89	69.45	62.76	50.77
H	4.42	4.62	4.40	3.60
O	0.73	5.70	6.78	11.49
N	2.30	2.03	1.57	0.98
S	1.59	3.50	3.05	0.72
Ash	0.94	12.61	10.59	5.58
Moisture	0.13	2.10	10.87	26.87
HHV, kcal/kg	8745	7068	6206	4849

TABLE 5

Typical Carbonizer Sorbent Analysis.

Description	Plum Run Dolomite	Longview Limestone
Supplier	Highland Stone Division of Davon, Inc. Hillsboro, Ohio	Longview Lime Saginaw, Alabama
Feed Size	-3.2 mm	-3.2 mm
Composition:		
CaCO ₃	55.96	96.90
MgCO ₃	42.82	1.91
S	0.19	0.15
Ash	1.03	1.05

Following completion of the bubbling bed tests, the carbonizer was converted to operate in a circulating bed mode, as shown in Figure 6. The I.D. of the carbonizer was reduced to 203 mm (8-in.), and it operated with a superficial gas velocity of approximately 3.3 m/sec (10 ft/sec.) Solid reinjection was via a 102 mm (4-in.) "L" valve. Since the objective of these tests was to see if circulating bed operation offered any improvement in the carbonizer performance, only one coal and sorbent was tested. The pilot plant operated for a total of 94 hours, during which four test points were completed.

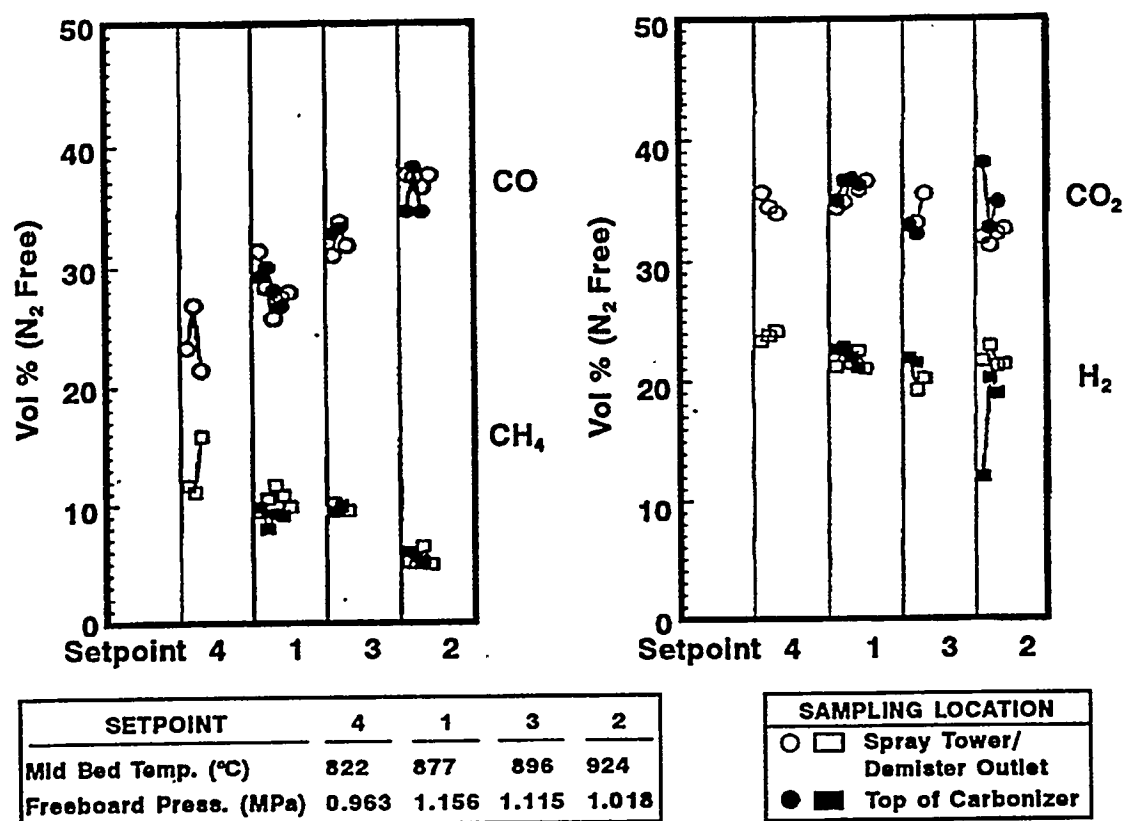


Figure 5. Pittsburgh No. 8 carbonizer fuel gas compositions (test run 1).

TABLE 6

Carbonizer Test Unit Conversions
(Pittsburgh No. 8 Coal)

Test Run	Bed Temp. (°C)	Coal Carbon Conversion	HHV _{gas} / HHV _{coal}
1.4	822	0.30	0.23
1.1	877	0.31	0.24
2.5	922	0.41	0.26
1.2	924	0.43	0.28
2.4	978	0.50	0.33
2.3	979	0.60	0.32

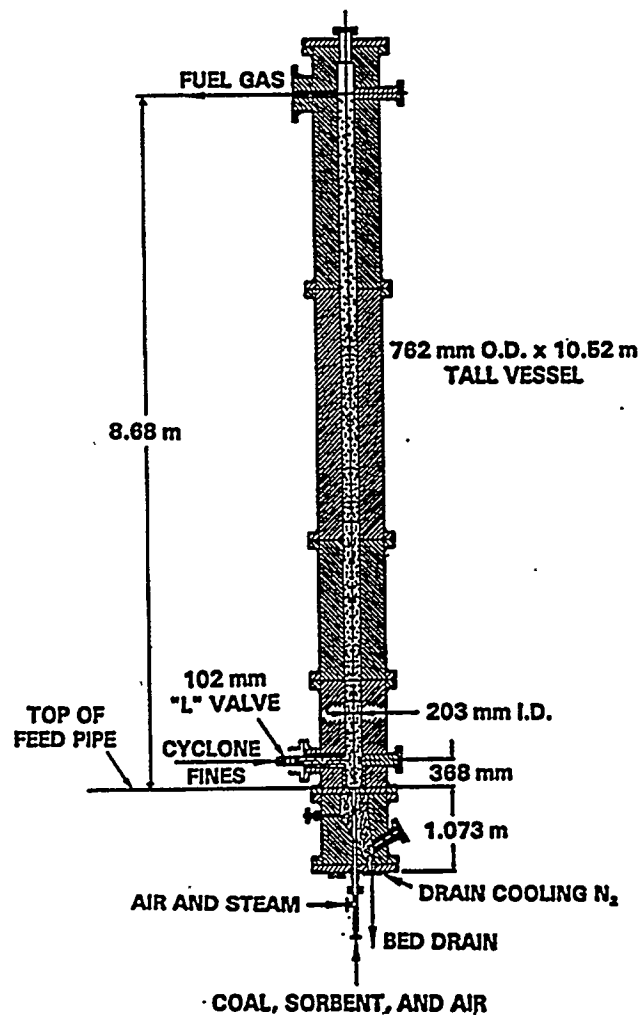


Figure 6. Circulating bed carbonizer test unit.

The results from testing of both types of carbonizers are summarized as follows:

- No tars or oil vapors were detected with the carbonizer operating in the 816-982°C (1500-1800°F) temperature range.
- No agglomerates were found, even with high-caking Pittsburgh No. 8 coal, while operating in the temperature range of 871-982°C (1600-1800°F).
- Fuel gas and char were compatible with ceramic barrier filters.
- Up to 96 percent of the coal sulfur released in the carbonizer was captured by the sorbent.
- 22 to 66 percent of coal nitrogen was converted to ammonia.
- More coal energy was transferred to the fuel gas than was estimated in the initial commercial plant design.

- Carbonizer operation was smooth and controlled. Both coal and sorbents could be changed without interruption.
- Very little difference was observed between the two (bubbling and circulating bed) modes of operation.

Circulating Pressurized Fluidized Bed Combustor

A CPFBC comprised of an 203 mm (8-in.) I.D. combustor, cyclone, and solids cooler (as shown in Figure 7) was constructed and tested in the Foster Wheeler's PFBC pilot plant. The cooled solids were reinjected into the combustor via an "L" valve. Similarly, as in the carbonizer tests, the fuels and sorbents, sized to 3.2 mm x 0 (1/8 in. x 0), were fed dry. In addition to the three coals previously used, one additional coal—Kentucky—as well as three chars from the carbonizer tests were combusted. The pilot plant operated in excess of 300 hours, during which a total of 23 test points were completed. The variables investigated are listed in Table 7. A summary of the test results is presented below [10].

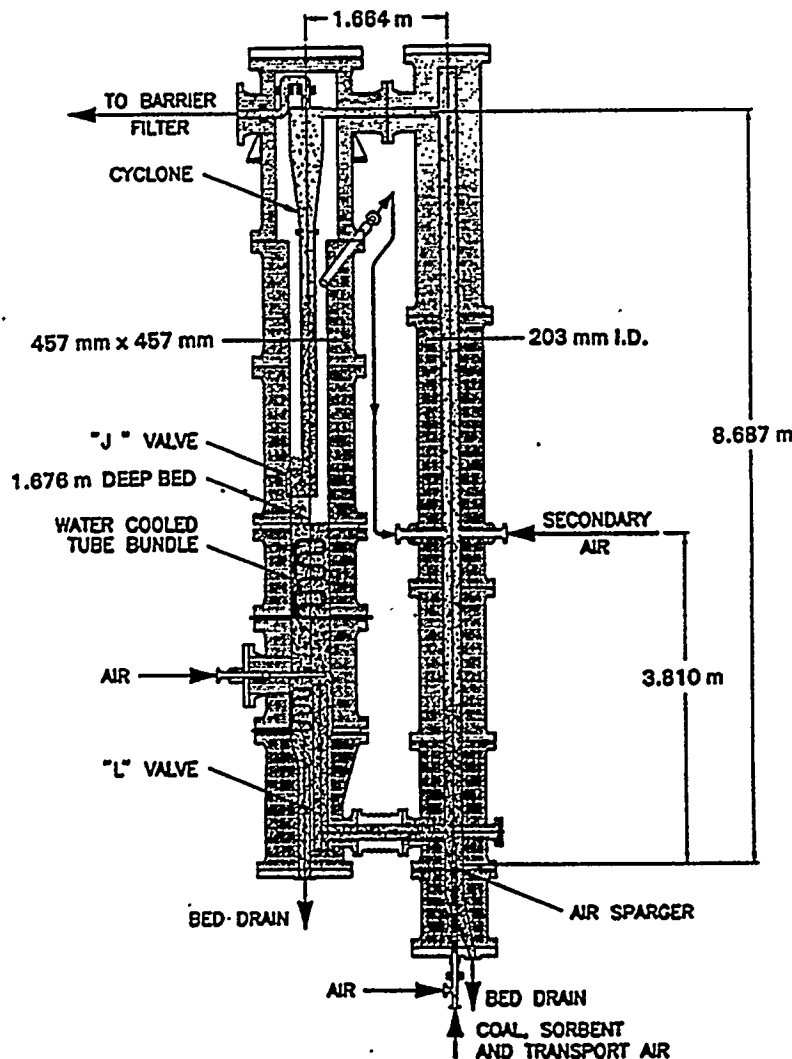


Figure 7. Integrated CPFBC and fluid bed heat exchanger test unit.

- Carbon conversion efficiencies were in excess of 99.5 percent, as shown in Figure 8.
- Carbon monoxide emissions were very low for all fuels tested and generally ranged between 18 and 36 gr/10⁶ kcal (0.01 and 0.02 lb/10⁶ Btu). A plot of CO emissions as a function of combustor bed temperature is shown in Figure 9.

TABLE 7

CPFBC Range of Variables Investigated

Pressure, MPa	0.7 to 1.4
Temperature, °C	843 to 954
Velocities (m/s)	
■ Primary Zone	1.22 to 1.83
■ Secondary Zone	3.05 to 3.66
Primary Air Stoichiometry, %	60 - 100
Excess Air, %	30 - 90
Solids Circulation Rate, kg/s	0.252 - 2.520
Fuels	Bituminous ■ Pittsburgh No. 8 ■ Illinois No. 6 ■ Kentucky Subbituminous ■ Eagle Butte 3 Carbonizer Chars
Sorbents	Dolomite (Plum Run) Limestone (Gen Star)

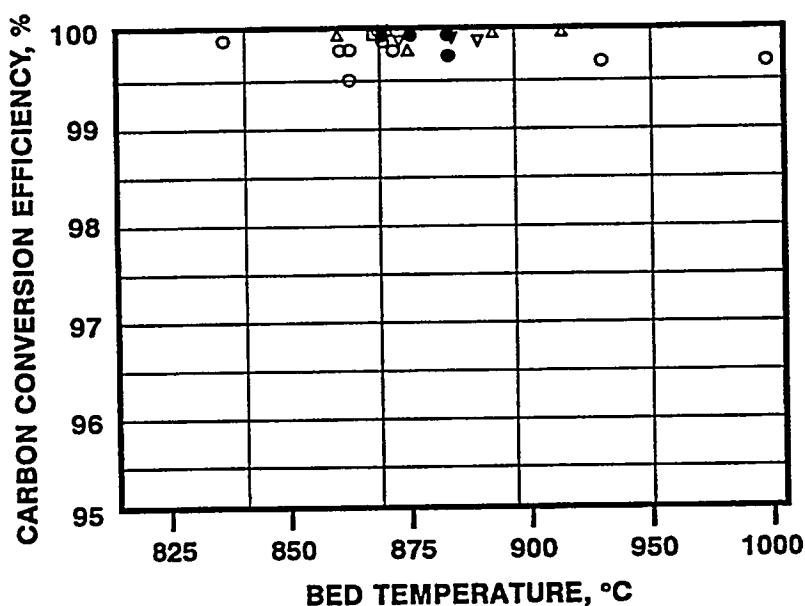


Figure 8. Carbon conversion efficiency as a function of combustor bed temperature.

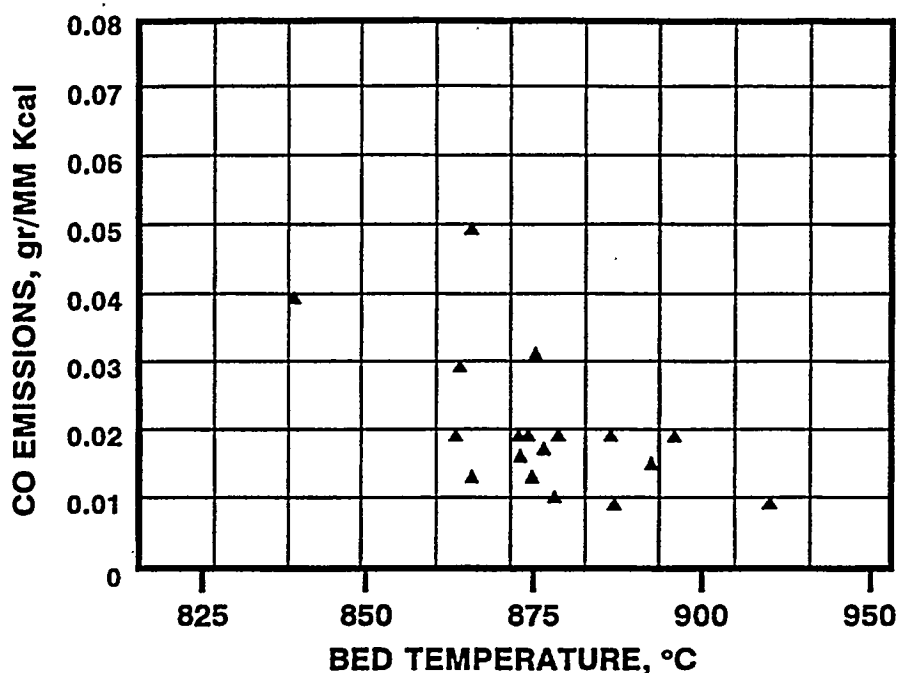


Figure 9. Carbon monoxide emissions as a function of combustor bed temperature.

- A sulfur capture efficiency greater than 96 percent was usually achieved with Ca/S ratios ranging from 1:1 to 2:1 as shown in Figure 10.
- Of all operating parameters, primary zone stoichiometry appeared to have the greatest impact on NO_x emissions. Figure 11 presents the test data on conversion of the fuel nitrogen to NO_x for Illinois No. 6 coal and chars.
- Conversion of CaS contained in the carbonizer char-sorbent residue was evaluated for four different char blends (Pittsburgh No.8/dolomite and three Illinois No. 6/limestone). The CaS content of these chars ranged from 1.8 to 4.3 percent. The conversion ranged from 68 to 82 percent.
- Carbon conversion efficiencies were in excess of 99.5 percent, as shown in Figure 8.

Gas Turbine Combustor

In the commercial plant, the fuel gas from the carbonizer and the vitiated air from the CPFBC entering the gas turbine combustor can be as high as 871° (1600°F). Since any ammonia and hydrogen cyanide present in the former tend to form NO_x during combustion, NO_x emission and wall cooling of the combustor liners have precluded the use of a conventional gas turbine-type combustor. A thick layer of the hot vitiated air on the inside of the combustor liners is required to provide the necessary cooling. Low NO_x, generated in the combustor, can be achieved by staging of the combustion process. A multiannular swirl burner (MASB), based on the design by Professor J. Beér of MIT [11] and shown in Figure 12, has been selected by Westinghouse for further development.

Testing of the proposed concept is being conducted by Westinghouse at the University of Tennessee Space Institute. The fuel gas is simulated by a syngas comprised of 11.6 volume percent CH₄, 8.95 volume percent H₂, and 79.38 volume percent N₂ with a lower heating value of 1133 kcal/kg (2040 Btu/lb). The objectives of the test are to:

- Verify that the metal wall temperature did not exceed 1700°F

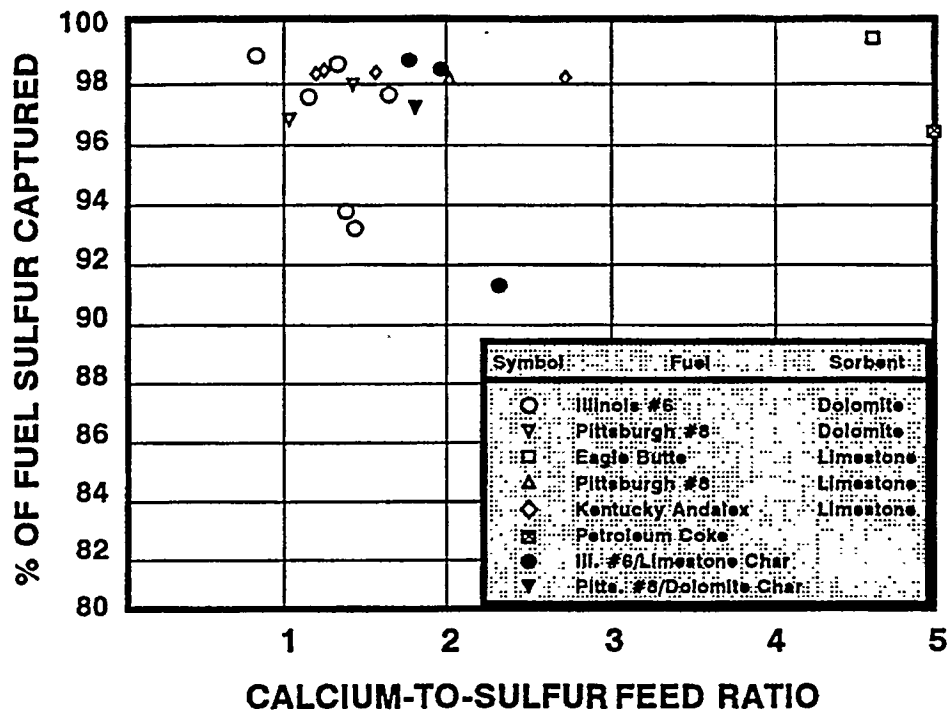


Figure 10. Sulfur capture as a function of Ca/S ratio.

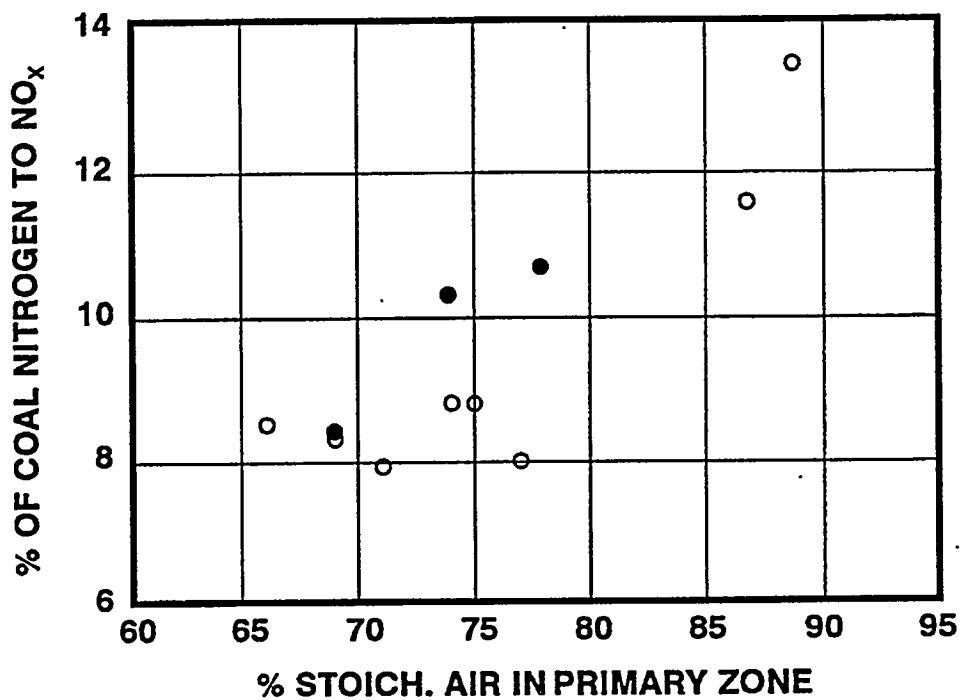


Figure 11. Nitrogen conversion to NO_x for Illinois no. 6 coal and chars.

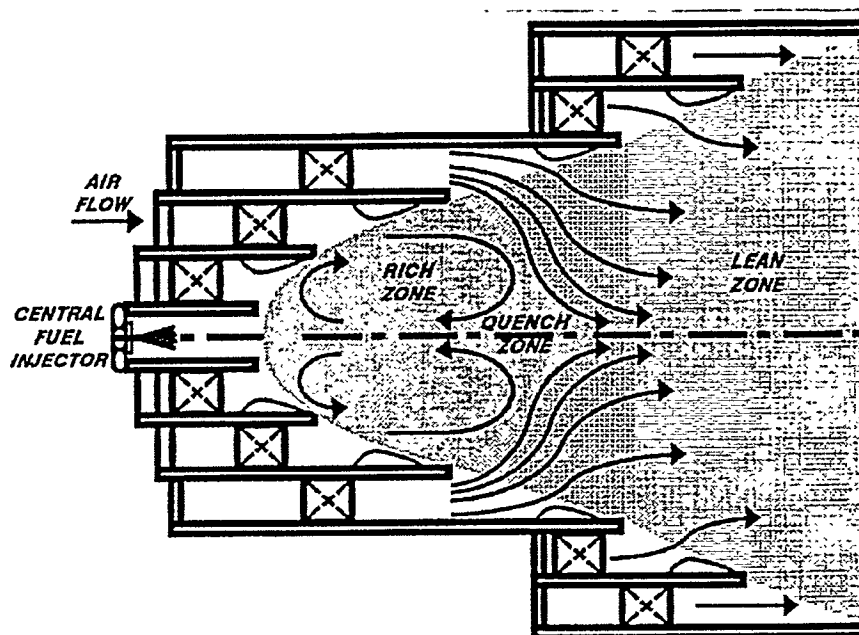


Figure 12. Multiannular swirl burner (MASB).

- Achieve stable and efficient combustion
- Minimize NO_x formation

Two series of MASB tests—one with a 301 mm (12-in.) diameter at 1149°C (2100°F) and one with a 356 mm (14-in.) diameter at 1288°C (2350°F)—were conducted. The results are presented below:

- The metal temperature of the MASB walls could be limited to 899°C (1650°F)
- Combustion efficiencies exceeded 99 percent
- Fuel gas ammonia conversions were as low as 10 percent.

Two more tests are scheduled for the second half of 1994. A full-size 457 mm- (18-in.) diameter MASB will be used in this series of the tests. In addition to burning synthesized fuel gas, the burner will also be tested with methane.

Integrated Subsystem

In Phase 3 of the program, presently underway, an integrated pilot plant facility comprised of carbonizer, CPFBC and their associated coal and sorbent feed and gas cleanup systems is being erected at FWDC and is scheduled to begin operation in the fourth quarter of 1994. Schematic of the pilot plant is shown in Figure 13. The plant is rated at 2.5 MWt. The significant changes from Phase 2 are listed below:

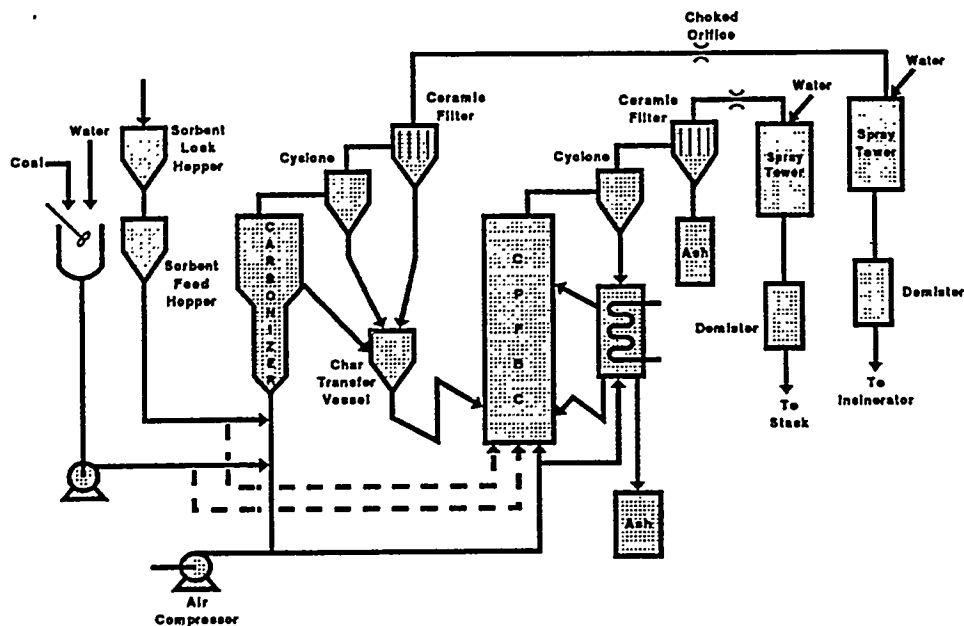


Figure 13. Schematic diagram of the integrated subsystem pilot plant.

- A coal paste feed system has been added.
- Carbonizer bed height was increased to 7.3 m (24 ft).
- CPFBC I.D. was increased to 330 mm (13 in.) and height to 11.6 m (38 ft).

Operation of this pilot plant, in addition to confirming process variables investigated during Phase 2 of the testing, will provide the needed information on transfer of hot char from the carbonizer to CPFBC.

Power Systems Development Facility (PSDF)

Under sponsorship of the DOE, Southern Company Services is constructing in Wilsonville, Alabama, a 145-million dollar plant to be used for testing of advanced power system components, including long-term testing and performance evaluation of hot gas cleanup (HGCU) systems [12]. Testing of the HGCU is also supported by EPRI. One of the first systems to be tested is the second-generation CPFBC. The system is rated 7 MWe equivalent and is schematically shown in Figure 14. It will have all the major components of a commercial plant with the exception of the steam turbine and heat recovery steam generator. The carbonizer is designed to operate as a jetting-bubbling fluidized bed, similar to that tested in Phase 2. The diameter of its lower sections is 914 mm (3 ft), and the height is 14.6 m (48 ft). The upper portion of the CPFBC has an I.D. of 838 mm (33 in.).

At full-load operation, the plant will consume 0.69 kg/s (5500 lb/h) of Illinois No. 6 coal. The facility is under construction and operation is scheduled to begin in the middle of 1995.

Four Rivers Energy Modernization Project (FREMP)

Air Products has been selected in Round 5 of the DOE Clean Coal Technology Demonstration Program to build, own, and operate the first commercial second-generation CPFBC plant. The project, known as the Four Rivers Energy Modernization Project, will produce 66 MWe of electricity and 50.4 kg/s (400,000 lb/h) of process steam [13]. It will consume 33.1 metric tons/h (36.5 tons/h) of Western Kentucky high-sulfur bituminous coal. Some of the pertinent parameters of this plant are listed in Table 8.

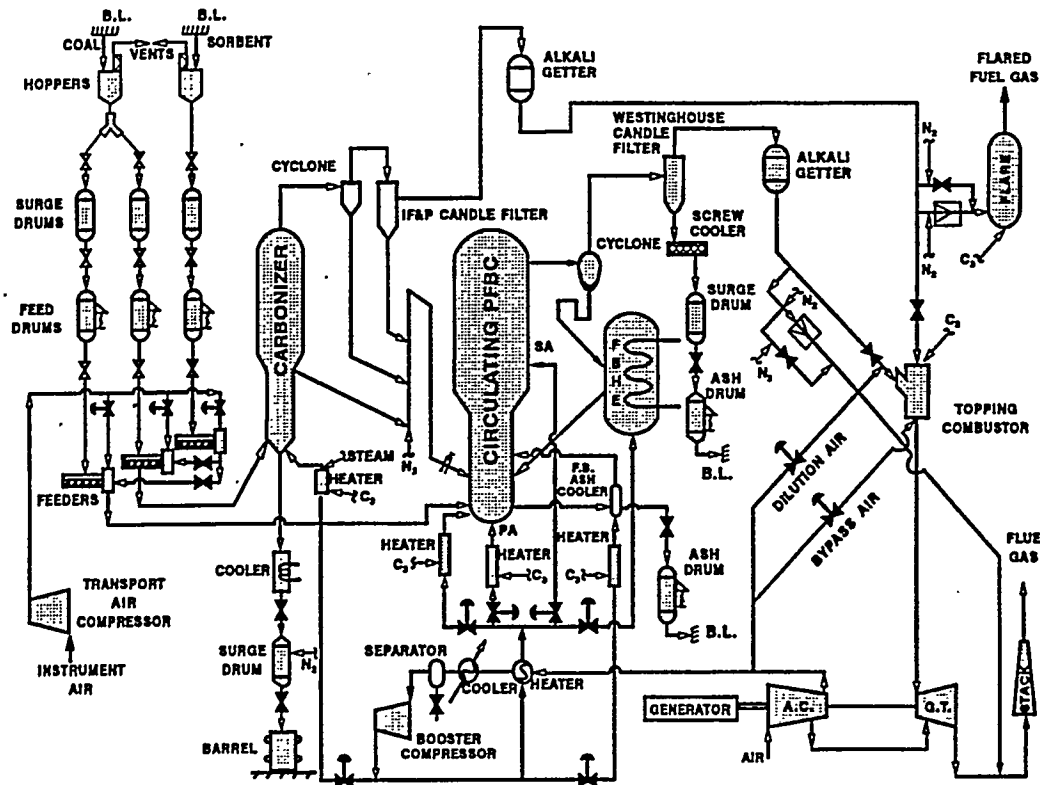


Figure 14. Wilsonville PSDF APFBC process flow diagram.

TABLE 8

Four Rivers Energy Modernization Project

- Gross MWe = 70 (38 GT/32 ST)
- Process Steam for Polymer Manufacture
— 39.14 kg/s @ 1.31 Mpa and 216°C
- Natural Gas Backup for Carbonizer
- Coal Paste and Dry Sorbent Feed Systems
— Western Kentucky Coal and Limestone
- Independent CPFBC and GT Operation
- 25-Year Operating Life

Scale-Up

Any development of new technology has to undergo a reasonable scale-up process. Process parameters obtained in the pilot plant operation have to undergo stepwise confirmation before they are used to design commercial plants. Furthermore, availability and operability of larger-size peripheral equipment must be assured. Such a progression has been chartered for the second-generation CPFBC plant. Figure 15 shows, in block diagram, the scale-up from the pilot plant testing through the proposed first commercial plant. Some of the physical dimensions as well as the operating parameters are shown in Table 9. The commercialization schedule is depicted in Figure 16. Also shown in Figure 16 is the testing of the high-temperature/high-pressure particulate cleanup devices which is being performed under DOE's sponsorship at the first-generation PFBC TIDD plant in Ohio.

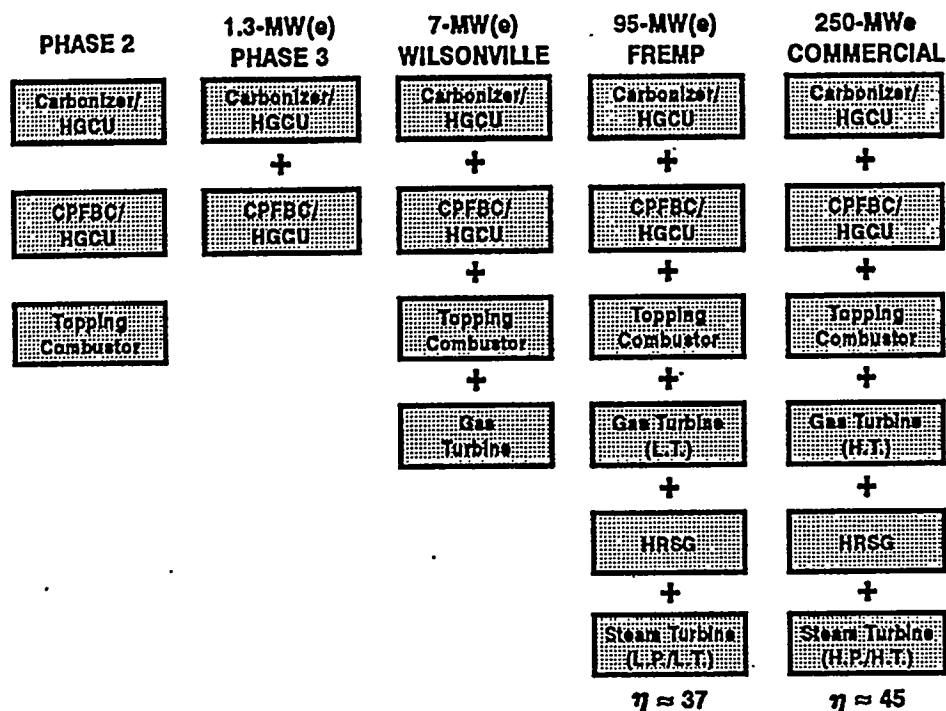


Figure 15. Scale-up of the second-generation PFBC.

TABLE 9

Parameters in Scale-Up of Second-Generation PFBC Technology

	Phase 2	Phase 3	Wilsonville	FREMP	Commercial
Nominal MWe (or equiv.)		1.3	7	95	≈250
Carbonizer Temperature, °C	816-923	816-923	871	871	871
Carbonizer Residence Time, s	5	5	5	5	5
Pressure, MPa*	1.013-1.419	1.013-1.419	1.013	1.216	1.419
Carbonizer ϕ, mm	254	254	914	2438	3505
CPFBC ϕ, mm	203	330	518	1737	2896
MASB ϕ, mm	305,357,457	—	457	457	457
Turbine	—	—	A-501 (4 MW)	W-251 (37 MW)	W-501 (107 MW)

* Air compressor discharge

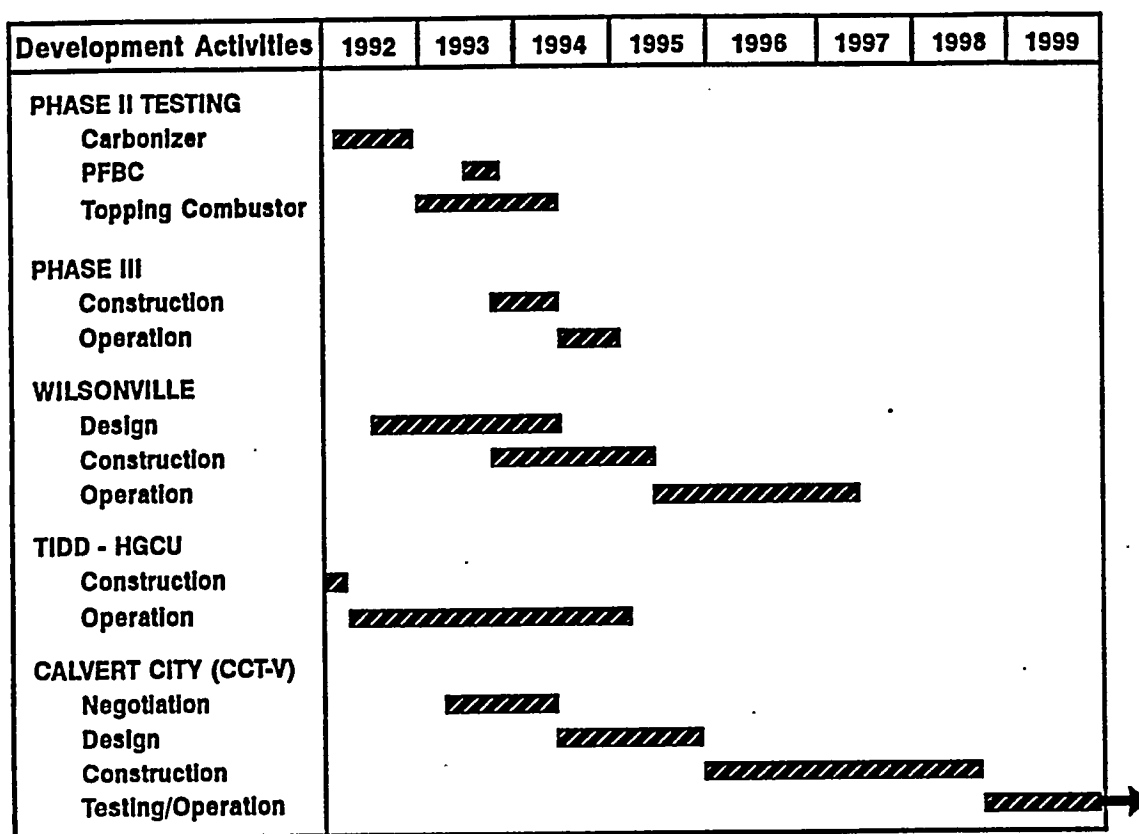


Figure 16. Schedule for commercialization of the second-generation PFBC.

CONCLUSIONS

Like any new energy conversion technology, the second-generation CPFBC plant has to undergo step-by-step solutions of all technical problems, both process and mechanical. Process variables are easily determined. Solutions of mechanical problems can be much more difficult. If the technology is to succeed, a compromise between the best energy efficiency and performance of the mechanical components will have to be found. This is the compromise we are looking for as we proceed with the development of the second-generation CPFBC technology.

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LIFAC FLUE GAS DESULFURIZATION PROCESS AN ALTERNATIVE SO₂ CONTROL STRATEGY

J.G. Patel, Vice President, New Technology

Tampella Power Corporation
Atlanta, Georgia, USA

J. Viiala

Tampella Power Inc.
Tampere, Finland

ABSTRACT

This paper discusses the results from two recently completed LIFAC flue gas desulfurization plants - 300 MW Shand lignite powered station owned by Saskatchewan Power Corporation and 60 MW Whitewater Valley high sulfur coal fired station owned by Richmond Power and Light. LIFAC is a dry FGD process in which limestone is injected into the upper regions of the boiler furnace and an activation reactor is used to humidify the unreacted limestone to achieve additional sulfur capture. The performance in both plants indicates that 70 to 80% sulfur is removed at a Ca/S ratio of 2. Cost performance data from these plants has shown that LIFAC both on construction cost and \$/ton SO₂ removed basis is very cost competitive compared to other SO₂ control technologies. The Richmond plant has been realized under the auspices of the U.S. Department of Energy's Clean Coal Technology program. The Shand plant is the first commercial installation in North America. The paper also discusses highlights of operating and maintenance experience, availability and handling of the solid waste product.

INTRODUCTION

This second International Conference of Energy and Environment provides an excellent opportunity to exchange information and experience about the energy production and pollution control issues which are currently important issues in Eastern Europe. In these countries environmental restoration and pollution control are critical tasks requiring major resources to be accomplished, but the funds available for environmental investments are limited. A combination of local resources and international expertise will result in the best solutions both technically and economically.

This paper contains a description of the LIFAC desulfurization technology and experience of LIFAC projects implementation in several countries. This technology is most suitable for conditions where the SO₂ reduction demand is not extremely high and the simplicity of the process and the economy are important.

TAMPELLA POWER'S PARTICIPATION IN THE CLEAN COAL PROGRAM

Tampella Power

Tampella Power is a Finnish-based international company which produces efficient and environmentally friendly systems for the pulp and paper industry as well as thermal and electrical power generation plants for energy producers. Tampella Power's investment into R&D and product development has resulted in several state of the art products. Tampella Power is continuously investing for product development to make better products and services for their users and customers. The LIFAC desulfurization process is one of the results from this development work. LIFAC has also been recognized internationally. The U.S. Government-funded Clean Coal Program

selected LIFAC in its third round to be demonstrated for U.S. customers. In Canada Shand Power Station, which has a LIFAC FGD system for SO₂ control, received the Power Plant Award issued by Power Magazine in 1993.

LIFAC TECHNOLOGY

Process Description

Tampella Power Inc. in Finland began developing an economical alternative for power plant's SO₂ control in early 80s. The research and test work resulted in the LIFAC Desulfurization Process. After intensive laboratory and pilot plant tests, the first commercial LIFAC plants were installed in the mid-80s. Today there are LIFAC installations, either in operation or under construction in five countries including the USA, Canada, Russia, China and Finland.

LIFAC is a unique sorbent injection technology capable of removing 70 to 80% of a power plant's sulfur dioxide emission. The LIFAC system combines conventional limestone injection into the upper part of the furnace with the post furnace humidification reactor located before the ESP. The process produces a dry, stable ash by-product which is a mixture of fly ash and calcium compounds.

Finely pulverized limestone is pneumatically conveyed and injected into the upper region of the furnace where the temperature ranges from 950 to 1150°C. At these temperatures limestone (CaCO₃) calcines to form calcium oxide (CaO) which readily reacts with the SO₂ to form calcium sulfate (CaSO₄). Approximately 25 to 30% of the SO₂ is removed in the furnace. Most of the sulfur trioxide (SO₃) is also removed in this first stage of the process.

Flue gas with the remaining SO₂ and the excess amount of unreacted lime passes through the air preheater to the LIFAC humidification reactor where fine droplets of water are sprayed into the flue gas stream to convert lime to hydrated lime (Ca(OH)₂). The hydrated lime readily reacts at the lower temperatures with SO₂ forming calcium sulfite (CaSO₃). Approximately 60 to 70% of the SO₂ is removed in the LIFAC reactor. The combination of the proper water droplet size and the correct residence time allows for effective hydration of the lime, efficient SO₂ reactions and complete water evaporation to create dry reactor bottom ash by-product.

After exiting the humidification reactor, the flue gas is heated before entering the ESP to eliminate any moisture condensation in the duct work and the ESP. The humidification and lower gas temperature improves the efficiency of the ESP because of lower ash resistivity and lower gas velocity through the precipitator.

Approximately 30 to 40% of the LIFAC by-product which is a mixture of calcium compounds and fly ash is collected by the humidification reactor and the remaining 60 to 70% by the ESP. Both the reactor and ESP ash may be recycled to a point ahead of the reactor to improve sorbent utilization and to improve the SO₂ removal efficiency of the system. The by-product can be disposed to regular landfill or utilized as a construction material. A schematic of the LIFAC process is shown in Figure 1.

Process Advantages

LIFAC's sulfur dioxide removal efficiency is not as high as traditional wet flue gas desulfurization systems', but its low cost and simplicity of design, construction and operation offer advantages over other FGD systems. Older plants which normally do not have very strict SO₂ emission limits can easily meet the SO₂ emission reduction requirement if using LIFAC for SO₂ control. LIFAC's low investment cost, small space requirement and simplicity of operation is certainly a benefit for the older plants too.

Specific advantages of the LIFAC system are:

- **Moderate SO₂ removal rates.** LIFAC has proven the ability to achieve and sustain 70 to 80% SO₂ removal rates.

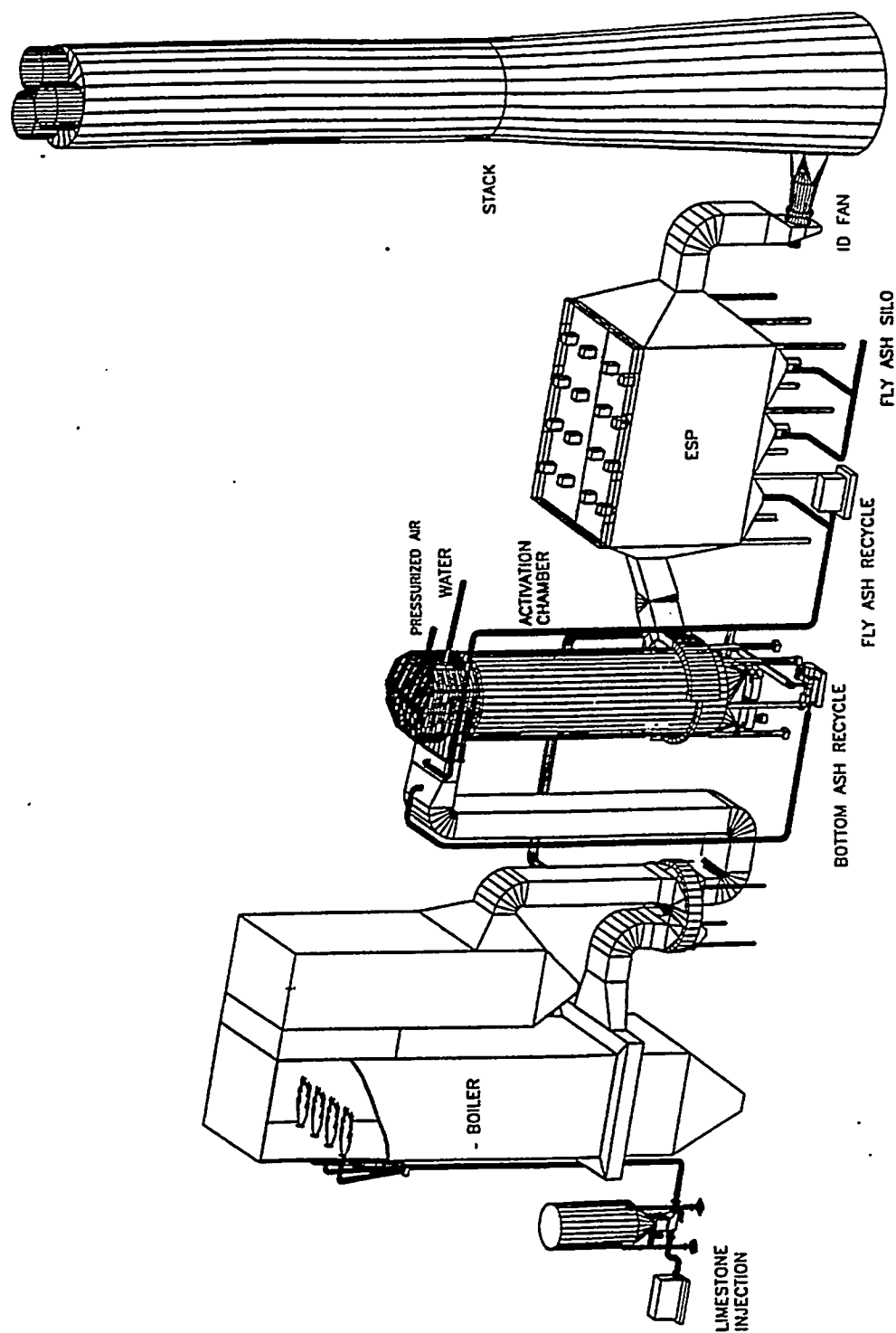


Figure 1. Tampella Power LIFAC FGD System

- **LIFAC uses limestone as a reagent.** Limestone is economical, easy and safe to handle and readily available in many countries.
- **LIFAC By-product.** Wet lime and limestone scrubbing systems create a wet by-product that must be further treated before disposal. LIFAC produces a dry solid by-product containing calcium sulfate, calcium sulfite and fly ash. It can be land-filled and it has several possible commercial applications in the construction material industry.
- **Minimal impact on the power plant's systems.** LIFAC effects primarily the boiler, ESP and ID fan, but seldom do any of those systems require modifications due to LIFAC operation.
- **LIFAC requires little space and few utilities.** LIFAC is easy to install even in small or cramped powerplant sites. Electrical power consumption is small. Humidification water can be almost any water available at the plant.
- **LIFAC is easy to operate.** Process is controlled with Programmable Process Control System (PLC). A process monitoring computer is located in the boiler control room. Additional operators are not required. Start up and shut down of the process takes less than one hour.
- **LIFAC is economical.** Even if the limestone consumption is higher than with wet systems, the simplicity of the process reduces the investment cost, auxiliary power cost, maintenance and labor cost.

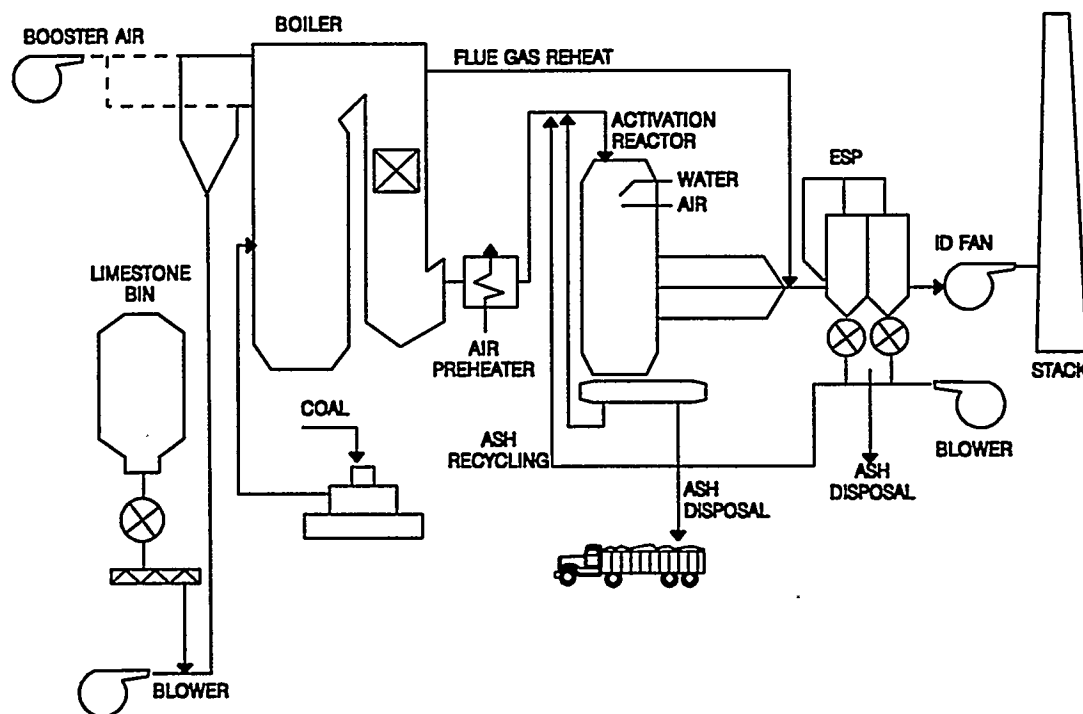


Figure 2. LIFAC Process

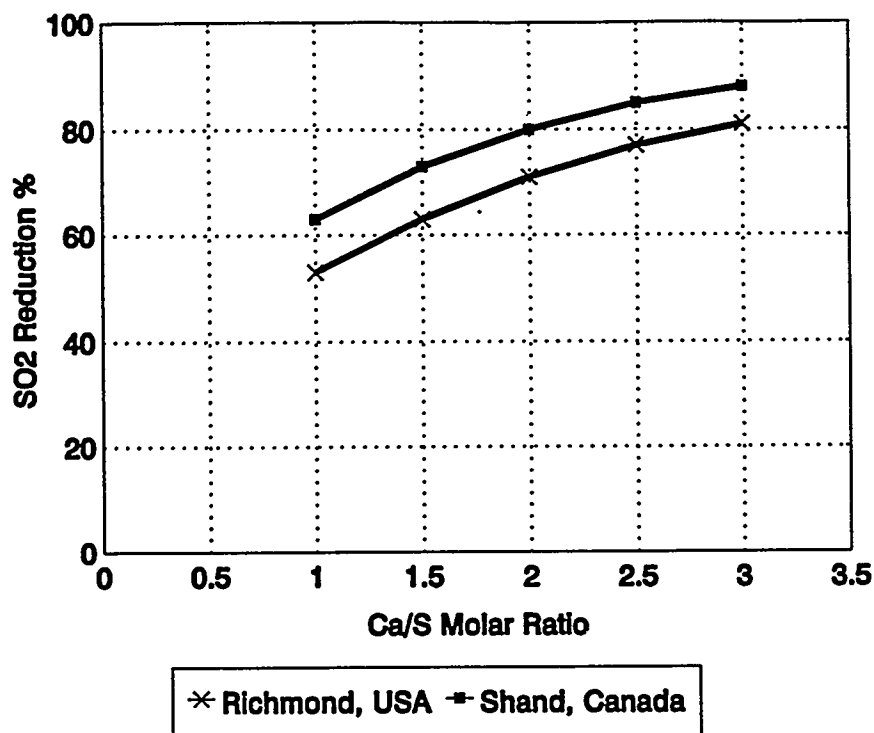


Figure 3. SO₂ Removal Efficiency in Richmond (US) and in Shand (Canada).

Process Performance

The SO₂ removal efficiency depends on few main process operation parameters and boiler operating conditions.

- **Limestone feed rate.** Ca/S molar ratio is 2.0 or less to achieve up to 80% SO₂ capture.
- **Reactor temperature.** The closer the temperature is to the adiabatic saturation temperature the better the SO₂ reduction. The temperature of the flue gas leaving the reactor is always so high that the reactor inside stays clean and the ash removed from the reactor is dry. The lowest possible reactor temperature is about 5°C above the saturation temperature.
- **Fly ash recycling.** Ash recycling is essential for high SO₂ removal and economical process operation. Ash, which contains unreacted calcium compounds, is recycled from the precipitator and from the reactor bottom back to the reactor inlet duct. The recycling will improve the SO₂ capture over 20% points.
- **Limestone quality.** Quality is determined with a particulate size, calcium content and the type of formation. Best results can be reached if the limestone is pulverized 80% < 40 μm or finer and it contains 90% or more calcium carbonate (CaCO₃).
- **Boiler operation.** The best place to inject limestone is in the upper region of the furnace. High temperatures result in poor SO₂ capture in the furnace. The furnace SO₂ capture is typically 25 to 35%.

- **Coal quality.** LIFAC installations are operating with lignite and bituminous coal fired boilers. Sulfur content of the coal varies from 0.6 to 2.5%. Coal quality does not effect process performance.

LIFAC Process Adaptability to Power Plant Systems

Boiler

Limestone injection has a minimal impact on boiler operation. Regular sootblowing can easily keep the boiler clean and remove any ash and limestone deposits from the heat transfer surfaces. Richmond LIFAC in the USA is the only place where boiler sootblowing had to be slightly increased. This is because a high sulfur coal (2.0 to 2.5%) is burned there and thus there is fairly high limestone injection rate into the furnace.

ESP Performance

Humidification improves the ESP performance significantly because of lower ash resistivity and lower flue gas velocity in the ESP. Solids loading to the ESP is increased because of limestone injection into the furnace and ash recycling from the ESP to the reactor. However this increased solids load is compensated with the improved ESP performance and is also reduced because 30 to 40% of the ash is separated in the reactor.

ID Fan Capacity

LIFAC reactor increases the system pressure drop about 1000 Pa or less. Very often plants have extra fan capacity for this small pressure drop increase and the ID fan does not need modification.

Ash Handling

The boiler ash and ESP ash disposal system do not require any modifications. The only addition to the ash handling system is the reactor bottom ash disposal system. This ash is fairly dry but not dusty due to humidification. It can be landfilled without any treatment.

Operability Of The Process

The process is controlled by the Programmable Logic Control System. It is either independent to the plants other control system or can be an extension to the existing control system. A computerized control and monitoring system makes the process control operator friendly and allows a required operation data to be collected and reported easily.

The process automatically follows any changes in the boiler operation. Load change reduces limestone and water flow. Stack SO₂ content changes the limestone flow rate if SO₂ content is an operation criteria.

The availability of the LIFAC system is high because it has few moving parts and it is very simple to operate. One fairly small pump is needed for humidification water, a blower to transfer limestone from the silo to the furnace, a compressor for the pressurized air to atomize humidification water and conveyors for ash recycling and ash disposal. If any critical component fails, the process can be discontinued in a few minutes and can be off as long as needed without any special action required.

Process Economy

Both the capital cost and the operation cost are very site specific but also country specific.

Capital Cost

The capital cost of the LIFAC system is slightly below the spray driers' and well below the wet scrubbers' cost. The capital cost of the installation in the USA and Canada are from 65 to 85 \$/kW depending on the unit size and the number of the reactors. The best boiler size for LIFAC is from 50 to 300 MW. The wet scrubber is more economical for the bigger units because one scrubber unit can handle large flue gas volumes.

Variable Cost

About half of the operation cost is the cost of limestone. The other half is waste disposal, auxiliary power, labor and maintenance costs.

To remove one ton of SO_2 , the process requires 4.3 tons of limestone, assuming that SO_2 capture is 75%, Ca/S molar ratio is 2.0, CaCO_3 content of the limestone is 95%.

The waste produced is a mixture of fly ash and calcium compounds. The quantity of the by-product produced is approximately the same than the quantity of the limestone fed into the process. Several LIFAC ash utilization tests have been done to use the by-product as a raw material for concrete. In Finland a test road was made out of LIFAC by-product several years ago. In Canada ash has been used in mining industry. The commercial value of the by-product is low but its utilization will reduce waste disposal cost.

Auxiliary power consumption is 0.3 to 0.6 % of the net unit capacity depending on the boiler size. The biggest power consuming components are air compressors for water atomizers and blower for limestone transportation.

The other major energy requirement is the reheat energy to increase the flue gas temperature exiting the reactor about 20 C before the ESP. This energy is about 0.5% of the boiler's thermal energy. Reheat energy can be taken from the boiler's flue gas which is less expensive than to use low pressure steam.

LIFAC AT RICHMOND POWER & LIGHT IN THE USA

Plant Description

Richmond LIFAC, Clean Coal Program Round 3 Project

The Clean Coal Technology Program (CCT) has been recognized in the National Energy Strategy in the USA as a major initiative whereby coal will be able to reach its full potential as a source of energy for the nation and the international marketplace. Attainment of this goal depends upon the development of highly efficient, environmentally sound, competitive coal utilization technologies, responsive to diverse energy markets and varied consumer needs. The CCT Program is an effort jointly funded by government and industry whereby the most promising of the advanced coal-based technologies are being moved into the marketplace through demonstration. The CCT Program is being implemented through a total of five competitive solicitations. Tampella Power's LIFAC sorbent injection technology was selected in the third round of CCT solicitations.

The LIFAC technology is being demonstrated at Whitewater Valley Unit No. 2, a 60 MWE coal-fired powerplant owned and operated by Richmond Power and Light (RP&L), and is located in Richmond Indiana. The Richmond LIFAC installation is a full size, commercial type of facility. The project was implemented as a demonstration project including a series of tests in different operation conditions. This is the first LIFAC installation in the USA.

The project is being conducted in cooperation between US Department of Energy, Richmond Power & Light, Tampella Power Corp., ICF Kaiser Engineers Inc., the Electric Power Research Institute (EPRI), the State of Indiana and Black Beauty Coal Company. The project was funded jointly

by the participants. DOE shared the biggest portion, 50%, of the costs. The rest of the costs were divided between the other participants.

The White Water plant consumes high quality coal with sulfur contents ranging from 2.0 - 2.9%. Limestone has high CaCO_3 content (95%) and is pulverized to $90\% < 40\mu\text{m}$.

Special Features of the Installation

Because this is a demonstration project, it was an excellent place to make tests with a full size installation with numerous process and boiler operating conditions.

The Richmond installation is the first full size LIFAC high sulfur coal application. The coal has high heating value and low ash and moisture content.

The site was very cramped for this retrofit installation.

The boiler is very hot and low SO_2 capture in the furnace was predicted. Six injection ports were installed on the highest possible furnace elevation and normal, 20 to 30% SO_2 removals, can be achieved.

The reactor vessel is round and the humidification section is in the upper part of the reactor. The reactor interior stays clean.

ESP is small but during the LIFAC operation, the particulate emissions are in the same level compared to operation without LIFAC.

LIFAC AT SASKPOWER AT SHAND AND POPLAR RIVER IN CANADA

Plant Description

Tampella Power has supplied two LIFAC units for the SaskPower Company, one at the Poplar River Power Station and the other at the Shand Power Station in Saskatchewan Province. Both installations are with 300 MWe boilers.

The Poplar River Power Station has two 300 MW units. The LIFAC desulfurization system is connected to one of the plants units. It is a retrofit installation where 100% of the boiler's gas stream has limestone injection and 50% of the flue gas is humidified in the LIFAC reactor. The boiler is a tangentially fired, tower type boiler burning Canadian lignite coal. This LIFAC installation was built in 1990.

The latest installation is at the Shand Power Station. It is a new power plant commissioned in 1992 as a Canada's most advanced coal fired plant. Environmental features include LIFAC for SO_2 control, zero discharge water management and Low NO_x burners.

The Shand Power Station uses a relatively low sulfur, low heating value lignite coal, which demonstrates an inherent ability to retain some of the sulfur in the coal ash. As a result, approximately 50% SO_2 removal with LIFAC is required to meet the current limit. The plant was therefore designed for 25% SO_2 removal in the furnace due to sorbent injection and 66% removal across one activation reactor handling half of the plants flue gas flow.

This arrangement was selected based on a detailed economical optimization study. It provides the required SO_2 removal efficiency with considerably lower capital cost than the installation of a 100% activation system. However, should these requirements be tightened, it is possible to add another activation reactor and achieve higher SO_2 removal efficiency, still at a cost far below a wet FGD system.

Special Features of the Installation

The Shand boiler was designed from the start to use furnace injection to meet the Canadian guidelines limiting SO₂ emissions to 258 ng/J. The boiler manufacturer accommodated in the original boiler design an 8 meter high cavity for the sorbent injection. While this new station was under construction, the positive results from the Poplar River LIFAC installation lead to decision by SaskPower to incorporate LIFAC in the Shand Station to improve the economics of the SO₂ control.

Both installations in Canada are with the boilers which burn lignite coal. They are also the biggest boilers with LIFAC installations.

For the first time the ash recycling from the bottom of the reactor was installed in the Shand LIFAC. It has had a significant improvement for SO₂ removal.

Because the Shand station has a zero water discharge system, it is an advantage that the water treatment plant blow down water can be used for the humidification in the LIFAC reactor. The original water source has a high chlorine content and thus also the humidification water has high chlorine.

LIFAC AT KOSTAMUKSHA IN RUSSIA

Plant Description

There are three LIFAC reactors installed now in Russia. One at the Lake Baikalsk and two in Kostamuksha in Northern Karelia, close to the Finnish border. The newest project in Kostamuksha is an industrial application where LIFAC reactors are connected to the furnace for the production of iron pellets.

The Kostamuksha Mining and Concentration Complex consists of an iron ore mining operation and the plant for production of steel pellets. It is one of the largest operations of its kind in Russia where low grade iron quartzite ores are converted into a high quality raw material for blast furnaces in three parallel production lines.

The production of pellets takes place in three equally large ovens. The process releases sulfur which is discharged directly into the air in the form of sulfur dioxide. Each oven emits about 20,000 tons of SO₂ annually.

The LIFAC system, with two reactors, has been provided to one of the three production lines. Two remaining lines may be provided with LIFAC later on.

The desulfurization project of the three Kostamuksha production units is part of the Eastern Europe Project launched by the Finnish Ministry of Environment. The ministry's involvement has significantly contributed to the completion of the contract.

Special Features of the Installation

The FGD process is developed from the original LIFAC process. A separate furnace was installed to convert limestone to lime. This lime is injected in the duct work upstream of the Reactor vessel. Humidification of the flue gas occurs in the upper part of the reactor. Unreacted lime is recycled back to the reactor from the reactor bottom and from the ESP.

This project has been implemented in very close cooperation with local entities. The first stage of the project included pilot tests of the suitability of the Tampella FGD system to this application. The test facility was built by the factory in Kostamuksha according to Tampella's design. Process performance tests were done also jointly. Due to successful pilot tests, Tampella's experience in air pollution control technology, and special financial and commercial arrangements, an agreement to

supply two LIFAC reactors for one of the three production lines was signed in 1992. This contract included also a concrete production and concrete block fabrication station for by-product utilization.

The second stage, the project implementation was also a joint effort. Tampella supplied the design and engineering, prefabricated reactor sections, critical mechanical and electrical components and construction supervision. The customer provided structural steel and duct work, insulation piping and installation.

The start up of the plant is scheduled for the fall of 1994. This plant will reduce 75% of the furnace's SO₂ emissions.

LIFAC AT NANJING IN CHINA

Plant Description

In cooperation with IVO International, Tampella is supplying a desulfurization plant to the Xiaguan Power Station located in Nanjing, the provincial capital of Jiangsu Provinces in China.

The LIFAC process will be installed with a new 125 MWe coal fired unit burning 0.9% sulfur coal. The heating value of the coal is 20.5 MJ/kg. The boiler will be supplied by a Chinese manufacturer. The SO₂ reduction requirement is 75%.

An agreement of the second installation in China has been signed and the design work will start in early 1995. This LIFAC system will be built also for the new boiler which should be ready in 1996.

Special Features of the Installation

Previously Tampella supplied a limestone injection system to China but this is the first complete LIFAC project.

The project will be implemented as a joint effort between two Finnish companies, Tampella Power and IVO International, and several local companies in China. Tampella Power and IVO will provide engineering, special equipment, construction and start-up supervision. Most of the fabrications and all installations will be done by Chinese companies.

LIFAC PROJECTS IMPLEMENTATION

Current LIFAC Installation

Tampella has built or has currently under construction nine LIFAC reactors. The smallest reactor unit is for a 45 MW plant in Russia and the biggest is for a 150 MW reactor treating half of the 300 MW boilers flue gas in Canada. The other installations are in the USA, China and in Finland. The complete reference list is Table 1.

LIFAC fits specially in small and medium size units, which burn coal with sulfur content ranging up to 2.5%. The maximum SO₂ capture requirement is 80%.

Project Implementation Schedule

LIFAC retrofitting requires typically 12 to 15 months. Engineering and procurement takes about six months, fabrication and construction about one year. Each plant has their own special features and requirements but most of the LIFAC systems consists of standard equipment and structures which makes the project implementation fast.

TABLE 1
LIFAC Reference List

Customer/Plant	Country	Delivery Year	Boiler Size & Limestone Injection	Flue Gas to LIFAC Reactor(s)
Imatran Voima, Inkoo 4/1 Pilot	Finland	1986	250 MW	20%
Neste, Kulloo	Finland	1986	3 MW	100%
Imatran Voima, Inkoo 4/2	Finland	1988	250 MW	50%
Prommashimport, Baikal	Russia	1988	45 MW	100%
Imatran Voima, Inkoo 4/1	Finland	1989	250 MW	50%
Saskatchewan Power, Poplar River	Canada	1990	300 MW	50%
Richmond Power & Light, Richmond IN	USA	1992	60 MW	100%
Saskatchewan Power, Shand 1	Canada	1992	300 MW	50%
Kostamuksha, Mining Combine	Russia	1994	230 MW	100%
Xiaguang Power Station	China	1995	125 MW	100%

The LIFAC system is especially suitable for retrofit applications where space is limited. Tie-ins to the plant's existing systems do not require any time other than the plant's annual outage time which is normally one to two weeks. During that time, the reactor inlet and outlet duct work and dampers are connected to the existing duct work. Limestone injection ports on the boiler wall can be installed in a few days. One limestone nozzle requires about a 100 mm opening. There are five to 10 nozzles in the upper region of the furnace.

Retrofit Project

Humidification water can be almost any water which is available at the plant. The water consumption of the 150 MW LIFAC unit is about 850 l/min.

Few instrumentation and electrical connections from the plant's systems to the LIFAC controls are needed.

Flue gas leaving the reactor is heated by by-passing small amount of flue gas from the economizer area to the ductwork before the ESP. This gas flow is max 5% of the total gas flow and requires a small duct work connection in the back side of the boiler.

Local Partnerships

Tampella has successfully used local companies and partners for marketing and implementing the LIFAC projects in several countries. Local partnerships and utilizing subcontractors benefit both the customer and the supplier. All LIFAC projects have been implemented utilizing local engineering companies, local manufacturers, power companies' expertise and local construction companies. The key issue is that Tampella will provide the technology know-how, project management and supervision, critical components for the system and performance guaranties. Local partners will provide access to local manufacturing and construction facilities and has an important role in providing local expertise to the projects.

Canadian suppliers that manufactured components for the two Canadian LIFAC installations were able to supply some equipment to Richmond LIFAC in the USA. During the execution of the projects in North America, Tampella helped Finnish manufacturers establish relationships with Canadian and US companies to manufacture equipment for LIFAC plants. There are also

opportunities to establish regular business arrangements with companies in Eastern European countries to implement LIFAC plants.

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Integrated Pollution Prevention and Waste Management

SESSION COCHAIRS:

*Karen Morehouse, Director
Centers and Special Programs Staff
Office of Exploratory Research
U.S. Environmental Protection Agency
Washington, DC, USA*

*Josef Janota, Senior Project Manager
EGÚ Prague
Prague, Czech Republic*

Session A6

U.S. ENVIRONMENTAL PROTECTION AGENCY NATIONAL NETWORK OF RESEARCH CENTERS: A CASE STUDY IN SOCIO-POLITICAL INFLUENCES ON RESEARCH

Karen Morehouse, Director, Centers and Special Programs Staff

Office of Exploratory Research
U.S. Environmental Protection Agency
Washington, DC, USA

ABSTRACT

During the 15 years that the U.S. Environmental Protection Agency (EPA) has supported university-based research centers, there have been many changes in mission, operating style, funding level, eligibility, and selection process. Even the definition of the term "research center" is open to debate. Shifting national priorities, political realities, and funding uncertainties have powered the evolution of research centers in EPA, although the agency's basic philosophy on the purpose and value of this approach to research remains essentially unchanged. Today, EPA manages 28 centers, through the Office of Exploratory Research. These centers are administered under three distinct programs. Each program has its own mission and goals which guide the way individual centers are selected and operated. This paper will describe: (1) EPA's philosophy of research centers, (2) the complicated history of EPA research centers, (3) coordination and interaction among EPA centers and others, (4) opportunities for collaboration, and (5) plans for the future.

INTRODUCTION

Unlike most of the other papers presented at this conference, this paper is not technical. It is, nevertheless, appropriate for inclusion in the conference, because inherent in the concept, "Transitions in Energy and the Environment in East Central Europe", is the idea that novel approaches may be needed to face new challenges. Nowhere is that more apparent than in the application of science and technology to solving environmental problems.

This paper was commissioned to describe EPA's network of research centers, particularly as regards pollution prevention and waste reduction. EPA's program is less a network than it is three loose confederations of centers. The centers program is itself in transition. A paper which addressed the program as a fixed entity would be confusing and unenlightening at this time. It would be more valuable to chart the course of the centers - to tell how they have evolved and why - can enlighten and instruct. The checkered career of research centers, in EPA and elsewhere, reflects the changing attitudes and the diverse pressures which influence the life of the researcher perhaps more than any technological considerations.

In many ways, technical obstacles are the least of our worries. Much more difficult to surmount are those problems which are driven by the economy, politics, and social psychology. This paper outlines pivotal historical events which gave rise to the current environmental situation and strategies being employed to address them, particularly the research center concept. By the end of this paper it should be seen that the historical context is necessary to understand why the centers are what they are and how it may be possible to generalize lessons from this experience into your own research setting. The presentation reflects the history of technological development in the United States, but the concepts are generally applicable to all industrialized countries.

I propose that research centers such as the ones described herein are potentially of enormous value to society. This value will only be fully realized, however, if society recognizes its responsibility to protect them. Things called research centers have proliferated all over the world in recent years. "Research center", as used here, means an entity formed to provide an in-depth examination of a difficult

or emerging problem, which has a stable funding base for a period of at least five years, and which is free to allow its research to go where the results take it." It is that last feature which requires careful guardianship, at least in the United States.

A Brief History of Civilization

Humankind has existed for about one million years. Although the concept of science has been understood for centuries, it was not until the 1800's when science was recognized both in Europe and the New World as a tool for economic development. During that time, we saw the invention of several modern processes and conveniences including electricity, mass transportation, and the automobile. Although the term did not come into use until later, what we were witnessing was technology, the application of science to industrial or commercial objectives. It took humanity a million years to evolve into an educated, but largely parochial and agrarian world, and only 150 years to become a global, industrialized, technology-based planet. That enormous leap required only the understanding that scientific principles could be applied to commerce.

Since 1945, we have been awash in technological marvels and the economic boon which accompanied them. We have also wreaked havoc on the environment. When we examine the extent of environmental degradation we have caused in the last 50 years, it is difficult to imagine why we waited so long to begin changing our ways. The answer lies in three simple concepts. First, it is a myth that environmental pollution is solely a problem of the modern age. London, Chicago, and New York were far dirtier in the 1800's than they are today. In the New York of last century, the clogged sewers, polluted water, garbage laden streets, particulate filled air, and free roaming pigs, were mild insults compared to the estimated 3.75 million pounds of horse manure produced daily.

The technological advances in the early part of this century caused profound and seemingly immediate improvements in the environments of virtually every city in the industrialized world. All of the economic and governmental power resides in these cities, and it was these freshly scrubbed powers whose enthusiasm propelled the fervor with which we then embraced technology.

The second basic consideration is war. The western world was absorbed by two world wars and several major regional conflicts during the first part of the 20th century and focused its social, scientific, and economic attention on solving problems immediately relating to these wars. It was not until the 1950s when people found themselves with the time to think about anything except planning, conducting, and cleaning up after war.

Economists, whether conservative or liberal, agree that while war itself is undesirable, prosperity generally follows the end of a war. That was certainly true after World War II, and the scientific and technical communities responded by introducing countless new amenities to make life easier. The United States, in particular embraced this "Age of Convenience". Refrigerators, frozen food, plastics, and television became not only commonplace, but essential. Automobiles, once luxury items, were now affordable and, therefore, deemed necessary. From there we saw the development of suburban living and the decentralization of populations. New technologies for fertilization, irrigation, building, and interior climate control made it possible to develop areas which had heretofore been unlivable.

All of this led to the third reason why we abrogated our environmental responsibilities - we were having a good time. Jobs were plentiful and salaries were generous. We owned houses with yards and air conditioners and electric lawn mowers and can openers and clothes dryers. We had leisure time and our new disposable incomes enabled us to travel, or pursue hobbies, or go to college and study engineering. No one was inspired to find anything wrong with that.

Paying the Piper

After little more than a decade of self-absorption, America glanced up and panicked. Dramatic upsurges in certain health problems showed a suspicious correlation with the state of the environment. The incidence of asthma, emphysema, and chronic obstructive lung disease was at an all-time high and, coincidentally, most of those cases presented in large urban areas. Birth defects, once rare, were becoming increasingly common. Cancer, heart disease, and ailments of the kidney and liver were

showing up more and more frequently in non-traditional populations. Livers were failing in young people. Cancer, recognized by medical science for almost a century as a rare but deadly condition, became such a common scourge that the fear of developing cancer, "cancerophobia", became an officially recognized psychiatric condition.

Meanwhile, Los Angeles, California disappeared in a toxic brown cloud of oxidants and particulates from the four million automobiles which daily traveled its freeways. Other cities were suffering similar conditions. The Cuyahoga River in Ohio spontaneously burst into flames due to the high levels of flammable solvents floating on its surface. Unexplained "red tides" caused massive fish kills. Birds fell dead from the sky. Virtually all of the surface water in the country was polluted.

In contrast to the decade before, the 1960's was a period of great activism and the environment became a rallying cry. Both candidates for President in the 1968 election had environmental planks in their campaign platforms. Richard Nixon was installed in office in January 1969 and within five months he had presented a plan to Congress to address the nation's environmental crisis. In December, 1970, the U.S. Environmental Protection Agency (EPA) was established by executive order.

The Changing Philosophy of EPA

EPA is a regulatory agency charged with preserving and protecting human health and the environment from the effects of pollutants and other anthropogenic stressors. Regulatory agencies are expected to write rules and set standards that will result in tangible improvements and they are often required to demonstrate the infallibility of their approaches. When EPA was formed, it was handed its original priorities by the President and Congress. By whatever means necessary, it was to effect a drastic improvement in the quality of the nation's drinking water and urban air and implement measures to clean up the millions of tons of trash, garbage, and industrial waste defiling the landscape.

Using the best technology available at the time, EPA rushed to write regulations that demanded air scrubbers and brought about taller smokestacks, catalytic converters, and redesigned landfills. They set stringent standards for emissions into the air and water and imposed strict penalties for exceeding those standards.

All of these decisions were made by a staff based in Washington, D.C. The only role for regional offices, States, and localities was to enforce the rules laid out in Washington. This departure from the decentralized government structure outlined in the U.S. Constitution was directed by the National Environmental Policy Act (NEPA) of 1970, which stripped the States of their traditional powers in the case of environmental protection. In addition, the specific laws which EPA was charged to enforce were written with the NEPA strategy in mind. This "command and control" approach engendered animosity among the States and localities against the federal government which, they argued, could not set national standards which were enforceable in every locality. These protests were largely ignored, so the States did not always make environmental enforcement a priority. Industries, too, complained that EPA's demands were economically impossible to meet. These industries hired cadres of lawyers to help them circumvent federal law. EPA responded with lawyers of its own and the burgeoning field of environmental law was born.

For almost 20 years, EPA operated in this way, urged on by Congressional demands, until it found itself with no allies and no reasonable prospect of success. By following the law, it had alienated its counterparts in the public sector. Environmental advocacy groups, which initially provided vocal support to EPA's efforts, were disillusioned by the agency's lack of progress and accused it of ignoring its responsibilities. Congress, whose laws and unrealistic demands were at least partially responsible for the problem, missed no opportunity to chastise the agency for its reactive approach, continued inability to enforce laws and standards, and its failure to support research on emerging and recalcitrant environmental problems. The agency's relationship with industry was adversarial. Each faction viewed the other as unreasonable and untrustworthy.

It was then-Administrator Lee Thomas who first articulated a new philosophy for EPA in 1989. Administrator Thomas eschewed the traditional and unpopular "command and control" tactics except as a last resort and advocated a partnership approach to environmental protection and restoration. EPA

would now look to industry, academia, states, and localities as allies and partners. Reactions to this new *modus operandi* ranged from cautious enthusiasm to hopeful skepticism.

THE ROLE OF RESEARCH IN THE ENVIRONMENTAL PROTECTION AGENCY

Another change which was begun by Lee Thomas and continued by his successor, William Reilly, was that EPA could no longer afford to view itself solely as a regulatory agency. Henceforth, the agency would embrace scientific research and become the primary supporter of academic environmental research in the U.S. This announcement, although welcome within the scientific and industrial communities, was even more difficult to accept than the first because of the traditionally antagonistic relationship that existed between the agency and its scientific arm.

EPA regulators have always recognized the need for data to develop and support their position on an issues, but their overriding concern is to publish the position and manifest positive results as quickly as possible. Often, they are asked to redirect their efforts in response to the latest political fad. They want results yesterday and, as we know, science doesn't work like that. They are also not always allowed the luxury of pursuing their own agenda. Politicians want to get re-elected. They don't win votes by taking the long view. They need to demonstrate immediate results. Consequently, EPA regulators are pushed to make policy or write regulations before they have reliable data upon which to base a decision.

Researchers, on the other hand, cannot respond that fast and are notoriously resistant to efforts to predict outcomes. Not only are these two groups often at cross purposes, they come from completely different cultures. These differences give rise to antipathy and tense relations. One way the EPA has strived to avert that tension is to man its own laboratories which focus almost exclusively on short term applied research and technical support. Few long term projects are undertaken by the EPA laboratories. Instead, their efforts are targeted at providing answers to regulatory questions of immediate concern. Without benefit of fundamental research on which to build these projects, there is the danger that the answers will be wrong and, as in the case of acid precipitation, damaging.

It was EPA that promoted building taller smokestacks to lower the levels of sulfur and nitrogen oxides in urban areas. They made this decision based on "quick and dirty" research which predicted dramatic reductions in ground level urban air pollution with taller stacks. They were right, and urban air quality showed immediate improvement. However, if someone had conducted the mechanistic research in advance, we would have known that these chemicals which we were injecting into the upper atmosphere were going to combine and come down somewhere where they could do serious and lasting damage over much wider areas than if they had been emitted from shorter stacks.

Research Centers in EPA

EPA has supported competitive, university-based environmental research centers since 1979, when Congress decreed that the agency had not demonstrated an ability or a willingness to protect resources to support fundamental or long term environmental research. There were eight centers originally. The process of competition and selection reflected the agency's reigning philosophy of centralized control. The specific areas to be studied were identified in advance by EPA headquarters and applications were only sought for studies in those areas. The topics selected were in direct alignment with the priorities of the agency at that moment, and included air pollution control technology, hazardous waste treatment and control, groundwater research, environmental epidemiology, and others. Immediate relevance to EPA's mission and research priorities was judged as a major review criterion.

Each of these original centers received annual base funding from EPA of approximately \$540,000. After paying overhead costs, there was little money left to support research. Management of the centers was clumsy, with administrative management responsibility residing in the Office of Exploratory Research, (OER), but project officer duties assigned to individuals in one of EPA's 12 laboratories. Each center had numerous advisory committees, each of which reflected the opinions and desires of a different, sometimes opposing, potential clientele. EPA frequently exhorted the centers to pursue special projects of concern to the agency, thus undermining the goals of the centers. In 1984, the program was re-evaluated. Plans were made to phase out the original centers and conduct a new competition in 1989.

In the meantime, two other things were happening. Tufts University, in Massachusetts, successfully lobbied Congress to appropriate funds to EPA to support a Center for Environmental Management. This center became the first of many which were established as part of a Congressional trend to earmark resources to support specifically designated research center activities. Because the center was not competitively established, EPA decided that management responsibilities should reside outside of OER, to avoid confusion with the competitive program. This center, and the others to follow, were managed out of the Office of Environmental Engineering and Technology Demonstration, the same office which manages EPA's two technology laboratories. Combining the agency's long-held belief in tight control of research with the decision to manage it out of an office with little experience dealing with academic researchers was a recipe for frustration. EPA's initial approach was too controlling and often inspired recipients to be coy in their dealings with the agency.

Also in 1986, Congress passed a law to reauthorize the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), also known as Superfund. One provision of the reauthorization allowed EPA to establish the Hazardous Substance Research Centers (HSRC) Program, a long term, university-based effort to study the programs associated with the management, treatment, control, and minimization of hazardous substances.

Hazardous Substance Research Centers

Using lessons learned in the original centers program, and working within the constraints of both the authorization and appropriate language, OER designed and implemented the HSRC program in 1988. The winds of philosophical change were now blowing in EPA, and OER, which was definitely in support of the rumored new philosophy, took advantage of the situation.

One provision of the law was that these centers had to be "equitably located across the country". The law dictated that there would be five centers. OER partitioned the country into five areas, each corresponding to two contiguous federal "regions" and held one competition per area. This made it easy for interested parties in the regional offices to participate directly with the centers. In addition, the centers cultivated relationships with each state they served. Although the problems to be studied had to have national importance, it was understood that the centers would focus on problems of particular interest to their home regions. Some other cogent features of the program are:

- all centers must be competitively established and consist of consortia of universities
- all centers must focus on some aspect of hazardous substance management or technology
- a minimum of 20% of the total cost for the center must come from the recipient institution
- the lifetime of the centers cannot exceed nine years
- each center must have an outreach and technology transfer program
- centers must each have an independent Science Advisory Committee and a Technology Transfer Advisory Committee which meet at least twice a year
- core funding for each center is approximately \$1.0 million
- each center is encouraged to find additional support for their activities and to form industrial partnerships.

After only a few years of operation, it became clear that the HSRC's represented perhaps the agency's first true victory under the new partnership approach to environmental management. The centers were able to take germinal ideas and bring them from the most basic stages of research through full field demonstration of their applicability. Because of their industrial affiliations, they also had the ability to bring their ideas to the marketplace. Finally, with representation from all areas of the public and private sector on their advisory committees, they were greatly assisted in building a continuing support base and conduits to disseminate and receive information.

The five HSRCs are listed below, with the lead institution, name and telephone number of the center director, and a brief statement of research focus:

Northeast HSRC -- New Jersey Institute of Technology (lead), Dr. Richard Magee, Director (201/596-5883 USA) - thermal destruction and in-situ treatment technologies

Great Lakes and Mid-Atlantic HSRC -- University of Michigan (lead), Dr. Walter Weber, Director (313/763-1464 USA) - development and refinement of biological remediation technologies

South and Southwest HSRC -- Louisiana State University (lead), Dr. Louis Thibodeaux, Director (504/388-6770 USA) - movement of hazardous substances through sediments

Great Plains and Rocky Mountain HSRC -- Kansas State University (lead), Dr. Larry Erickson, Director (913/532-5584 USA) - movement and removal of organics and metals in soil

Western HSRC -- Stanford University (lead), Dr. Perry McCarty, Director (415/723-4131 USA) - groundwater clean-up and site remediation, with emphasis on biological approaches

Targeted Centers

"Targeted centers" is the name recently coined by EPA to describe the collection of Congressionally-mandated research centers, such as the Tufts center mentioned above. The name derives from the idea that Congress "targeted" certain environmental problems, types of research, or institutions as priorities. These centers cover a broad range of topics and range in size from \$500,000 annually to several million dollars each year through Congressional line item appropriation to EPA's budget. Although EPA eventually developed productive relationships with the targeted centers, the agency generally disapproves of this approach to research priority setting because it presupposes priorities which may not be appropriate and circumvents the competitive solicitation and review process.

In 1993, all 15 of the targeted centers were transferred to OER to manage, overturning the earlier position to separate competitive from non-competitive centers. This decision was a positive one, in part because of OER's long experience in managing academic efforts. OER was forced to learn early that the best way to "control" what a researcher does is to set up an atmosphere in which he can thrive, guide him through the bureaucratic maze, make it clear that you will not undermine his technical judgement, and befriend him. That establishes a collegial environment in which he is in charge of doing good research and you are in charge of keeping him out of trouble.

Many of the targeted centers are not technical research centers. Several of them concentrate on issues relating to environmental policy, education, and management. Others are housed at institutions which are not known for their research capabilities, but are trying to develop an environmental research infrastructure. The list below includes those technically oriented centers with missions relating to pollution prevention and waste reduction:

Center for Environmental Management -- Tufts University, Dr. David Gute, Director (617/627-3486 USA) - broad mission which includes, among other things, pollution prevention, waste treatment, and monitoring technologies

Gulf Coast Hazardous Substance Research Center -- Lamar University (lead), Dr. Allen Ford, Director, (409/880-8707 USA) - basic and applied research on innovative hazardous substance technologies including pollution prevention technologies

Center for Excellence in Environmental Science and Engineering -- University of Detroit Mercy, Dr. Daniel Klempner, Director, (313/993-3385 USA) - research on the environmental impacts of polymers and their products, focusing on innovative production techniques and environmentally friendly polymer based products

Small Business Pollution Prevention Center -- University of Northern Iowa, Mr. John Konefes, Director (319/273-2079 USA) - basic research on pollution prevention in small industries, and technology demonstrations at actual business sites.

National Center for Excellence on Air Toxic Metals -- University of North Dakota, Dr. Steven Benson, Director, (701/777-5177 USA) - practically-oriented program on the formation, behavior, control, and prevention of potentially toxic metal emissions from energy producing and waste incinerating systems.

National Microscale Chemistry Center -- Merrimack College, Dr. Ron Pike, Director, (508/837-5222 USA) - development and promotion of new microscale chemistry techniques

Exploratory Environment Research Centers

In 1990, the original eight Environmental Research Centers (ERCs) were phasing out and OER was preparing to solicit for four new centers. By now, the agency's new partnership philosophy was in full swing, so the solicitation was not directed at certain areas of research. The applicants were free to propose any topic in environmental research, except hazardous substance research, human toxicology, or epidemiology. The applicant's defense of the importance of the proposed topic to the overall environmental community - not just EPA - was the primary criterion for review. Annual base funding for each center was planned at \$1.0 million. The organizing principles and mode of operation of the new generation of Environmental Research Centers was similar to those of the HSRC program. There were a few differences, however. With one national competition rather than several regional ones, there was no way to know whether the opportunities for regional coordination would be as good as with the HSRCs. Also, by their nature, the HSRCs were heavily weighted toward technology which attracts industrial participation and can often show results within only a few years. Many valuable topics which could be proposed under the new solicitation would require many more years before the research was mature enough to illustrate its applicability. In addition, many disciplines do not have obvious or immediate links to industry or to technological application.

After reviewing 87 applications, four winners were selected and funded by early 1992. They are:

Center on Airborne Organics -- Massachusetts Institute of Technology (lead), Dr. Adel Sarofim, Director (617/253-4566 USA) - connecting the identities and concentrations of airborne organic compounds with major anthropogenic pollutant emission sources

Multiscale Experimental Ecosystem Research Center -- University of Maryland, Dr. Thomas Malone, Director (410/228-8200 USA) - problems of scale associated with ecosystem modeling

Center for Ecological Health Research -- University of California at Davis, Dr. Dennis Rolston, Director (916/752-2113 USA) - examining the combined effects of natural and anthropogenic stressors on several ecosystems

Center for Clean Industrial and Treatment Technologies -- Michigan Technical University (lead), Dr. John Crittenden, Director (906/487-2798 USA) - identify and assess alternatives to conventional manufacturing technology

The last of these centers, known by the acronym "CenCITT", is of particular interest to this conference because of its theme of industrial pollution prevention and treatment technologies. The center, which is a consortium of three universities, focuses on manufacturing design improvements. A truly exciting development within this center is a palette of manufacturing design tools called the Clean Process Advisory System (CPAS) which is being developed jointly by the center and the Center for Waste Reduction Technologies (CWRT), an arm of the American Institute of Chemical Engineers (AIChE). In October, the National Center for Manufacturing Science agreed to sponsor a portion of the developmental work for CPAS. The State of Michigan, which provides matching funds to the center, is considering giving additional funds to further the development of CPAS.

CPAS is a computer-based information retrieval system for use by process and product designers to identify candidate clean technologies and methodologies to accomplish source reduction. CPAS tools currently under development include technology and design option information databases to help designers narrow down candidate design options, and several tools aimed at comparing costs and multimedia environmental benefits for various design options. The goal of CPAS is to make information about environmentally benign options and a wide range of pollution prevention evaluation methods readily available to designers. CPAS represents an early victory in the new centers program, which would not have been possible without a true government/industry/state partnership.

As stated above, not all research topics lend themselves to industrial collaboration. The two ecology centers, for example, have been unable to generate industrial interest in their efforts because of the theoretical nature of their work. They have been told that if they ever get workable ecosystem models running the industry would find them to be valuable tools, but industry is not interested in supporting the development of those tools. The air toxics research center is in a slightly better position because regulators have long been ready for workable atmospheric transportation, fate, and source-receptor models. They are farther away from being able to take strong regulatory positions on ecosystem health.

Similarly, it is difficult to generate interest among regulators and environmental policy makers in the basic research taking place in the non-engineering centers, evidently because it is difficult for them to see the ultimate applicability of studies which are theoretical or mechanistic. A recent example holds hope of becoming a rare victory. EPA's regional office in San Francisco, California is regularly apprised of the ecosystem health research being conducted at the ecosystem center at Davis, California. Regional regulators had been grappling with an issue regarding threshold levels of pollutants in the San Francisco River delta. They recently set pollutant standards for the delta which are not currently defensible. One main thrust of the Davis Center's basic research program is being conducted in the San Francisco River delta and will lay the ground work for the agency's defense of the standard. The regulators, who had complained on numerous occasions that the center's research was not "relevant", had not understood the importance of the center's program to their own regulatory problem.

Getting the Most Out of Centers

The above example illustrates the importance of one of the "Three C's" of successful research centers programs. Communication is essential, within the center itself, with other institutions engaged in related work, and with potential client groups. Basic researchers are not used to having to explain the ultimate utility of their work because the U.S. traditionally was generous in its support for fundamental science. In recent years, that support has diminished in favor of funds to stimulate technological advances. As a result, the "ivory tower" view of academic researchers must give way to a more pragmatic approach in which all proposed research must be justified in terms of ultimate utility. In the case of Davis, scientists and regulators had been talking past one another and did not realize that they were allies addressing different aspects of the same problem. More frequent communication could have helped, as well as greater attention on both sides to the differences in cultural and vocabulary.

Coordination and cooperation go hand in hand and are both important features of successful centers. Researchers must be aware of related efforts in other organizations and need to be willing to coordinate, to achieve the greatest impact. In a program such as the Hazardous Substance Centers program, this coordination is relatively easy to achieve. It is understood at the outset that all five centers are working toward the same goal -- controlling and minimizing hazardous substances. During their first two years of operation, the centers devoted considerable energy to defining roles for themselves which capitalized on their individual strengths, did not duplicate effort, and provided opportunities for collaboration. Most centers programs are not so homogeneous, so coordination becomes more difficult. In EPA, we are attempting to enhance coordination by sponsoring topical national workshops. A topic such as pollution prevention, analytical methods development, or bioremediation technology is selected and centers are invited from around the country. It is not necessary that these centers all be supported by EPA or even by the federal government. If their mission is related to the topic and EPA is aware of their existence, they are invited. Unfortunately, although such meetings are supported conceptually by the agency, when budget priorities are set, such activities may be seen as luxuries and not funded.

The role of the federal project officer is different in centers management than in any other research support. The project officer's role in this partnership is to form a strong, interactive relationship with the center without attempting any direct influence on its mission. The project officer helps to recruit a strong technical advisory committee and formulates procedures which facilitate the advisory process. It is critical for the project officer to keep the center director actively interested in the administrative management of the center. The project officer also plays a role in the communication and coordination activities of the center and should always be looking out for opportunities to improve communication and dissemination of research results. Perhaps the most important job of the project officer is to know the elaborate and often confusing bureaucratic rules which apply to federal grants and to make it as easy as possible for the center director to follow them.

PLANS FOR THE FUTURE

The future of the EPA research centers is uncertain at the moment, due to sweeping organizational changes taking place in EPA. As individual entities, the centers will certainly continue to exist and thrive. However, EPA is now in the process of examining its research program from the ground up and major organizational changes will almost certainly occur in the near future. These changes may be directly beneficial to the research center effort because there has been a resurgence in the agency's commitment to extramural research. How this commitment will manifest is still unclear.

CONCLUSION

The original intent of research centers in EPA was to provide a reasonably long period of stable support to academic researchers who are willing to focus their efforts on understanding and solving one complex or persistent environmental problem. That remains a primary goal, especially because of the lack of support for fundamental environmental research elsewhere in the United States. However, remaining true to that goal has become increasingly difficult because of a basic and prevalent misunderstanding of science at all levels of society. We are all beholden to technology for our present and we will rely on it for our future. But technology is not science and it is a dangerous thing to equate the two. Science is a necessary condition for the development of technology. It is not a luxury, to be pursued only when the coffers are full. Individuals at the highest levels of government, who are sincerely interested in the future of science in America, are confused on this point.

To those of us dedicated to expanding the boundaries of knowledge and promoting innovation, the increased emphasis on scientific products and relevance is a frightening concept. Another unsettling development was the redirection in 1993 of the mission of the U.S. National Science Foundation (NSF). NSF was founded as the country's basic science support function. Federal science administrators used to joke that in most agencies you could not fund any research unless you were so sure it was relevant that you already knew the outcome whereas to fund research in NSF they had to prove that no one anywhere had any use for the proposed work. Obviously, this is an overstatement, but in the new NSF mission, demonstrated utility has become the overriding necessity for work to be supported. Outside of the biomedical research community, there now remains no federal agency which is charged with supporting non-directed, innovative, or truly fundamental research. There are signs in many industrialized nations that they are following a similar path.

How do we protect the continued existence of basic research centers such as the ecosystem center described above? Despite EPA's new dedication to supporting fundamental academic research, when funds get tight the first impulse is to divert any resources being spent on theoretical or mechanistic studies. Even the engineering centers are faced with pressure to abandon the fundamental end of their work in favor of enormous pots of money being made available for straight technology development. As we continue to starve the front-end research, the urge to go where the money is becomes increasingly difficult to resist. Certainly someone needs to do the field work and academia should have its fair share at it, but if the scholars all move toward application and demonstration just to survive, who will produce the ideas which are the feedstock of tomorrow's technological advances?

I believe that it has fallen to those of us who are involved daily with scientific research and technology development to make people aware of the difference between science and technology and the need to strike a balance between the two. Those of you who are primarily engaged in technology development are particularly valuable in this regard. You know better than anyone that to funnel all of our resources into technological development at the expense of basic scientific research is to eat our seed corn. We cannot afford to do that.

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ECOLOTREE™ CAP AT THE BARJE LANDFILL, LJUBLJANA, SLOVENIA, PROTOTYPE DEMONSTRATION

Louis Licht, Associate Research Scientist
Jerald Schnoor, Professor

Department of Environmental Engineering
University of Iowa
Iowa City, Iowa, USA

ABSTRACT

The Ecolotree™ Buffer uses strategically planted *Populus* spp. (poplar) trees and forbs to prevent water pollution while growing fiber for biomass fuels, paper pulps, and construction materials. The concept, developed at the University of Iowa, uses root systems that act as a pump to predictable depths greater than 1.5 m (5 ft). The plant uptakes water, nutrients (nitrogen, phosphorus, etc.), and adsorbable organics (such as herbicides) from soil. When the plant survival, growth rate, rooted soil depth, and water uptake are predictable, the site's hydrology can be managed, and regulatory agencies are more willing to issue operating permits that include this vegetated barrier.

Poplars transpire 600 to 1000 kilograms of water for every kilogram of stem dry matter (DM) growth. Measured poplar growth rates for 4-year old trees was 16,600 kg DM/hectare/yr. Conservatively, the water uptake calculated using the 600:1 water/stem growth ratio is 10,000,000 liters/hectare/yr. When transpiration exceeds rainfall, plants remove stored water from rooted soils. This dehydrating action effectively gives the soil a water storage capacity during winter dormancy.

This Ecolotree™ Buffer technology develops the ability to greatly reduce water leakage without the need for membrane or clay layers in landfill cover soils. This concept is now being used to manage water at American and Slovenian landfills. In contrast with U.S. Environmental Protection Agency-approved clay or geomembrane covers designed with slight regard for plant growth, this cover focuses on reestablishing a vigorous ecosystem. While accomplishing the primary goal of protecting groundwater purity, the Ecolotree™ Buffer grows a productive cover that stabilizes soil slopes, produces marketable crops, develops wildlife habitat, and provides a more pleasing ambiance.

In addition, this technology is being used to revegetate industrial demolition sites, mine tailing piles, and agricultural drainages.

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NEW TECHNOLOGIES OF WASTE DISPOSAL IN CZECH REPUBLIC, EVOKED BY NEW LAWS

Luděk Peleška, M.Sc.

Czech Power Company (ČEZ)
Prague, Czech Republic

CONCEPTION OF WASTE HANDLING

Of the utmost importance for the conception of waste disposal in any country is the fact how rich the respective country is and how realistic its legislators are.

The apparently ideal approach to solving this problem is that chosen by more affluent European countries where wastes are recycled, are charged with taxes and duties, and where wastes that necessitate to be disposed are handled similarly as the nuclear wastes.

The benefits are evident. The amounts of wastes to be deposited are minimalized. The waste repositories can be sealed by using layers of clay, foil and clay, and during a period of 50 to 100 years, any communication of the repository with the ambient environments can be eliminated.

The disadvantage of such waste repositories, if applied to most of wastes, are the high costs associated with their deposition. The prices of products, which the costs of waste disposal are being reflected in, are thus increasing, and, for this reason, many of products are becoming unmarketable, even on the domestic market. These financial means are often spent for nothing because the service life of some protective elements being at present used for construction of waste repositories is limited in time (for example, the service life of isolating foil is 50 to 100 years).

Thus the problems of final solution of the waste repositories are being passed on to the descendants of our descendants.

Another approach is more complex and complicated because it requires some professional knowledge of the public service officials and cooperation of many specialists. This approach differs from that followed by affluent countries, consisting in the individual consideration of each of the repositories which are "made to measure" and not covered with a single all-knowing regulation.

Owing to the fact that there are now being available no suitable technical facilities allowing to permanently fix the wastes so as not to communicate with their surroundings in future, the communication of these wastes, for example with the underground waters, should be under control.

The decisive factor for selection of minimalized technical provisions for safeguarding the waste repositories and their location should be the local hydrologic conditions, especially the quantity and quality of the underground waters which are being mostly endangered by the waste repository.

The slowdown of extraction process of wastes can be modified by the waste conditioning, for example, by applying the solidification technique.

PRESENT LEGISLATION IN THE CZECH REPUBLIC

The legislators of the Czech Republic (and previously also of the Czech and Slovak Federal Republic), who have been reordering the waste handling legislation since 1991, may not have built up the system of the individual approach to the particular wastes and to the particular waste repositories. However, the result of their work has not been poor.

In accordance with the Waste Handling Order of the Czech Government, No. 513/92 Sb., which all the equipment of waste repositories for the individual categories of wastes is being subject to, the waste can be deposited in any of five types of the waste repositories.

The most decisive factor for selecting the respective type of the waste repository are the results of the chemical and toxicological tests carried out by the independent laboratories. These tests can simulate the long-term effects on the live organisms and can prove to be a reliable index of the effects of extracts on the environment.

For example, the waste, the extracts of which meet the requirements for extracts of soils and waste rocks, can be - if the toxicological tests will prove its unexceptionable character - deposited in the waste repository which may not be in any way sealed. This allows the large volumes of unexceptionable wastes to be deposited at low costs.

DISPOSAL OF POWER PLANT PRODUCTS

Ash, flue gas desulphurization products and waste waters produced by the power plants rank among the large-volume wastes in any industrial country.

Power company ĚEZ, a.s., where I have been employed, keeps looking for the optimum way of deposition of 8 to 10 millions of power plant products of ash, but especially of gypsum and of waste water, which will be the result of the flue gas desulphurization process introduced in the power plants.

Namely, it cannot be assumed that the existing leaky sludge beds, in which ash is now being deposited hydraulically, could allow also receiving the desulphurization products.

The large tests have proved that the best evaluation of the chemical and toxicological effects has obtained a mixture of ash with a low content of water, and/or even with the power plant gypsum added. In a few cases, the mixture has necessitated to be stabilized by adding lime.

In compliance with the Waste Handling Order of the Czech Government, No. 513/92 Sb., the mixtures thus produced are valued as the soils and waste rocks ranked with "The Other Wastes Category". Such wastes can be deposited in the waste repositories being equipped with a lowly-pervious subgrade, with the internal drains and with the monitoring system.

Adaptations of the existing sludge beds to the repositories for depositing the wastes thus conditioned represent a viable and relatively easy way. The old sludge beds should be sealed by using the ash stabilizer, and the sludge beds that are already equipped with the internal drains, will be completed with the monitoring system so as to be able to meet all legislative requirements.

Thus, when expending some reasonable financial means, the negative impacts of the power plant waste repositories upon the underground waters can be minimalized, even after a change made in the power plant waste deposition technology.

CHANGES IN LEGISLATION UNDER WAY

The environmental damage caused by applying an unfitting approach to the environment of the previous Czech and Slovak Federal Republic should be removed by expending enormous financial means. With regard to the fact that this necessitates to be done as soon as possible, it is necessary to do the necessary provisions purposively and not only on a planary level, with a view to exploiting the limited financial sources quite efficiently.

The foundation of a civilized conduct of any developed country having a corresponding care for its environment is the legislative basis in the environmental protection area, which can establish the reasonable and attainable aims.

In order to attain the entire satisfaction of the governmental agencies and of the waste producers there is only missing the issue of the new regulation that could be used for changing the categories of the existing wastes, the original classification of which in the catalogue of wastes does not correspond to their qualities shown, and that would allow to classify also the wastes not specified in the catalogue up till now.

In accordance with the proposal for the environmental policy of the government, elaborated by the Ministry of Environment in April, 1994, that missing regulation is under way to be passed and issued in this year.

According to my opinion, the legislation in the Czech Republic, when finished and completed, will be the optimum tool for prevention of the unjustifiable negative effects of waste repositories at the reasonable costs.

STREAM B

SOCIOECONOMIC ISSUES

Moving to a Market Economy

SESSION CHAIR:

*Sharon Marchant
Office of Clean Coal Technology
U.S. Department of Energy
Pittsburgh Energy Technology Center
Pittsburgh, Pennsylvania, USA*

Session B1

ENERGY POLICY OF THE CZECH REPUBLIC

Milan Černý, Vice Minister

Ministry of Industry and Trade
Prague, Czech Republic

INTRODUCTION

On February 16, 1992, the Government of the Czech Republic sanctioned, by its Decree No. 112/82, its first Energy Policy. Since that time, a number of conditions have changed: first of all, there was the partition of the former Federal Czechoslovak Republic, then the privatization of most of energy producing corporations, the deregulation of a significant proportion of power and energy commodities, the decision to bring to an end the construction of the Temelín nuclear power station, the creation of conditions for the construction of the Ingolstadt oil pipeline, etc. These steps, on which the final decisions have been made, have brought about the necessity of updating the existing general Energy Policy.

The updated Energy Policy is based on the Programme Statement by the Government of the Czech Republic of July 1992, as well as on other materials associated with energy and power generation, either approved or negotiated by the Government, in particular the State Environmental Policy the Rules of the State Raw Materials Policy, the European Association Agreement, the European Energy Charter, the results of the Uruguayan Round of GATT, the Convention on Climate Changes, the Ecological Action Programme for central and East-European countries, and other international documents that have either been, or are likely to be sanctioned by the Czech Government (especially the European Energy Charter Treaty, and the protocol on Trans-boundary Air Pollution and on Further Reduction of Sulphur Oxide Emissions).

MAIN TOOLS OF THE ENERGY POLICY

To achieve the aims of the Energy Policy, targeted at securing reliable supplies of energy at acceptable prices, the Government will utilize in particular the following tools:

- Legislative tools
- Pricing and tax policy
- Controlling and activities of natural monopolies
- Export-import policy for fuels and energy
- Direct engagement of the State in selected activities in the energy sector
- Regional energy policies

All of the steps taken by the Government during the transitional period of energy management transformation will be introduced in the legislative forms of acts or other legal regulations.

The Government envisages the sanctioning of the following legislative regulations:

- Energy Act(1994)
- Energy Management Act(1994)

- Mining Act(1994)
- Nuclear Energy Act(1995)

The policy cornerstone for regulating the activities of the individual energy generating and distributing subjects will be based on the principle that any damage to the environment will have to be paid for by whoever has caused it. The external ecological costs in the form of taxes and pollution fines will be included in the production costs like other cost categories.

The pricing and tax policy is one of the basic tools of the Energy Policy. During the transition to market economy, the price deregulation and possibly liberalization of prices and trade, jointly with demonopolization and privatization, will constitute the elementary conditions for the creation of a competitive environment. The existing deformations in the field of fuel and energy prices will be gradually eliminated in order to create price relations corresponding to economically justified costs.

The process, including the addition of external environmental costs to the prices of energy (the so-called internalizing of environmental externalities), should be concluded at the latest by 1998, and possibly earlier if allowed by a generally favorable economic and social situation.

The fuel and energy suppliers that have the character of natural monopolies, will be influenced by the State solely through Regulating Authorities. The purpose is to create a substitute competitive environment for these monopolies, to check and ensure compliance with public interests and to protect the consumers. The respective regulating conditions for the fuel and energy market, and the rights and obligations of the Regulating Authorities will be specified in detail in the Energy Act and the associated regulations.

The Government envisages formation of the Regulating Authority by January 1995, and creation of the regulating and stimulating tools ensuring efficient utilization of energy by the end of 1996.

The State and Export Policy will be implemented in conformity with the European Association Agreement, the European Energy Charter Treaty, and the other sanctioned international commitments. Imports of fuel and energy will only be restricted in cases of a danger of unfair competition by foreign suppliers, or when such an import could result in a disproportionate dependence of the import on a single supplier or territory. In view of the limited raw material resources available, the State will not support export of fuels and energy.

In the energy sector, the State will be directly committed to the following activities:

- Support of energy conservation efforts and alleviation of the negative environmental effects of energy consumption.
- Support of more extensive utilization of renewable and secondary energy resources.
- Attenuation programs for coal and uranium ore extraction.
- Creation of an efficient system of nuclear and radiation safety management and supervision.
- Putting increments in the power distribution system out to a public tender.
- Support of research and scientific activities aimed at a more efficient and ecological utilization of fuels and energy.

The conditions and extent of State participation will depend on the finances available from the budget, and will be effected in the form of contracts between the State and the recipient of the subsidy.

Energy Conservation will be promoted in particular by the following incentives:

- Grants to the industrial sector motivating saving in energy (closing of agreements on savings between the Government and the individual decisive major energy consumers).
- Granting of favorable long-term credits in the form of targeted energy conservation subsidies within the framework of publicly proclaimed programs.
- Power and energy consumption audits in industry and housing, including detailed evaluation of the economic effectiveness of the potential savings in energy.
- Expanding and improving the quality of all forms of consulting services and publicity drives aimed at promoting general awareness of the relation between consumption and rational utilization of energy on the one hand, and the state of the environment on the other.

The Government considers the method of Third Party Financing (TPF) as being particularly suitable for financing the energy conservation measures.

The tools mentioned above are to be used even after the end of the transient period to stimulate rational consumption of energy; additional ones are being considered, for example:

- Introduction of gradually stricter standard specifications for thermal insulation of buildings in connection with the construction technologies, for the purpose of attaining the degrees of insulation currently requested in Western Europe.
- Within the framework of approving regional development plans and building permits, the State and municipal authorities will request analyses prepared with the use of the integrated resource planning methods (LCP, DSM).

The Government will stimulate the development of technologies ensuring utilization of coal resulting in minimum environmental impacts. This is above all the joint generation of electric power and heat (co-generation), the fluidized-bed combustion, the gas-steam power generation systems, and treatments of local coal yielding ecologically more acceptable fuels. The Government envisages that by the year 2000, small co-generation units with a joint output of the National Economy, the Government will support implementation of energy conservation measures and changes in the structure of fuels consumed in favor of energy resources with less negative effects on the environment, and will stimulate changes in technology in the processes of energy conversions. Substitution of coal with gaseous or liquid fuels will be supported in particular in the worst environmentally affected regions, i.e. North Bohemia, Prague and North Moravia. Coal should be substituted with coke preferably in regions where centralized heat supplying is economically unviable (e.g. in mountainous areas).

Local municipal authorities responsible for the development of the respective territory will prepare the energy-related programs so as to make the entire system of energy infrastructure conform to the regional and ecological policy.

BASIC LONG-TERM AIMS OF THE ENERGY POLICY

Ensuring the reliable energy supplies for the economy at acceptable prices

By means of a market environment

The Government considers creation of conditions for making the most of the competitive elements in the energy sector as one of the key factors for its reliable operation. This is why the fuels and energy market is going to be opened and liberalized to a degree which would force the producers to raise the productivity of extraction and utilization of fuels, and that of energy and power generation and distribution. The Government will support further increases in the efficiency of the sector under precisely specified conditions (fuel and energy conservation programs renewable energy resource programs, etc.) The respective legislative regulations are going to be continuously supplemented and perfected.

By means of the pricing and tax policy

As a restructuring of the energy balance as a whole cannot depend solely on the effects of a market environment, as is the case of the other sectors of the National Economy, suitable supplementary pricing and tax tools will also be used in the Czech Republic (as is customary in other developed countries) in order to achieve the desired solutions and aims. The development of fuels and energy prices will be influenced so as to make the final price relations correspond to economically justified costs of import, extraction and possible energy. Purchase of electric power co-generated in integrated power and heating plants will be compulsory (for the distributors), and so will be that of power generated from secondary and renewable sources, the latter under favorable pricing conditions.

Diversification of Energy Resources

An adequate operational reliability of the entire energy and power supply system will be achieved by minimizing the risks specific for each of the sources, by diversifying the structure of energy and power resources, and by securing a well-balanced combination of imported and local energy resources. The closing of long-term contracts for the supply of natural gas and a diversification of oil imports are the main ways towards achieving a corresponding commercial and regional diversification of energy resources.

Minimizing the unfavorable effects of energy generation, distribution and consumption of the environment to the levels customary in the EEC countries

The negative effects of the energy sector of the Czech Republic on the environment will be suppressed in particular in the following ways:

- by an absolutely reduced utilization of primary energy resources,
- by promoting co-generation of electric power and heat,
- by restructuring the energy balance in favor of fuels less harmful to the environment,
- by raising the share of nuclear power plants in power generation,
- by desulphurizing and denitrifying selected coal-fired power stations and district heating plants,
- by promoting the use of the least-cost planning and demand-side management methods in the energy sector,
- by promoting higher utilization of secondary and renewable energy resources.

The main trends mentioned above will be supported above all by the Government pricing policy and legislative. Attainment of the ecological goals will be based in particular on the utilization of legislative tools and on the State Environmental Policy, while respecting all the accepted international commitments. Close interdisciplinary cooperation in the preparation of legislation concerning energy, raw materials and ecology will be continued in order to reduce to a minimum the harmful effects of the energy sector on the environment.

In conformity with the Environmental Policy of the Czech Republic financial resources from the budget will only be allocated to those energy-related programs which are a subject of public interest and whose culprits are unknown. A limited State subsidy will also be provided in cases when ecological sins from the past will have to be repaired (the so-called internal ecological debt).

The coal mining will be oriented so as to conform to the atmospherical pollution limits and to improve the general situation with respect to emissions on the territory of the Czech Republic. Some of the coal-fired power stations are going to be reconstructed using introduction of new technologies, such as fluidized-bed boilers and desulphurization, composite gas-steam turbine systems, lignite will be replaced with black coal, etc. In connection with starting the operation of the Temelín nuclear power station and the envisaged introduction of new independent electric power plants, the Government will

exert pressures aimed at closing down additional coal-fired power station blocks, of course without putting at risk the stability of the power supply systems.

In agreement with the State Environmental Policy of the Czech Republic, the Government plants to:

- specify the coal extraction limits as a basis for formulating the Raw Materials Policy in 1994
- link the attenuation programs for the mining industry with the creation of funds for recultivation purposes in 1994
- strengthen the mechanisms of ecological supervision over mining by 1996
- implement the Program for Recultivation of Devasted Territories by 2000
- prepare and introduce the Carbon Tax by 2000
- determine and attainment of permissible plan emission load limits by 2005.

SHORT-TERM TARGETS OF THE ENERGY POLICY IN THE ENERGY SECTOR

Finalization of privatization and restructuring of the energy sector

The aim is to reduce the ownership share of the State in joint-stock companies and thus to restrict the possibility of direct involvement of the State in the management of joint-stock companies. The process of reducing the ownership share can only be started when conditions are created for certain alternative ways of regulating the operation of the sector, in place of the majority share holding by the State in the companies. It is also necessary to first stabilize the running of the joint-stock companies in the energy sector and to make sure that their management is not at variance with State interests.

Finalization of the energy legislation, a fully operational Regulating Authority, and a pricing system respecting the market principles and implementation of the State Energy Policy, are the essential prerequisites for reducing the State ownership share.

Finalizing the Status of the Energy Agency

On the basis of experience gained so far from the operation of the Energy Agency, whose status, aims, main tasks, way of control and relations to other authorities and institutions of the Czech Republic are at present based on preliminary statutes, it is necessary to prepare definitive statutes by the end of 1994. The range of activities of the Energy Agency and those of the State Energy Inspection, will also have to be newly delimited.

Determination of the Regulating Framework, and Establishment of the Regulating Authority

The suppliers of energy and fuels, who are natural monopolies, will be economically influenced by the State solely through the Regulating Authority. The rules and extent of the regulating activities will be precisely defined by the respective legislation.

Reducing the Production of Pollutants by the Existing Large Sources of Contamination in the Energy Sector

The production of pollutants by the existing large sources of contamination will be reduced first of all by cutting back their operation, by changing the structure of fuel consumption, by modifying the combustion technology (transition to fluidized-bed combustion), and by the application of desulphurization and denitrification of flue gases. Inclusion of externalities (environmental fines and compensations) in the energy production costs will likewise have its favorable effects. The development trends in the field

of generation of pollutants must be aimed at minimizing the negative environmental effects of energy generation, distribution and consumption, and at achieving the respective standards customary in EEC countries.

Finalizing the Basic Legislation and the Information System in the Energy Sector

All of the steps taken by the State during the transient period of transformation of the energy sector and its management will be introduced in the legislative form of acts, or will be based on this legislation and focused on achieving the target state of power and energy generation and consumption. The documentary techniques and the complete information system of the energy sector should be transformed in terms of system and methodology by 1996 so as to be compatible with the information system at present employed in OECD and EEC countries.

CONCLUSION

The target state of the energy management will be characterized in particular by the following:

The structure of energy-related legislation, corresponding to a stabilized market economy, and also taking into account possible emergency situations.

- The structure of prices based on the existing local conditions and on the situation in the European and world markets, and including all externalities, namely environmental costs.
- A stabilized trade and territorial diversification of energy resources, both domestic and imported ones, including the creation of reserves for emergency situations.
- State interventions in the field of energy and power management will be restricted to legislative and fiscal ones as is usual in market economies.
- The Energy Policy will be focused first of all on a permanently tenable development of the society.
- Regulation of fuel and energy suppliers having the character of natural monopolies.
- An information system methodically compatible with information systems employed in OECD and EEC countries.

Attainment of these goals should create conditions for the establishment of trends ensuring satisfaction of all the present necessary needs of the society without impairing the potential for satisfying the needs of future generations.

The Updated Energy Policy is supplemented with a document called "Comments on the Updated Energy Policy of the Czech Republic". The latter material comments in detail the starting points for, and the connections between, the individual targets and tools of the Energy Policy, and the respective bonds to the present stage economic development both at home and abroad. Also included is a prediction of future developments in energy management and the assumptions on which the prediction is based. The Government assumes that the Comments will be updated at two-or three-year intervals, whereas the Energy Policy should have a long-term validity.

GOVERNMENT POLICIES AFFECTING FOREIGN INVESTMENT

Jan Pouček

Department of International Cooperation
Prague, Czech Republic

Giovanni Caprioglio

Ministry of Industry and Trade
Prague, Czech Republic

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BUSINESS MANAGEMENT PRACTICES IN THE POWER INDUSTRY: DECISION MAKING IN A MARKET ECONOMY

James H. Brown, Principal

Fieldstone Private Capital Group
New York, New York, USA

Vladimir Rosel, Associate

Fieldstone Private Capital Group
Prague, Czech Republic

ABSTRACT

Management of a free market power industry, or managing the transition from a planned economy to a free market one, is driven by a fundamental economic premise - it is unrealistic (and economically unsound) to try to shelter end users (manufacturers or otherwise) from the true cost of energy:

- (i) energy prices are a function of fuel inputs
- (ii) fuel inputs are world priced
- (iii) end users must pay prices based on true costs

Trying to counter any of these dictates will cause economic inefficiencies and misallocations.

Managers of energy production in a free market economy must therefore learn to acquire data, and learn to extrapolate. As information is never complete, or perfect, managers must learn to consider contingencies, alternatives and options. In a free market economy, the decision to build a power facility is not controlled simply by the recognition of a perceived need for more power in an area. Because survival in a free market economy requires making a profit, as part for the decision process managers must:

- (i) talk to their customers to determine power needs into the future
- (ii) talk to their input suppliers, and arrange contracts
- (iii) make sure that there is a spread between cost and revenue

As stated this is a simple recipe, but is difficult in practice. To perform any forecasting, managers must acquire control over cost, so as to have a base from which to judge the continued profitability or potential profitability, of any current activity or future ventures.

It should be noted that planning for the future is difficult at any time but even more so when moving through an era wherein the entire economy is undergoing systemic changes. Historic customer base, and historic supply arrangements, may not mean much. Therefore, managers must keep acquiring information, and updating forecasts.

INTRODUCTION

We think it best to narrow our presentation at this point to a specific issue within the power sector and yet at the same time touch topics which are relevant in a more general context. We will focus our discussion upon the decision making process with respect to either the building of a new power

generating facility or the purchase or significant refurbishment of an existing facility. We can proceed in this manner because in either of those endeavors the process by which the decision maker will resolve most of the issues would be the same for any task within the industry. We also proceed under the premise that in a market economy, with constraints upon access to capital, decision making is almost completely dependent upon cash flow analysis.

In a market economy, decision makers must be guided by the "invisible hand" identified by Adam Smith in his book, *The Wealth of Nations*. To be so guided it is necessary to identify and consider as many of those elements which influence the movement of the "invisible hand" as possible.

In a market economy, it is not prudent to contract for the construction of new power facilities merely after quantifying the existing sources of power, applying factors of age and obsolescence to those facilities, considering hypotheses of growth in demand and calculating how many megawatts of new generating capacity are needed. One must add to those factors the consideration of many others: free market prices of fuel; environmental issues within the sovereign state and beyond; differing technologies and the financial support of the suppliers of that technology; the financial support of equipment vendors; the stability of the EPC contractor; the financial strength of the purchaser of the power; providing prices; competing power alternatives from outside the sovereign state; and, overshadowing all of the foregoing, the legal framework in which all the contracts are written. Moreover, since in a market economy the price of financing is also a variable, one must be cognizant of the fact that the more compelling the overall plan, the less the cost of the financing. By "compelling" we mean the plan demonstrates an excess of revenues over operating and financing expenses in a credible scenario.

As the decision maker works his way through all of the foregoing issues, as well as many others too numerous to mention here, he must be developing a cohesive plan which will be able to be financed. We speak of "financed" here in the most general way possible, gathering the revenues to fund and build the project. If, for example, a large utility uses cash from its balance sheet to develop a generating cost, as such funds cannot then be used to fund other projects or pay dividends to shareholders, etc. The guiding premise concerning the ability of a plan to be financed is the cash flow generated by the venture. If energy is sold at a price sufficient to provide revenues which exceed the cost, both direct and indirect, to generate that energy there will be a positive cash flow and the opportunity to run the facility for its expected useful life. Of course, should a Government, or utility or large industrial company decide to ignore the impact of the marketplace, any given power plant can be built or refurbished regardless of cost. In the long run, such an action will however, result in economic dislocation. This paper presumes that the decision process will be undertaken in a manner consistent with economic efficiencies.

Let's turn to some of the issues just mentioned, examine them in slightly more detail and develop this theme into a rudimentary blueprint for the realization of a power project in a market economy.

ENERGY NEEDS

The developer of a new power project or one who is purchasing or refurbishing an existing plant in a market economy must consider power needs on several levels. On a macro basis, it is important to consider the overall capacity of the economy in which one is operating and the economic predictions for that economy for some 20 years into the future. On the other hand, the local conditions will likely impact even more directly the decision process. To whom will this power be sold? Is there a local user of energy whose needs are such that it will commit to take sufficient power to justify the building of the plant? Does the distribution utility for the geographical area find itself in a position where it is willing and able to purchase the power under a long term contract? Is the utility willing to pay for capacity? The answers to these questions will guide the decision maker along the process of determining whether the power contemplated is needed or appropriate in both the macro economy and the local economy. The answers will further help determine whether the plant can be sustained economically. That is to say, "will it pay for itself?" If it won't pay for itself, some other sector of the economy will be penalized to allow the power plant to exist, and more importantly, the capital sources might not be persuaded to invest.

TECHNOLOGY ISSUES

When considering a power plant and the technology to be used, market forces impact upon the decision as heavily as do scientific and engineering data. Competing technologies might be offered at different pricing so as to influence a decision away from the "ideal" technology toward another technology offered at a lower overall price. Price in this instance can be adjusted many ways. The supplier might be willing to provide a long term payment schedule, invest equity or provide some other economic inducement or the supplier's government may have an export financing agency which assists in the transaction. The objective is to maximize the cash flow of the project. One other area of consideration when choosing technology is the predictability of operating costs, and production efficiency related to the technology as well as the reliability of the overall facility when completed. Financial models developed based upon simple, tried and true systems will be more credible than those based upon new or exotic technology. The "best" decision in a market economy is not only technology driven, it is financially driven.

FUEL ISSUES

Many disparate factors must be considered when making decisions with respect to fuel. Of course there are the technological issues such as BTU content or its equivalent and the attendant complexity or simplicity of the power plant required to use the fuel being considered. But there enter into this formula other factors such as the long term availability of the fuel, whether viable contracts can be drawn to establish the price, consistency, delivery, etc. of the fuel of choice. Of course, in many East Central European countries, there are also political issues surrounding fuel choice such as the impact on the environment, the availability of the fuel within the local economy, employment in other sectors such as mining. As you of course realize, the political issues cannot be easily quantified. Once a choice of fuel is at hand however, the ability to write contracts to provide for its availability at a price is significantly important, in fact a virtual necessity in almost all instances, if financing is to be obtained.

ENGINEERING, PROCUREMENT, CONSTRUCTION

The choice of EPC contractor is as vital as the technology decision, in this market economy process. The choice is important not only because of price quotes from the competing bidders but also for the experience which financial sources have with the contractor. The credibility which the contractor has in the financial marketplace is part of the "compelling" story we alluded to earlier. The EPC contractor must have sufficient financial strength in his own right to satisfy the scrutiny of financing sources, and he might even be looked upon as a de facto investor in the project. Unless the plant under consideration is being developed by a large utility or equivalent which is acting as its own general contractor, it would be normal to engage a creditworthy contractor to carry out design, engineering procurement and construction on a fixed price date certain turnkey basis. The turnkey contractor will, in effect, guarantee the performance of subcontractors and equipment supplier and assume "single point" responsibility for the overall construction of the project. The contract will contain completion tests and liquidated damages which will be payable if the tests are not met by the specified date.

POWER PURCHASER

As was discussed earlier, the decision process must include an analysis of the potential power purchasers. Whether the purchaser be an industrial company or a utility or a municipality or a combination of all three, their individual or collective financial strength must be sufficient to satisfy the financial community that the revenue stream is predictable. The concept of a "merchant plant" is being developed in some countries in the West, (a merchant plant being one which is built under the assumption that the power can be sold profitably on a spot basis in an unlimited wheeling environment) and some have been developed on that basis. For the present, within the boundaries of the East Central European countries, developers will have to assume that the markets will demand that sufficient offtake relative to revenue projections has been sold under long term purchase agreements from creditworthy customers if they wish to have their project financed.

CONSUMER ISSUES

In most market economies, a local monopoly for the sale of power is created in order to deal with the factor of economy of scale when it comes to the production and distribution of electricity and heat. Notwithstanding that fact, the concerns of individual consumers must be considered. Maintenance must be scheduled to minimize or eliminate power interruption. Prices must be realistic. If prices are set too low energy will be wasted and the revenues sufficient to support the system will be required to be subsidized. If on the other hand they are set too high, consumers and industry will suffer and react. World prices for energy become a benchmark against which prices are compared. A "service" mentality must be fostered, so that consumers do not feel totally abandoned to the system. Regulatory systems must be seen as fair-weighing the concerns of both consumers and industry. This last point is primarily political but it is one which must be considered.

COMPETING ALTERNATIVES

As countries become more integrated into the economic communities of Western Europe, their decision makers will be impacted by the prices, availability and service, of the power producers in neighboring countries. The world prices for power will impact decisions, since it will become more and more possible to buy and sell power across sovereign borders. The decision maker can then assess, based upon his internal cost analysis whether his power plant is competitive and using that assessment realize whether his plant is viable. Obviously if there is a great disparity between his prices and competition, he is faced with a realization that his plant is on uncertain financial foundation or, on the other hand, able to wheel power for sale into his competitors' markets. Of course tariffs and protectionism are potential factors, but they are able to be added into the decision model once they are identified.

CONTRACTS

As the countries of East Central Europe gravitate to market economies, the governments must protect the viability of contracts. Whether we are speaking of taking a government owned facility or the private sector or developing a new facility, the ability to provide protection and price/cost comfort through enforceable contracts is absolutely essential. The commercial contracts form the basis of the security structure which creates the project cash flow and hence underpins a project financing. The typical principal contracts are as follows:

Engineering, Procurement and Construction Agreement

An experienced and credible turnkey contractor is key to the development of a project as lenders will be placing significant reliance on the contract to ensure that a project is completed on time and performs, from a technical perspective, as expected.

Site Agreements (lease, etc.)

Obviously, the ability of the owner to utilize the site for the projected term must be affirmed through satisfactory documents of ownership or lease and contained within those documents must be the freedom to conduct business in the manner required by the facility.

Fuel Supply Contract

A fuel supply contract exceeding the term of debt or other forms of capitalization is required. The contract must specify the amount and characteristics of fuel to be delivered on a daily, monthly and annual basis.

Operating Agreement

The operation of the plant will be expected to be carried out by a company or entity with an appropriate track record of successful operation. This is of course more important to technologies where operation is more complex rather than projects where operation is relatively straight forward.

Power Purchase Agreement

This contract is the cornerstone of most power project/plants. As with the fuel supply contract, the power purchase agreement is required to be of sufficient length and with pricing mechanisms to satisfy the needs of all parts of the capital structure.

Shareholders Agreement

This agreement governs the relationship between the shareholders or joint ventures and will be reviewed carefully by all providers of capital.

SUMMARY

In all of the foregoing, it is by now very apparent, we have expressed our belief that the discipline of a market economy is provided by the need to have sufficient capital to accomplish one's goals and the subsequent performance of the enterprise will be expected to provide a return on that capital. We have attempted in this short session, to bring into focus a number of issues which will face decision makers in the power industry as the countries of East Central Europe continue to develop their market oriented economies. Certainly these are not all the issues but we believe that they are central to the process. They have been taken from our firm's experiences in dealing with the power sector in countries wherein market economies have long since impacted upon the decision makers.

Capital/Financing

SESSION COCHAIRS:

*Joe Peyton, Engineer
Southern Electric International
Birmingham, Alabama, USA*

*František Kopřiva, Managing Director
Citibank
Prague, Czech Republic*

Session B2

STRATEGIES FOR FINANCING ENERGY PROJECTS IN EAST CENTRAL EUROPE

Stephen E. Fortino, Senior Project Coordinator, Finance Department

Texaco Inc.
White Plains, New York, USA

ABSTRACT

This paper discusses financing options available for energy (power/steam) projects in East Central Europe. It is intended to be an overview and practical guide to such options in today's environment.

A survey is made of the principal multilateral and other financial institutions providing funding and/or credit support in the region. These include the European Bank for Reconstruction and Development, the World Bank, the International Finance Corporation, the export credit agencies, and the commercial banks. Specific guarantee and other support mechanisms which some of these institutions provide are covered, including the latest developments. In addition to loan financing, potential sources of equity financing are discussed.

Next, a description of the credit rating process by such institutions as Standard and Poor's, and an example of a successful rating effort in the Czech Republic, lead into a discussion of accessing foreign and domestic bond markets to finance energy projects in the region.

Good afternoon. It is a pleasure to speak before this group today on the key financing mechanisms and strategies available for energy projects in East Central Europe. By "energy" projects I mean those involving one or more of power, steam, and district heat production.

Over the past several years, I have been heavily involved in project finance and development efforts by Texaco and its partners on Integrated Gasification Combined Cycle (IGCC) projects in the Czech Republic and China.

Permit me to say briefly that the Texaco Gasification Power Systems technology has broad applicability in East Central Europe, with its abundant supply of coal and lignite, and excess supplies of heavy vacuum residual (HVR) fuel requiring economical, environmentally friendly disposition. In addition to gasification project development, Texaco's Alternate Energy and Resources Department is engaged in operating and/or developing traditional cogeneration facilities worldwide. I would direct your attention to the appendix to the text of this speech for an interesting paper comparing the economics of IGCC and other clean coal power options.

I would like to begin with a discussion of the World Bank's guarantee program as I feel it can be of particular value in East Central Europe. To date, the Bank's support for infrastructure projects has been predominantly in the form of direct loans, rather than guarantees. Under recent policy changes in the Bank, much greater emphasis will be placed upon guarantee operations in the future, for both public and private sector projects. For those governments in East Central Europe willing to provide the counter-guarantees required to be made to the World Bank under its charter, World Bank guarantees represent a powerful mechanism to help finance public and private sector energy projects. The Bank's objective is to cover those risks it can bear on account of its preferred creditor status and overall relationship with emerging market countries, particularly in situations where projects might not otherwise occur.

World Bank guarantees can take the form of either partial risk guarantees or partial credit guarantees. In the context of private sector project financings, partial risk guarantees cover specific government-related or political risks that contractual obligations undertaken by governments or their

agencies may not be honored. Partial risk guarantees may also cover the risk of currency inconvertibility. Examples of government contractual obligations would include those involving the regulatory system, including electricity prices, power plant fuel supplies, payment for power by the government or its agencies to an independent power project, and compensation for project delays or interruption caused by government actions or political force majeure events.

Partial credit guarantees are typically used to extend debt maturities beyond the terms that private lenders might otherwise provide. This could be done by guaranteeing later debt maturities or that financing will be rolled over. I would now like to review with you some recent applications of the World Bank guarantee program to power project development in emerging markets.

The Hub Power Project in Pakistan is one of the largest privately owned power projects currently being implemented in the developing world. Total financing of \$1.9 billion for this 1292 MW project is to consist of 75% debt and 25% equity. The Bank is to provide a guarantee against specific political risks on principal payments of \$240 million to a commercial banking syndicate under a twelve year loan. The covered risks include payment by the national utility under the long term power sales contract, performance by the government-owned fuel oil supplier, and the obligations of the Central Bank to provide foreign exchange. Force majeure coverage includes changes in law, local political events, specified natural events and foreign exchange transfer.

Utilizing a World Bank guarantee, the Yangzhou Thermal Power Project was able to raise \$120 million equivalent of competitively priced loans from commercial banks and insurance companies for a term of fifteen years, significantly longer than maturities typically available to China.

And, in the Philippines, a World Bank guarantee enabled the National Power Corporation to issue \$100 million of bullet maturity bonds for a geothermal power project for fifteen years rather than the ten years typically available to Philippine borrowers in the international capital markets.

World Bank guarantees should be viewed as a complement to the private sector financing activities of the World Bank Group's International Finance Corporation (IFC). The IFC lends without sovereign loan guarantees, usually for overall terms of from seven to twelve years, and enjoys the preferred creditor status of the World Bank. The IFC can provide debt (so-called "A" loans) and/or equity financing of up to \$100 million on its own account. Owing to its preferred creditor status and the protective "umbrella" this creates, it can attract commercial bank participation in loan syndications (so-called "B" loans) at a multiple of its own participation. For certain project financing "packages" to succeed may require the provision of both World Bank partial risk and/or partial credit guarantees and IFC "A" loans and "B" loans.

The European Bank for Reconstruction and Development (EBRD) is similar to the IFC in its preferred creditor status, its own "A" loan/"B" loan structure, and in providing debt and equity financing for private sector projects without sovereign loan guarantees. For the EBRD to attract commercial bank participation in some private sector project financings with particular sovereign risks may, however, require certain sovereign performance guarantees, analogous to the IFC co-financing with World Bank partial risk guarantees. The maximum term of an EBRD power project financing would typically be fifteen years including construction.

What I would like to focus on here is a proposed performance guarantee or "Indemnity" mechanism which the EBRD has been developing in connection with Polish power projects, but which could be applicable in other East Central European countries as well. I want to thank my colleague Roland Crabbe of the EBRD's Power and Energy Utilities Group for information on this development.

To leverage its limited capital resources wherever possible, the EBRD must be able to attract the maximum participation of commercial banks as project co-lenders. The Indemnity is designed to deal with the commercial banks' well known aversion to risk by laying off certain political or non-commercial risks to the EBRD.

The Indemnity would guarantee immediate indemnification of commercial bank defaulted principal repayments, up to an annual pre-determined cap. The Bank's expected maximum exposure to a project's total investment cost, including capitalized interest, is ordinarily 25 % (although under the Bank's policy

guidelines this can be increased to 50%). The Bank would set its total debt Indemnity exposure by taking the present value of the stream of project loan principal repayments and by ensuring that this present value does not exceed two thirds of its expected maximum exposure. The balance of one third is likely to be the EBRD's debt participation, although an equity participation is also possible. The 2/3:1/3 ratio could be modified depending on a project's requirements.

Certain very specific events would have to contribute to the defaulted loan repayments before the EBRD's Indemnity could be called, similar to the World Bank's partial risk guarantee. In the EBRD's view, the allocation of project risks for an independent power project would then typically be:

- The public utility offtaker assumes fuel price, power purchase and foreign exchange risks.
- The independent power producer assumes post-completion performance and currency transfer risks.
- The EBRD assumes defaulted commercial loan principal repayment obligations for certain events of contractual non-performance such as failure to supply fuel and to offtake power, and assumes certain force majeure risks.
- The Government assumes, through a counter-indemnity form of guarantee to the EBRD, the same defaulted commercial loan principal repayment obligations borne by the EBRD, and also assumes certain force majeure risks.
- The commercial banks rank *pari passu* or equally with the EBRD, which is the lender of record.

It is the EBRD's view that the mechanics and accounting for its Indemnity as compared to sovereign loan guarantees result in a significantly lesser impact on governments' contingent liabilities, thereby enabling governments to support a larger volume of projects under the Indemnity scheme.

The European Investment Bank (EIB) has a program to finance projects in Central and Eastern Europe. In general, the loan maturities can be for up to ten to twelve years for industrial projects and twelve to fifteen years (exceptionally up to twenty years) for infrastructure, including energy. The EIB lends hard currencies at fixed rates at a modest margin over its AAA cost of borrowing. However, the EIB requires either sovereign loan guarantees or other "first class" security, including bank and corporate guarantees.

The OECD Consensus for export credit allows export credit agencies to finance or guarantee a maximum of 85% of export contract value. Two particular trends are enhancing the availability of such export credit for projects in East Central Europe. First is the more liberal attitude toward private sector credit risk in East Central Europe. For example, the U.S. Eximbank, which until last year required either commercial bank or government guarantees for loans to the private sector in the Czech Republic, Hungary, Poland, and Slovakia, no longer has such a requirement. Second, the U.S. Eximbank, the Export Credits Guarantee Department (ECGD) in the U.K., and other export credit agencies are devoting more resources to providing limited recourse export credit financing to infrastructure projects generally. Given their respective present OECD income classifications, the Czech Republic and Slovakia would qualify for a maximum export credit period of five years following construction, and Hungary and Poland 8.5 years following construction.

While foreign currency financing of large energy projects in East Central Europe is likely to predominate for quite some time, local currency financing mechanisms are available which can be used to finance local working capital requirements and to mitigate foreign exchange exposure. The slide outlines some of the local financing mechanisms currently available. Note the availability of short term loans, overdrafts, and commercial paper for short term financing purposes. In the corporate bond market, maturities in the Czech Koruna are now mainly in the three to five year range but have gone out as far as seven years. The Hungarian forint bond market is at present mainly in the three to five year range and dominated by subsidiaries of multinational corporations. The expectation is for the local currency bond markets to expand or develop throughout East Central Europe.

Turning to equity capital potentially available for energy projects in East Central Europe, there are a good number of sources. These would include U.S. and European utility subsidiaries, such as Southern Electric International, equipment and technology vendors, engineering contractors, pension funds, insurance companies, the IFC and the EBRD as direct investors, and closed-end mutual funds specializing in power projects or in Eastern Europe. The latter would include the Global Power Fund sponsored by General Electric Capital, the IFC, and the Soros interests, and Capital International's New Europe East Investment Fund, whose shareholders include pension funds, the IFC and the EBRD. Having made an equity investment, an investor can insure it against loss caused by political risks through agencies such as the World Bank's MIGA. Such risk coverage by MIGA would include currency transfer, expropriation, war, revolution and civil disturbance, and breach of contract, and is subject to a limitation of \$50 million per project.

Having surveyed the principal sources of capital and financing for energy projects in East Central Europe, I would like to outline briefly a typical Build, Own, Operate, Transfer ("BOOT") project structure for an independent power project. Whether or not there would be a transfer of power facility ownership to the utility offtaker after a pre-determined period could vary from country to country and from case to case. For example, I have been advised that the environment in Hungary today would favor a Build, Own, Operate or "BOO" structure.

A joint venture project company with foreign and local equity ownership would be formed to develop, build, own, and operate the power facility. Under the terms of the BOOT Agreement between the project company and the offtaker utility, facility ownership would after, say, fifteen years be transferred to the utility without charge, the project sponsors having recovered their capital and earned a return on investment. During the fifteen year operating period, the utility would pay a power price consisting of a capacity fee covering debt service and return on investment, a fixed operating and maintenance fee, and a variable energy fee recovering fuel costs and other variable operating costs.

The ability to raise debt financing for such a project will depend on an assessment of its overall creditworthiness. I would therefore like to conclude with a discussion of the credit rating process by such institutions as Standard and Poor's (S&P) and how it can open up the international capital markets to energy project financings in East Central Europe.

In rating projects issuing debt cross border, S&P imposes a sovereign risk limit that rates the projects no higher than the countries in which the projects are built. This limit reflects the risk that, in a crisis, a country may impose exchange controls or put other restrictions on the ability of a project to pay foreign debt holders. Thus, foreign debt financed projects in the Czech Republic, Hungary, and Slovakia, rated BBB+, BB+, and BB-, respectively, would be rated no higher than these respective sovereign ceilings. I would also like to note the expectation by some that Poland, which is presently not rated, could receive an investment grade credit rating of at least BBB- by sometime next year.

In rating power project debt, regardless of location, S&P would consider the following seven risk factors, whose weightings could vary widely from project to project: output sales contracts (including the capacity, operating and maintenance, and variable energy fee structure I mentioned earlier), power costs, fuel risk, default risk structure (i.e. capitalization, financial covenants, debt service reserves, insurance), technology risk, power purchaser's credit strength, and the project's projected financial results. For projects with political and currency risks, such as foreign debt financed projects in East Central Europe, would assess the level of risk and the strength of the strategies for mitigating them.

In May of this year, S&P announced its assignment of a BBB- rating to CEZ, the (Czech national power utility. With this investment grade rating, CEZ can tap the international capital (bond) markets cost effectively. And, a power project financing with CEZ as principal offtaker would benefit greatly from the credit strength represented by this rating.

I would like to outline briefly some of the advantages and disadvantages of utilizing the international capital markets for emerging market project financings, especially compared to commercial bank financing. Some advantages would include:

- The greater willingness to take country risk exposure than commercial banks

- Longer maturities, up to twenty years
- Less restrictive financial covenants
- The ability to lock in favorable long-term rates and
- Quicker execution, assuming all project documents and third party studies have been finalized

Some disadvantages would include:

- The difficulty of negotiating amendments with passive investors
- Possibly prohibitive issuance costs for smaller projects
- Potential market volatility and
- The problem during construction of investing bond proceeds at interest rates below the rate on the bonds, so called "negative arbitrage"

Let me say in conclusion that I hope I have shed some useful light on the subject of energy project financing in East Central Europe. Time permitting, I would be happy to entertain your questions.

SLIDES

WORLD BANK GUARANTEES EXAMPLES

- Hub Power Project
(Pakistan)** **Partial Risk
Guarantee on
\$240MM of 12 Year
Loan**

- Yangzhou Thermal Power
Project (China)** **Extended Maturity
of \$120MM (equiv.)
Loan out to
15 Years**

- National Power Corp.
(Philippines)** **Extended Maturity
of \$100MM of
Bonds from 10 Years
to 15 Years**

WORLD BANK GUARANTEES DEFINITIONS

- Partial Risk Guarantee - Covers Contractual
Performance by Government**

- Partial Credit - Guarantees Debt Repayment/
Rollover**

INTERNATIONAL FINANCE CORPORATION

- **Loan Maturities** **7-12 Years**
- **Max. "A" Loans/Equity** **\$100 Million**
- **No Sovereign Loan Guarantees**
- **"A" Loan/"B" Loan Syndication Structure**

EBRD PERFORMANCE INDEMNITY

- **EBRD Max. Exposure** **Ordinarily 25%
of Total Cost**

- **PV** Principal **≤ 2/3 (Max. Exposure)**

 Repayments

- **Balance of 1/3** **EBRD Loans/Equity**

- **2/3:1/3 Ratio is Flexible**

EBRD PERFORMANCE INDEMNITY RISK ALLOCATION

Risks

- | | |
|-------------------------------------|---|
| ● Public Utility Offtaker | Fuel Price,
Power Purchase,
FX Rate |
| ● Independent Power Producer | Post-Completion
Performance,
Currency Transfer |
| ● EBRD | Commercial Bank Loan
Repayments, Certain
Force Majeure |
| ● Government | Counter-Guarantees
EBRD, Certain Force
Majeure |
| ● Commercial Banks | Pari Passu with EBRD |

SOME LOCAL CURRENCY FINANCING MECHANISMS

	Czech Republic	Hungary	Poland	Slovakia
Short and Medium Term Loan Facilities	✓	✓	✓	✓*
Overdrafts	✓	✓	✓	**
Leasing	✓	✓	✓	✓
Commercial Paper	✓	✓	✓	—
Corporate Bonds	✓	✓	***	✓****

* Medium term loans possible but difficult to obtain

** Prohibitively expensive

*** Expected soon

**** Disadvantaged by tax exemption on Government bonds

SOURCES OF EQUITY

- **Utility Subsidiaries**
- **Equipment/Technology Vendors**
- **Engineering Contractors**
- **Pension Funds**
- **Insurance Companies**
- **IFC, EBRD**
- **Specialized Mutual Funds**

POWER PRICE COMPONENTS

- **CAPACITY FEE**
- **FIXED O&M FEE**
- **VARIABLE ENERGY FEE**

STANDARD AND POOR'S (S&P) RATINGS

Rating Categories

AAA	Highest Rating
AA	
A	
BBB	Minimum investment grade (BBB-)
BB	Top end of speculative grade (BB+)
B	
CCC	Vulnerable to default
CC	
C	

Sovereign Ratings

Czech Republic	BBB+
Hungary	BB+
Poland	Not yet rated
Slovakia	BB-

S&P PROJECT CREDIT RATING FACTORS

- **Output sales contracts**
- **Power costs**
- **Fuel risk**
- **Default risk structure**
- **Technology risk**
- **Power purchaser's credit strength**
- **Projected financial results**

Plus: Strategies for mitigating political and currency risks

APPENDIX

TEXACO POWER GENERATION INTEGRATED GASIFICATION COMBINED CYCLE



TEXACO INC.
2000 Westchester Avenue
White Plains, NY 10650

COMPARISONS OF THE ECONOMICS OF INTEGRATED GASIFICATION COMBINED CYCLE POWER GENERATION AND OTHER CLEAN COAL POWER OPTIONS

Richard Weissman

Alternate Energy and Resources Department
Texaco Inc.
White Plains, New York, USA

INTRODUCTION

Since the second World War, the electric industry, however organized in each European country, has shown the characteristics of a monopoly supplier. Today, a new perspective is emerging and is forcing the electricity industry to change its ways: across Europe electricity is being seen as a commercial commodity that must be supplied to customers by efficient business at competitive prices. This change is driven by competition and commercial orientation, the transition of the Eastern European economies, and public demand for a cleaner environment.

Competition is an important new feature of the European electric power industry. Competition within the industry will lead to cost reductions. From competition new players will emerge. One of these players will be - independent generators or cogenerators.

Central and Eastern European countries and the new independent states are currently developing market-oriented economies and are dismantling their previous centrally planned economic systems. Coal for several of these countries represents a major if not the only indigenous energy resource. The power generating sector will remain the overwhelmingly predominant market for coal through the period from 1990 to 2010. The first challenge will be to ensure continued supply of power, while making big strides to improve the environmental conditions. The second challenge will be to upgrade the quality and reliability of power supply.

All European governments face growing public demands for more aggressive action to protect the environment. Generation expansion is for the most part limited to oil, gas or coal. Coal and solid fuels have traditionally been the dominant fuels, and still generate almost one-third of Europe's electricity. Outside of the former Soviet Union, over 60 percent of electricity supplied to Eastern Europe is generated by solid fuels (mostly brown coal and lignite). Many of these countries are examining improved technologies for burning coal more cleanly and efficiently. Gasification offers feedstock flexibility and the ability to coproduce other products while generating electricity. Texaco has just completed a Texaco Gasification Power Systems (TGPS) Study based on gasification of low grade brown coal and heavy vacuum residue to produce hydrogen plus carbon monoxide (synthesis gas) for the ultimate production of electrical power, steam and district hot water.

While it is recognized that coal consumption will continue in the region, including Eastern and Western Europe, there is a heightened awareness for the environmental impact that this coal usage will have. Emissions from coal and other fossil fuel consumption have been cited for such environmental problems as smog, acid rain, and global warming. The use of clean coal technology, and specifically Integrated Gasification Combined Cycle ("IGCC"), can provide a cost effective means for reducing emissions related to the above environmental issues.

IGCC PROCESS DESCRIPTION

IGCC is the most efficient and cleanest method for utilizing coal in the production of electric power (Figure 1). The gasification process converts coal into a clean burning synthesis gas (also known as syngas). Rather than burning the coal directly, gasification achieves its energy conversion through partial oxidation, significantly reducing emissions of pollutants such as sulfur dioxide (" SO_2 ") and nitrogen oxides (" NO_x "), which are major contributors to acid rain and smog. Up to 99% of the sulfur present can be removed and recovered in its elemental form and used for fertilizer manufacture. Any ash in the coal is converted into a non-leachable glassy slag, which encapsulates the heavy metals that exist in the coal. This material is usable as construction aggregate in applications such as roofing, road construction, etc. With the removal of sulfur and particulate, the clean syngas is an ideal fuel for high efficiency combustion turbine/combined cycle power generating equipment.

The IGCC process can utilize either a quench mode or heat recovery mode configurations (Figure 2 shows the full heat recovery mode). The coal feed in the IGCC process is wet ground and slurried to a concentration of about 60-65%. This slurry is fed simultaneously with oxygen to the gasifier through an injector. The water in the slurry not only serves to eliminate dust explosion hazards during the grinding step, but also serves as a transport medium and temperature moderator in the gasification process.

In the gasification reaction, the fuel is partially oxidized to syngas, which is composed of carbon monoxide (" CO ") and hydrogen (" H_2 "), rather than fully oxidized to carbon dioxide and water. Sulfur is primarily converted to hydrogen sulfide (" H_2S ") rather than sulfur dioxide, as would be the case in normal combustion.

The hot gas exiting the gasifier is cooled directly in a quench chamber with water (in the quench configuration) or indirectly in syngas cooler(s) (heat recovery configuration) to generate high pressure steam used in the steam turbine of the combined cycle to produce electricity. Most of the ash is removed as a glass-like slag through a lockhopper system in the bottom of the gasifier vessel.

The cooled raw syngas from the gasifier is water scrubbed in the syngas scrubber, removing all traces of entrained particles. The particulate-free syngas is then processed through a conventional acid gas removal process which scrubs the hydrogen sulfide from the syngas. Not only does this process eliminate the need for expensive stack gas scrubbing, but it also recovers the sulfur in a high purity elemental form as a salable by-product.

The clean syngas can then be used as a fuel for a combustion turbine/combined cycle power system. Nitrogen oxides are controlled by either water saturation of the syngas or nitrogen injection.

The syngas also has applications for uses in chemicals production, as a source of hydrogen, as well as for town gas heating fuel. Power generating configurations utilizing these co-production options offer potential cost advantages.

CAPITAL AND OPERATING COSTS FOR TEXACO IGCC POWER GENERATION

The basis for the economics presented here is for plants located in the United States Gulf Coast ("USGC"). While there are potential pitfalls trying to extrapolate economics from region to region (as will be discussed later in the paper), it is currently the most consistent economic basis available.

Figure 3 shows the capital costs for a typical 255 MW Texaco Gasification Power Systems IGCC facility in a full heat recovery configuration. The \$1439/KW capital cost figure has been validated by the design and cost estimate engineering done for the Polk County Tampa Electric IGCC Project currently under construction in Florida, which also incorporates an award from the U.S. Department of Energy's Clean Coal Technology Program for a demonstration of a hot gas clean-up system. (Based on engineering estimates made by Texaco, differences between the above cost figures and the actual Polk County Project costs are attributed to unique and extraordinary site preparation costs, costs associated with the hot gas clean-up demonstration project, as well as inflation during construction).

While the above capital costs are for a typical full heat recovery configuration, there is the potential for capital cost savings by utilizing a quench configuration. Typically a quench configuration would result in a reduction of capital costs by approximately \$100-150 per KW, with a resulting overall thermal efficiency of approximately 38% (LHV). Alternatively, higher thermal efficiency designs are possible than the 41.5% base configuration full heat recovery (at a higher cost per KW) by utilizing more low temperature heat recovery as well as increased integration between the air plant and combustion turbine. Other factors can affect capital cost and efficiency, including coal specifications, ambient conditions (temperature, altitude, etc.), in-place or existing infrastructure, as well as specific environmental requirements.

The typical operating costs for the Texaco IGCC facility are shown in Figure 4.

COMPARISON OF COSTS OF CLEAN COAL TECHNOLOGIES

The cost of power production from Texaco IGCC compares favorably with other commercially proven Clean Coal technologies. Figures 5 and 6 compares Texaco IGCC economics with other technologies such as pulverized coal with flue gas desulfurization ("PCFGD") and atmospheric fluidized bed combustion ("AFBC"). The economics for the PCFGD and AFBC were derived from published EPRI data assuming a Pittsburgh coal feedstock(2), and was adjusted for size (250MW), location (USGC) and time frame (mid-1994). The economics for Texaco's IGCC are the information for the full heat recovery configuration presented previously (normalized for size). The capital costs are all presented on an instantaneous basis (mid-1994), and do not include inflation, or any charges associated with the cost of money such as interest during construction.

As most analyses of this type show, IGCC with full heat recovery has a somewhat higher capital cost estimate (approximately 10% higher), but higher efficiency (approximately 15 % higher) and lower operating costs. For the alternate case, Texaco IGCC quench configuration has equivalent (or slightly lower) capital costs than the other clean coal technologies with a slightly higher efficiency. Using realistic economic assumptions such as a 15% per year capital cost recovery factor and a \$30 per tonne coal cost (equivalent to \$4.00 per million kcal or \$1.00 per MMBTU), Texaco's IGCC has a cost advantage versus the other two technologies, even without any allowance for superior environmental performance. At higher fuel prices, the advantage of IGCC becomes even more significant (Figure 7).

For larger sized plants, IGCC would also enjoy a greater economy of scale advantage over AFBC, since 250 MW represents the largest proven sized train for AFBC.

Texaco offers IGCC configurations at even lower capital costs which can utilize low value liquid fuels, such as heavy refinery residuum (Figure 8). When utilizing fuels at equal value to coal (on a Kcal or BTU basis), the lower capital costs (approximately 15% less expensive), as well as a higher thermal efficiency (approximately 5% more efficient) will result in lower cost of power.

As shown in Figure 9, in regions lacking inexpensive natural gas, IGCC may compare favorably with LNG for power usage. For power production using LNG in an advanced combined cycle mode, the equivalent burner tip price for LNG would have to be about \$18.27 per million kcal (\$4.60 per million BTU) to generate power at the equivalent cost of IGCC with \$30 per tonne coal.

ENVIRONMENTAL CREDITS FOR CLEAN COAL TECHNOLOGIES

In fully assessing the cost of power generation using different technologies, it is critical to understand the environmental costs (i.e., external costs) associated with each. External costs are a means of monetarily quantifying the relative impact of controlling emissions of various substances into the environment. Figure 10 is a sample of these costs as established by several U.S. state agencies, as well as by Pace University.(3)(4) The values represent either the marginal cost to control the various substances, or the cost to mitigate them (e.g., in the case of CO₂, the cost of planting trees).

Figure 11 shows a calculation of the environmental external costs of various clean coal technologies, using criteria developed by Pace University(4)(5). Major benefits of the Texaco IGCC process as compared to other Clean Coal technologies are: five fold reduction in sulfur emissions, a two to seven fold reduction in NO_x, up to a 15% reduction in CO₂ emissions, and a hundred fold reduction in particulate. This superior environmental performance would result in a \$16-18 million annual environmental cost savings for a 250MW Texaco IGCC plant versus the other clean coal technologies, or about a one cent per KWH advantage (as shown in Figure 12).

Another major environmental advantage that IGCC has over other clean coal technologies is its minimal production of solid wastes. Unlike the other clean coal technologies, IGCC does not require the use of substances such as lime to react and remove the sulfur compounds, thus creating large quantities of solid wastes such as gypsum. Instead, IGCC recovers sulfur in its elemental form, which is salable, and converts coal ash and other inorganic to a glassy slag, which is usable as construction aggregate. For a 250 MW plant, PCFGD/AFBC produce 294 to 394 thousand tonnes per year more waste solids than IGCC. Assuming \$10 per tonne solid disposal fee, IGCC would result in an annual cost savings of between a \$1.7-\$3.9 million which could be equated to a \$45-\$105/KW capital cost reduction relative to the other technologies.

All of the environmental cost benefits discussed previously can be equated to an environmental capital value of over \$500/kw vs. other clean coal technologies (Figure 13). The benefit to the environment of IGCC utilization must be considered in any comparison.

WASTE GASIFICATION - ADDITIONAL MEANS OF REDUCING THE COST OF POWER FOR TEXACO IGCC

One of the most important features of the Texaco Gasification process is its ability to use many different types of materials for fuels, including a number of waste materials. The Texaco Gasification process is able to destroy organic compounds while capturing undesirable components such as heavy metals and sulfur. Carbonaceous fuels that have been used commercially or demonstrated in Texaco gasifiers includes heavy oils and refinery residues, petroleum coke, refinery byproducts, sewage sludge, contaminated soil, mixed plastics, used oils, as well as hazardous wastes.

The advantage of this capability means that relatively inexpensive fuel sources can be used to augment the coal feed, reducing overall fuel costs. In certain instances, nuisance materials and waste products can command a tipping fee, further reducing power generating costs.

DIFFICULTIES IN ESTIMATING CAPITAL COSTS IN DEVELOPING REGIONS

As made evident from the above discussion, the most significant direct cost component of overall power costs is the capital cost. Ideally, construction costs should be less expensive in developing regions by making use of local manufacturing facilities and materials, engineering, project construction management, as well as construction labor. Not only will the potentially lower costs of using local content reduce barriers to the acceptance of clean coal technology, but it will reduce the foreign exchange requirements, further facilitating its use.

While cost engineers have derived simplified methods for estimating differences in construction costs for various developed regions, there are no easy shortcuts when estimating optimized costs in developing regions. Differences in manufacturing capabilities, basic raw material costs, mechanical and construction codes, construction techniques, labor costs and relative labor skills/productivity, as well as the uniqueness of advanced clean coal technologies make the use of regional cost scaling factors almost meaningless when trying to develop relatively accurate capital costs estimates.

In order to obtain accurate capital cost estimates for its IGCC and other gasification projects in developing regions, Texaco has found it helpful to obtain the cooperation of local participants who are familiar with the previously mentioned regional considerations and have experience in process cost estimating and construction. In addition, it is usually necessary to utilize the services of an engineering

contractor familiar in both local fabrication capabilities as well as requirements for advanced technology in order to make an identification and evaluation of potential local equipment vendors.

Only after a careful and thorough analysis can the best and most cost effective technology solution be made. It is too easy to be misled into extrapolating the relative results of an economic evaluation from one particular region to another.

CONCLUSIONS

- Texaco IGCC technology cost of power generation compares favorably to other commercially proven clean coal technologies, even before allowance is made for its superior environmental performance. The slightly higher capital costs of Texaco IGCC is more than offset by higher fuel efficiency and lower operating costs as compared to PCFGD and AFBC.
- In regions without access to inexpensive natural gas, IGCC technology may be cost competitive with LNG for use in power generation.
- When the environmental external costs for SO_2 , NO_x , CO_2 , and particulate are included, IGCC enjoys an additional advantage over other clean coal technologies (equivalent to an additional one cent per KWH). Additionally, IGCC generates substantially less solid wastes than other clean coal technologies. When quantified, these environmental benefits can be equated to a \$500/KW capital advantage compared to other clean coal technologies.
- Feedstock flexibility of the Texaco IGCC process which allows for the utilization of low value and waste products for fuels in an environmentally beneficial manner can further reduce the costs of power generation.

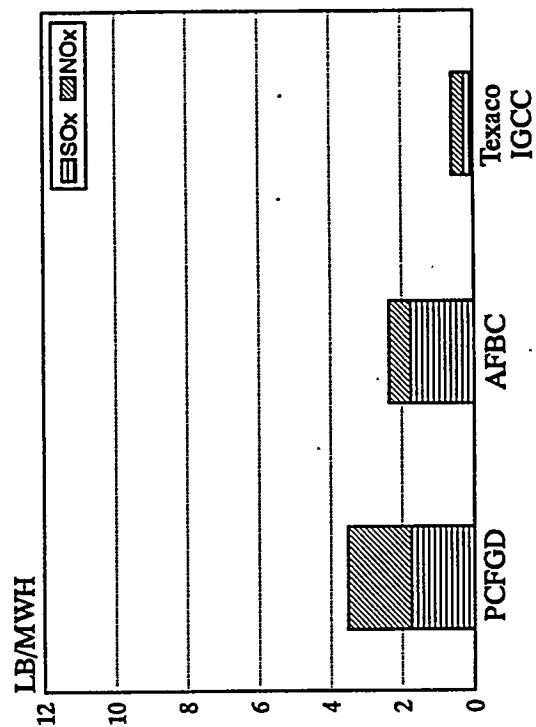
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- (2) Electric Power Research Institute Technical Assessment Guide, 1993
- (3) SFA Pacific Quarterly Report, April, 1994
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- (5) EPRI Report, "Emissions Comparisons for Power Generation Technologies, 1991



COMPARISON OF COMPETING TECHNOLOGIES

Air Emissions



Solid Waste

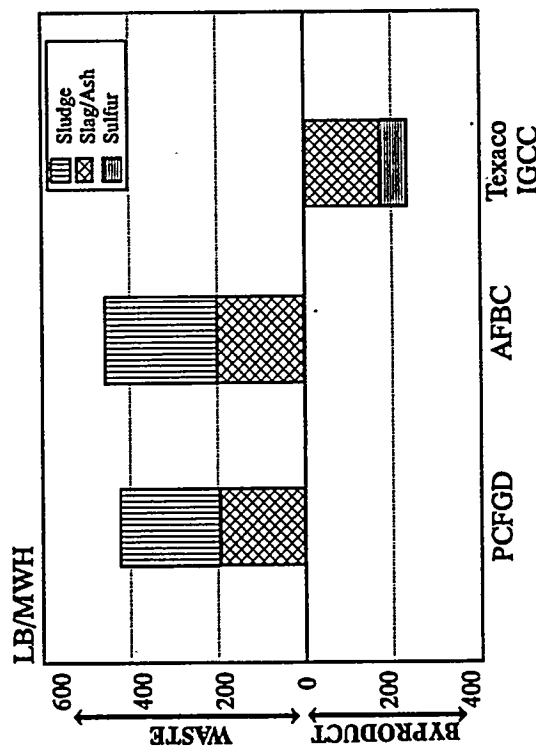


FIGURE 1
NEGOS.PPR

TEXACO GASIFICATION POWER SYSTEMS

FULL HEAT RECOVERY

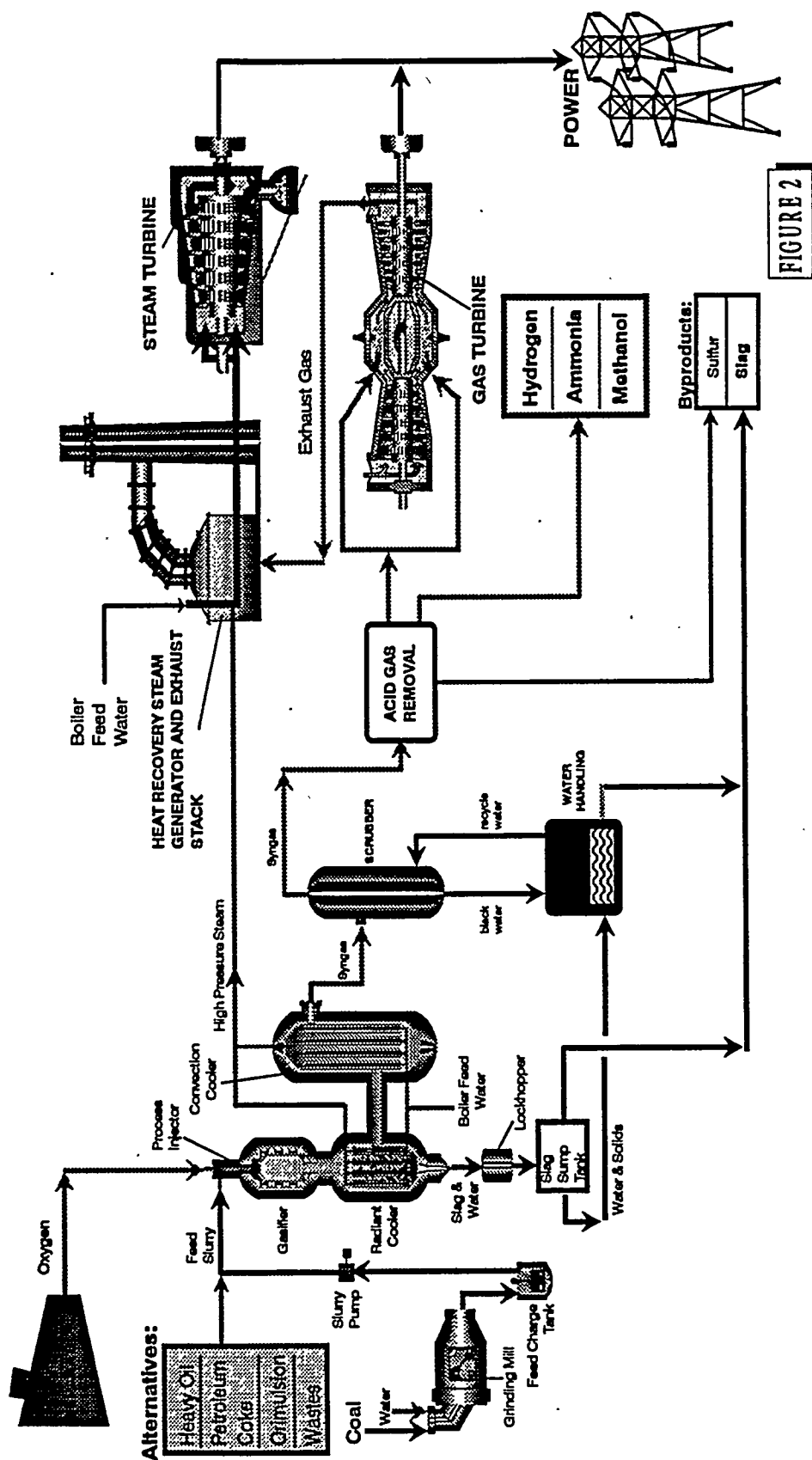


FIGURE 2



Capital Cost Estimate

Texaco IGCC -Full Heat Recovery Overnight Costs (Mid 1994)

Site	U.S. Gulf Coast
Coal	Pittsburgh, #8
Net Output	255 MW
Total Project Cost	\$367MM
	\$1439/kW
Thermal Efficiency	41.5% (LHV)
	(2075 kcal/kwH)
	(8235 BTU/kwh)
Direct Field Costs	Cost (\$1,000)
Site Work & Buildings	2,754
Fuel Handling	11,546
Air Separation	32,718
Gasification	61,881
Gas Treating & Process Steam	22,303
Power Generation	102,329
Water Systems	10,334
Electrical	17,678
Balance of Plant	<u>9,161</u>
TOTAL DIRECT FIELD COSTS	270,703
Indirect Field Costs	<u>24,476</u>
TOTAL FIELD COSTS	298,179
Office Costs	34,167
Contingency	<u>34,958</u>
TOTAL PROJECT COST	367,304

FIGURE 3

NK2994.PPR



Annual Operating & Maintenance Costs

Texaco IGCC -Full Heat Recovery
USGC Basis
Mid 1994 Costs

	255 85% 1,899 41.5% 2,075 8,235	MW Capacity factor GWH/Year Production Thermal Efficiency (LHV) Kcal/kwh BTU/kwh	Million \$ per year	Cents per kwh
Variable Costs				
Coal (@ 7371 kcal/kg)	\$33 per tonne	534,554 tonnes per yr	\$17.7	0.931
Maintenance & Materials			\$3.1	0.163
Catalysts & Chemicals			\$0.5	0.027
Start-up Costs/Back-up Fuel			\$1.5	0.079
Sulfur Credit	\$90 per tonne	13,502 tonnes per yr	(\$1.22)	(0.064)
TOTAL VARIABLE COSTS				1.136
Fixed Costs (Including Labor)			\$4.6	0.244
TOTAL OPERATING & MAINTENANCE COSTS				1.380

FIGURE 4
NK2884.PFR



Relative Cost of Power from Various Clean coal Technologies

Basis -	U.S. Gulf Coast 250 MW Mid 1994 Coal - Pittsburgh	7,500 Kcal/Kg 13,500 BTU/Lb	Atmospheric Fluid Bed Combustion *	Pulverized Coal with Flue Gas Desulfurization *	Texaco IGCC Full Heat Recovery **	Texaco IGCC Quench **
Capital Costs Recovered @ 15% per Year						
Capital Cost (\$ per KW)	\$1,301	\$1,320	\$1,446	\$1,301	\$1,446	\$1,300
Efficiency (LHV)	35.9%	35.5%	41.5%	35.9%	41.5%	38.3%
Heat Rate Kcal/Kwh (LHV) BTU/KWH (LHV)	2,396 9,509	2,420 9,604	2,075 8,235	2,396 9,509	2,075 8,235	2,248 8,922
Availability	85.7%	90.4%	85.0%	85.7%	85.0%	85%
Fixed Costs (\$/KW-Yr)	\$42.20	\$30.28	\$18.29	\$42.20	\$18.29	\$18.29
Variable (\$ per KWH) w/ By-Product Credit	\$0.0030	\$0.0054	\$0.0021	\$0.0030	\$0.0021	\$0.0021
Cost of Power (Cents per KWH)						
Capital @ 15% per Year Recovery	2.60	2.50	2.91	2.60	2.91	2.62
Coal @ \$30 per Tonne \$4.00 per MM kcal \$1.00 per MMBTU	0.96	0.97	0.83	0.96	0.83	0.90
Fixed Costs	0.56	0.38	0.25	0.56	0.25	0.25
Variable Costs	0.30	0.54	0.21	0.30	0.21	0.21
Total Cost of Power	4.42	4.39	4.20	4.42	4.20	3.98

* EPRI TAG - 1993 Normalized for 250 MW/USGC/Mid 1994
 ** Texaco Normalized for 250 MW/USGC/Mid 1994

FIGURE 5

NG2894.PPR



Comparison of Cost For Various Clean Coal Technologies USGC/Mid 1994/\$30 per Tonne Coal

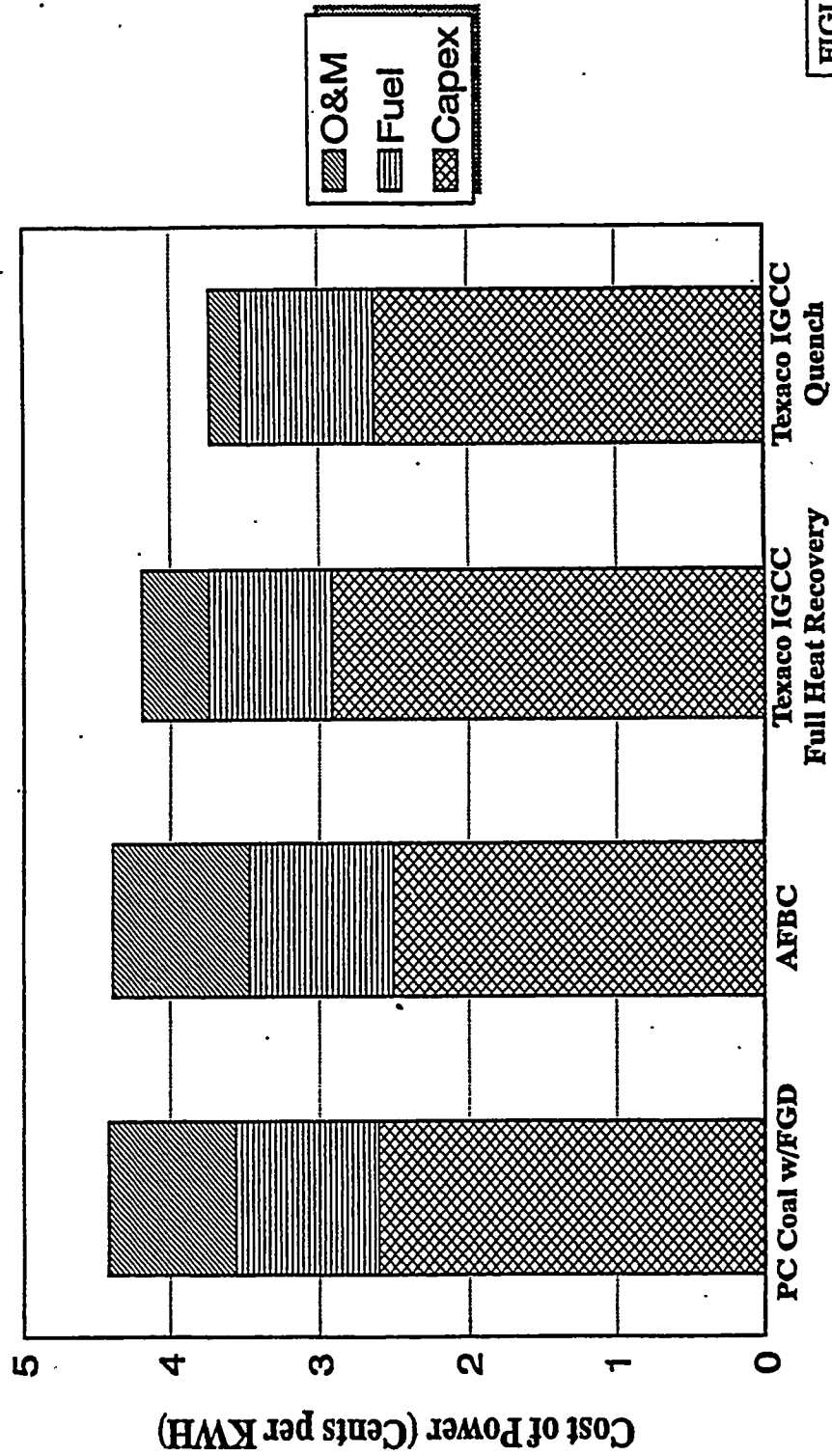


FIGURE 6



Cost of Various Clean Coal Technologies at Various Fuel Costs

USGC/Mid 1994/Coal Heating Value @ 7,500 KCal/Kg

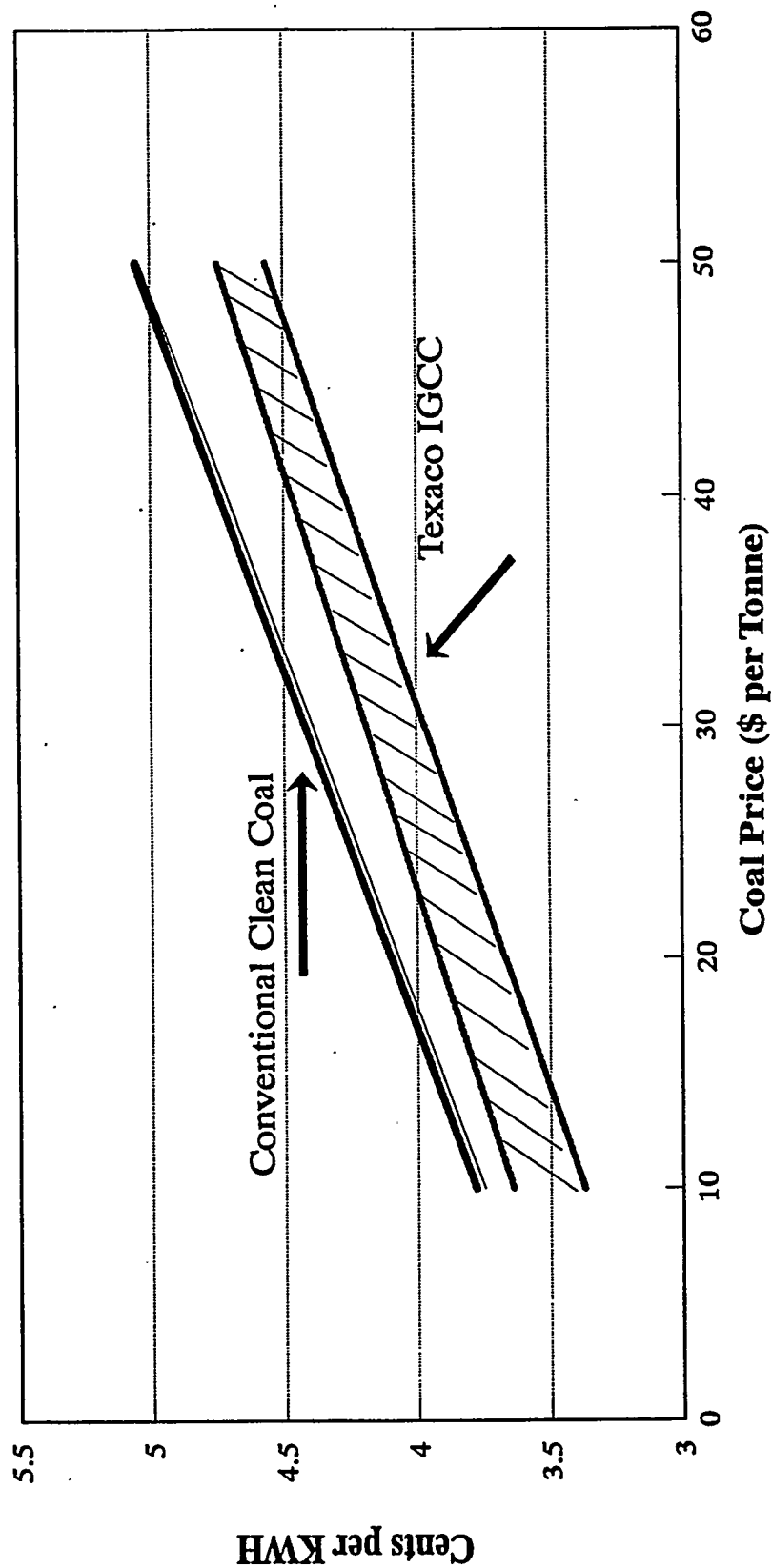


FIGURE 7

NK2994.PPR



Comparison of Cost For Various Texaco IGCC Configurations USGC/Mid 1994/\$30 per Tonne Coal/\$6.25 per Barrel HVR

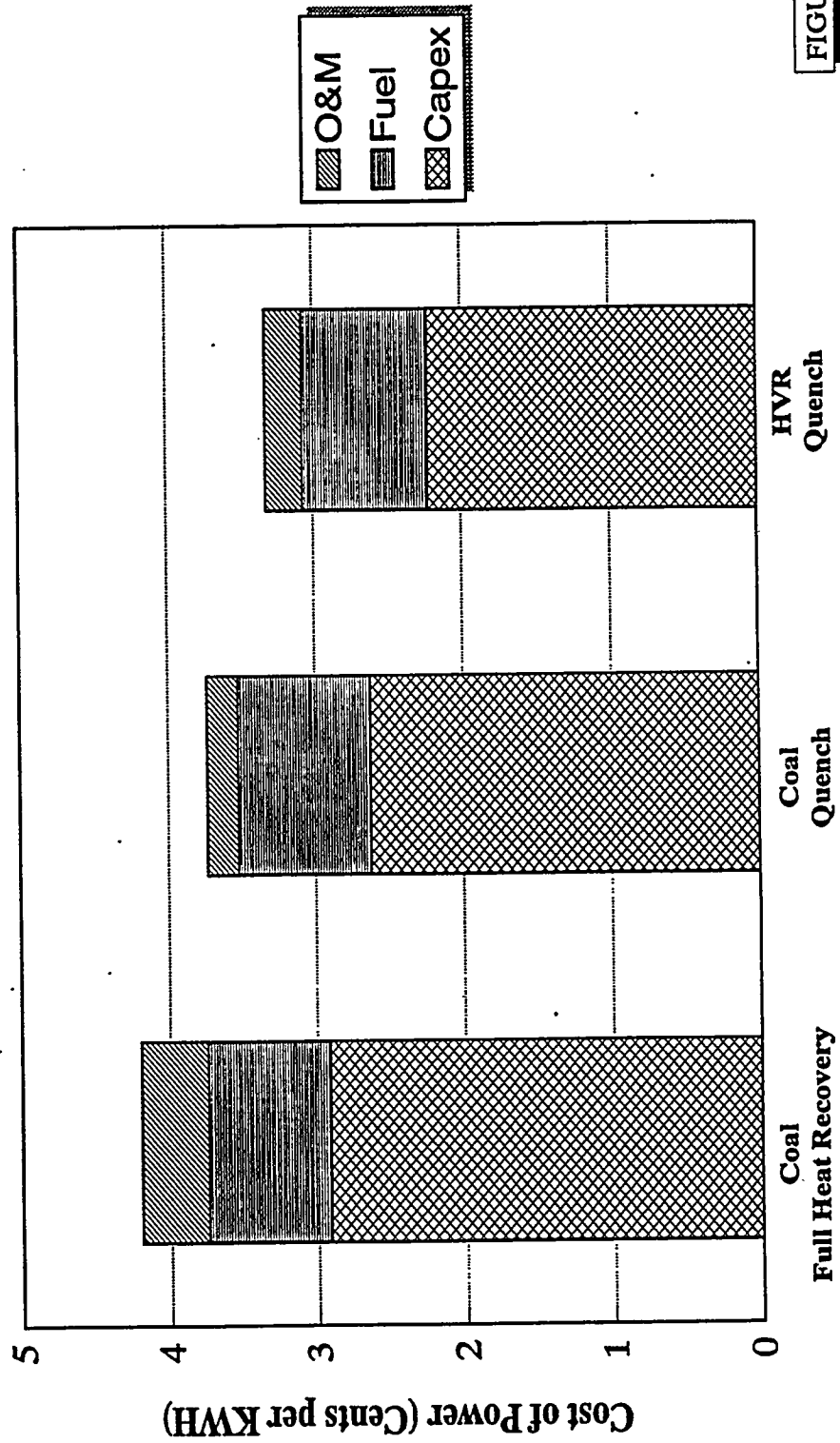


FIGURE 8
NK2994.FPR



Value of LNG for Power Production vs. Coal/IGCC Coal at 7,500 BTU/Kcal (13,500 BTU/LB)

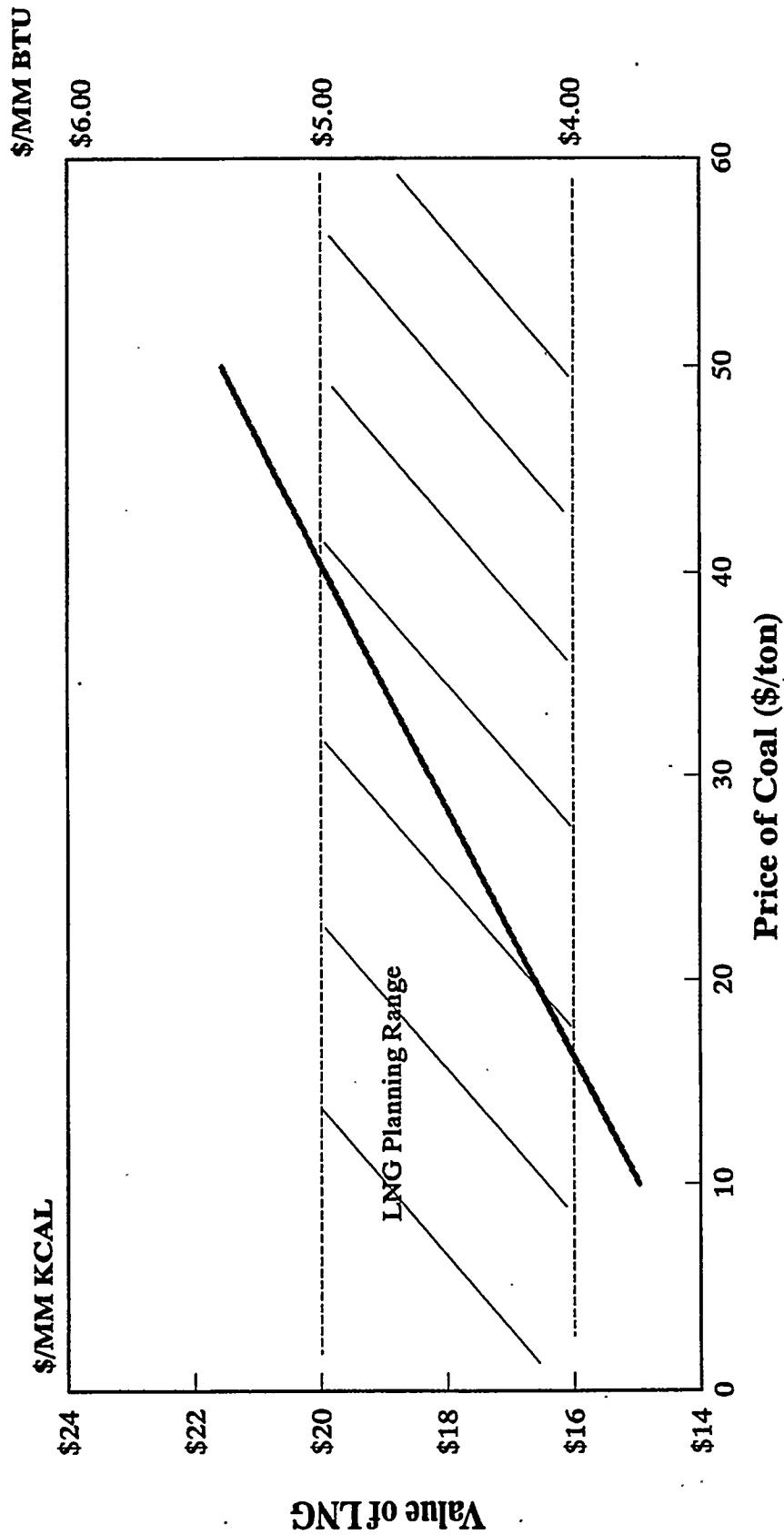


FIGURE 9
NK2994.FPR



Environmental Externality Value Estimates (1993 Dollars/ton)

	<u>SO2</u>	<u>NOx</u>	<u>ROG</u>	<u>PM10</u>	<u>CO</u>	<u>CO2</u>	<u>CH4</u>	<u>N2O</u>
California								
Northern	4,600	9,400	4,400	2,700		9		
Southern	24,200	32,400	23,100	7,000		9		
Out of state	1,800	7,700	1,340	4,800		9		
Massachusetts	1,700	7,400	6,100	4,600	990	25	250	4,500
Nevada	1,700	7,500	1,300	4,600	1,010	24	240	4,500
New York	950	2,100						
Pace University	4,500	1,800		2,600		15		

Source: SFA Pacific Quarterly Report, April 1994

FIGURE 10
NK2884.PPR



Environmental Emissions and Externality Costs for Various Clean Coal Technologies*

Basis - Illinois #6 Coal, 4% Sulfur
250 MW Plant/80% Operating Factor

	PCFGD			AFBD			IGCC		
	Kg/MWH	Tonnes/Yr	Millions\$/Yr	Kg/MWH	Tonnes/Yr	Millions\$/Yr	Kg/MWH	Tonnes/Yr	Millions\$/Yr
SO ₂	1.74	3,052	\$13.7	1.75	3,068	\$13.7	0.32	564	\$2.5
NO _x	1.76	3,083	\$5.6	0.59	1,041	\$1.9	0.26	453	\$0.8
CO ₂	926	1,621,987	\$25.0	978	1,713,377	\$26.4	834	1,461,457	\$22.6
Particulates		79.5	\$0.2	0.0454	79.5	\$0.2	0.0004	0.7	\$0.0
Total Annual Costs (250 MW Plant)	0.454		\$44.5			\$42.3			\$25.9

Value of Emissions (\$ per Tonne, 1992 \$s)**

SO _x Emissions, \$/Tonne	4,475
NO _x Emissions, \$/Tonne	1,808
CO ₂ Emissions, \$/Tonne	15
Particulates, \$/Tonne	2,623

* EPRI, 1991

** Environmental Costs of Electricity, Pace University Center for Environmental and Legal Studies, 1992

FIGURE 11

NRC8804.PPR



Externality Cost Advantage of IGCC vs. Other Clean coal Technologies

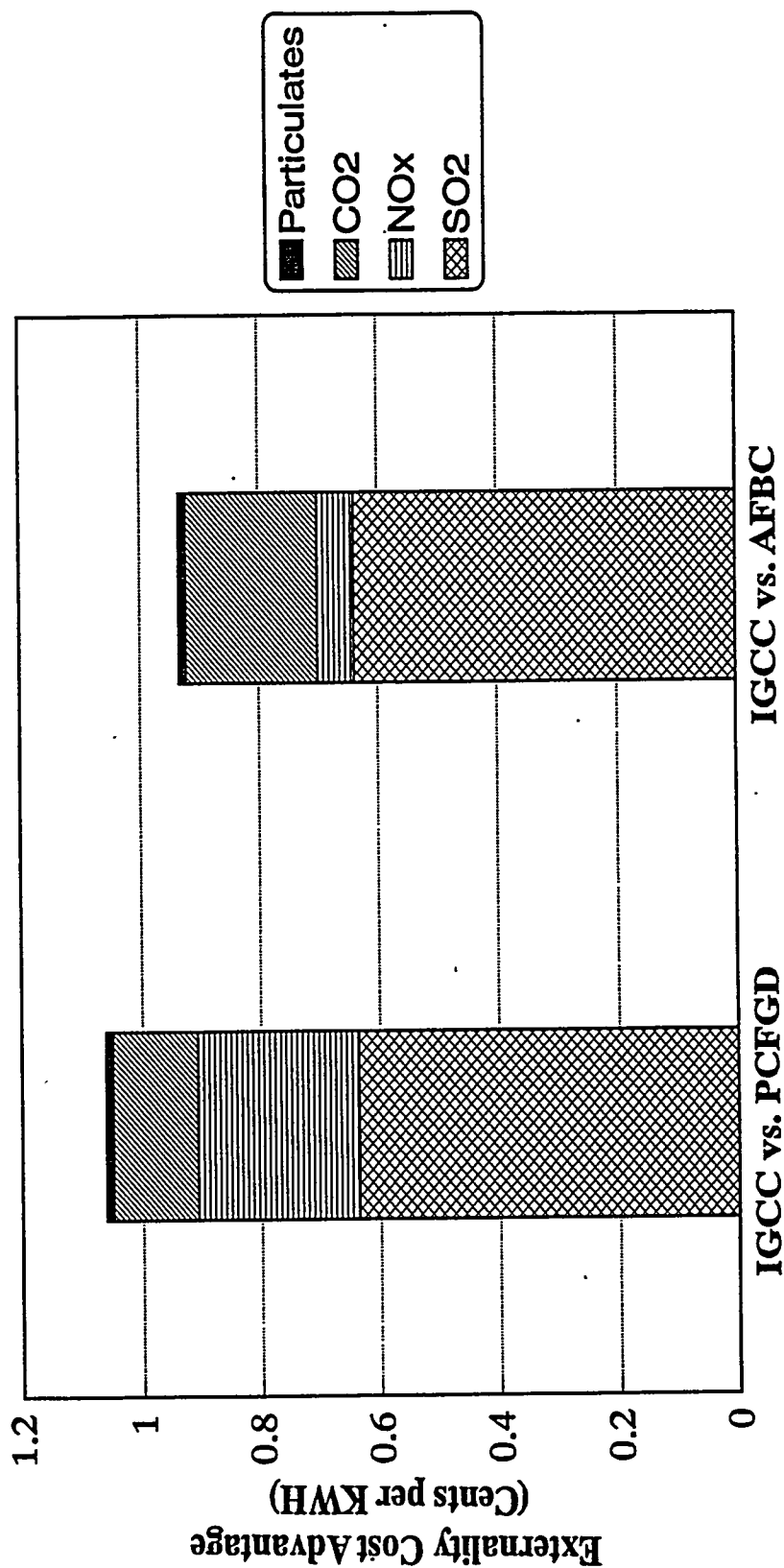


FIGURE 12
NK2004.PPR



Equivalent Environmental Capital Value of Texaco IGCC

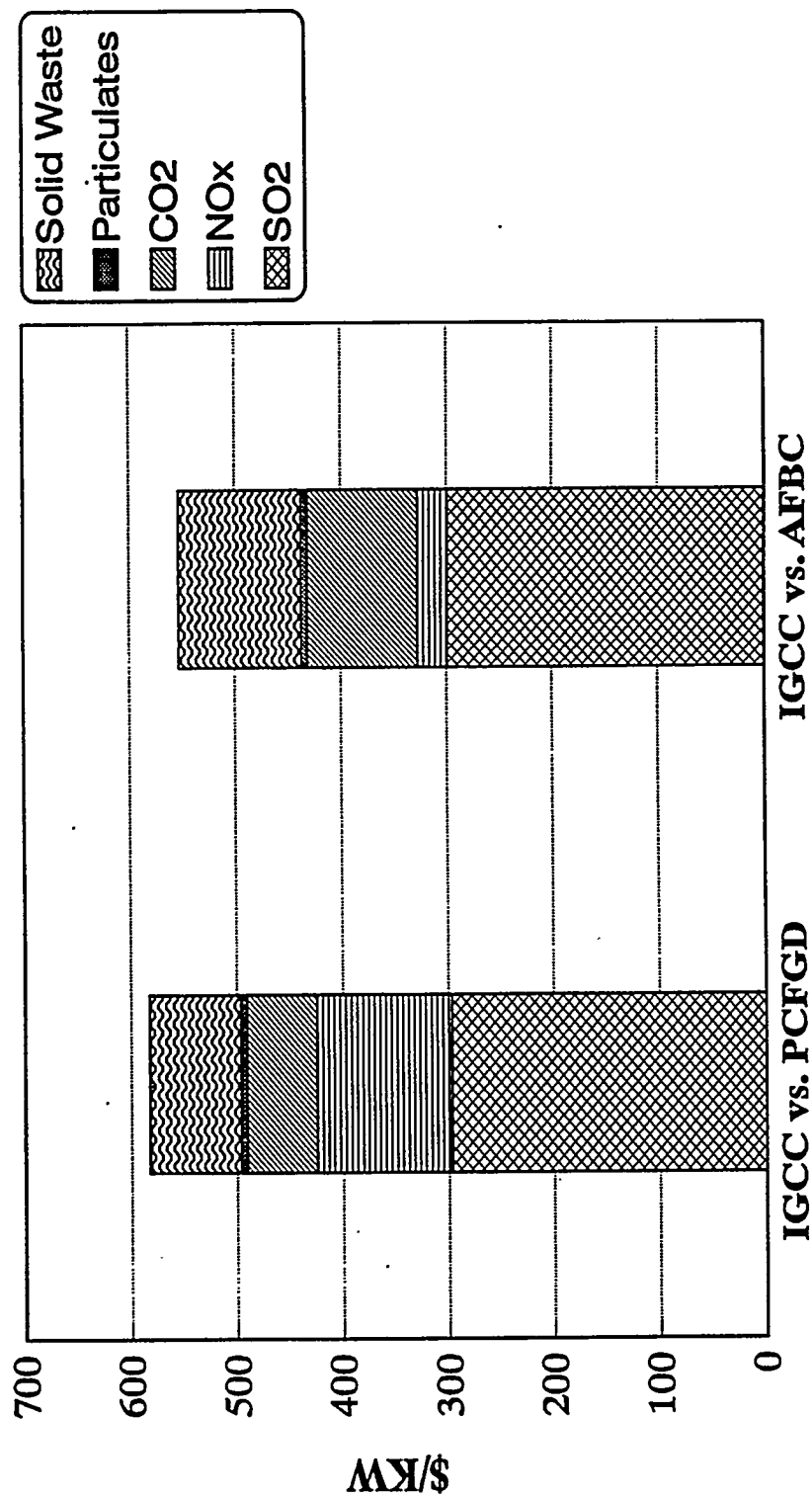


FIGURE 13
NRC/BSA/PPH

DEVELOPING FINANCEABLE PROJECTS IN CENTRAL EUROPE

Robert Chelberg, Director
Vladimir Prerad, Director of Project Finance

POWER International
Josefov, Czech Republic

ABSTRACT

POWER's engineering and development experience in the Czech Republic creating financeable projects within the power generation industry will be presented. POWER has been involved in the Czech Republic's privatization process, environmental legislation as well as formation of the regulatory environment.

Strategic methods for accomplishing the development of financeable projects often include ownership and financial restructuring of the projects. This is done by utilizing internal cash flows, external debt and equity placement (provided by international financial institutions) by restructuring the facility's contractual relationships and operations (providing as least cost solution to engineering) and possibly using existing governmental guarantees.

In order to make any recommendations on how to come into compliance with the country's environmental legislation, it is necessary to begin with an analysis of the existing facility. This involves preparation of technical and economic feasibility study, evaluation of technology and preliminary engineering solutions. It further involves restructuring of power sales agreements, heat sales agreements, and fuel supply agreements. The goal is to provide suitable security for the equity and debt financing participants by mitigating risk and creating a single purpose business unit with predictable life and economics.

The result of a facility which has its contractual relationships in place, risks managed, efficiently operated, with identified least cost technical solution; and therefore, increased profitability.

Paper unavailable at time of publication.

MINIMIZING RISK TO QUALIFY FOR FINANCING

Peter Foltin

Creditanstalt Securities
Bratislava, Slovak Republic, and Vienna, Austria

Information not available at time of printing.

Regulatory Issues

Session B3

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Washington, D.C., USA*

REVIEW OF CURRENT AND ANTICIPATED REGULATIONS ON AIR PROTECTION IN THE CZECH REPUBLIC

Pavel Jílek
Vladimír Novotný

Ministry of the Environment of the Czech Republic
Prague, Czech Republic

ABSTRACT

Environmental issues, especially the solution of the air pollution problem, have taken on great significance in the Czech Republic (which was a part of the Czech and Slovak Federal Republic until the end of 1992) since the 1989 "Velvet" Revolution. The former CSFR Federal Committee for the Environment and both the Republic Ministries started immediately with creating new environmental legislation, which is the main governmental tool for protecting the environment in the newly developing democracy state system with a market oriented economy. The inspiration for that activity was found in legislation of developed countries - member states of the European Union, and in German environmental law in particular. This paper surveys the major laws and regulations that gradually came into force in the Czech Republic since 1990. The provisions of the primary significance are the Act No.309/1991 S.B., dated July 9, 1991, on the protection of the air against pollutants - The Clean Air Act, the Act No.218/1992 S.B., dated April 27, 1992, which changes and supplements the Act No.309 - The Clean Air Act, the Measure of the Federal Committee for the Environment of October 1, 1991 to the Clean Air Act, and its amended wordings of June 23, 1992, 84/1991 S.B., and 84/1992 S.B., the Act No.389/1991 S.B., dated September 10, 1991 on the state administration of air protection and charges for the pollution of air, and several regulations based on the Act No.389/1991 S.B., issued in the period 1992 - 1993.

INTRODUCTION

In the last four years, many and various, wide and deep changes of economy and social conditions were carried out in the Czech Republic (which was a part of the former Czech and Slovak Federal Republic until 1992). Also a large and very important activity in drafting and approving of new legal provisions was appeared, directed to formation of new legal grounds of the modern and democratic state.

The problems connected with the quality of the environment and the hot need of their solution formed a set of serious arguments supporting the necessity of basic changes in the state organization and administration forward democracy, which started during the so-called "Velvet Revolution" in November 1989. Immediately in 1990, new conception of the state environmental administration was created and three state environmental administrative bodies were established - The Ministry of the Environment of the Czech Republic (MŽP ČR), on January 1, 1990; The Slovak Commission for the Environment (SKŽP), on April 1, 1990; The Federal Committee for the Environment (FVŽP), on July 19, 1990, countermanded again in June 1992.

Main tasks of the new ministries consisted in drafting and finalization of new legal provisions for control and regulation of environmental pollution and their discussion at the floor of the Czech Parliament and, finally, their implementation and enhancement for benefits of the environment.

A new philosophy was used in the process of preparation of new provisions, consisting in the formation of a good groundwork for building up the legislation, allowing the basic change in environmental protection activities, which meant first of all the protection against loading the environment over some admissible level and respected simultaneously economic conditions and general political aims of the State. The Czech Republic wishes to join other democratic countries of the world as a reliable and fully qualified member of the community at the shortest possible period. The Czech Republic will continue

inspiring itself in principles of environmental legislation of the European Communities and other developed countries.

The Czech and Slovak Federal Republic began to create a system of care for the environment similar to those in the other developed countries of the world (where such systems have been in existence for 15 - 20 years). This system is in close connection to the principles of the Czech economic transformation and is a natural consequence of it and of acceptance of newly formulated principles of the state environmental policy of the Czech Republic. The policy is based on the synergic implementation of environmental standards, economic incentives and institutional instruments for care of the environment, which should be developed further into a complete system.

Since 1990, the environmental legislature has undergone a basic change. The most important of the laws that have been passed include the Act No. 17/1992 S.B., on the environment, passed by the Federal Assembly on December 5, 1991, which came in legal force on January 16, 1992. The law defines the basic concepts and principles of environmental protection, which are given in greater detail in other legal provisions on protection of the individual components of the environment (protection of the air and water, waste disposal, etc.).

New proposals for legal provisions dealing with the main environmental issues (e.g. the Federal Act on the Environment, the Clean Air Act, the Waste Act) were drawn up on the federal level and the laws were passed by the Federal Assembly.

Some of these acts were elaborated in greater detail for the Czech Republic in the corresponding laws of the Czech National Council (ČNR) and for the Slovak Republic in laws of the Slovak National Council (SNR). In the Czech Republic this is, for example, the Act No. 389/1991 S.B., on the state administration of air protection and charges for the pollution of air.

After the splitting of Czechoslovakia into two single states, the supervision and all responsibilities regarding environmental issues are fully the competence of the Ministry of the Environment of the Czech Republic, which includes also preparing and drafting new bills and other legal provisions and meeting commitments under international bilateral and multilateral agreements, and first of all mitigation of transboundary long -range pollution transport.

More details are given in the following paragraphs regarding main principles of the acts and other legal provisions valid in the Czech Republic for the air protection against pollutants.

THE CLEAN AIR ACT

On July 9, 1991, the CSFR Federal Assembly passed the **Act No. 309/1991 S.B.**, on protection of the air against pollutants (The Clean Air Act), which came into effect on October 1, 1991. The law replaced the Act No. 35/1967 S.B., on measures against pollution, which was based on concepts that were unsuitable for the **active protection of the atmosphere**.

The Act No. 218/1992 S.B., and the Act No. 158/1994 S.B., include changes and supplements to the Act No. 309/1991 S.B., and modify and amend its wording. These amendments to the law do not affect the concept of The Clean Air Act and are the contributions to better understanding and application of the Act.

The Clean Air Act is intended to create a basis for an extensive limitation of the emissions of pollutants into the atmosphere and thus to work for a gradual improvement of its quality. The law emphasizes the **prevention** at pollution sources, increases the effectiveness of economic incentives, clarifies and specifies the legal responsibility of the subjects in question (polluters, importers, transporters, investors, designers and state bodies), takes a complex approach to changing the quality of the air protection, specifies sanctions to be taken for the concrete infringements of the law, provides the complex set of limits for emissions, immissions and depositions, ensures the differentiated approach to new and

already existing stationary sources of air pollution, extends the number of sources liable to payments and sets requirements for the production and operation of mobile sources.

The Clean Air Act is divided into four separate parts:

Part One: General Provisions

The part defines general concepts for the purposes of the law - the subjects concerned, the definition of pollutants and sources of air pollution, the definition of legal subjects, which are assigned to concrete rights and obligations (duties) in subsequent parts of the law (operators of pollution sources, designers, investors, manufacturers, importers) and gives definitions of the emission, immission and deposition limits.

Part Two: The Obligations of Legal and Natural Persons - Air Pollution Sources Operators

This part formulates general obligations, the rights and duties of the operators of stationary and mobile pollution sources, the position and jurisdiction of state administrative bodies, means of determining acceptable air pollution levels and conditions for special atmospheric protection.

Part Three: Payments (Charges) and Fines for Air Pollution

This part sets economic incentives - payments and fines to be paid by natural and legal persons - air polluters.

Part Four: General and Concluding Provisions

This part contains a review of special regulations to be issued by the Republic authorities for the purposes of this law and defines the effectiveness of this law.

The rights and obligations of legal and natural persons in the protection of the outdoor air against pollution through human activity and means for limiting the causes of pollution and alleviating the consequences of air pollution are treated in the paragraph of the law.

According to the law, the pollutants are solid, liquid and gaseous substances. The main criteria for determining the detrimental consequences of a pollutant are its effect on the health of human beings and the life of organisms, the consequences for the environment, and the effect of the substance on both immovable and movable property.

Sources of Air Pollution

The law classifies sources of air pollution as stationary and mobile ones. The stationary pollution sources are classified on the basis of their outputs, relating the degree of effect of the technological process on the state of the atmosphere or the extent of pollution:

1. **large pollution sources** are technological objects containing stationary equipment for the combustion of fuels with a heat output greater than 5 MW and the equipment of especially important technological processes.
2. **medium pollution sources** are technological objects containing stationary equipment for the combustion of fuels with a heat output from 0.2 to 5 MW, equipment in important technological processes, open-face coal mines and similar areas with the possibility of burning, vaporization or emission of wind-blown pollutants and pollutant particles.
3. **small pollution sources** are technological objects containing stationary equipment for the combustion of fuels with a heat output of less than 0.2 MW, equipment in technological processes not included among medium and large pollution sources, areas on which work is carried out that can lead to air pollution, storage areas for fuels, raw materials, products, and

waste and collected exhalations and other construction sites, equipment and activities leading to serious air pollution.

In contrast to the directives of the European Union, where large pollution sources are considered to be those with a thermal output of greater than 50 MW, this law defines large sources as those with heat output greater than 5 MW.

This classification of sources for the purposes of the law is based on the current practice in classification of sources and means of their monitoring. The state-wide "Register of Emissions and Sources of Air Pollution (REZZO)" gives good possibility for completing the Republic's emissions inventory.

The category of mobile sources includes all types of mobile equipment employing internal combustion or similar motors as a source of motion.

Definition of Concepts

The paragraph defines who, in the sense of this law, is considered to be - the source operator, the source investor, the source designer, the manufacturer and the importer.

Pollution Limits

Pollution limits are defined in the law as emission, immission and/or deposition limits.

An emission limit is the highest permissible amount of a pollutant released into the air from a pollution source, expressed as the weight concentration of polluting substances in waste gases or the mass flow of a pollutant per time unit or the weight of the amount of a pollutant related to a production unit.

An immission limit is the highest permissible weight concentration of a pollutant contained in the air.

An deposition limit is the highest permissible amount of a pollutant deposited per unit area of the Earth's surface per unit time.

The law states that the pollution limits, the list of the pollutants and the categories of pollution sources will be announced by the Federal Committee for the Environment as a Measure in the Statute Books.

Simultaneously, the law permits the appropriate Republic authorities to amend the list of the categories of the pollution sources and the pollutants and to set the limits and also to make the limits more stringent.

General Obligations

According to the law, all individuals, who carry out activities that can lead to the air pollution, are obliged to protect the atmosphere. Those include manufacturers, importers, transporters and sellers of equipment, products and materials, who, through their own activities and because they provide the tools and equipment for production for a wide range of consumers, can contribute to fulfilling the purpose of the law in the first stages. The choice of the best instruments for the air protection at this level ensures a gradual decrease of the air pollution.

As installations for combustion of fuels ever belonged to the largest and most extensive sources of the air pollution, the law has paid its special attention to the operators of these sources. A decrease in the amount of pollution from these sources can be achieved through setting some more stringent requirements on technological and working parameters and on use of suitable fuels. Thus, the law without exceptions requires that all operators of equipments for combustion of fuels have to employ the fuel which

specified by the manufacturer of the equipment. The operators of large pollution sources are obliged to use the fuel specified in the set of technical instructions and hold on the operating parameters and technical and organizational measures derived for an equipment.

For construction of new sources and for modernization of existing sources, the law requires the best available technology to be employed, but taking into account the costs of this technology.

Duties of the Operators of Pollution Sources

The duties of the operators of large and medium pollution sources are formulated in 11 paragraphs. The operators have to put the pollution sources into operation and operate them in conformity with the conditions for operating such facilities and with the conditions determined by the air protection authority. They also must keep good operational evidence and operation records on released amounts of pollution to the air.

This part of the law also defines the relationships between the operator of the pollution source and the air protection bodies. In cases of serious and immediate danger to the air quality or of rapid decrease in it, the operators must immediately stop or limit operation of the pollution source. The important obligations of the operators also include informing public on the air pollution from the pollution source and on measures taken to limit this pollution.

The operators of large pollution sources are also obliged to draw up and submit to the state administration bodies for their approval a set of technical operating parameters and technical organizational measures to ensure the proper operation level of the pollution source, including measures to prevent the operation from accidents and eliminate their possible serious consequences.

The duties of the operators of small pollution sources are formulated in two separate paragraphs. The requirements placed by the law on the operators of small sources are far less stringent, nevertheless, the sources are to be operated in accordance with the technical parameters specified by the manufacturer. The air protection bodies can make these conditions more stringent. The operators of small pollution sources are obliged to allow an access of the control bodies to the source(s) and to submit them all documents necessary for evaluation the proper operation level of the source.

Approval of the Air Protection Authorities

The air protection authorities are understood to be the authorities responsible for state administration of the air protection. In the Czech Republic, these authorities are specified by the Act of the Czech National Council No. 389/1991 S.B., on the state administration of the air protection and charges for the pollution of air. Those are first of all the Ministry of the Environment of the Czech Republic and the Czech Environmental Inspection.

The air protection authorities represent the interests of the State in the air protection. In cases specified by the law, they can issue permits for certain projects and activities that could cause negative effects on the quality of the air. In practice, this involves particularly issuing of permits for locating and construction of pollution sources, for proposals for certain type of documentation, for pilot projects for construction of pollution sources, for projects introducing new products and technologies for medium and large pollution sources, for proposals for land-use planning documents, for changes of fuels and raw materials and for changes in utilization of technological equipment by large and medium pollution sources, for the production, import and transportation of equipment, material and products that pollute or could pollute the air and for issuing and modification of the set of technical and/or organizational measures drawn up by operators of large sources.

Proposals, projects, measures and requests for permits from the air protection authorities are to be submitted by the operators, investors, designers, manufacturers or importers in question. These requests must include the reasoning behind the solution that best suits to the air protection. In some cases, professional expert reports are also required, to be drawn up by legal or natural persons who authorized to do so.

The air protection authority is obliged to submit a decision on negotiation of remediation provided that the operator of the pollution sources does not fulfil the duties set by the Act and by other regulations for the air protection.

The Act also specifies the high legal authority of the air protection agency (state inspection) by permitting this agency to take decisions on limiting or stopping the operation of an air pollution source.

The air protection agencies are obliged to ensure timely and complete information on the air quality and on the contribution of the individual sources to the pollution level. They must always inform the public of smog situations.

Permissible Level of Air Pollution

The permissible level of air pollution is determined by emission, immission and deposition limits for the individual pollutants. The numerical values of the pollution limits are specified in the Measure of the Federal Committee for the Environment. The Ministry of the Environment can make the pollution limits more stringent.

The Act sets the emission limits for new pollution sources. The limits attain values corresponding to those for the best achievable means.

The emission limits for existing sources are derived from the minimum attainable emissions for the given type of technological equipment and correctly applied technology. The limits are established by the air protection agency, in the Czech Republic it is the Czech Environmental Inspection, which simultaneously specifies the period within which the value of the emission limit set for new pollution source must be attained also for the existing source.

The law enables the appropriate Republic authorities to set special immission limits for the purposes of smog warnings and regulation systems during the duration of unfavourable meteorological conditions and the temporary increased level of air pollution. In the Czech Republic, the Decrees of the Ministry of the Environment of the Czech Republic, No. 41/1992 S.B. and No.279/1993 S.B., were issued for this purpose, which delimit the areas requiring some special air protection measures and establish principles for the creation and operation of smog regulation systems and other measures for the air protection. The special limits were set as a result of close cooperation of the environmental authorities with the health authorities and hygienic services.

The control of adherence to the pollution limits in the Czech Republic is defined by the Act of the Czech National Council No. 389/1991 S.B., on the state administration of air protection and charges for the pollution of air.

Charges for Air Pollution

The operators of large and medium pollution sources are obliged to pay charges in relation to the amount and kind of polluting substance released - the "polluter pays" principle.

The amount of the charge, the number and means of payment are defined in the Czech Republic by the Act of the Czech National Council No. 389/1991 S.B.

Penalties

Penalties to legal and natural persons authorized to carry out a business are imposed by the Czech Environmental Inspection in the Czech Republic for failure to fulfil duties as defined in the appropriate provisions of the law.

The individual sanctions are defined as to amount and, in deciding on the size of the penalty, the air protection authority takes into account the amount and composition of the polluting substances and

the complexity of the obligations not fulfilled. The penalties are of wide range - from the lowest of 500 Ck (Czech crowns) to the highest of 10,000,000 Ck.

The Act allows that, under conditions defined, the penalty imposed can be up to double the amount set in the law. The air protection authorities can impose this penalty if, within one year from the time that a legal decision came into effect on the imposition of a penalty, the operator in question once again fails to fulfil its obligations in the sense for which the first penalty was imposed and the operator does not take remedial measures within the set time limit. Under these conditions, the air protection authorities can also order the operation of the pollution source to be stopped or limited.

A penalty can be imposed within one year of the date on which the air protection authority learned of failure to comply with the law, and at the latest three years from the date on which the emission limit was exceeded or obligation neglected.

MEASURE OF THE FEDERAL COMMITTEE FOR THE ENVIRONMENT OF OCTOBER 1, 1991 TO ACT NO. 309 OF JULY 9, 1991, ON PROTECTION OF THE AIR AGAINST POLLUTANTS, AND MEASURE OF THE FEDERAL COMMITTEE FOR THE ENVIRONMENT OF JUNE 23, 1992, AMENDING AND SUPPLEMENTING THE MEASURE OF OCTOBER 1, 1991

The Federal Committee for the Environment, pursuant to § 5, paragraph 4 of the Act No. 309/1991 S.B., on protection of the air against pollutants, declares:

The list of pollutants; Categorization of the sources of pollution; Emission limits for selected pollutants from selected technologies and facilities, and generally binding emission limits; Immission limits for pollutants; Recommended special immission limits for declaring regulatory steps.

The list of pollutants divides pollutants into five groups:

- Group 0: Basic Pollutants
- Group 1: Pollutants with carcinogenic effects
- Group 2: Solid inorganic pollutants
- Group 3: Gaseous inorganic pollutants
- Group 4: Organic gases and vapors

Pollutants are assigned to categories primarily on the basis of their negative consequences for human health and on other living organisms. Additional criteria include the amounts and occurrence of these substances. In drawing up categories of pollutants, consideration was also given to the recommendations of the World Health Organization.

Classification of the sources of pollution

The classification of the sources of pollution divides large and medium size air pollution sources into six categories:

1. The fuel and power supply industry
2. Production and processing of metals
3. Production of non-metallic mineral products
4. Chemical industry
5. Waste treatment
6. Other industries and equipment

When assigning the sources to the single categories, consideration was taken of the source classification introduced in the European Community and of the official state information system of the Czech Republic "REZZO - Register of Emissions and Sources of Air Pollution".

Emission limits

This provision sets emission limits on the basis of §§ 14 and 15 of the Act No. 309/1991 S.B., for new sources of air pollution in the scope of categorization of sources. Emission limits or technical parameters are set for operating the equipment in the Part A "Emission limits for selected polluting agents in selected technologies and equipment". The Part B "Generally valid emission limits" sets emission limits for pollutants classified in all the five groups of the "List of pollutants".

The example of emission limits for selected pollutants and technological installations containing stationary equipment for combustion of fuels is shown in Table 1 Generally valid emission limits which are defined by these regulations for basic kinds of pollutants given in Group O in the list of pollutants (solid particulate, sulphur dioxide, nitrogen oxides, carbon monoxide) are quoted in Table 2.

The emission limits were set up on the basis of the appropriate directives of the European Union, using also some experience with the air protection law of other developed European countries (e.g. German Federal Republic).

Immission limits for pollutants

The immission limits are defined for the following pollutants:

air-borne dust, sulphur dioxide, sulphur dioxide and air-borne dust, nitrogen oxides, carbon monoxide, ozone, lead in air-borne dust, cadmium in air-borne dust, and odorous substances.

The immission limits are set as the values of the average annual, daily, eight-hour and half-hour concentrations. The general requirement states exactly the permissible exceeding of the given immission limit for some of these pollutants. The immission limits were proposed in the framework of close cooperation with the Ministry of Health of the Czech Republic - with the Chief Hygiene Officer of the Czech Republic, and took also into account the recommendations of the World Health Organization.

ACT OF THE CZECH NATIONAL COUNCIL NO. 389/1991 S.B., DATED SEPTEMBER 10, 1991, ON THE STATE ADMINISTRATION OF AIR PROTECTION AND CHARGES FOR THE POLLUTION OF AIR

The Act has four parts, in which it states:

Part one: State administrative air protection authorities

Part two: Charges

Part three: Informing the public of air pollution

Part four: Common, temporary and final provisions

TABLE 1

Example of Emission Limits for Combustion of Fuels in Boilers

Specification	Output of the equipment [MW _{th}]	Emission limit [mg.m ⁻³]
Solid particulates		
solid fuel	50 and more	100
	5 - 50	150
	0,2 - 5	250
liquid fuel	50 and more	50
	0,2 - 50	100
gaseous fuel	0,2 and more	10
Sulphur dioxide		
solid fuel	more than 300	500
	50 - 300	1700
	0,2 - 50	2500
liquid fuel	more than 300	500
	5 - 300	1700
	0,2 - 5	Sulphur in oil to 1%
gaseous fuel	0,2 and more	
		35
Nitrogen oxides		
solid fuel	0,2 and more	650
	slag-tap furnace	1100
liquid fuel	5 and more	450
	0,2 - 5	500
gaseous fuel	0,2 and more	200
Carbon monoxide		
solid fuel	0,2 and more	250
liquid fuel	0,2 and more	175
gaseous fuel	0,2 and more	100

Emission limits are valid for concentration recalculated for a dry gas, 101.32 kPa and 0°C and for oxygen content in flue gas:

6 % vol.- combustion of solid fuel, no wood

11 % vol.- combustion of wood

3 % vol.- combustion of liquid fuel

3 % vol.- combustion of gaseous fuel

TABLE 2

Generally Binding Emission Limits for Basic Kinds of Pollutants

Pollutant	Mass flow of the pollutant [kg.h ⁻¹]	Mass concentration of the pollutant in the flue gas [mg.m ⁻³]
Solid particulates	less than 2.5	200
	more than 2.5	150
Sulphur dioxide	more than 20	2500
Nitrogen oxides (as NO ₂)	more than 10	500
Carbon monoxide	more than 5	800

Emission limits valid for concentrations of wet gas, 101.32 kPa and 0°C.

The act also includes an appendix "establishing the annual payment for the emission of pollutants into the air for large and medium pollution sources", which is divided into three parts: A, B and C. **Part A** gives the list of principal pollutants for which payments must be made and their assignment to three classes (I., II. and III.). **Part B** gives the payment rates for pollutants produced by large and medium pollution sources. **Part C** gives the manner of calculating payments.

According to the Act No. 389/1991 S.B., the following authorities are responsible for state administration of air protection in the Czech Republic:

1. The Ministry of the Environment of the Czech Republic
2. The Czech Environment Inspection
3. The District Offices
4. The Municipal Offices

Part one gives details of the jurisdiction and duties of these bodies.

The Ministry of the Environment of the Czech Republic carries out the following principal activities:

provides the supreme state supervision in the matters concerned with air protection, adopts decisions with regard to projects for development of individual sectors and branches, announces beginnings and ends of smog situations and promulgates the regulation measures, carries out research and follows technical development, supports the technologies limiting air pollution, monitors the maintenance of immission and deposition limits, makes the proper information available to the public, issues permits defining conditions for air protection on the basis of the Clean Air Act, cooperates in carrying out its activities with the Ministry of Health of the Czech Republic and with other official bodies of the state administration.

The Czech Environment Inspection supervises the observance of legal regulations and decisions made by legal and/or natural persons concerning the protection of the air as one of the components of the environment.

The Czech Environment Inspection monitors the pollution produced by large and medium pollution sources, especially their compliance with the emission limits, the duties of the operators of sources, the regulation measures for operating sources under smog conditions and regulation measures announced for these sources during a smog situation and also keeps a source inventory.

The inspection also carries out the following activities:

issues permits containing air protection conditions, makes decisions on the amount of the charge for polluting the air by large sources, imposes remedial measures upon operators of large and medium sources who do not comply with the air protection regulations, including stopping or limiting of operation of the pollution source, imposes fines upon operators of medium and large pollution sources, and manufacturers and importers of mobile sources for not complying with the set regulations, provided that such fines are not imposed by the municipality, on the basis of its own findings or on the basis of notification by the district council, takes decisions on emission limits for existing large and medium stationary pollution sources and on the time period within which the emission limits set for new pollution sources must be attained, issues permits for the use of new technology, products and equipment for air protection and approves proposals of and changes in emergency measures.

The District Office is the authorizing body in territorial and construction matters from the point of view of air protection, provided that these matters do not fall in the jurisdiction of the Construction Office. In the framework of its jurisdiction, it is responsible for:

controlling the activities of the town councils, announcing, in cooperation with the relevant bodies under smog conditions, the appropriate warning and regulation measures to limit emissions and

controls the compliance with the measures, makes decisions on charges for medium pollution sources, enables the public access to information, derives the region in which smog warning and regulation systems are to be in operation.

The Municipality is the authorized body in territorial and construction matters from the point of view of air protection, provided that these matters do not fall in the jurisdiction of a Construction Office. The municipal bodies carry out especially the following functions:

they can issue decrees specifying municipal zones with limited operation of pollution sources under the smog conditions, they announce warning and regulation measures to limit emissions from sources and control compliance with these measures, control the compliance with obligations by operators of small pollution sources and emissions of dark smoke, can instruct operators of mobile pollution sources to undergo monitoring of the amount of substances emitted, can impose fines on operators of pollution sources that do not comply with the measures of the smog regulation system, make decisions on charges for small pollution sources, enable the public access to information.

Charges for air pollution are paid by legal and/or natural persons operating large, medium and small pollution sources. The decision on the amount of the charge is made and the charge is collected

1. for large pollution sources by the Czech Environment Inspection,
2. for medium pollution sources by the District Office,
3. for small pollution sources by the Municipality.

The annual payment for a single large or medium pollution source is set for all the kinds of emitted pollutants subject to charges in the manner described in Appendix. The charge rates are based on one ton of pollutant, see Table 3.

The annual charge rate for one small pollution source is established at a set rate of up to 10 000 Ck, in dependence on the size of the pollution source and toxicity of a pollutant.

The operator is obliged to calculate the charges independently and to notify the air protection authority of this calculation by February 15 of every calendar year; after verification of this information, the authority issues a decision on the amount of the charge.

The Act came into legal force on October 4, 1991.

TABLE 3

An example of basic charges for the air pollution

Pollutant	Rate [Ck.t ⁻¹]
Solid particulate	3000
Sulphur dioxide	1000
Nitrogen oxides	800
Carbon monoxides	600
Hydrocarbons	2000

Pursuant to § 12 letter d) of the Act No. 389/1991 S.B., the Ministry of the Environment of the Czech Republic issued following Decrees:

DECREE OF THE MINISTRY OF THE ENVIRONMENT ESTABLISHING REQUIREMENTS FOR KEEPING WORKING RECORDS ON LARGE AND MEDIUM SOURCES OF POLLUTION AND THE EXTENT OF FURTHER INFORMATION TO BE PROVIDED BY THE OPERATORS OF SUCH EQUIPMENT TO THE AIR PROTECTION AUTHORITIES (Decree No.205/1993 S.B., dated July 8, 1993)

Working records are defined as the maintenance of records of information that is important from the standpoint of air pollution in connection with the operation of the source, especially records on the properties and amounts of emissions of pollutants. The working records are to contain records of constant and variable information to the extent defined in Annex of the Decree and are to be kept separately for each individual source of air pollution. The working records are to include records on the overall monthly and yearly evaluation of working record data for all the pollution sources covered by the records.

**DECREE OF THE MINISTRY OF THE ENVIRONMENT OF THE CZECH REPUBLIC ESTABLISHING REQUIREMENTS FOR THE QUALITY OF FUEL FOR IMMEDIATE COMBUSTION AND THE SALE OF SUCH FUEL
(Decree No.206/1993 S.B., dated July 8, 1993)**

According to the purpose of its use, fuel is classified as a fuel for the public, for business facilities and for power-production facilities. The requirements for the fuel quality are defined in Annexes to the Decree. When supplying a fuel, the vender is obliged to provide a certificate of its quality. The certificate must contain also information on its conformity with the requirements for maximum specific sulphur content, maximum sulphur content or maximum specific emission of sulphur dioxide for the established purpose of use, and the actual specific sulphur content or sulphur content.

DECREE OF THE MINISTRY OF THE ENVIRONMENT OF THE CZECH REPUBLIC ON MEANS OF DETERMINING THE AMOUNTS OF EMISSIONS AND ON THE TECHNICAL EQUIPMENT FOR MEASURING EMISSIONS FROM LARGE AND MEDIUM POLLUTION SOURCES (Decree No.270/1993 S.B., dated October 7, 1993).

The Decree lists in detail requirements on the method of emission measurements, sets the duties of complying with the emission limits and of continuous monitoring and measuring, for example for the following cases: The continuous measurements have to be employed for determination of the amounts of emissions for pollution sources from which the emissions of pollutants in annual operation are greater than 200 t of solid pollutants or 1000 t of sulphur dioxide or 1 t of chlorine and/or its compounds expressed as chlorine or 10 t of organic substances expressed as elementary carbon or 200 t of nitrogen oxides expressed as nitrogen dioxide or 1 t of hydrogen sulphide or 2 t of inorganic fluorine compounds expressed as fluorine or 10 t of carbon monoxide. The continuous measurements are used also when the pollution source is fitted with FGD technology. For power plants, heating plants and local heating units with a thermal output of greater than 150 MW, information on the amount of emissions of solid pollutants, sulphur dioxide, nitrogen oxides, and carbon monoxide and oxygen content in the flue gas is determined by the continuous measurements too.

CONCLUSIONS

The paper overviews the basic legal provisions for the protection of air valid in the Czech Republic, which serve first of all as the administrative and regulation instruments. The Act No. 309/1991 S.B. (The Clean Air Act) and especially the Act No. 389/1991 S.B. introduce also some economic instruments which are, for example, penalties for not complying with the provisions and charges for long-term polluting the air.

Many discussions deal currently with the so-called "emission permits". The other economic tools impose financial recourse on the air polluters for their polluting of the environment. Through being an "emission permit" the polluter gains "the right to pollute". The emission permits could be sold or

exchanged. This introduces a substantially new approach to the environmental pollution treatment. The idea of a new, big and heavy polluting plant, started by an economically strong polluter who bought "emission permits enough", is fully non-acceptable. A very basic condition for forming a "emission permits" sale is establishing of a real market friendly environment. Such a situation will appear in the Czech Republic most probably only in several years. The currently valid legislation of the Czech Republic displays some rules for the air protection and for regulation of air polluters' acceptable behavior. Those rules are supposed to be valid at least until 1999. The marketable "emission permits" suppose a very principle change of those rules and the acceptance of them would need also deep changes of the currently valid Czech legislation for the air protection. As we know, also not many of the world developed countries have been preparing such amendments of their general and legally supported approach to the air protection.

The Czech Republic wishes to join the European Union in not a very far time horizon and it means that it has to harmonize its law with the law of the Union. The changes in the Czech legislation will be proved having also in mind the legal provision valid within the space of the EU Member States and the Czech Republic wishes to support all the increasing harmony of the all mentioned legal systems.

The Czech Republic respects fully and tries to comply with all its commitments under international agreements of the United Nations level. The Czech Republic is the Party to the Convention on Long-Range Transboundary Air Pollution and acceded to all its concluded Protocols excluding the Protocol on Decrease of VOC Emissions in 30 % by 2000. The accession of the Czech Republic to the Protocol is being investigated and prepared at present.

The Czech Republic acceded also to the UN Framework Convention on Climate Change.

All those internationally binding commitments will be gradually projected into the changes and supplements to the Czech air protection legislation. Its last amendments dealing with the Acts Nos. 309/1991 S.B. and 389/1991 S.B. were realized passing the Act No. 158/1994 S.B., which came into legal force on October 1, 1994. In the nearest future, an extensive transformation of all principal environmental laws generated by the former Czech and Slovak Federal Republic will start to the own law of the Czech Republic.

In the field of the air protection especially the regulation provisions to The Clean Air Act will be adapted, first of all regarding the air emission limits. Many of concrete measures will be precise, especially those the practical application of which was troublesome and complicated. The clearer dictions of several measures with a stronger stress of their observance will be gradually completed too.

REFERENCES

- Act No.17/1992 S.B. Act on the Environment
- Act No.244/1992 S.B. Act on Environmental Impact Assessment
- Act No.309/1991 S.B. The Clean Air Act
- Act No.218/1992 S.B. Amendment to the Clean Air Act
- Vol.84/1991 S.B. Measure (1) to the Clean Air Act
- Vol.84/1992 S.B. Measure (2) to the Clean Air Act
- Act No.389/1991 S.B. Act on the State Administration of Air Protection
- Decree No.41/1992 S.B. Decree on Smog Regulation System
- Decree No.205/1993 S.B. Requirements for Keeping Working Records

Decree No.206/1993 S.B. Requirements on the Quality of Fuel

Decree No.270/1993 S.B. Means of Determining the Amounts of Emissions

ENERGY CONSERVATION, ENERGY EFFICIENCY AND ENERGY SAVINGS REGULATORY HYPOTHESES - TAXATION, SUBSIDIES AND UNDERLYING ECONOMICS

Thomas Trumpy, Attorney

International Legal Counsel
Brussels, Belgium

ABSTRACT

More efficient use of energy resources can be promoted by various regulatory means, i.e., taxation, subsidies, and pricing. Various incentives can be provided by income and revenue tax breaks—deductible energy audit fees, energy saving investment credits, breaks for energy saving entrepreneurs, and energy savings accounts run through utility accounts. Value added and excise taxes can also be adjusted to reward energy saving investments and energy saving entrepreneurial activity. Incentives can be provided in the form of cash refunds, including trade-in-and-scrap programs and reimbursements or subsidies on audit costs and liability insurance. Pricing incentives include lower rates for less energy use, prepayment of deposit related to peak load use, electronically dispatched multiple tariffs, savings credits based on prior peak use, and subsidized "leasing" of more efficient appliances and lights. Credits, with an emphasis on pooling small loans, and 5-year energy savings contracts are also discussed.

PAPER

Public policy favors energy savings and the replacement of energy wasting, polluting equipment. Several utilities are interested in sponsoring DSM programs to REDUCE the need for environmentally retrofitted or new plant. Equipment suppliers and financiers (ESCOs) are eager to promote RUE/DSM. What should be the regulatory response?

Should there be a regulatory response? Of course.

We are asking eastern Europe to eliminate energy subsidies. What nonsense. Energy prices are always determined by the state through taxes and incentives.

- Privatization is not the answer. The United Kingdom privatized and then has fought how to regulate.
- At least in this area the USA looks rather good - despite oil and gas depletion allowances, low severance taxes for Western coal and other distortions the USA does not subsidize and then re-tax as much as the Germans do with coal and the Kohlenpfennig.

The countries of central and eastern Europe wish to join the European Union. What sort of model does the EU offer for harmonization of policies and regulations on energy pricing and DSM/RUE incentives, tax relief and promotion?

Alas the EU is no model at all, and there is no work being done, yet. So we have the unfortunate situation that while the EU and everyone else is talking in favor of improved energy efficiency and energy savings, DSM programs and Megawatts -

- It is relatively easy for utilities and financiers to determine the price of new Megawatts, building new power plants, (and combined heat and power) capacity

- No one can tell you what will be the after-tax value of SAVING energy, the cost of Megawatts and the savings they bring.

If the economic, accounting and fiscal rules for DSM/RUE/energy savings in eastern Europe are not set soon, uncertainties as to future energy demand will have a serious negative impact on projects to renew and to clean up old heat and power plants. To speak bluntly, if the economic and financial rules are not clear, no serious banker will finance any pending project - and your energy supply, environment and economic competitiveness will suffer.

My subject today is a suggestion how to analyse what regulation is needed for various types of energy supply and demand, and to open a debate on this important issue.

1. Energy saving may or may NOT help energy efficiency, savings and the environment. This is the "off-peak savings" puzzle.
 - A quick saving in industry may be to eliminate a boiler or to turn it down or shut it off at night. That creates savings - unless the boiler uses only waste heat from an electricity-dispatched CHP plant needed by the grid. "Savings" feed the cooling tower!
 - Installing thermostatic valves on radiators and closing the windows of blocks of flats in the spring and fall may in similar circumstances also NOT save energy.
2. Energy savings investments may save little energy and be uneconomic. This is the "utilization required to give payback puzzle".
 - A high efficiency light bulb in a rarely used lamp is uneconomic.
 - Hi-tech controls on a rarely used (or unnecessary) boiler are a waste.
 - Thermostatic valves always left open are a waste (e.g. because of an undersized radiator, lower-set controls on other radiators or wasteful behavior).
3. It is very difficult to reallocate benefits of "savings" if a user's "savings" increase per unit heat or electric costs (decrease rate of equipment utilization). This is the "who will benefit - who should pay" puzzle. How should we reallocate current and future loss of revenue and avoided cost (operating and capital) between utilities (electric, heat) and users (industrial, consumer)?
4. The only real energy savings and efficiency gain is a total system gain (e.g. electric appliances which do not draw electricity at peak load) - if it permits reduced fuel use, reduced use of old dirty power plant (not a "clean" new hydro or gas turbine). A real gain must affect primary energy (fuel) use.
 - Policy and subsidies should favor most the practices and devices which "save" primary energy, or save peak hour use of electricity (e.g. wasteful furnaces and heaters, daytime electric use (in offices), not theatres). Do policy and subsidies do this?
5. Before starting a program of audits and promoting energy savings "investment" -
 - We need public information on energy efficiency options, management versus investment/expense, and then an informed debate on how, and how much, government should support or subsidize energy efficiency training and re-equipment programs.
6. Moves to "real" energy prices (i.e. only "hardship" subsidies) and the collapse of heavy industry in eastern Europe have created great uncertainty about the future level and structure of energy demand (particularly heat and electricity) in eastern Europe.

7. Delays in deciding on the type and extent of demand side measures to be taken has paralyzed estimation of energy demand. Delay in estimating demand paralyzes investment in efficiency and environmental upgrade of energy plant (district heat, industry, CHP).
8. Each country and (heat or electric) utility of eastern Europe must decide what sort of an energy savings/efficiency program (e.g. RUE/DSM) it should plan and implement. Incentives, taxing relief and pricing measures necessary for an effective program must be determined. We suggest criteria of choice and elements necessary for regulation to promote energy savings/conservation/efficiency.

Taxation (income and revenue)

- Audit fees deductible from income - x % (50%) if not used, 100% if used
- Energy saving investments - fixed (insulation, windows) or equipment (appliances)
 - Deduction and/or partial tax credit [limited to (2) times prior years energy use]
 - Accelerated amortization [e.g. 60% + 30% + 10%], or 120% amortization
- Energy savings investment to real property (new or renewal)
 - Exclusion from real property tax base (and imputed realty income) for (10) years
 - Real property tax deduction or partial credit [e.g. up to X (30%) for Y (4) years]
- Energy saving entrepreneurs (audits, engineering, contractors, EMC or ESCO)
 - Reduced taxation on any "profit sharing" on energy savings [vs Polish 40% tax].
- Energy savings accounts (to accumulate money for and from energy savings). {Note - such accounts could be run by a bank or utility to pay utility bills net of savings.}
 - Preferential (subsidized) interest rate
 - Tax free accumulation of savings, interest, and "profit sharing"
 - Reduced rate loans after (3 years)
- [Benefits tied to use of X% (80%) on energy savings investment with (3) years.]
- For commercial clients with tax deductible energy expenses, the above benefits, and -
 - Allowance of PRE-investment energy cost deduction (cost indexed, or supplemented) (i.e. No loss of tax deduction to the extent energy savings reduce costs.)

Value Added Tax (VAT) and excise taxes

- Energy savings investments
 - Preferential (lower) VAT rate (particularly appliances programmed off-peak only)
 - VAT tax base reduced by residual value of wasteful appliances scrapped
 - Reimbursement of VAT to purchasers which cannot deduct VAT (individuals, co-ops)
 - Credits usable for payment of other "eco-taxes"
- Energy savings entrepreneurs [pro-rate to activity, and subject to licensing]
 - Reduced taxes - professional franchise, income (profits), salary (social security)
 - Reduced (subsidized) workmens' compensation and unemployment taxes/liability

Incentives (based on cost and/or on savings/value/efficiency gain formula)

- Cash refund (state or utility) of part of cost of energy saving investment
 - Efficient lights [requier proof of use to avoid resale - the CEZ/Polish problem]
 - Trade-in-and-scrap programs - appliances, heaters, cars
 - Audit costs if and to extent used
- Energy savings entrepreneurs
 - Reduced (state supported/subsidized) liability insurance
- Public sector deferral or waiver of reimbursements/profits on state-funded share

Pricing (electricity, heat, gas, water, (heating and motor fuels))

- Change from degressive to progressive tariffs (higher rates for more use)
- Require prepayment of deposit for utility's capital use, related to peak-load use
- Electronically dispatched multiple tariff (day, peak, night, weekend, vacation)

- Electric savings credits to reduce bill (based on reduction of prior [peak] use)
- Subsidized "leasing" of more efficient appliances and lights

Credits (with emphasis on pooling small loans and sequestering cash flows)

- Subsidized interest or leasing rate; preferential Central Bank reserve/deposit ratio
- Purchases and collection of payment through utility bills (showing savings made)
- Supplier credits on improved rates by pooled administration (town or utility)
- Allow borrowing for energy savings investments against "capital deposit" with utility

Contracts - Require (5 year) energy savings contracts and "energy saver" revolving

'Third Party' Finance - Matrix of Possibilities
Poland - Thermie/OPET Review

<u>Finance Types</u> (Codes : '-' = noted item; 'o' = possible; '*' = believed do-able, Western experience)	<u>Energy Supply</u>	<u>Energy Transformation</u>	<u>Energy Use</u>
● <u>Asset Based</u> - Realty - Fixed Assets * Inventory (Factoring) - Receivables * [Leasing] ● <u>Supplier Credit</u> - (hire purchase/lease) - Rental + option ● <u>Buyer Credit</u> - Cash flow pledge - (sequestration) - ect Finance [Project service] ● <u>Intermediation</u> (definition) - Sequestration ● <u>Public aid</u> - Grants, Loans ● <u>Accounting</u> ● <u>Tax options</u> (rules, calculations)	● <u>Coal - Mining</u> * Preparation * Briquetting ● <u>Gas - Develop</u> (right to gas) * Pipelines (CIS transit) ● <u>Oil - Transport</u> * Storage - Distribution ● <u>Biomass/Raps</u> - o Refining ● <u>Renewables</u> - o Wind - Solar - o Hydro - small - o Waste burning [also group c] ● <u>Heat recovery</u> * Industrial - agro/food - heavy - CHP / Power	● <u>Power * Efficiency %</u> - o Management * Renewal / New ● <u>CHP * Retrofit</u> * Load management - o Transport loss * Controls ● <u>District/Collective</u> Heating : o Public * Industrial - o Residential * Load management * Transport loss * Controls ● <u>Home heating</u> - o Furnaces - o Controls ● <u>Public transport</u> - Rail / - Metro - o Bus / - Tram ● <u>'Import/Export'</u> * Coal terminals * Ports / Piers * Pipeline Moorings	● <u>'Public buildings</u> * Government * Municipal * Service (Hospital) - Social (Swimming) ● <u>Industrial: o Plant</u> * Machinery/equipment - o Process waste heat * Heat recovery ● <u>Commerce/Shop.Cent.</u> * Insulation * Efficient Lights - o Heat recovery/sharing ● <u>Residential :</u> * Collective o Heating - o Insulation * Controls - o Individual: - Heat - o Insulation - Controls ● <u>Vehicles (car/truck)</u> * Electric camionettes - Catalysor retrofit - Turbo-diesel hybrid
Groups for study : 'leasing' 'ESCO' 'ESCO/IPP' IPP (priorities)			

Draft 3/6/94

ASSESSING COAL COMBUSTION AND SOURCING STRATEGIES USING EPRI'S CQIM™

G. Scott Stallard, Project Manager
Kevin D. Jennison, Performance Analyses Section Leader

Black & Veatch
Overland Park, Kansas, USA

ABSTRACT

Understanding the cost and performance issues associated with coal quality or, more precisely, specific constituents within coal is an important ingredient of engineering and planning processes. Such processes can cover a wide range of activities, including how to most cost-effectively burn local coal supplies, how to identify what technologies or designs should be employed for new facilities, and how to identify potentially viable "new" coal supplies. Selection of coals, coal blends, or coal beneficiation processes is a complex problem. Similarly, it is difficult for industry participants (ministries, regulators, distribution companies, etc.) To correlate fuel selection strategies to overall power system performance costs. The underlying need to understand coal quality impacts on the financial efficiency of a plant is increasingly important in light of economic and environmental pressures faced by today's power industry.

The Coal Quality Impact Model (CQIM™) offers an ideal platform for understanding and evaluating coal quality impacts. Developed by Black & Veatch for the electric Power Research Institute (EPRI), CQIM is a computer "tool" that is dedicated to maintaining state-of-the-art status by continually incorporating the latest technologies or modeling techniques as they become available. By taking advantage of research efforts and a sound engineering modeling approach, the CQIM is capable of predicting plant-wide performance impacts and translating them into costs.

This paper provides an overview of CQIM and how it can effectively be applied to evaluate pertinent fuel and technology selection processes.

THE NEED TO UNDERSTAND COAL QUALITY ISSUES

The availability of reliable, reasonably priced energy is a necessary cornerstone for established and emerging economies. Further, given new levels of international cooperation, increasingly open power and commodities markets, and more stringent demands to limit environmental impacts, it is often necessary to assimilate power generation and fuel sourcing strategies from an increasingly global perspective. However, many plants were designed primarily on the basis of geographic origin, rank, composition, and volatility of a single design coal. Alternative coal fuels available internationally will vary significantly from this design coal in quality, combustion, and handle ability. Thus, market conditions, emission considerations, government policies, and individual plant characteristics all increase the need for methods to evaluate alternate coals and their impacts.

To evaluate alternate coals in a more comprehensive manner, it is important to develop both an approach and a set of tools which can support the various phases of the planning and analysis processes. The processes must consider the following:

- Cost/availability of other potential coals supplies, including "raw" domestic sources, "cleaned" domestic sources, and other internationally marketed coals.
- Power plant performance issues as a function of plant design and fuel properties. Critical coal quality parameters and a summary of their relation to plant design and performance are listed in Table 1.

TABLE 1

Impacts of Coal Quality Parameters on Design and Performance

Coal Quality Parameter	Impact on Plant Design/Performance
Heating (Calorific) Value	The heating (calorific) value directly affects the required fuel burn rate and, therefore, directly impacts the design and performance of most of the systems within the power plant. Decreasing heating value results in higher design flows for coal handling, fuel preparation, combustion air, ash handling, and waste systems.
Moisture	The moisture content affects boiler efficiency (and, thus, fuel burn rate), combustion zone flame temperature, convective heat transfer, air preheat/coal drying requirements, pulverize capacity, and coal handle ability.
Ash	
Ultimate Analysis	Ash content directly affects design capacities of ash handling systems, particulate removal, and waste disposal land needs. Characteristics of the ash also have significant impact on system design, including ash erosion considerations and steam generator design impacts to avoid slagging and fouling.
Sulfur	The ultimate analysis determines combustion air and flue gas flows. Design impacts include fan sizes and power requirements, air heater size, and ductwork and emission limit system sizing. The major effects of the constituents of the ultimate analysis are presented separately.
Chlorine	Besides design impacts on the SO ₂ removal system, sulfur content can affect the cold-end corrosion of regenerative air heaters and, thus, control the air heater outlet temperature and affect boiler efficiency. Sulfur content can also have secondary impacts on electrostatic precipitator performance.
Nitrogen	Chlorine affects the fouling potential of coal ash. The boiler design must consider nitrogen content to ensure that NO _x limits are not exceeded.
Volatile Matter	The volatile matter affects the fineness to which coal must be pulverized to provide acceptable combustion characteristics and, thus, affects pulverize design and operation.
Ash Composition	Ash composition affects the propensity of coal to slag or foul steam generator heat transfer surfaces, the reflectivity of ash deposits, the abrasiveness of ash/flue gas passing through various systems, and the collection efficiency of electrostatic precipitators. Hence, ash composition affects the size and surface arrangements of a boiler, the size of the electrostatic precipitator, boiler and ash handling material selection, and ductwork arrangement/sizing.

- System expansion plans, candidate technologies, and associated capital and operating costs.
- Projected load demand for system and for individual units within the system.
- Legislative issues, such as environmental pressures, power purchase agreements, etc., which could alter the solution.

- Economics of potential plans/strategies based on overall cost-effectiveness of the utility system, not just individual units.
- Anticipated unit configuration, including addition of environmental control equipment or other repowering options.

One of the major hurdles which must be cleared to deliver a comprehensive set of analysis tools to the utility industry is the integration of data and knowledge available from a wide range of sources or techniques. Historically, one means for determining performance impacts and, ultimately, operational costs of a potential fuel has been by burning the "test" coal for a period of time in the unit in question. Another means, referred to as pilot-scale testing, burns small shipments of coal in scaled down units. And, still another means, commonly referred to as bench-scale testing, burns small samples of coal in a laboratory setting. While the results from these types of tests can be extremely beneficial and insightful, they can be costly, somewhat time consuming, and tend to be run on a limited suite of coals. It is for these reasons that computer modeling techniques are becoming an essential tool which utilities use to perform their day-to-day fuel procurement activities.

Computer based solutions can furnish relatively rapid, low-cost evaluations and a consistent means for comparing alternate coals. Technological advancements made through research offer the opportunity to improve the accuracy of computer simulations by providing improved algorithms and/or additional input data. Continual integration of new technologies into computer simulations ensures that the best estimates/predictions are available to the utility community. Similarly, users that apply these models inform the research community about problems which need further research.

Recent advances in theory and technology, coupled with the ever-growing base of experimental data, continue to improve the ability to predict performance impacts associated with coal quality variations. Research organizations and government agencies (internationally and domestically) continue to give the utility community invaluable information needed to evaluate fuel switching strategies in existing coal fired plants. Even though such information on operational impacts is a key ingredient in making fuel procurement decisions, the bottom line to a utility is the ability to relate these impacts to total generation costs. Hence, to "maximize" the benefit to the utility, it is important to also focus on the interplay between performance-related issues and costs, and to develop practical delivery vehicles for such integrated performance and cost analyses. Existing computer models could be an excellent delivery vehicle for such efforts since computer codes like EPRI's Coal Quality Impact Model already provide the necessary framework.

This paper focuses on how the CQIM can be effectively applied to evaluate alternate coals and the technical basis of the model itself.

CQIM CAPABILITIES

It is important to focus on how coal quality impacts are considered within the CQIM to understand how CQIM can be used to predict the impacts of coal quality with coal purchase activities. Coal quality affects unit operation and the associated cost of power in many ways. On a direct level, variation in coal quality affect the mass flows at virtually all points in the power plant. More precisely, for equal power generation, each coal is characterized by a unique fuel burn rate, gas composition and flow rate, primary and secondary air requirements, particulate and SO₂ removal requirements, and waste disposal quantities. Changes in these flow rates, coupled with changes in the composition of the fuel itself, directly impact both equipment performance and unit heat rate. Other impacts in addition to efficiency and waste disposal impacts include availability, capability, maintenance, and operational impacts.

The CQIM predicts performance and cost impacts for all systems and equipment that are directly affected by coal quality, including coal handling, fuel preparation and firing, fans, steam generator, particulate removal, flue gas desulfurization (FGD), and waste disposal.

These impacts affect not only unit performance but generation costs as well. It is important that the predicted equipment performance and annual consumption rates match the desired net power

generation. The CQIM considers impacts on net generation resulting from change in auxiliary load, equipment availability (sparing and frequency of use), steam attemperation or turbine throttle conditions, soot blowing steam requirements, and flue gas reheat requirements, if applicable.

The CQIM provides a comprehensive analysis of all power plant equipment systems impacted by coal quality. In general, the analysis focuses on coal quality issues at three levels:

- Equipment/Equipment System Performance.
- Unit Performance.
- Unit Economics.

Each of these levels is discussed briefly below.

Equipment System Performance

The methodology used by the CQIM's calculational program is summarized on Figure 1. Inputs include coal properties, equipment data and performance data. Detailed models for each major equipment system directly impacted by coal quality are modeled in the CQIM. These systems include the following:

- Steam Generator. Steam generator analysis available in the CQIM covers a wide range of performance issues, including boiler efficiency, heat transfer analysis (through a built-in one dimensional heat transfer model), tube failure analysis, and thermodynamic analysis of steam cycle impacts (such as level of attemperation, main steam outlet temperature, reheat steam temperature). The CQIM also evaluates unit load capability as function of required (calculated) full-load fuel heat input, boiler design (dimensional data, surface arrangement, etc.) and the slagging and fouling propensity of the fuel. Boiler efficiency calculations are based on predicted economizer gas outlet temperature, unburned carbon losses, and air preheat system performance.

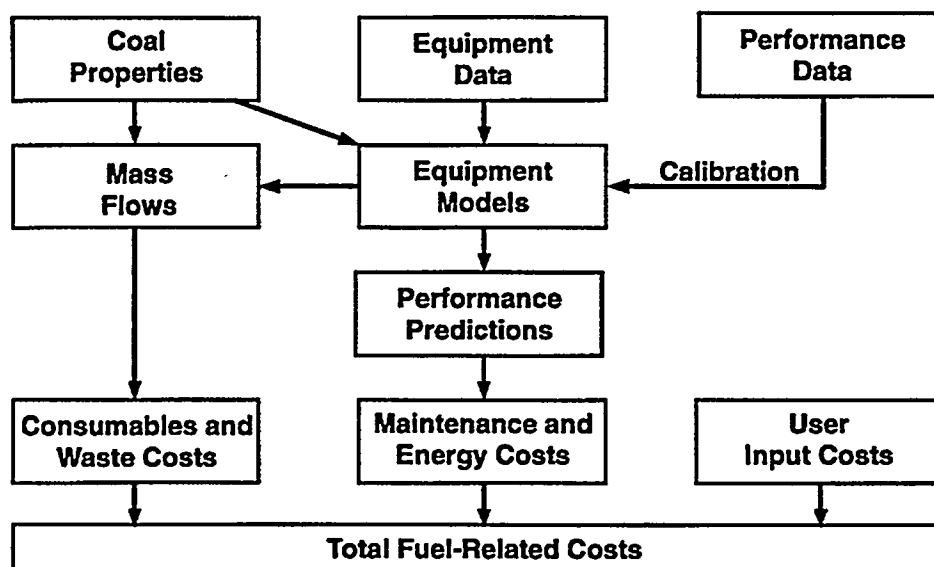


Figure 1. CQIM General Calculational Approach

- **Coal Handling.** The CQIM's treatment of coal handling systems focuses principally on the calculation of system/component usage rate or duty cycles, impacts of duty cycles on system capacity, and the identification of any capacity or handling limitations.
- **Fuel Preparation and Firing.** The primary concern associated with fuel preparation and firing equipment when utilities switch coals is a potential decrease in system capacity. To this end, CQIM models evaluate mill capacity impacts according to two factors. First, CQIM calculates expected mill throughput as a function of coal quality (grind, moisture content, etc.), required fineness, and fuel inlet size. Second, the CQIM calculates heat balance around the system and predicts the ability of air preheat/mill system to meet coal drying requirements. Other performance calculations include the number of mills required to meet various user-specified load points and system/component wear/failure rates.
- **Particulate Removal.** The CQIM can evaluate performance of both hot- and cold-side electrostatic precipitators (ESPs) as well as fabric filters. The principle focus of such analysis is system capability, as characterized by relationship between predicted ash removal efficiency and required removal efficiency. The CQIM's ESP calculations consider geometry (plate size, aspect ratio, etc.), ash resistivity, gas temperature, gas velocity, and ash properties. The CQIM can also consider SO_3 injection.
- **Air Heaters.** As noted in the discussion above, air heater performance is principally tied to boiler efficiency and air preheat (fuel preparation and firing) needs; other concerns also modeled by CQIM include cold end corrosion and air heater pluggage.
- **Fans.** CQIM models primary air, forced draft, induced draft, and scrubber booster fans, as applicable. Fans may be either centrifugal or axial. For centrifugal fans, various flow control mechanisms considered are damper, inlet vane, or variable speed drive. Complete fan curve data may be entered; principal concern for fans lies in capacity and is, hence, closely associated with fan curve and pressure drop calculations provided by the CQIM.
- **Bottom Ash Handling System.** As ash characteristics vary across the fuel supplies in terms of quantity, composition, and split (fly ash to bottom ash), the effective capacity of existing bottom ash systems may change dramatically. The CQIM considers ash parameters and load factors to determine if cycle times are adequate; in addition, CQIM calculates wear and tear on bottom ash system components. Sluice, vacuum, and submerged chain conveyor systems can be modeled.
- **Fly Ash Handling System.** Fly ash system treatment in the CQIM is quite similar to that for bottom ash. Pressurized and vacuum pneumatic systems, as well as sluice systems, are modeled. As in the case of bottom ash, the CQIM focuses principally on capacity and wear and tear calculations.
- **FGD/Waste Disposal System.** The CQIM can model wet limestone and dry lime FGD systems. FGD models relate target removal requirements and SO_2 loading to required stoichiometry, L/G ratio, etc. On the basis of stoichiometry and its associated mass balance the CQIM is able to predict both system performance (in terms of stoichiometry), maximum flue gas to be treated, dewatering requirements as a function of emissions regulations, fuel quality, and load demand. Sludge handling and storage (landfill, ponding, or off-site) are analyzed by the CQIM's waste disposal system model.

Each CQIM equipment system model can be calibrated to actual conditions on the basis of performance data furnished by the user. Calibrated equipment performance models can then be used to predict system performance, capability, auxiliary power requirements, and duty cycles as a function of fuel supply or varying operating assumptions.

Unit Performance

After completion of individual system performance calculations, CQIM carries out two additional performance assessments to quantify impacts of coal quality, equipment duty cycles, and capacity on the unit as a whole:

- **Derate Analysis.** The CQIM uses specialized derate performance calculations to consider the effects of coal quality variability on system performance and overall unit capability as a function of coal quality parameters. The CQIM employs a Monte Carlo treatment to develop "random" sets of self-consistent coal properties to simulate the variability of the coal; each "set" of coal quality is then evaluated by the equipment system to determine if capacity limitations exist. If such limitations exist, the most constraining system is identified as well as the level of expected derate. Derates calculated for each set of coal quality are then aggregated and matched to the overall unit load curve to determine level of annual lost generation.
- **Maintenance/Availability Analysis.** The CQIM employs a maintenance/availability model which considers the effects of coal quality on individual component capacities, sparing, duty cycle, and failure rates. Coal quality can impact expected availability in two ways. First, expected failure rates can change as a direct result of changes in coal quality, such as abrasiveness. Second, failure rates and availability can be indirectly impacted by component/system capacity changes with coal quality changes. Coal quality can alter the effective component capacity and, therefore, alter the number of on-line spares and duty cycles, thus requiring that requirement run for different periods of time. In addition, the amount of capacity lost during partial outages by the coal quality dependent capacity of the components.

A reference maintenance/availability database provides basic failure and repair data for each component. These data furnish information on types of failures and frequency of outages, logistics time, availability of spare parts, and repair time and costs for each type of failure (failure mode). All data are user-adjustable to allow modeling of unit-specific equipment failure rates and repair policies.

Results of the derate and maintenance/availability analysis are subsequently factored into the CQIM economic analysis.

Relating Performance to Economics

The bottom line of CQIM's economic analysis is the calculation of overall fuel-related costs as a function of coal supply. Translating the changes in equipment and unit performance to generation costs is relatively straightforward because the CQIM performance predictions are used to determine the cost relationships discussed below and illustrated on Figure 2:

- **Efficiency.** Efficiency impacts are factored into the calculation of net plant heat rate and, therefore, are reflected in the total annual delivered fuel cost and ash disposal costs. The plant efficiency calculation factors in changes to boiler efficiency, plant auxiliary power requirements, and turbine heat rate deviations due to changes in attemperation or final superheat/reheat steam temperatures.
- **Component/System Duty and Capacity.** Unit availability and auxiliary power requirements are impacted by equipment duty cycles and number of components in operation.
- **Lost Generation Resulting from Changes in Unit Capability.** Inadequate capability results in lost generation and the need to purchase replacement power.
- **Equipment Maintenance.** Every component failure, regardless of the impact on unit availability, directly impacts system maintenance costs. Predicted repair costs (manpower plus materials) are estimated for each major system.

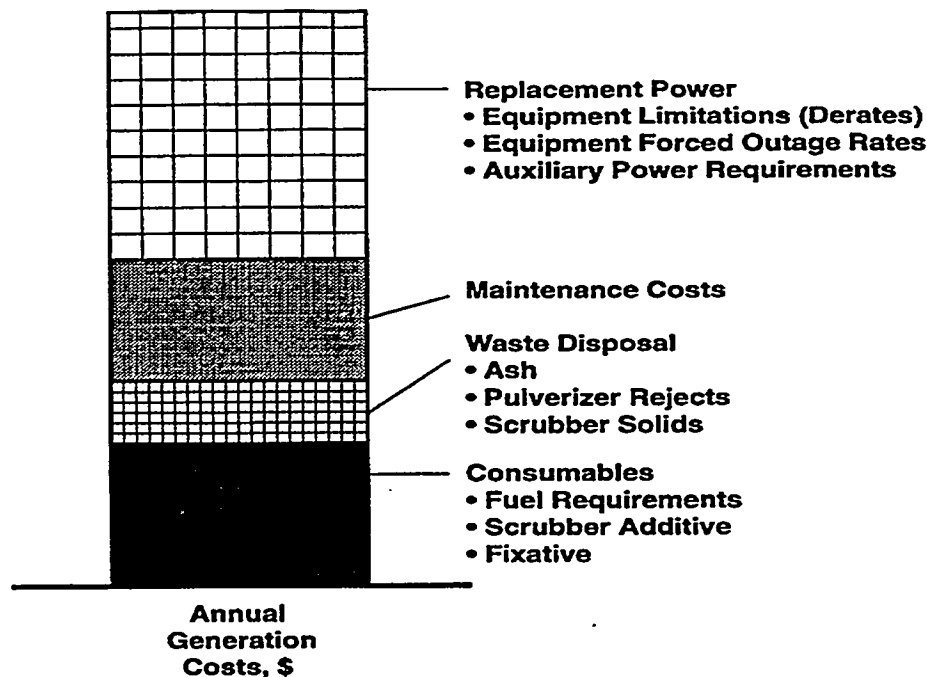


Figure 2. CQIM Economics Based on Performance Results

Total Fuel Related Costs

Based on these relationships, CQIM presents the relative economic impacts of alternative fuel supplied on a total fuel-related basis. This cost is, in reality, a fraction of the total production cost to be expected for that particular coal supply. Cost components of production costs not considered explicitly by the CQIM are recovery of capital and "baseline" fixed and variable operations and maintenance (O&M) costs. O&M costs are considered on a differential cost basis. CQIM total fuel-related costs consist of the following components:

- **Fuel Costs.** Costs are a function of unit fuel price and annual fuel requirements; annual fuel requirements are based on the CQIM's calculation of overall plant efficiency.
- **Fuel Transportation.** The CQIM calculates these costs as a function of total fuel consumed, and can consider rail, barge, truck, and terminal costs as well as combinations of the above.
- **Maintenance.** Maintenance costs are calculated by aggregating the result of the components level failure analysis. Components repair costs are a function of the number of components required for operation to meet load (duty cycle), the continuous operating failure rate (failures per year), and the cost (material plus manpower) per failure.
- **Availability.** As in the case of maintenance analysis, availability costs are based on expected failure rates determined by the maintenance routines. Availability calculations evaluate each predicted failure to determine if equipment/system capacities are impacted by the equipment failures and to what extent resultant unit capacity is limited. For such situations, all significant probability states (the percent capability and the probability of having that capability) are then compared to the input load curve to directly determine the replacement power.
- **Derates.** The CQIM calculates replacement power requirements corresponding to predicted derates.

- O&M. Annual O&M calculations consider changes in ash or waste disposal rates, as well as other O&M cost considerations entered by the user, such as sale of byproducts and additive costs. Changes in plant staffing levels or inventory levels are not considered in these costs; rather, these costs are included in maintenance costs discussed previously.

Total fuel-related costs are presented on first-year and levelized bases for multiple periods of evaluation. In addition, the CQIM can calculate "break-even" FOB mine fuel costs for a coal relative to another coal; that is, the CQIM can calculate the required fuel price for a candidate coals relative to a "base" coal so that the two coals will have equal total fuel-related costs.

APPLYING THE CQIM

The design basis for the CQIM was the creation of a computer program which could be readily understood and operated on commonly available computer equipment. The CQIM was designed so that all the required unit and equipment design and performance data, coal data, etc. needed could be easily entered into the models by the user rather than requiring customizing by software experts. CQIM uses the OS/2 operating system on standard IBM-compatible computers (80386 or higher processors) which provides a windows environment for data entry. An example screen is shown on Figure 3. Results are presented on-screen as well as through various detailed hard copy options, including report writers. A typical on-screen summary showing break-even total fuel-related costs is provided on Figure 4.

In conclusion, CQIM has been used by electricity and steam producers, coal producers, and engineering consulting firms to solve a number of complex problems encountered on a day-to-day basis. As illustrated on Figure 5, these applications cover the entire spectrum of short- and long-term issues dealing with coal sourcing, fuel procurement, plant operation, electric generation, and emissions. Over 100 EPRI members have copies of the program and an additional 14 companies have licensed the program from Black & Veatch. Black & Veatch has been directly involved in modeling over 120 units which further demonstrates CQIM's widespread use.

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COIM - Version 1.2

File Build Project Edit/Create Tools Calculate Output F1=HELP

Coal Data Entry

File Tools Properties Economics Historical F1=HELP

Proximate Analysis

☒ Wet Analysis ☒ Dry Analysis

		Input	Default (Wet)
Higher Heating Value, Btu/lb	Typical	5300	
	Minimum	4900	
	Maximum	5700	
Moisture, percent	Typical	31.00	
	Minimum		
	Maximum		
Ash, percent	Typical	24.00	
	Minimum	20.00	
	Maximum	30.00	
Sulfur, percent	Typical	1.15	
	Minimum	0.80	
	Maximum	1.50	
Volatile Matter, percent		20.00	

Cancel Next Fuel Select Fuel Ok

Coal #2 of 2: czech - Czech Brown Coal

Figure 3. Example of COIM Data Entry

COIM Version 1.2

File Build Project Edit/Create Tools Calculate Output F1=HELP

Interactive Output Utility Unit 1

Fuel Comparison Program Diagnostics Sort by... Overall Plant Exit F1=HELP

Break-even Analysis, First Year Costs

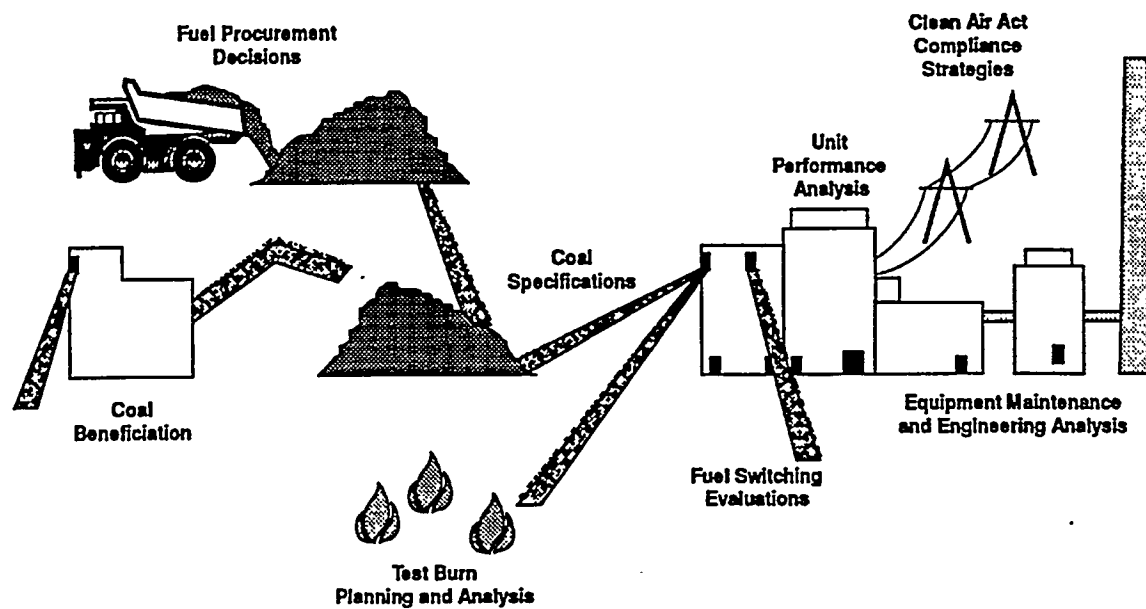
Case Title	czech0	czech	cz2
Heating Value, Btu/lb	6600.0	5300.0	8950.0
Coal Burn Rate, MTPY	0.63	0.82	0.45
Capital	0.00	0.00	0.00
Misc O & M	0.00	0.00	0.00
Diff. Emissions	0.00	0.00	0.00
Diff. Maintenance	0.00	0.76	-0.57
Derate	0.00	1.06	0.00
Diff. Availability	0.00	0.56	-0.68
Diff. Aux. Power	0.00	0.00	0.00
Diff. Turndown	0.00	0.00	0.00
User Input Costs	1.00	2.40	1.00
F.O.B. Coal Cost	10.03	10.47	9.65
Natural Gas Cost	0.00	0.00	0.00
Coal Transportation	0.00	0.00	0.00
Total Cost	11.83	15.26	9.29
Break Even Fuel Cost	10.03 (base)	7.22	11.32

All costs are displayed in units of: \$/ton

Econ. Params. Fuel Prices Cost Elim. Cost Units Base Fuel Exit

Project File: A:\COIM386\PROJECT\CZECH.PRJ

Figure 4. Example of On-screen Results



Figures 5. CQIM Applications

Cost vs. Benefits – Case Studies of Energy Systems

Session B4

SESSION COCHAIRS:

*Dušan Ložek, Department Head
Slovak Power Enterprise
Bratislava, Slovak Republic*

*Ken Gelle, Managing Director
NRG Energy Inc.
Minneapolis, Minnesota, USA*

SECURED ELECTRICAL SUPPLY AT LEAST COST: COAL, GAS, NUCLEAR, HYDRO

Jiří Gavor, Partner

ENA Ltd.
Prague, Czech Republic

Oldřich Starý
Jiří Vašíček

Electrotechnical Faculty
Czech Technical University
Prague, Czech Republic

ABSTRACT

Electric power sector in East Central European countries finds in a difficult period. In the situation of demand stagnation, enormous investments must be realised in a very short time. Today's decisions in the development strategy will influence the long term future of the industry. The optimal structure of the sources is one of the most important problem to be solved.

Paper describes the current structure of the sources in electric power sector in the Czech Republic. The importance of coal, oil and gas, nuclear and hydro in electric power generation is compared. Taking into account the different position in the load coverage, economy of individual sources is evaluated and basic results of discounted cash flow calculations are presented. Information on specific investment programmes and projects are included and further trends are estimated.

THE CURRENT SITUATION IN ELECTRIC POWER SECTOR

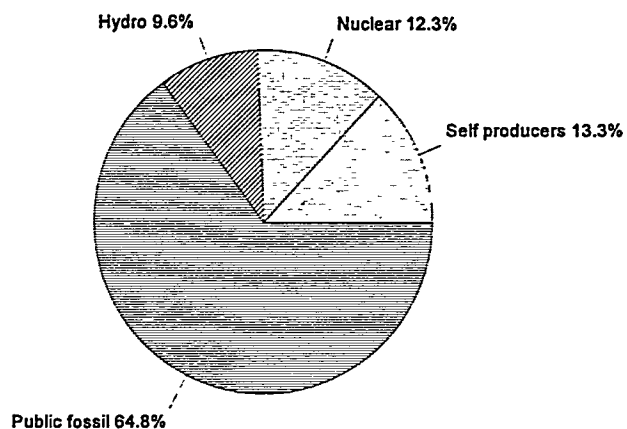
Consumption of electric power is closely related to economic development. Therefore it is a common feature for all countries in East - Central Europe that consumption of electricity during the first years of transitions from planned to market economy significantly decreased, mainly due to the restructuring and decrease of industrial production. In the Czech Republic (CR), net consumption of electricity dropped by 10 % in 1990 - 1993¹. Since 1993, the overall recession was stopped and in the next years the period of increase is expected. However, demand in 2000 will not differ very much from the situation in 1990 [1]. Therefore, there is no urgent need for an absolute increase of generating capacity in the near future. Instead of it, the least cost optimization of the structure of sources is the most important task.

The current structure of installed generating capacity and electricity production in CR is shown in Figures 1 and 2. Both public fossil and self-producers power plants are almost totally conventional steam, coal fired power plants. The share of liquid and gaseous fuels in power generation is only about 2 %. Similar situation is in Poland, where the dominant position of coal in power generation is even greater because of the absence of nuclear power. It is a considerable difference from the situation in OECD countries, where oil and gas fired plants contributed by 18.8 % of electricity production and by 28.1 % of installed capacity (1991 data according to [2]). Therefore it is clear why coal based technologies for environmental friendly power production are so important for countries in East - Central Europe.

¹Data taken from [3], a comprehensive description of main parameters of both Czech and Slovak electric power systems.

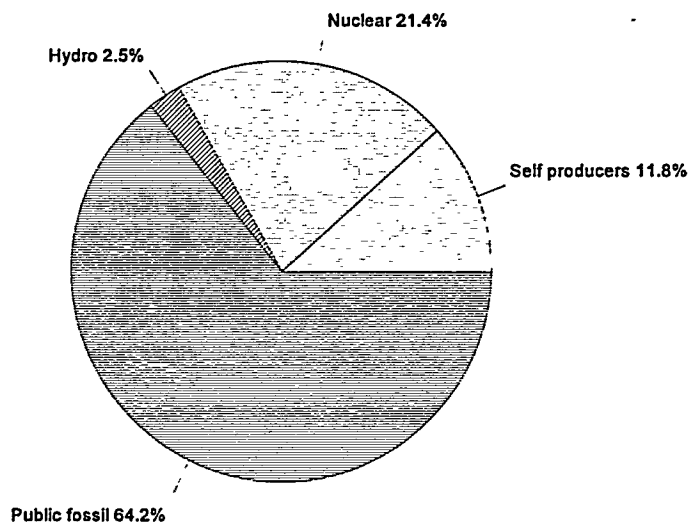
The Structure of Installed Capacity

CR - 31.12.1993



Electricity production

CR - 1993



Figures 1 and 2.

Starting since January 1, 1999, new strict environmental limits for air polluting emissions will come in force in CR, see the paper "Review of Current and Anticipated Regulations" in Session B3. The Air Act brought a necessity of enormous accumulation of investment in a very short time. The main responsibility lies on Czech Power Company (CEZ), a market leader in CR (now cca 85% of electric power production). In 1994 - 2000 only CEZ alone will invest 126 bil.Kc in 1993 prices. A time coincidence of nuclear power plant Temelín completion (2 x 1000 MW blocks) with the desulphurization programme concentrates 66 % of all investments into years 1994 - 1996. The next paper in this Session "Activities of CEZ and Improvement of the Environment" by Mr.Kindl gives the detailed description of CEZ's environmental programme. The major part of this programme, desulphurization of coal fired power plants, is analysed in the Mr.Kašparů's paper "A Minimum Cost SO₂ Scrubber Study" in Session A3.

The least cost optimization of further development of large energy systems is different and more complex task than a decision making process from the point of view of an individual auto-producer. However, some common principles and methods are always applied. In any case, economic and financial analyses are necessary. Because of a long term character of investments in power sector, the discounted cash flow (DCF) analysis, respecting the different value of cash flows in time, must be applied.

To demonstrate the method on specific examples from real situation in CR, we selected for our case study the nuclear power plant Temelín, wet - limestone desulphurization of 200 MW domestic brown coal fired 200 MW block and construction of a new gas fired combined cycle 90 MW. This selection clearly indicates that it can not be interpreted as a comparison of interchangeable alternatives. Each of the above mentioned sources has its own individual position in the electric power system. The completion of Temelín, not regarding to the aggressive campaign of certain groups, can not be stopped because of a large amount of sunk costs. No other nuclear capacity is planned in this and next decades. Costs of desulphurizing devices remarkably decreased in the last time. This fact together with usual advantages of reconstruction compared with a new erection makes desulphurization of 200 MW blocks highly efficient.

On the contrary, construction of a new gas fired combined cycle can be a solution of environmental problems for an independent self-producer or district heating company with old smaller blocks. We did not include any hydro power plant in our calculation, taking into account a limited potential of hydro power in CR (a different situation is for instance in the Slovak Republic).

ECONOMIC AND FINANCIAL ANALYSIS

From the moment when we consider any investment, we must evaluate three factors: revenue, risk and liquidity. The decision about investment can be divided into two phases - **investment** decision and **financial** decision. The first phase is sometimes referred to as **economic** analysis, the second as **financial** analysis.

Investment decision is not a subject of any transfer items - taxes, interests, etc. Only the whole contribution is evaluated irrespective of the fact who shares a distribution of this contribution (investor, state, creditor, bank ...). It is a suitable tool for evaluation of investment from a macroeconomic point of view. This approach can be recommended for strategic tasks where various types of energetic sources are compared. The indexes of profitability of the project are not deformed by insufficiency of tax system, and therefore the institutions as World Bank and European Bank require these calculations when discussing about loans for energy industry. Deformed prices (e.g. in developing countries) are used together with so called shadow prices expressing real expenses for raw materials, energy, etc. The certain advantage is represented by the fact that a view on efficiency is not influenced by the way of financing and taxes, but only by technical and economic indexes of evaluated variant, stages of construction, etc.

For an investor such calculation is insufficient because it does not answer question what financial funds must be invested into a project and when, and what financial funds will be obtained from its participation. **Financial decision** is based not only on the selection of optimal variant of technical solution of investment (power and heating plant, back-pressure or condensation, etc.), but also on an optimal way of financing of the whole event and an influence of the investment on the tax situation of an investor.

When comparing variants with identical effect (production of electric power and heat) we recommend to use absolute indexes (see below), which are mutually comparable. In practice this situation occurs very seldom and then we must use relative specific indexes related to a production unit - kWh or GJ. Specific indexes are suitable to be used under the presumption of comparable volume of compared variants. In the case that using specific indexes we compare, for example, 330 MW block of coal power plant and 100 kW wind plant, we must realize, whether our data are real. Is it possible to build 3300 wind power plants under the considered conditions? Will a delivery of electricity be the same from a standpoint of diagram, usage, quality of control? It is necessary to compare only comparable things and it is not possible to make incorrect conclusions on the base of specific indexes.

Basic Indexes for Investment Decision Making

All below mentioned indexes are calculated from data of all years of economic lifetime. In our opinion the indexes of particular years are insufficient (target year, the first year of operation, etc.) because they do not reflect a possible development during the evaluated period.

The profit of a project is calculated after deduction of operational expenses, depreciations and interests from the whole revenues according to the formula

$$P_t = R_t - OC_t - a_T \cdot I_t$$

where P_t is before tax profit in the year t
 R_t revenues in the year t
 OC_t operational costs in the year t
 a_T relative annual annuity containing depreciations and annuity interest
 I_t investments in the year t

Cash-flow of the project - CF - is a basic quantity for economic analysis of investments. In contradistinction to a profit, cash-flow does not contain accruing of investment costs through depreciations, because as it is evident from the name, it is the deduction between incomes and expenses in cash. In each year it is valid

$$CF_t = R_t - OC_t - I_t$$

Discounted profit during the lifetime T is calculated as net present value of profits in the particular years

$$P_T = \sum_{t=1}^T P_t \cdot (1+r)^{-t}$$

where r is discount

Discounted cash-flow, it is net present value during the lifetime of the project, gives the same result for investment decision making as discounted profit, because the sum of depreciations and annuity interests during the lifetime is equal to present value of invested funds [4]. The advantages of cash-flow is represented by a possibility to evaluate cumulatively a balance of financial funds in any year from the beginning of realization. For selection of an optimal variant we consider it as the basic index.

Internal rate of return, (internal interest rate) r_i is such value of interest rate which being used for discounting gives just zero value of discounted cash-flow during a lifetime.

$$DCF = \sum_{t=0}^T (R_t - OC_t - I_t) \cdot (1+r_i)^{-t} \stackrel{!}{=} 0$$

The variant with maximal value of DCF for certain discount rate can be generally different than the variant, for which internal interest rate is the highest. The usefulness of this index is based on a possibility to evaluate absolutely the efficiency of evaluated investment in comparison with selected discount rate, i.e. with supposed certain rate of returns of own funds.

If a variant with maximal value of DCF during the lifetime has internal interest rate considerably lower or considerably higher than discount rate, the decision about a refusal or acceptance of a project is unique. If the result is represented by internal interest rate, e.g. in the range 6-12% with discount 8%, it is suitable to decide after analysis of risks connected with realization of a project.

Basic Indexes for Financial Analysis

For calculation of cash-flow of investor the own investment funds and instalments are calculated depending on the way of financing, so the result is **cash-flow of investor**²

$$CF_t = R_t - OC_t - IC_t - T_t - IE_t - P_t$$

where IC_t are interests from loans and obligations
 T_t income taxes
 IE_t own investments
 P_t instalments of loans and obligations

To evaluate investments from a view of investor the same indexes are calculated which are described in the previous paragraphs. To interpret them correctly, it is necessary to realize some differences from the indexes of a project. A choice of optimal variant will be performed according to a maximum of discounted cash-flow of investor after taxation during a lifetime. Due to a relatively high taxation in CR (now 42 %) the net present value of real revenue of investment is considerable lower than DCF of a project which is not loaded by taxes.

Adequate Price of Electricity

Electricity is generally considered as goods of special character, because it is bound with distribution systems creating a monopoly against customers. Calculations described in the previous paragraphs are always performed for determined price of electricity. After deduction of costs, or also taxes, an investor will have a certain profit (or loss). However customers will always be interested in the question which price will be proposed by an investor, or future operator. As an initial point we recommend to use so called minimal price of electricity according to below mentioned principles.

What is "adequate price of electricity"? This price should cover all necessary costs for construction and operation of source and distribution up to consumer. The word "necessary" must be understood in the sense "minimal", i.e. such expenses which are optimal for selected technical solution. A spending of "wasted" costs (e.g. oversizing of construction part, non-adequate reserves, etc.) can lead to the situation when consumers are able to ensure cheaper electricity (industry). An adequate rate of a profit from

² For long-term evaluation we suppose that incomes are equal to revenues and operational costs are equal to expenses

investments in energy industry in the Czech Republic is not defined yet. Due to a long duration of an investment and great stability and certainty of revenues for its realization, this value should be a little bit lower than in other industries, e.g. processing industry.

A minimal price can be considered as such one which fulfils a condition of DCF investor = 0. For this price an internal interest rate of an investor is equal to just determined discount rate and maturity period is just lifetime.

Discount rate in the indicated calculations is an economic parameter factually expressing a price of opportunity costs, i.e. the price of a capital. A discussion about the level of discount is out of the scope of this article, a detailed analysis can be found e.g. in [10]. The calculation of DCF is possible to be performed in nominal as well as real values. In case that an inflation influences CF items by the same extent, the decision is identical for both approaches. Then the calculation in fixed prices is more advantageous and we need not to estimate future inflation which is determined very hardly (mainly in the East Central European conditions). However, from a point of view of an investor the calculation is more transparent in nominal prices, because the calculated CF can be compared with its financial plan and with the reality.

Specific Production Costs

The total discounted costs TC during the period of operation (or selected period of operation) can be calculated as follows:

$$TC = TI + TOC = \sum_{t=0}^T (I_t + OC_t) \cdot (1 + r)^{-t}$$

where TI are the whole investments at present value
TOC the whole operational costs

The whole production of electric energy TDE on the terminals of generator are discountly calculated in the same year as costs according to the formula:

$$TDE = \sum_{t=0}^T 8760 P_{jt} L_{ft} (1+r)^{-t} \quad (MWh)$$

where P_{jt} is installed output (gross output) in MW
 L_{ft} load factor, i.e. ratio of given annual usage to the value 8760

If we substitute for output in the previous formulas the output of the source (net output) which is installed output reduced by own consumption, according the same formulas, we can calculate the whole discounted delivery of electric energy. A delivery of electricity is possible to be divided into condensation and back-pressured, or for production of gas and steam turbines for combined cycles, because it is possible to suppose the different prices of deliverables into electrification network.

Then specific production costs of electric energy c_E (Kč/MWh)

$$c_E = \frac{TC}{TDE}$$

Such calculated specific costs contain all items spent from the beginning of construction up to the termination of operation (including possible liquidation of equipment). When comparing with minimal, adequate price, they are usually lower, because they do not contain transfer items (taxes, interests from loans). They are suitable for investment decision making. A minimal price is calculated from a point of view of an investor and it will be compared with competitive price on the market, or will be used as a basis for determination of a regulated price.

When using above mentioned procedures it is necessary to realize, for what purpose we perform a calculation of economic efficiency. When making decision about a possibility to terminate of already introduced construction and its replacement by new investment we will not consider sunk costs. Then specific costs of an investment in progress depend on a rate of completion of a construction. The shorter period of termination of an investment, the lower specific costs are. However, these costs cannot be used as an initial basis for price determination and they serve only for decision making whether to finish (to complete) or to terminate a construction and to start some new alternative from the beginning.

Possibilities of Comparison of Various Types of Sources in Electrification System

Electrification system of the Czech Republic is the system, where a dominant position is represented by ČEZ, a.s. This firm is not the only producer in the sector of so called public electricity, because besides of the firm there are independent electric and heating firms disposing with installed outputs from tens of MW to 300 MW. Besides of it there is an important share of enterprise power plants which have been originally constructed to ensure electricity for their own production processes (so called self-producers). Entrepreneurial plans of above mentioned firms contain greater or smaller investments which are necessary for reconstruction and modernization of the sources to fulfill mainly requirements of ecological legislation. In many cases variants with considerably capacity expansion are considered, so there is a certain pressure on the side of offers, leading to a greater competition.

To be able to keep all principles of LCP methods, in the Czech Republic there are not all system presumptions. Energy legislation is not completed yet. This legislation should determine conditions for selective proceeding and evaluation of planned investments. Therefore, newly proposed investments are compared with sources of the dominant producer - ČEZ, a.s. and with those investments into the sources, which complete a balance of output and electric work in the electrification system of the Czech Republic.

At present, an output in electrification system is completed by increments of outputs, or output is renewed in already operated electric power plants. New sources are represented by the nuclear power plant Temelín with installed power output 2x1000 MW for basic load and water power plant Dlouhé Stráně 2x325 MW which is determined for covering of peak load and further dynamic services in the electrification system. Besides these sources ČEZ is an investor of a wide desulphurization programme of classical blocks mainly of 110 and 200 MW, fuelled predominantly by domestic brown coal. These reconstructions are performed on the current equipment, so resulting indexes are influenced by possibilities of usage of current equipment for further operation. The further possible type of new sources, is represented by gas fired combined cycles. Their realization is evaluated in connection with heat production for heating or for technological purposes in certain locality. These new sources can significantly influence the market situation in district heating.

Renewable sources of power and heat are important from an ecological point of view, but as a whole they will not represent a significant item in the balance of the Czech Republic in the near future. New hydroenergetic potential in accumulation and stream flowing water power plants new localities are found very hard and the construction of small water power plants is connected with higher purchase price for electricity. The same situation is e.g. in the case of wind power plants where a high investment demand and non-guaranteeing of deliverables leads to their non-competitiveness in the common market

conditions. However various forms of support of renewable sources are considered in the state energy policy with the aim to stimulate their further development.

The next possible source which could be implemented in the output balance is represented by import of electricity. The problem of import of electricity is not always connected with the price of imported electricity in comparison with current costs of domestic sources, but with the question of dependence on this import. Besides of this the price of import must be evaluated depending on guarantee of electricity, reliability of contractual partners and in dependence on the life of a contract and possibilities of its prolongation or its cancellation by one of contractual party. Although the overall volume of foreign trade with electricity will probably increase as a result of removing technical and legislative barriers, the total balance will fluctuate very near to zero.

MODEL CASE STUDY

As an example of economic evaluation of variants of construction of new sources or reconstruction of already operated sources, we calculated some economic criteria for selected variants. This article, due to a limited space, includes only an evaluation of three types of sources - nuclear power plant Temelín, desulphurization of a block 200 MW and gas fired combined cycle. Technical and economic parameters reflect investment plans of really realized or prepared events in the Czech Republic.

The construction of nuclear power plant represents total investment costs in amount of 68.8 billion Kč, the output will be used in the basic load with supposed annual utilization of 7000 hours. The lifetime of an equipment depends on technical possibilities of its prolongation, we suppose 30 years with liquidation costs in amount of 14 billion Kč. The construction is financed partially by foreign capital - loans and emission of obligations under various conditions. We expected a long term stable exchange rate about 28 - 29 Kč/USD.

The economic evaluation of desulphurization of 200 MW block by wet limestone method supposes the total investment of 1.25 billion Kč, from which about 800 mil.Kč represent the cost of desulphurization devices. Additional cca 350 mil.Kč are necessary costs connected with refurbishment of boiler, electric precipitation, primary denitrification, control system etc. After 15 years it is supposed to renew desulphurization unit (about 50% of original investment). Net output of the block is on the level 185 MW (may be higher up to 190 MW) with expected utilization within 4500 - 6500 hours per year (6000 hours for the base case). A fuel is brown coal at the price 26 Kč/GJ.

Combined cycle which represents the further evaluated variant, supposes net electric power 90 MW in condensation operation (with efficiency 49%). When heat and power are produced, 70 MW_e (efficiency 38%) with thermal power 65 MW are supposed. The introduction of this source cannot be considered fully in the basic part of loading diagram. An average usage of heating operation is 2500 hours and in condensation regime it is possible to suppose up to 4000 hours. Gas price is a very sensitive criterium for combined cycles. In our calculation, we adopted price 3 Kč/cm. Initial investment are cca 1.6 bill.Kč. After 15 years, additional 30% of initial investment is necessary (replacement of gas turbine).

All variants are evaluated in fixed prices of 1994 in such a way that their comparability is ensured. Discount rate is supposed to be 8%, the same for all variants, because we consider the same industry and we suppose approximately the same rate of entrepreneurial risk. We suppose the purchase price of electricity at price level of 1994, i.e. about 1,050 Kč/MWh and the price of delivered heat cca 150 Kč/GJ.

In above given text we mentioned only selected basic input data, total investment and cost flows are shown in Figures 3 - 5. The individual description of other necessary items, included in the calculation, such as maintenance, labour cost, insurance, environmental fees etc), is out of the scope of this paper.

Desulphurisation Investments and Costs Flow

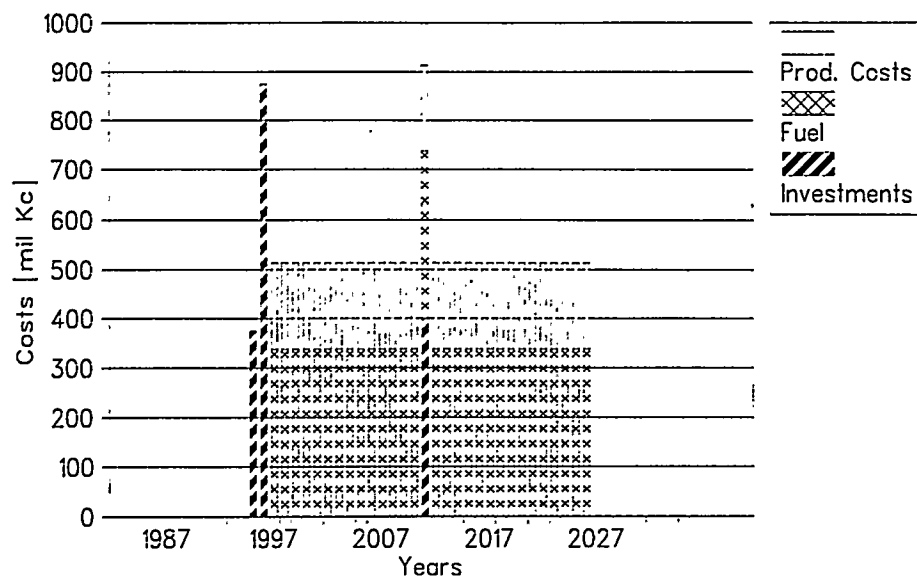


Figure 3

Combined Cycle Investments and Costs Flow

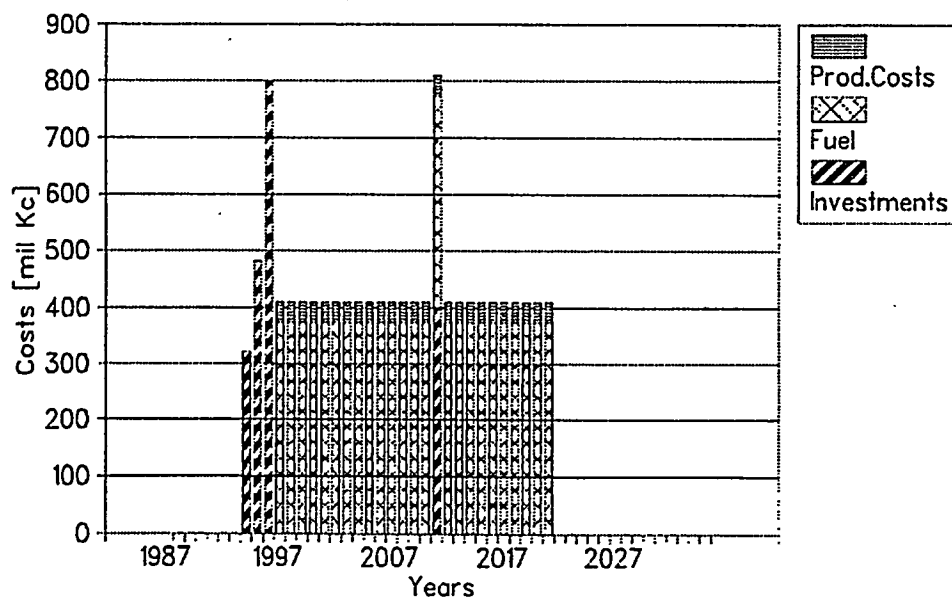


Figure 4

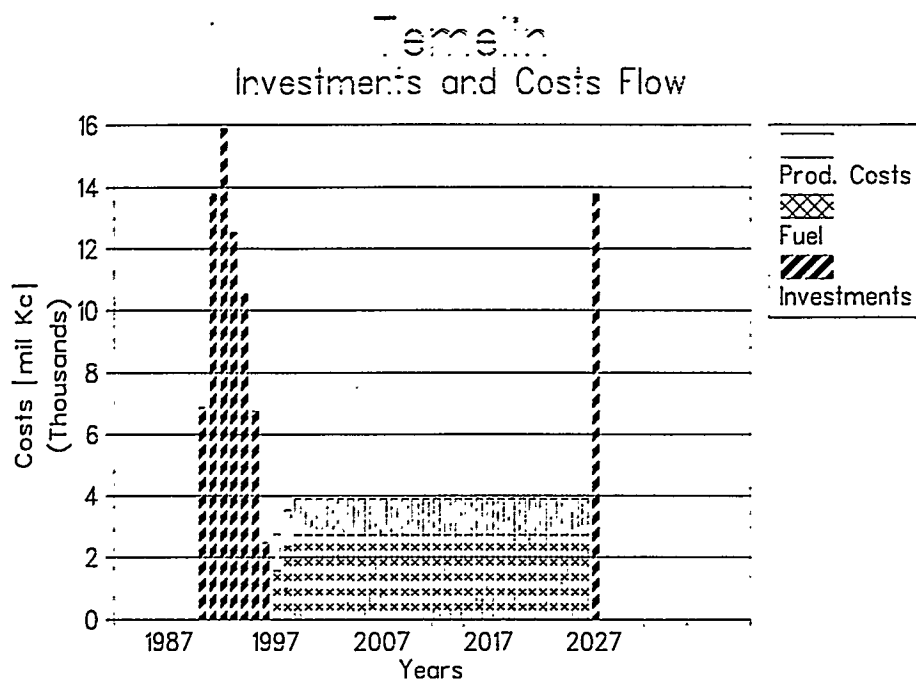


Figure 5

In reality, economic and financial analysis of specific investment programme is a subject for a quite extensive study.

Results

Resulting specific production costs of supplied electric energy for above mentioned variants in dependence on discount rate are given in Table 1. Following Table 2 contains minimum prices of electric energy in Kč/MWh for investors with presumed real return of capital (the discount rate), taxed by 40% and partly financed by loans. Minimum price of electricity as a function of discount is also graphically presented in Figure 6.

Specific costs and minimum prices in Table 1 and 2 assume comparable utilisation 6000-7000 hours. Load factor is a very important parameter for economic analysis and therefore we carried out also the sensitivity analysis on annual utilisation. Results are shown in Figure 7. It is apparent, that nuclear power plants can work effectively only with very high load factor. Results of desulphurization are

TABLE 1

Specific production costs of supplied electric energy in Kč/MWh			
Discount rate	Nuclear	Combined Cycle	Desulphurisation ¹⁾
8 %	982	924	576
6 %	826	881	558
4 %	699	843	541

¹⁾ Desulphurisation includes reconstruction only while others involve new erection

TABLE 2

Minimum prices of supplied electric energy in Kč/MWh			
Discount rate	Nuclear	Combined Cycle	Desulphurisation ⁷
8 %	1265	1040	618
6 %	1026	936	592
4 %	829	837	566

⁷ See previous table

influenced by the fact, that reconstruction does not include the cost of old equipment. If new coal fired block were considered, the slope of the curve would be higher. The dependence of combined cycle is relatively flat, because of high share of fuel costs.

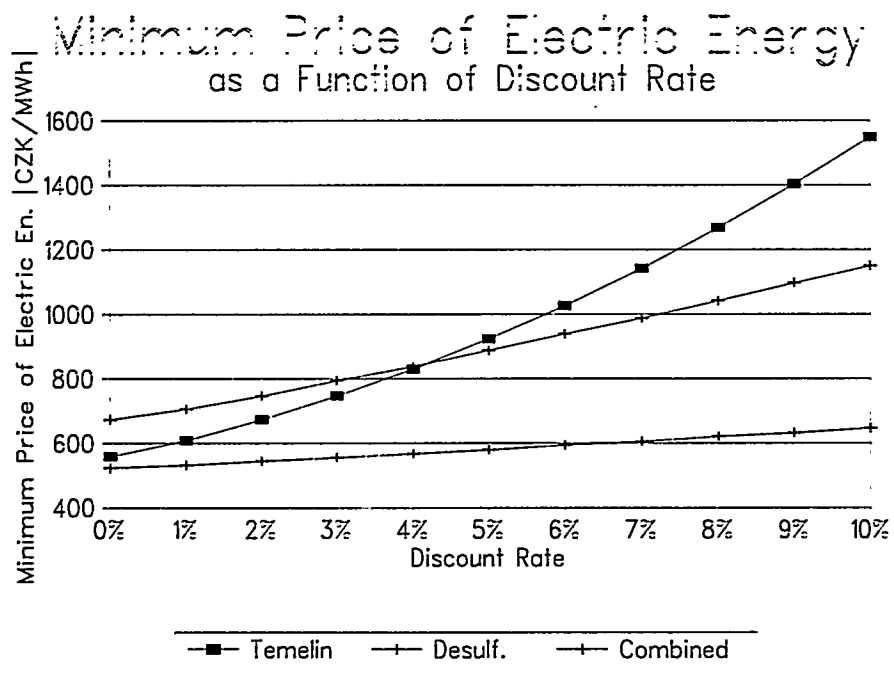


Figure 6.

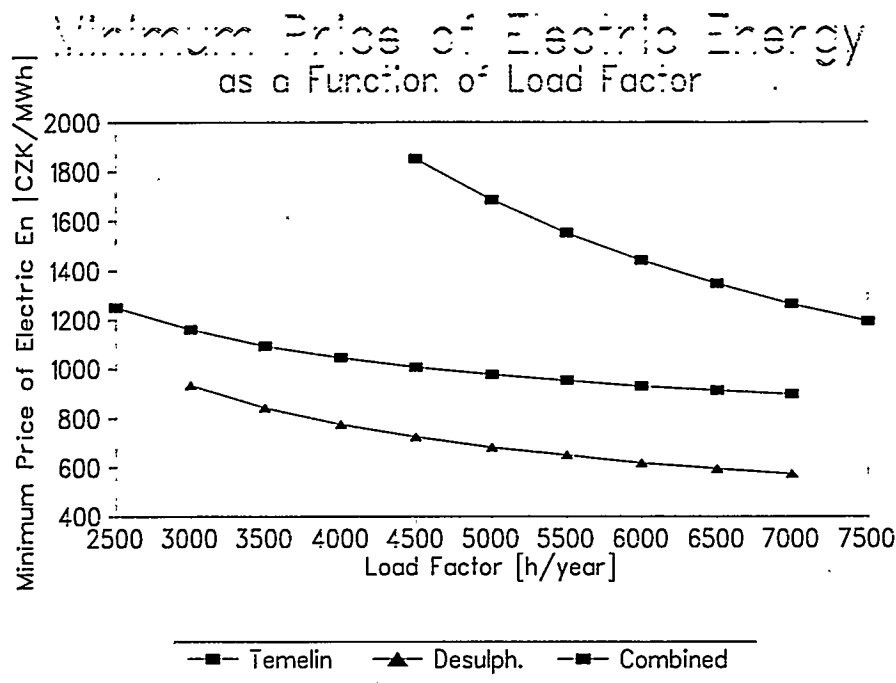


Figure 7

CONCLUSIONS

Strategic decisions on the further development of large energy systems require an extensive amount of studies starting from market research and demand forecast, analyses of changes in the structure of consumption and consequently changes in daily and seasonal load curve, optimal solution of technical and technological problems, regulatory issues etc. Economic and financial analyses is only one, but very important part of any decision making process. Some basic principles of economic and financial analysis were illustrated in our simplified model calculations.

In the Czech conditions, practically all types of sources will contribute to electric power balance. However, their position significantly differ. As a conclusion, the main features of next development can be shortly summarized as follows:

Coal

Due to the shutting down programme of least economic coal fired, conventional steam power plants, the share of coal in electric power generation will decrease to the level about 45 % in 2000 year. The dominant part of coal fired capacities will be formed by desulphurized conventional blocks (most frequent wet limestone desulphurization). However, advanced clean coal technologies are also prepared. Fluidized bed combustion (FBC) is a part of the CEZ's investment programme (for instance power plants Tisová I, Hodonín). There are also interesting investments out of CEZ. The reconstruction of Komofany heat and power plant to FBC is detailly described in two papers during this conference. There is a 200 MW PFBC project for heat and power plant Třebovice, investor is Moravia-Silesian Power Plants. In Sokolov Coal Company the reconstruction of town gas production to IGCC 2 x 200 MW will be completed in 1996-97. So, the gradual implementation of advanced clean coal technologies will help to keep the leading role of coal in power generation in a long term outlook.

Nuclear

After completion of 2 x 1000 MW PWR blocks in Temelín, the share of nuclear power plants in electric power generation will be comparable with coal. One of the reasons of this high share is of course a high load factor of nuclear power plants. All units will operate in a base load with utilisation cca 7000 hours.

Hydro

Although the hydro component of CEZ represents about 10 % of the total generating capacity in CR, its energy contribution is only cca 2.5 %. It indicates that hydro plants operate mostly for peak demand. The pumped storage plant Dlouhé Stráně is practically completed and this facility will add 650 MW for dynamic services. Because of natural conditions in CR, we do not expect any further significant increases in hydro generation.

Gas and oil

For CEZ, natural gas fired combined cycles are alternative for a longer term plan. Combined cycles are more interesting for companies with smaller and old units below 50 MW, where desulphurization or retrofitting to FBC is not in all cases the optimal solution. At present, there are 2 - 3 projects of heat and power gas fired combined cycles in CR and we expect that at least one of them will be successfully realized. Financing and contractual problems will be decisive factors. Gas fired projects must undertake greater risks associated with more volatile gas prices compared to coal.

Smaller cogeneration units can be the best alternative only for self-producers, where majority of heat and power are determined for their own consumption. One of the reasons is the distortion in electricity prices. Households prices are cross-subsidised by industrial customers and it results in considerable higher final industrial prices in comparison with purchase prices to distribution companies. Consequently, this distortion can give a false stimulus for some self-producers.

Not regarding to above mentioned uncertainties, gas fired heat and power units mean a serious competition for coal based generation with exception of base load.

Oil as a main fuel does not play an important role in heat and power generation in CR and we do not expect significant changes in market situation.

International trade, renewables and DSM

As we already indicated, international trade with electricity in Central Europe is important rather for an mutual increase of stability of electric power systems than for a massive export or import flows. Renewable forms of energy will be certainly supported by energy regulation. However, this support should not introduce any serious distortions into the market. Therefore we expect only gradual increase of renewable sources, depending on technical progress.

The current capacity reserve of approximately 30 % above peak demand is not conducive for development of Demand Side Management (DSM) programmes. However, taking into consideration a high energy intensity of GDP formation in all East - Central Europe, introduction of DSM and IRP is a big challenge for the future.

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LEAST COST OPTIONS FOR LIFE EXTENSION

Floyd Davis, Manager
Miljenko Bradarić

International Technology and Resources
Bechtel Corporation
San Francisco, California, USA

ABSTRACT

Rehabilitation of existing electric generating capacity offers one of the most cost-effective ways of meeting near-term power needs in many Eastern and Central European countries. In particular, the uncertainty associated with other supply sources and severe capital constraints tends to favor investments which maximize the utilization of existing fossil-fired equipment. However, it is critical that least-cost planning principles, including the consideration of environmental impacts, be applied to the economic analysis of rehabilitation options. This paper draws on Bechtel's experience in applying least-cost planning to plant rehabilitation studies in Bulgaria, Romania and Slovakia. The examples provided illustrate the importance of least-cost planning and the effect of the value placed on environmental emissions.

INTRODUCTION

Bechtel has performed over 60 plant life extension and rehabilitation studies and implemented projects for more than 100 units of fossil power plants. Most recently Bechtel performed the Power Complex Rehabilitation Feasibility Study in Bulgaria and the Bucharest District Heating System Feasibility Study in Romania. We are currently performing the Trnava District Heating Plant Reconstruction Feasibility Study in Slovakia. This paper discusses the evaluation of life extension with particular emphasis on environmental considerations with examples from our recent experience in Central and Eastern Europe.

We would like to thank the U.S. Trade and Development Administration which funded the Bulgarian, Romanian and Slovak work mentioned above. We would also like to thank Bulgarian Committee on Energy, the National Electric Company, the Romanian Electric Authority, the Western Regional Distribution Company of Slovakia, as well as our subcontractors which included Energoproekt and Totema of Bulgaria and the Institute for the Study of Energy Project (ISPE) and Institute for the Examination of Energy Modernization (ICEMENERG) of Romania. The examples provided in this paper are provided to illustrate key issues in the evaluation of life extension and do not necessarily reflect the policy of any of these organizations.

Rehabilitation includes a wide variety of improvements including improved efficiency, increased net capacity, reduction in air emissions, reduction of forced and planned outages, which may or may not extend the life of existing equipment. Measures to extend the physical life of existing equipment are often considered a special category of rehabilitation. In this paper the term life extension is used to refer to both measures to extend physical life and measures to improve operations and reduce environmental impact, extending economic life.

INCLUSION OF REHABILITATION OPTIONS IN LEAST-COST PLANNING

Methodology

As least-cost planning techniques are increasingly utilized to support the development of such plans, it will be important that the evaluation methodologies accommodate the evaluation of such options.

Conceptually the approach is analogous to the evaluation of purchasing a new piece of equipment. In practice there are significant differences. Another paper, Technical and Economic Evaluation of Life Extension Options, presented at the Improvements in Availability and Life Extension of Existing Units workshop of this conference examines these differences in detail. In summary, the evaluation of life extension requires a detailed investigation of existing equipment and operating procedures, the problems identified are often interrelated and the solutions must be packaged in coherent investment options for comparative evaluation with new equipment, and implementation is closely related to plant operations and maintenance.

Costs reflect capital or investment cost. The benefits are estimated based upon improvements in the following factors:

- Increases in capacity
- Improvements in availability
- Increased electric generation
- Savings in fuel and O&M costs
- Reductions in air emissions or other environmental impacts

The benefits of measures which extend the physical life of equipment can be measured in capacity and electric generation (and heat generation if appropriate) in the years of life extension.

CONSIDERATION OF ENVIRONMENTAL BENEFITS

Example

Three rehabilitation options from the Bulgaria study (Reference 1) are given to illustrate the application of the method. The primary characteristics of the various examples are described below:

- Option 1 (Plant A)- a group of three 210 MW units currently using surface-mined brown coal
 - Continue with the same fuel supply.
 - Replace economizers.
 - Install new soot blowing system.
 - Reconstruct air heater to improve mixing and introduce automatic control to reduce air leakage.
 - Make pulverization/burner system improvements
 - replace inlet valves and regulation system with modern digital electro-hydraulic system.
 - Tube cleaning system
 - Install automatic, closed loop water analysis and chemical injection.
 - Increase water treatment plant capacity through automation and process change to counter-flow regeneration.
 - Install new instrument and control system.
 - Add stator cooling packs to generators.
- Option 2 (Plant A)- the addition of flue-gas desulfurization (FGD) for the above units
 - Current emissions are estimated at 12,000-13,000 mg/m³. Post 1995 regulatory limits for local coals is 650 mg/m³.
- Option 3 (Plant B)- a group of three 210 MW units currently using underground mined brown coal with adequate reserves to only supply one unit
 - Mix existing fuel with imported coal.
 - Upgrade fuel handling system including additional stacker reclaimer, and on-line instrumentation.
 - Make boiler and mill modifications to accommodate new fuel
 - Replace low pressure cylinders of turbines.

- Install fine screening for cooling water and a tube cleaning system.
- Install turbine condensate polishing unit.
- Replace existing dewing equipment.
- Replace control system.
- Replace excitation system and automatic excitation controllers with static excitation system.

The Table 1 provides the key characteristics of these potential projects.

TABLE 1

	Option 1	Option 2	Option 3
Increase in Capacity	15.3	-11.7	0
Decrease in Heat Rate (kJ/Kwh)	650	-238	282
Increase in Availability (%)	5.8	0	28.0
Increase in Life (years)	0	0	14
Decrease in O&M Costs (\$/Mwh)	.02	-.05	1.00
Decrease in Fuel Cost (\$/GJ)	0	0	.03
Decrease in So _x Emissions (kg/GJ)	0	18.00	3.51

Options 1 and 2 do not result in a direct increase in physical life, although the improvements could affect economic life and environmental acceptability. Options 1 and 2 are both for Plant A, but have been considered separately even though an FGD system will be required if the plant is to meet proposed 1995 emission standards. Option 3 results in an additional 14 years of life due primarily to increased fuel supply to Plant B.

Example Results Without Consideration of Environmental Benefits

If capacity and energy are valued at the investment and production cost of gas-fired combined cycle plant considered by many to be the marginal unit addition in Bulgaria, the economics of the three options were calculated to be 2.5, -0.3, and 4.5, respectively without consideration of environmental benefits. The negative value for Option 2 is to be expected if no value is placed on reducing emissions. Without considering this value the only effect of the investment in FGD is to decrease the capacity of Plant B, increase its fuel costs by decreasing overall heat rate, and increasing O&M costs.

Figure 1 illustrates the breakdown of the various cost and benefit categories for the options. Also shown in Figure 1 are the combined costs and benefits of implementing Options 1 and 2 together (i.e., rehabilitating Plant A and adding FGD). The negative fuel and O&M savings for Options 1 and 3 (i.e., fuel and O&M cost increases) are associated with the increased electricity generation that result in these options. The capacity and generation benefits of Option 1 are due to the increased output of the plant and its improved availability. The capacity benefit of Option 3 is due to the extended life of the plant. The increased generation is due both to the extended life and to increased availability. The negative capacity, electric generation, fuel and O&M savings for Option 2 are due to the negative impact of FGD on plant capacity, heat rate, and O&M cost.

Without consideration of environmental factors, one could easily draw the conclusion that both Option 1 and 3 are attractive investments and if only one investment option is possible due to capital constraints, Option 3 is more attractive. One would never choose Option 2 if the reduction of SO_x emissions were not valued. The effect of the consideration of air emission reductions is the focus of the next section of the paper. Furthermore, if investment in the rehabilitation of Plant A requires the addition of FGD (Options 1 and 2 together), the combined costs exceed combined benefits, if no value is placed on emissions reduction.

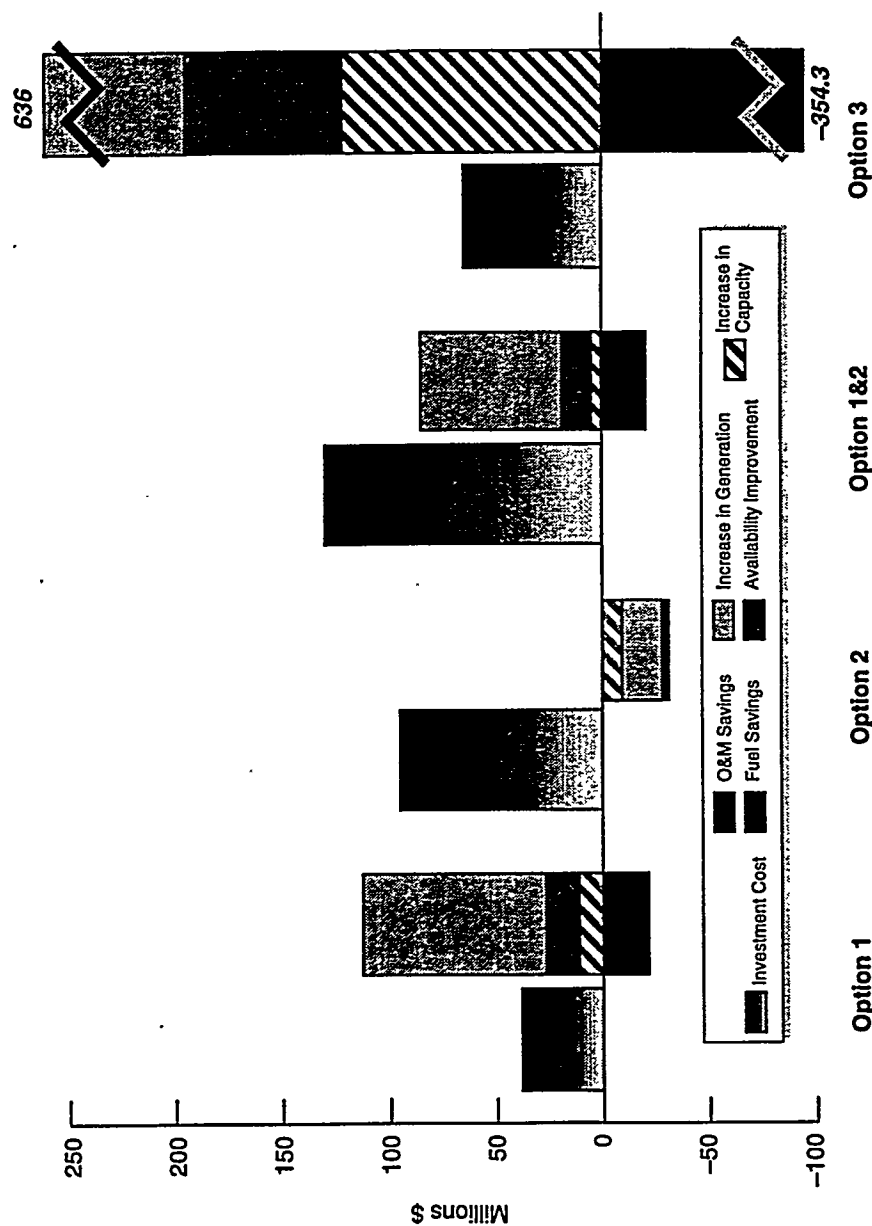


Figure 1. Breakdown of Costs and Non-Environmental Benefits

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Results Considering Environmental Benefits

Traditional analysis of power supply options, as exemplified in the previous analysis, has focused on the out-of-pocket costs and benefits of power production. Environmental impacts have generally been external to economic analysis and, for that reason, are often referred to as "externalities". The limitation of this approach is that either environmental impacts are not considered at all, or that they are only considered indirectly through the use of design criteria to meet a set of regulations. There is no mechanism to allocate limited capital resources to environmental control which provide the most benefit.

An alternative is to assign a value to the reduction of emissions. Ideally, this value reflects the perceived value to society for such reductions. For emissions that have localized or regional impact, it is reasonable that this value varies on a geographic basis. For example, California regulations assign different values for in-state emissions of SO_x for local generation and out-of-state emissions from plants providing imports to California in the evaluation of power supply options. For purposes of analysis, we have assigned a range of values. In this example, only SO_x emission reduction has been considered in this paper. The same approach can be used for other emissions as well.

The high of \$1,700 per tone of SO_x emissions corresponds to the value given by California regulations to out-of-state emissions. A medium value of \$170 per tone of SO_x emissions (i.e., 10% of the high value) is used. It should be noted that Bulgarian regulations have already internalized at least part of the value of SO_x emission reduction. The low value in this analysis corresponds to the 1993 levy under Bulgarian regulations for exceeding emission levels (i.e., approximately 12.5 \$/ton).

Figure 2 illustrates the effect of including this range of values on SO_x emission reduction. Benefits are greater than costs for Options 1 and 3 without consideration of the value of SO_x reduction. Option 1 results emission reductions because of a decrease in heat rate. Heat rate reduction and fuel switching in Option 3 also results in environmental benefits. Therefore, the economics of these options improves as greater value is placed on SO_x reduction.

As discussed previously, there is no benefit provided by the addition of FGD (Option 2) if no value is assigned to SO_x emission reduction. As illustrated in Figure 2, the low level of benefits, reflected in current levies for exceeding emission, is not adequate to justify the addition of FGD to Plant A (benefit/cost ratio of 0.5). However, the benefits associated with SO_x reduction far exceed the costs of FGD installation at the medium to high values.

Figure 3 illustrates the comparison of the rehabilitation of Plant A without FGD (Option 1), Plant A with FGD (Options 1 and 2) and the rehabilitation of Plant B as a function of the value place on SO_x emission reduction. Since the efficiency improvement associated with the rehabilitation of Plant A (Option 1) is greater than for Plant B (Option 3), its relative economics improves more rapidly as greater value is placed on emission reduction. Rehabilitation of Plant A is economically superior to Plant B, even if FGD is required for Plant A, if the value of SO_x emission reduction is greater than approximately 75 \$/ton. At these higher values, the rehabilitation Plant A, without the addition of FGD, is economically superior to Plant B.

The development of a least-cost investment plan requires more complex analysis than that presented. Additional options, system operating constraints, capital investment constraints, and financial and tariff impacts all must be considered. However, it is clear from the example that the consideration of environmental benefits can affect the allocation of scarce capital resources. The example described in the next section, taken from a study of the Bucharest district heating system, illustrates some additional complexities.

CONSIDERATION OF ADDITIONAL FACTORS

The previous analysis is based primarily on project-by-project evaluation. Both electric power and district heating systems are operated as unified systems so that investment decisions for one plant affect the operation of others. Additionally, other constraints, such as fuel supply and capital, can affect an

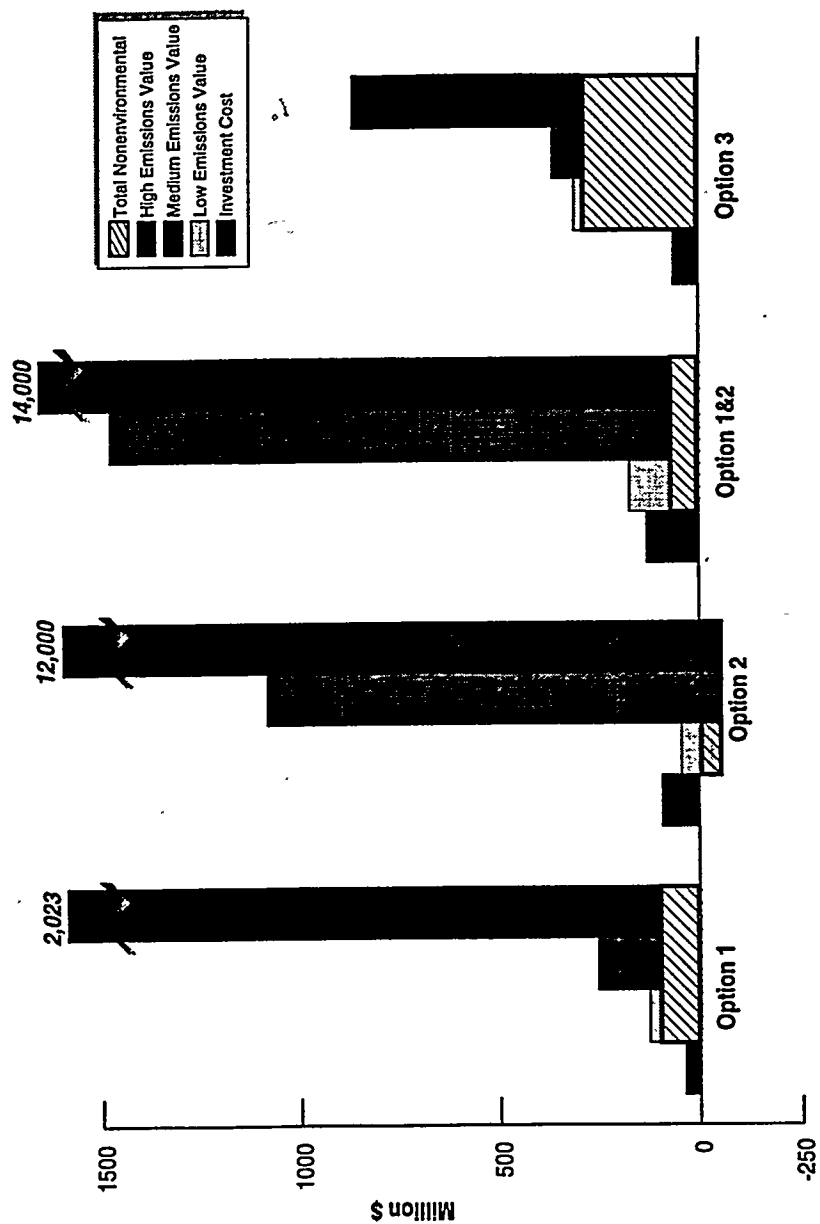


Figure 2. Consideration of SO_x Emissions Reduction Benefits

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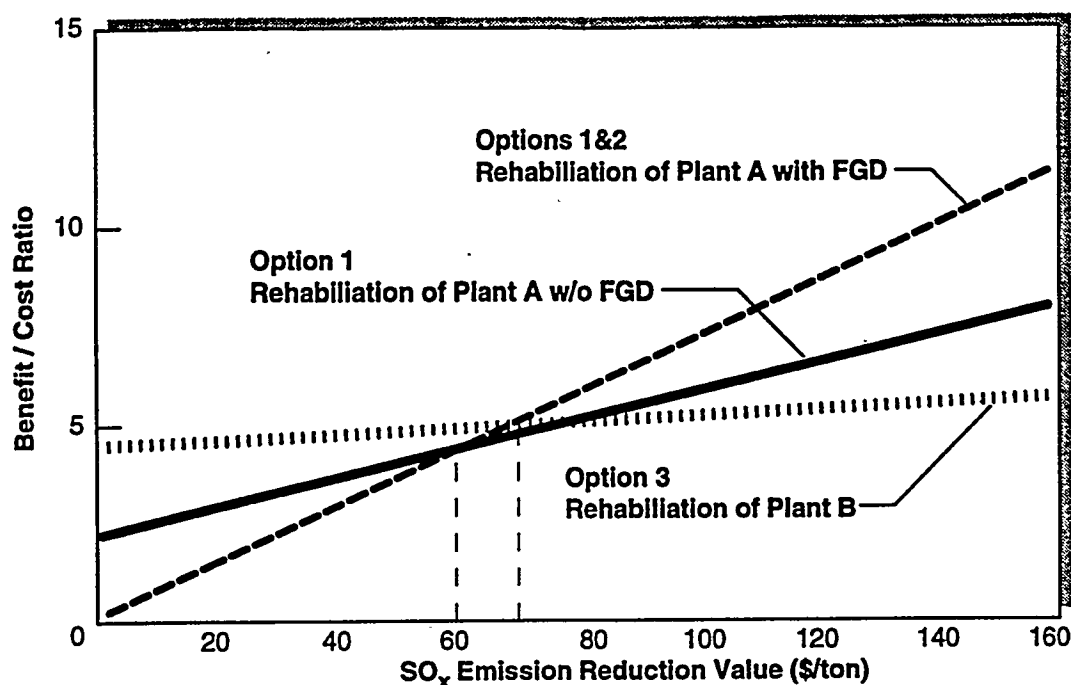


Figure 3. Bugaria Example - Benefit Cost Ratio as a Function of SO_x Emission Reduction Value

investment plan. Some of these complexities are illustrated in the following example based on a study of the Bucharest district heating system (Reference 2).

Plant X is a cogeneration plant with an net electrical capacity of 2x23 MW (2x50 MW installed) and a current heating capacity of 140 Gcal/hr serving a district heating system. It is 30 years old and in need of either rehabilitation or replacement. It is located in a central area of the city having many other natural gas users whose supply of gas takes precedence. During the winter months when domestic gas consumption increases dramatically, the pressure of the gas delivered to the plant drops below the point where it can be safely burned in the boilers. The plant is then forced to burn high sulfur fuel oil for much of the winter. Distribution of fuel oil to the plant is by rail with deliveries tending to be disruptive to local traffic and vice versa. Age of the facility, the corrosion as a result of high sulfur fuel use, and fuel supply difficulties have acted to reduce both the electrical and thermal capacity of the plant and reduce availability.

Plant Y is another cogeneration plant with an net electric capacity of 2x94 MW (2x125 MW installed) of electrical capacity and 320 Gcal/hr of heating capacity. It also burns a combination of gas and high sulfur fuel oil. Gas pressure is significantly higher at this plant. However, it is better designed for fuel oil consumptions than is true of Plant X and there is room for the addition of confined zone dispersment (CZD) SO_x reduction equipment, which is not true of Plant X because of its confined site.

In the near term, it is not realistic to increase overall gas consumption because of scarcity of hard currency. One possible solution is to increase the gas supply capacity to Plant X, reduce gas consumption in Plant Y and use more gas in Plant X. Two general options exist for upgrading both plants under this redistribution of fuel. It should be noted that, unlike the previous example, the options are defined in terms of measures to be taken at more than one plant. The actions at the two plant are related by fuel and foreign currency constraints. Both options require upgrades in Plant Y to improve its ability to handle the problems associated with high sulfur fuel oil consumption, thus increasing its electrical output. Other characteristics are summarized below:

- Option 1- Plant X replacement
 - Implement minor upgrade to turbines and boilers of Plant X immediately. This involves installation of low NO_x burners, MgO additive sprays in boilers, replace corroded sections of the ductwork and add insulation, replace key boiler control loop, repair boiler pressure parts and revamp low stages of turbines. These measure are expected to have the effect of increasing electrical output to 100 MW and thermal output to 200 Gcal/h for the remaining three years of life.
 - Install new 2x40MW combustion turbines heat recuperators to supply 212 Gcal/hr of heat in 1998
 - Upgrade at Plant Y without SO_x control is expected to increase plant life for approximately one year.
- Option 2- Plant X upgrade and life extension and SO_x control and Plant Y
 - Implement to minor upgrade to the turbines and boilers of Plant X.
 - In addition, replace turbine casings. This is expected to extend the life of the plant for an additional 7 years.
 - Implement CZD SO_x removal system at Plant Y by 1998.
 - Use of SO_x control Plant Y is expected to increase plant life by an addition two years.

Without consideration of fuel and foreign currency constraints, the ideal solution would probably be to either provide natural gas to both plants, or to replace Plant X as Option 1 and install SO_x control at Plant Y. These two options described represent alternative compromises that reflect these constraints. The first option provides a longer term solution. The second option is more environmentally benign. As in the economic comparison, ranking of options is dependent upon the value placed on reducing SO_x emissions. Figure 4 shows this comparison as a function of this value. As can be seen, Option 2 appears to be economically superior if the value placed on SO_x reduction is greater than approximately 120 \$/tone.

Simulation of electric system and heating system operation, the timing of investments through the use of mathematical optimization techniques, consideration of rehabilitation/life extension options along with new capacity and demand-side options, and the consideration of uncertainty in the evaluation are all steps that are taken in more detailed analysis. However, the two examples illustrate how environmental and social factors can be integrated into an engineering economic analysis and alternatives related through various investment and operating constraints, such as fuel supply and foreign currency requirements, can be evaluated.

CONCLUSIONS

Rehabilitation/life extension of existing electric power and heating equipment provides a potentially cost-effective way for many of the countries of Central and Western Europe to increase the reliability and capacity of their electric and heat generation systems. Environmental and social issues are an important part of any evaluation of electric and heat options. Examples have been presented to illustrate how the value place on SO_x can be incorporated into the analysis. Some of the conclusions that can be made are:

- Placing no value on environmental benefits can result in under-investment in environmental projects such as FGD equipment. This may appear expedient in the current capital-scarce situation in Central and Eastern Europe.
- The prioritization of projects, even those not specifically thought of as environmental, is affected by the value placed on environmental benefits.
- Prescribing technical solutions to meet emissions criteria, such as the addition of FGD, as a condition for rehabilitation, without the direct consideration of environmental benefits can preclude investment in options having significant environmental benefits.

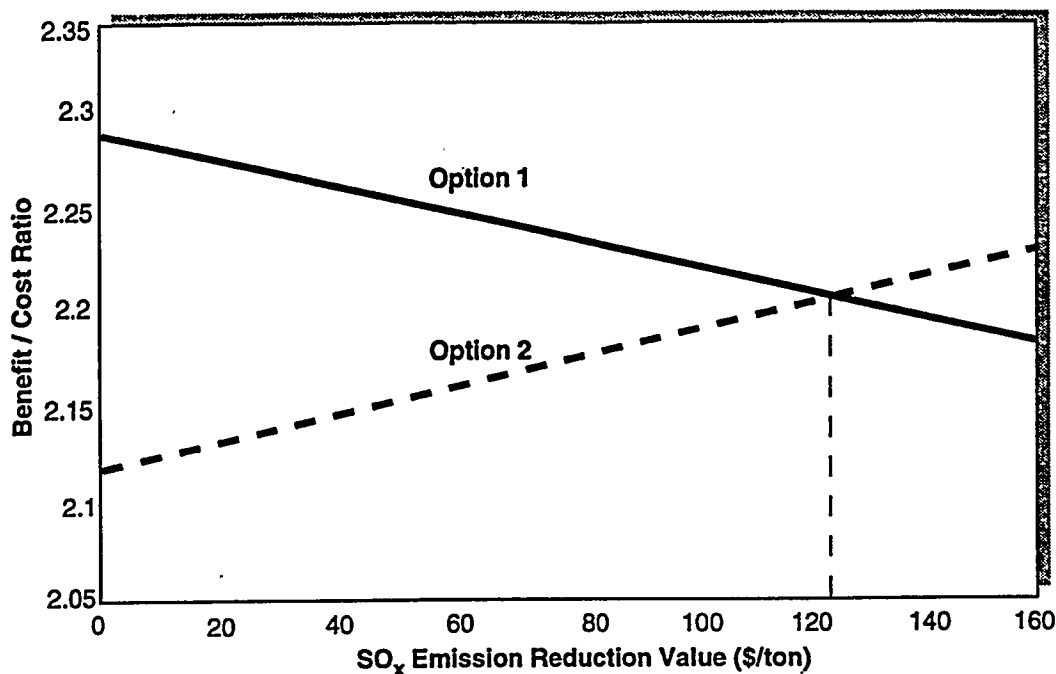


Figure 4. Romania Example - Benefit Cost Ratio as a Function of SO_x Emission Reduction Value

- It may not be practical to implement the best techno-economic solutions on a plant-by-plant basis. Consideration of operation, fuel supply, foreign currency and other constraints must be considered.

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ACTIVITIES OF ČEZ INC. AND IMPROVEMENT OF THE ENVIRONMENT

Ing. V. Kindl, Manager of Technological Section

Czech Power Company (ČEZ)
Prague, Czech Republic

ABSTRACT

All highly developed nations round the world have gradually assumed the responsibility for the quality of the environment at their respective territories by creating the preconditions (by setting forth concepts, and the legislative, economic and institutional framework as well as the educational information and resources systems) stimulating both individuals and corporate bodies to take care of the environment. Damaging the environment is punished. The approach has been successful in most of the countries. Companies and individuals have begun to recognise the correlations existing between their production and consumption activities and the environment and their direct responsibility for the environmental conditions, realising that to remove a source of environmental damage or to minimise the damage caused by it in both necessary and more beneficial than being penalised (up to ban of operation) both economically and in broader social terms for failing to comply with the relevant laws.

Since 1990 a number of the so-called "ecological" laws, formerly sorely lacking, have been enacted, such as the Environment Act, the Environmental Effects Assessment Act, and the Wastes Act, and the Clean Air Act has been fundamentally amended so that to meet again the requirements of effective protection of the atmosphere from pollutants. In the area of economic tools, the duty of the waste producer to pay for the waste produced was introduced, the fines for air pollution were raised significantly and the polluted waste water discharge fines were amended to keep pace with the devaluation of the local currency. Unfortunately, only marginal tax exemptions for activities protecting the environment were introduced by the tax reform.

The Clean Air Act Act No. 309/91 Sb. introduced emission limits (the maximum acceptable amounts of pollutants discharged in the atmosphere by the pollution sources) The emission limits set forth for new installations are defined in the Federal Environmental Committee Directive of 23/06/1992. The emissions limits for the current air pollution sources were set by the competent institution, the Czech Inspection of the Environment, Division of Protection of the Atmosphere, at the current technological standard. At the same time, the timetable for applying the emissions limits for new systems also for the old installations was specified by the Inspection.

Currently, all CEZ power plants are pollution sources. In view of the necessity to improve the situation in atmospheric pollution in North-Western Bohemia by the earliest possible date, the timetables set forth for six power plants situated in the area (Prunerov I and II, Tusimice I and II, Ledvice and Pocerady) to meet the SO₂, NO_x, ashes and CO emission limits for new installations were as early as 1994-1996. The process of meeting the emission limits for new installations for other CEZ power plants must be finished by 31st December 1998 with specific timetables set forth for each unit separately.

The strategy of CEZ in the area of environmental protection has been based upon including the ecological activities in the main development programmes such as the three-year business performance improvement programme and the company development programme by the year 2000. CEZ is aware of the fact that generating and distributing electric power by methods which are in keeping with the environmental protection laws is one of the major preconditions allowing the company to retain its current position in the electric power market. Therefore, the ecological activities of CEZ have been aimed as follows:

- reducing the gaseous and solid particle emissions of coal-firing power plants. The emissions reduction shall be accomplished by permanent de-commissioning of the obsolete units and

temporary shut-downs of units with future service potential until fitted with effective devices for emission reduction, by construction of de-sulphurisation devices and improvement of solid particle separators, by modifications of the combustion technologies and also by fuels substitutions;

- environmentally more suitable dumping of coal-firing power plants wastes and possible recycling.

These activities shall include especially:

- * processing ashes to obtain a stable compound
 - * arranging for ashes to be used in construction materials production
 - * using ashes for re-cultivation of the closed open pits
 - * utilising the products of the desulphurisation process
- safety and reliability of the operation of the Dukovany power plant
- securing safe operation of the Temelin power plant which is currently under construction
- assessing the impact of the power plant operation upon the environment and providing information on the relevant findings.

In these activities CEZ Inc. shall use the Power Engineering Emission Information System (EISE) the data of which have been taken over by the national REZZO information system for several years already, the SO₂ atmospheric pollution measurement stations network and the link with the national Automatic Emissions Monitoring (AIM) system operated by the Czech Hydrological and Meteorological Institute in Prague, an entity subordinated to the Ministry of Environment of the Czech Republic.

The sulphur dioxide emissions of the 14 power generating and two power and heat generating plants operated by CEZ in 1993 have steadily declined since 1981. The favourable trend has been achieved especially thanks to firing coal with lower sulphur contents and also thanks to the step-wise process of decommissioning the selected coal-firing power plant units. Between 1990 and 1993, the total of 10 coal-firing units of CEZ have been shut-down with the overall power rating of 1060 MW. The reduction of solid particle pollutants has been the result of the long term programme of reconstructions and replacements of the electric filters and optimisation of the combustion process.

In 1993 the planning and construction of air pollutant facilities proceeded as follows:

The construction of the wet lime washing process desulphurisation plants at the Pocerady II (units 5, 6 - 2 x 200 MW), Prunerov I (units 3,4,5,6 - 4 x 110 MW) and Prunerov II (units 21,22,23,24,25 - 5 x 210 MW) facilities either progressed or was started. The preparatory activities related to the construction of the desulphurisation plants for the Pocerady I, Ledvice, Tusimice II, Tisova, Chvaletice, Detmarovice and Melnik II and III (construction licensing, bidding and bidding evaluation processes, funding procurement and contract execution) were under way.

Preparatory works related to the construction of the new fluidised-bed boilers were started at the Ledvice, Hodonin and Porici plants. The construction of the fluidised-bed boiler No. 1 at the Tisova plant was started.

The electric filters at the Prunerov II (unit 21), Pocerady (units 3,5,6) and Ledvice (units 2,3) were either reconstructed or replaced by new and more efficient units.

The optimisation of the combustion process by burner modification and air intake control was implemented as the primary measure for boilers of the Prunerov I (unit 5), Prunerov II (unit 21), Tusimice II (unit 23), Pocerady (units 3,6) and Ledvice (units 2,3) facilities.

Solid waste - ashes - is another by-product of the power generating process. In keeping with the Wastes Act No. 238/1991 Sb. and the related regulations the ashes are dumped in special dumps designed to minimise the impact for the surrounding environment. CEZ has been operating ashes dumps

of the total area of 1300 ha. In 1993 the preparatory design stage of a new and environmentally more acceptable method of ashes dumping in the form of a stabilised compound was started. The product is produced by a process involving the ashes, waste water and the desulphurisation products.

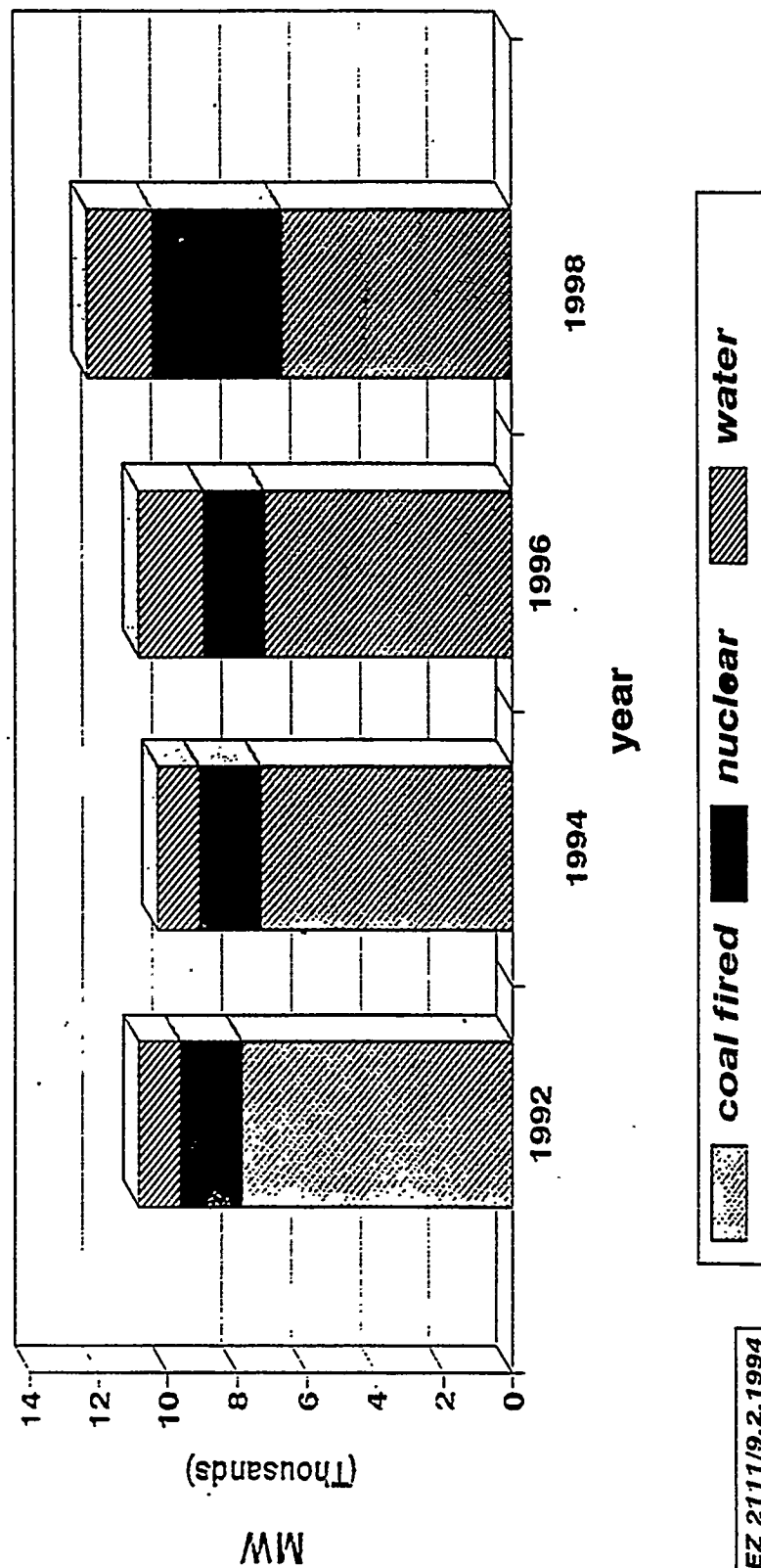
Analogously with other major foreign power generating companies, and at the realistic scope, CEZ has been involved in the development of renewable power resources. The activities in the area have been aimed especially at:

- small hydroelectric plants. The first project of this type is the commissioning of the small hydroelectric plant in Obristvi by Melnik
- utilisation of the wind energy. The first CEZ wind power generating plant was commissioned in Dlouha Louka in the Krusne Hory mountains in 1993
- the use of waste dump gas as fuel for small power generating plants is at the experimental stage
- a feasibility study will be launched in 1994 to assess the potential of growing bio-mass for utilisation in power generation
- reducing the environmental impact of transport - CEZ has been an active promoter of introduction of electric cars in the transportation systems of Prague and Brno.

As indicated by the official data sources of the Ministry of Environment of the Czech Republic (the 1992 Bulletin of the Ministry of Environment), the reduced impact of the power generating industry for the environment has been due to reduced industrial power consumption. However, the main causes of the reduced demand for fuels and energy and their reduced production result from changes in the structure of production related to the change in orientation of the national economy towards free market principles. These changes have been accompanied by reduced outputs in industries with high power and raw materials demands. In 1992 the power consumption in the Czech Republic was lower by 7.3% compared to the 1991 level. The biggest share in the reduction was due to solid fuels (9.8%). The lower demand for electricity in the production sector was reflected in the power sources output by a reduction by 3.3% (to which conventional steam plants contributed by 4%). The share of conventional power plants in the overall power generation dropped in 1992 to 76.5% which is less by 18.5% compared to 1980.

However, the declining power consumption pattern encountered in the Czech Republic since 1990 has been envisaged (the Czech Power Industry Control Centre, World Bank, CEZ a.s.) to stabilise in 1993-1994. For the 1994 - 2000 period the power demand has been estimated to grow at the annual rate of 1.7 %. Therefore, the improvement of the environmental impacts of the power generation industry is one of the hottest and most demanding issues to tackle by both the power industry and CEZ Inc.

Real and scheduled installed capacity of the CEZ power plants



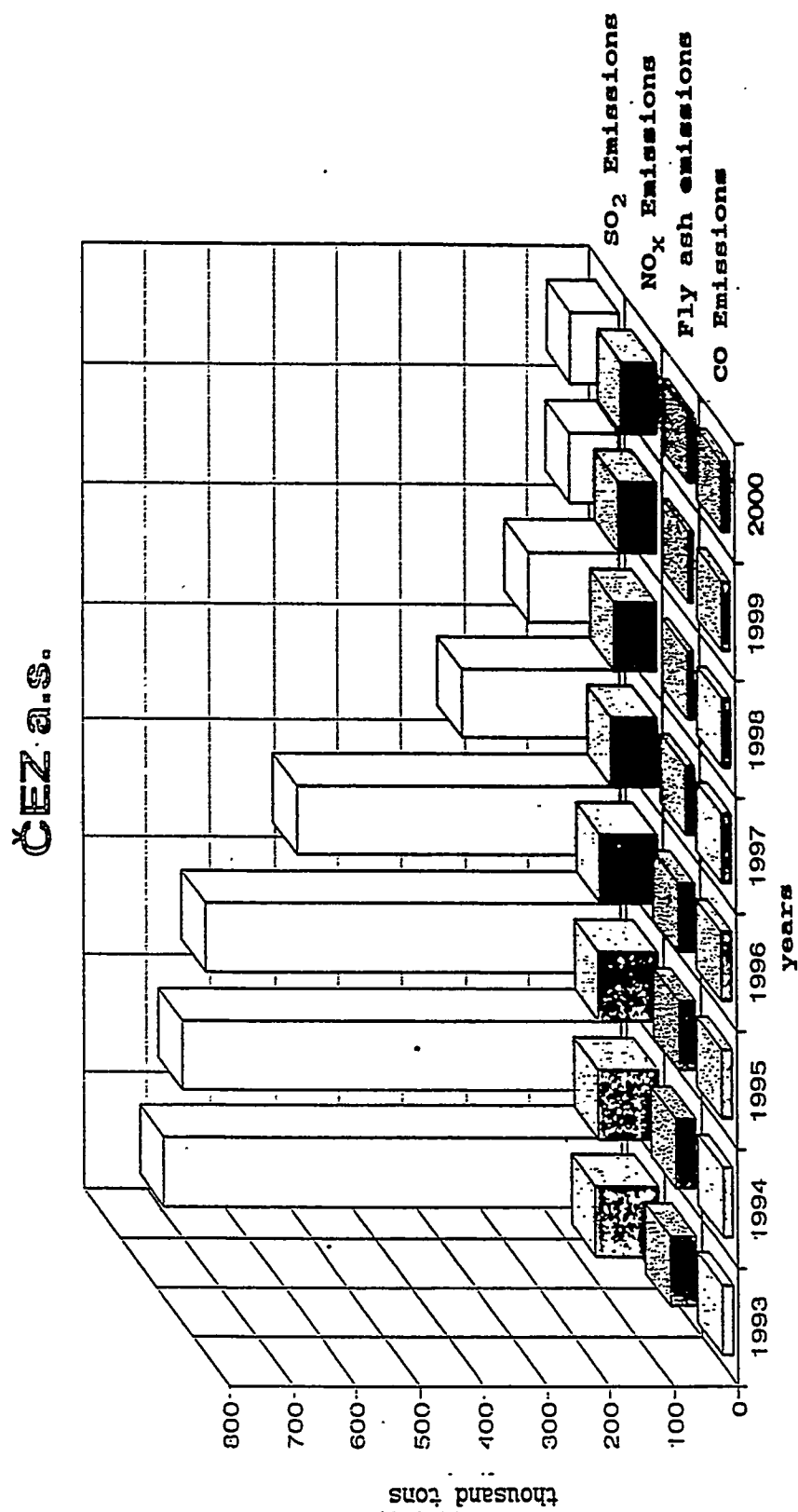


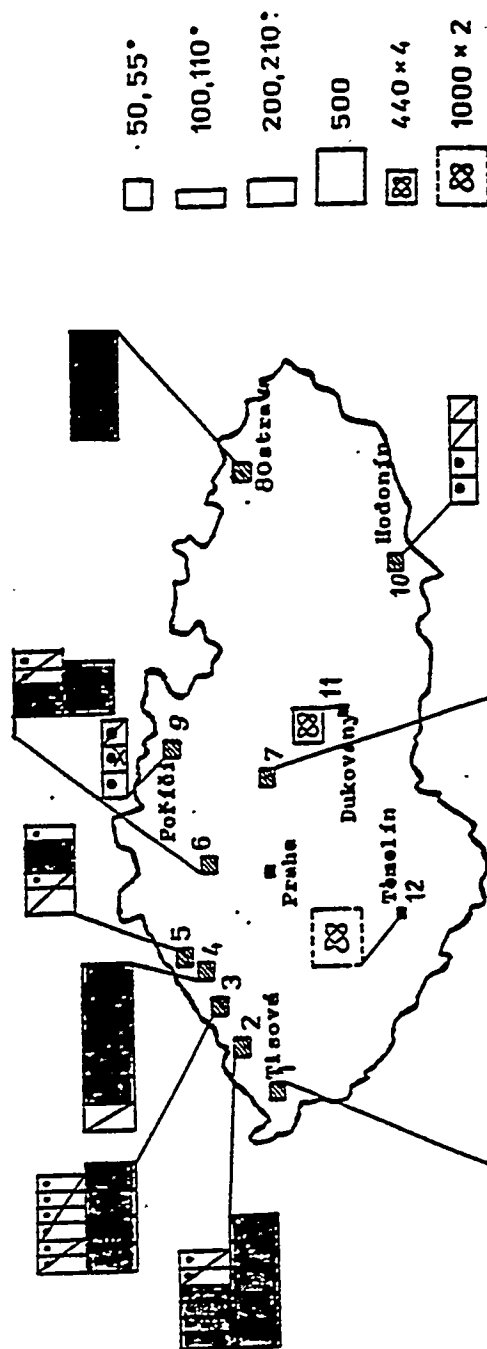
Table 1 - Clean Air Act (Czech Republic) - Limits for facilities burning fossil fuels

	SO ₂ (mg/Nm ³)	NO ₂ (mg/Nm ³)	CO (mg/Nm ³)	Ash (mg/Nm ³)
Over 300 MWth:				
Solid fuel	500	650	250	100
Liquid fuel	500	450	175	50
Gas	35	200	100	10
50 - 300 MWth:				
Solid fuel	1700	650	250	100
Liquid fuel	1700	450	175	50
Gas	35	200	100	10

If SO₂ limits cannot be met without FGD, then FGD must be installed and the following limits apply:

- Over 300 MWth - emissions must be no more than 15% of pre-FGD levels
- 50 - 300 MWth - emissions must be no more than 30% of pre-FGD levels
- FGD bypass (for maintenance, etc.) allowed for maximum 98 consecutive hours, and cumulative total of 360 hours p.a.

REGIONAL DISTRIBUTION OF THE SYSTEM POWER PLANTS OF CZECH POWER COMPANY (MW) 1998

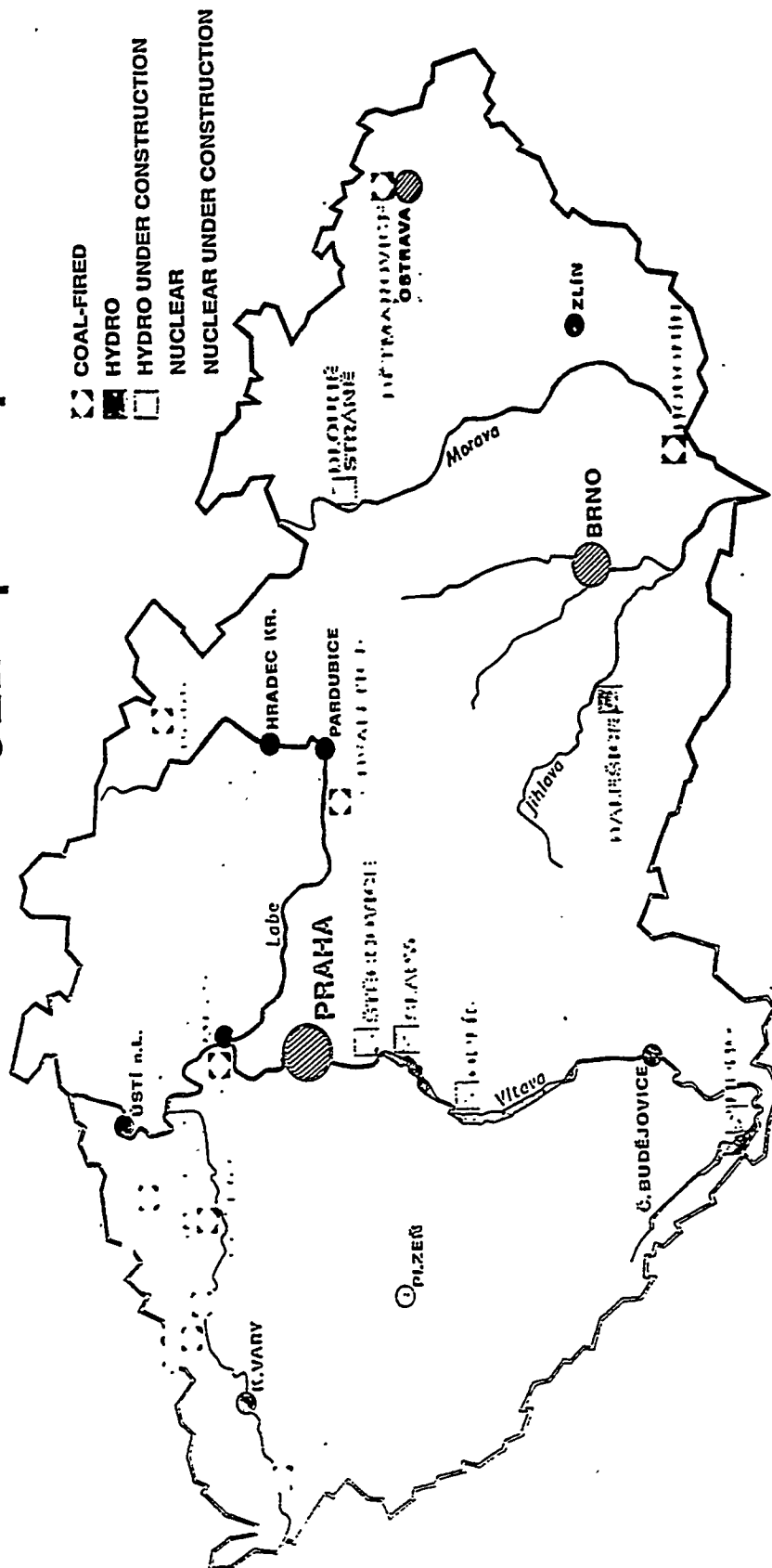


1. POWER plant Tisová	- ETI	3x100, 4x55
2. POWER plant Pruněk	- EPRU	5x210, 6x110
3. POWER plant Tušimice	- ETU	4x200, 6x110
4. POWER plant Poděbrady	- EPOD	6x200
5. POWER plant Ledvice	- ELJ	1x200, 4x110
6. POWER plant Mělník	- EME	1x500, 4x110
7. POWER plant Chvaletice	- ECHVA	4x200
8. POWER plant Dětmarovice	- EDE	4x200
9. POWER plant Poříčí	- EPO	3x55
10. POWER plant Hodonín	- EHO	2x55, 2x50
11. Nuclear power plant Dukovany	- EDU	4x440
12. Nuclear power plant Temelín + (in construction)	- ETE	2x1000

Ekological Program of Czech Power Company

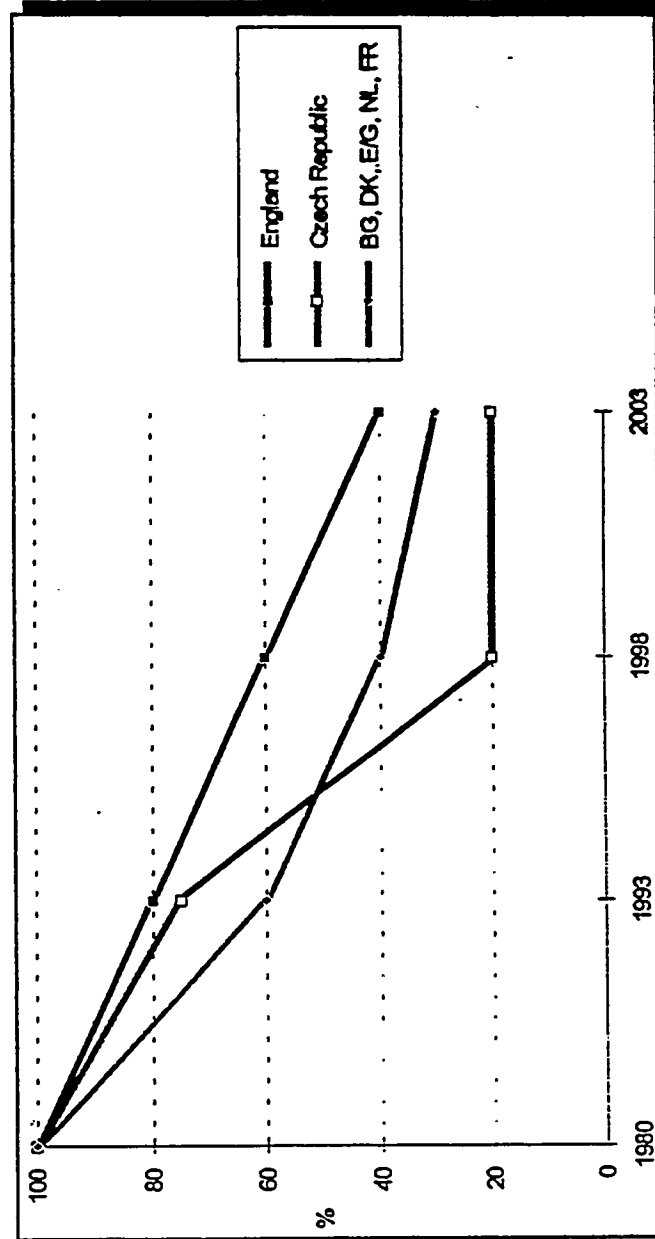
	dry sprayer lis. method
	wet lis. method

ČEZ - power plants



ČEZ and its contribution to air protection in the Czech Republic
(Jointly with ČEZ a.s. / P. K. K.)

Targets for SO₂ Reduction



**POWER-GEN
EUROPE '93**

Energy Resource Options

Session B5

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THE ROLE OF COAL IN THE ECONOMY OF THE CZECH REPUBLIC

Josef Doruška

Ministry of Industry and Trade of the Czech Republic
Prague, Czech Republic

ABSTRACT

The Czech Republic ranks among the countries with high total reserves of hard coal and lignite. Therefore coal always had and still has a significant role in covering the power demand of the Czech Republic. Transition of the national economy, based on the principles of the market economy and private ownership, affects among others also behaviour of the mining companies. A strong emphasis is also aimed at the environmental aspects concerning both the process of coal mining and the process of its utilization. Within these intentions the power policy of the Czech Republic is formulated.

The Czech Republic, which has 10 mil. inhabitants, ranks among the countries with a high share of industry in the process of creating the gross national product. This state has its historical roots as on the present territory of the Czech Republic there had been concentrated a majority of industrial and mining capacities of the Hapsburg Empire. The First World War resulted among others in the decline of the Hapsburg Empire. Within this process Czechoslovak Republic was established (apart from other things the centre of democracy in the Central Europe). In that republic the industry had an important position. The industrial potential had been expanded even during the occupation of Czechoslovakia by Nazi Germany in the years 1939 - 1945. After the Second World War when Europe was divided into two political spheres Czechoslovakia became a significant industrial base of so called East Bloc. Such a development and the needs of the Eastern Bloc resulted in the intensive development of the heavy industry on the territory of Czechoslovakia.

All that resulted in a steep rise of the energy consumption.

For example in 1989 (compared to 1937)

- electricity production was approx. 22 times higher (89 200 MWh), and
- steel production approx. 8 times higher (15 465 thousands of tons).

From the standpoint of domestic more significant primary power sources there are on the territory of the Czech Republic (respectively of the former Czechoslovakia) only deposits of hard coal and lignite. Therefore coal always was and still is of a great importance in the power and fuel balance.

This short return to the history should help to understand the present opinions of the role of coal in the power industry of the Czech Republic.

In 1992 more than 90% of the consumed energy was obtained - according to /2/ from fossil fuels (Figure 1).

The coal share in the electric power production corresponded to that (Figure 2).

The share of the fossil fuels in the Czech Republic in 1992

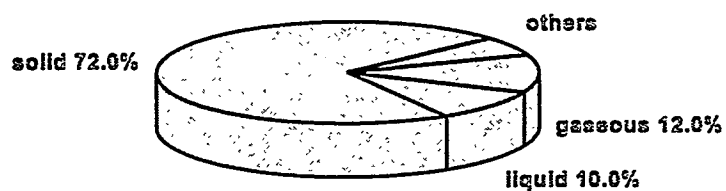


Figure 1

The share of fuels in production of electric power in 1992

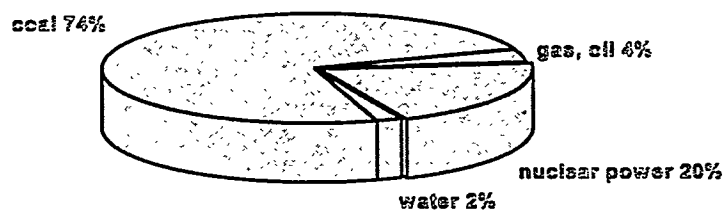


Figure 2

On the territory of the Czech Republic there are 5 coal basins with hard coal deposits /1/. The basins are as follows:

- Ostrava-Karviná Basin
- Central Bohemian Basin divided into:
 - Kladno Basin
 - Plzeň Basin
 - Trutnov Basin
 - Boskovice Basin

From the standpoint of the coal mining the Ostrava-Karviná Basin is the most significant and the Boskovice Basin is of the smallest importance because the coal mining has been already stopped there as well as in the Trutnov Basin.

On the territory of the Czech Republic there are also 8 deposits of brown coal and lignite /1/. The deposits are as follows:

- North Bohemian Brown Coal Basin
- Sokolov Brown Coal Basin
- Cheb Basin
- Žitava Basin

Lignite

- South Bohemian Basin
- South Moravian Basin
- Žitava Basin

The greatest share of brown coal is being mined in the North Bohemian Brown Coal Basin. The production of brown coal in Sokolov Basin is also of great importance. In the South Moravian Basin there is being mined lignite only for the local power station and inhabitants needs.

The process of coal mining had culminated in 1984 and has been constantly decreasing ever since. In 1993 the process of coal mining amounted to approximately 68% to the size in 1984. (Table 1.)

From the standpoint of utilization of coal we can state that about 40% of coal is used for the purposes of power and the rest of it constitutes of coking coal.

Brown coal is being put on by generation of electrical energy and heat and its certain part is being combusted in households.

TABLE 1

The Development of Coal Mining in the Czech Republic /2,3/

Year	1948	1984 (mil. t.)	1990	1993	Index 93/84
Hard coal	16.8	26.4	20.1	8.3	0.69
Brown coal	22.8	99.0	80.4	66.9	0.67
Total	39.6	125.4	100.5	85.2	0.68

The content of sulphur in brown coal signifies a great problem, it ranges from 1 to 3% on average.

It is understandable that this fact causes the need to search for the ways to decrease environmental impacts. In this respect a considerable stress is put on building up a desulphurization equipment, respectively on putting aside some selected blocks of power stations situated in the area of North Bohemian and Sokolov Brown Coal Basin.

Despite the increase of import (consumption) of natural gas (Table 2) as well as the planned putting of the two blocks (2x 1000 MW) of the Temelin Nuclear Power Station into operation and even the pressure that is being put on savings of the fuels and energy the role of coal is going to take an important place in the power and fuel balance of the Czech Republic in the next ten years (Table 3), /2/.

It is obvious from the values of the above mentioned Tables 2, 3 that there is an attempt to increase the consumption of the noble fuels in the Czech Republic.

"The Power Policy of the Czech Republic" /4/ is in accordance with this effort and was approved by the Government of the Czech Republic in 1992.

This policy is based on several principles. The main ones are the following:

- ensuring the diversification of energy sources
- attempt to achieve a high quality of the environment and removing the environmental damages from the past
- respecting the principles of the market economy and private ownership

In relation to the first principle it is possible to remark that the mining companies have been ranked among the second wave of the coupon privatization. By the end of the coupon privatization (the end of 1994) the ownership relations will have been changed.

We can assume that the new owners will be laying great emphasis on the effectiveness of those companies. Table 4 gives us the idea about the structure of the coal mining industry before and after the end of the second wave of the coupon privatization.

TABLE 2

Planned Import (Consumption) of Natural Gas in the Czech Republic

Year	1995	2000	2005
Billions of m ³	7.7	10.0	12.5

TABLE 3

Expected Development of Coal Mining in the Czech Republic

Year	995	2000	2005
	Mil.t.		
Hard Coal	15.8	14.5	11.5
Brown Coal	62.7	50.7	49.0
Total	78.5	65.2	60.5

TABLE 4

The Structure of the Coal Mining Industry Before and After the End of the 2nd Wave of the Coupon Privatization

Before the privatization	Companies privatized in the 2nd wave
Name of the company, residence	Name of the company, residence
Ostrava-Karvina Mines a. s. Ostrava	Ostrava-Karvina Mines a. s. Ostrava
CSM Mine s. p. Stonava Kladno Mine s. p. Libusin Tuchlovice Mine s. p. Tuchlovice	Bohemian-Moravian Mines a. s. Kladno
West Bohemian Coal Mines s. p. Zbuh u Plzne	West Bohemian Coal Mines s. p. Zbuh u Plzne
East Bohemian Coal Mines s. p. Trutnov	a part of the company dealing with mining will not be privatized but will remain state-owned
Rosice Coal Mines s. p. Zbysov u Brna	Rosice Coal Mines a. s. Zbysov a part of the company dealing with coal mining will not be privatized but will remain state-owned
Mines and Preparation Plants Komorany s. p. Komorany Lezaky Mines s. p. Most Hlubiny Mines s. p. Litvinov	Mostecká Mine Company a. s. Most
Bilina Mines s. p. Bilina Nastup Mines s. p. Tusimice	North Bohemian Mines a. s. Chomutov
Brown Coal Mines s. p. Brezova Fuelworks s. p. Vresova Reclamation Company s.p.Sokolov	Sokolovská Coal Company a. s. Vresova
Fuelworks s.p. Usti n.L.	a part of the company dealing with coal mining will not be privatized but will remain state- owned
South Moravian Lignite Mines s. p. Hodonin	a part of the company dealing with coal mining will not be privatized but will remain state- owned

The pressure that is being put on the effectiveness of coal mining requires certain mines to be closed down. This has direct impact on their ex-workers and contemporary employees and their requirements that are laid down in the rule of law of the Czech Republic. In this regard the Government accepts so-called inhibition program and earmarks certain funds from the national budget.

The effort to decrease the environmental impact on our territory resulting from both coal mining and its consumption is one of the most serious problems of the Power Policy of the Czech Republic.

In this respect there has been accepted a program of a desulphurization of large energy capacities. Supposedly there should be built some sulphur removal devices on blocks with total output higher than 5500 MW till the year 2000. These activities are going to request an amount higher than 32 billion Kc /2/.

Besides that there is being prepared an application of fluid combustion of coal in series of power stations and heating plants. There is expected an investment of approximately 7 billion Kc till the year 2000.

In our opinion sulphur removal, fluid combustion and other used technologies of coal combustion represent some significant moves toward the environmental protection in these days. In long-term period we need to develop technology that would enable to gain gaseous, respectively liquid fuels from the coal under economically acceptable conditions.

In this regard the programs providing technical help for selected countries and transfer of science-technical knowledge should play an important role. What I have on my mind is the program of the European Union and UNDP as well.

The stated problem must be considered in the global rate from the following standpoints:

- amount of oil, natural gas and coal reserves
- geographical arrangement of particular fossil energy sources
- expected energy demands of world population in relation to the increasing number of inhabitants

Signing the "European Agreement" the Czech Republic had demonstrated its intentions to become a full member of the European Union. The European Agreement deals with energetics in articles 79 and 80. The basic idea of those articles is the idea of progressive integration of energy markets of the Czech Republic and European Union, paying appropriate attention to European Energy Charter and all that occurs simultaneously with integration of additional energy markets with other Central and Eastern European countries. The areas of mutual cooperation and technical help are listed as well. On the first place, in those areas the energy policy is being formed and planned on both national and regional levels.

Gradual integration of energy markets of the Czech Republic and European Union might be achieved if the attempt to create a stabilized sector out of Czech energetics succeeds. The function of this stabilized sector will be based on market principles with economic efficiency comparable to other member states of European Union.

Energy policy of the Czech Republic is also subordinated to the following goals:

Reaching those goals assumes apart from other things

- to state again precisely the legislative instruments
- formation of regulatory body
- direct commitment of the Government to selected activities concerning energetics
- price and tax policy specification
- formulation of import and export policy concerning the area of energy and fuels

The above mentioned and other activities are going to be provided by appropriate legislative standards. In this connection we can mention at least the so-called

- Energy Act
- Mining Act

These and other unlisted legislative measures are formulated along the same lines with appropriate acts enforced on the countries of European Union and along the same lines with European Energy Charter as well.

After all it might be observed that the coal mining industry of the 90's in the Czech Republic has been in totally different situation than that in the period of 1950 to 1989.

The recent experiences show that the management of coal mining companies was not prepared for those conditions.

This reality together with other facts (loss of sales, a pressure that is being put on the removal of enviromental damages) produce a certain scepticism in the opinion of the importance of the coal reserves in the Czech Republic. This kind of scepticism can lead in its consequences to unalterable changes or decisions.

Therefore it is necessary to pay great attention to those problems. An important role should be taken by programs formulated and supported by advanced countries to help to the transforming economies of Central and Eastern Europe.

The goal of those programs should be as follows:

- to help to overcome problems have been created during the transition from a centrally planned economy to free market and a change in ownership relations
- implementation of new technologies that would enable to mine and use coal under the conditions of
- minimalization of the enviromental damages
- respecting the future energy needs

In this respect the Czech Republic has ideal conditions because

- there are high reserves of coal available
- there is a widespread chemical industry on the territory of the Czech Republic
- the labour quality is of the high standard

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IMPORTED RESOURCES – GAS

Jan Marxt, Director of Gas Department

Metalimex Ltd.
Prague, Czech Republic

ABSTRACT

This paper examines the availability of various crude oils, addressing specifically crude oil pipelines to the Czech Republic, both existing and under construction. Secondly, the economic status of two main Czech refineries is examined in comparison to international trends, technical configurations, and product supply and demand.

INTRODUCTION

Nearly two years ago the Czechoslovakia was split into two parts - the Czech Republic and Slovakia. Although this change had a substantial impact on the gas industry of both republics, the transit of Russian gas through the Czech Republic and Slovakia remained safe and reliable.

Gas consumption per capita is higher in Slovakia than in the Czech Republic because gasification of households began sooner in Slovakia, the Czech Republic's chemical industry is structured differently, and only Slovakia possesses a gas fired power station (near Ukraine-Slovakian border in Vojany).

At present, natural gas accounts for 12.84% of primary energy consumption in the Czech Republic. Consumption has been rising gradually in recent years:

1988	10.2%
1989	10.8%
1990	11.6%
1991	12.2%
1992	11.5%
1993	12.8%

Concerning the structure of primary energy sources in the Czech Republic, the outlooks for the next decade (2005) account for a substantial decline of coal use (44% from the current level of 63-65%), and a sliding decline of petroleum products (13% from the current level of 17%), in favour of a remarkable increase in natural gas (26% from today's 15%) and primary electricity (17% from today's 8%).

Unfortunately, the Czech Republic (as well as former Czechoslovakia) has only very limited indigenous gas resources. This disadvantage is compounded by exclusive dependence on imports from Russia.

What is the history of this dependence on the gas imports from the East? The situation in the newly organized east European countries, which were in the past connected in the economic organization COMECON, is not as explicitly as it is nowadays modern to consider and describe. Apart from this, just thirty years ago in Czechoslovakia, Algeria was considered to be the only potential gas supplier and significant preliminary technical and commercial activities had been done to create the necessary preconditions for the future gas export from Algeria to Middle Europe. Nevertheless, the situation developed somewhat differently and the supply of the Soviet gas to West Europe, which has been negotiated in the second half of the 60's, resulted in the conclusion of a chain of mutually favorable import agreements. We could remember the huge number of pipes delivered for the construction of pipelines in the Soviet Union, which in fact secured the connection and the partial payment of the gas of the future gas supplies. In this way the import of gas became a significant accelerator for the commercial activities of other European countries such as France, Italy and Austria. It is true, however, that the dependence

on Soviet gas of these countries was never decisive and covered at the most 30% of the gas consumption in these countries. The position of Austria is different in that apart indigenous production, which in the last years stands at the level of 22%. Austria was fully dependent on the Soviet gas deliveries until the beginning of the flow of gas supplies from Norway, which came on stream in October 1993.

Soviet gas deliveries to West Europe were directed via Czechoslovakia, which was chosen and proved to be the shortest way. Because of the utmost reliability and stability of the transit of gas, this way was also used for the supplement contract amounts of gas from Soyuzgazexport totaling 30 bcm/y at plateau level, which served as a substitute for the planned delivery of Iranian gas to West Europe.

In connection with the Iranian project Czechoslovakia diversified its gas import for the first time considering the fact that the same way as Germany, France and Austria, Czechoslovakia had to swap imported gas for gas, which was delivered from Iran by the export pipelines IGAT for consumption in Caucasian republics. This project was abandoned in the early 80's and Iran, by cutting the deliveries to crossing point Astara, lost for years the opportunity of becoming a significant exporter in the range which would correspond to their giant gas reserves totaling nearly 21.000 bcm.

Considerations about the diversification of gas import of Czechoslovakia date from the middle 80's in connection with the at that time existing situation and technical possibilities. There were some possible suppliers and technical import variations which were considered for either direct delivery of gas to Czechoslovakia or by the use of a swap operation.

An example of interest would be the project of reconstruction of the then not fully used oil pipe ADRIA from Omišalj to Bratislava and the fact that some Czechoslovak legal subjects participated in the ownership of this pipe. The development of events in the former Yugoslavia ironically proved this project to be unrealistic, the oil pipe has been blocked in Serbian Krajina for many years and not a single tanker has been discharged in Croatian Omišalj.

The present situation of the diversification of the gas suppliers to the Czech Republic and the other states of Central and East Europe is characterized by the following general factors:

- liquidation of the gas supply dependence on one exporter
- securing gas supplies from other suppliers in the case of accidents or if other problems occur during the transport of gas from the supplier
- covering the future higher demands of natural gas

Main challenges of diversification:

- market of suppliers (one of the reasons is the predicted gap in gas supply in the beginning of the next century)
- higher costs for deliveries from remote sources
- lack of finance for enormous, costly projects; reserved approach of banks and governments to support these projects

From the technical viewpoints many projects and routes have been evaluated in recent years. The Czech Republic joined common projects like the Pentagonal initiative (extended to so-called Hexagonala) and different consortiums of potential buyers of North Sea gas, Iranian gas, LNG Ardian and others.

ADRIA LNG PROJECT

Liquefied natural gas (LNG) would be committed from Algeria (or from another supplier of LNG) and delivered to a receiving terminal proposed on the Krk peninsula near Omišalj (Croatia). It would then be unloaded, stored, re-gasified and transported by pipe to the Austrian - Hungarian border for consumers in Austria, Hungary, Slovakia and Czech Republic. The transport through Austria would be carried out by a proposed pipeline called "Penta".

A feasibility study for the LNG project was completed and the decision should be taken in this year. The minimum economically acceptable, annual volume of the LNG terminal is, in this project 5.5 bcm/y.

Although the LNG chain which covers liquification facilities, tankers, the receiving terminal, storage tanks and onshore transmission grid is very expensive, it permits variety on the suppliers side. Recent spot cargos delivered to the Belgian terminal, Zeebrugge, from Australia confirmed such a possibility from the economic viewpoint.

TRANSMED PIPELINE

The extension of the pipeline system running from Algeria through Tunisia and Sicilia to central Italy has been envisioned for additional quantities of Algerian gas committed by SNAM during the IGU Congress in June 1994. A pre-feasibility study for possible use of this route for concerned partners, mainly from Hungary, Slovakia and the Czech Republic was completed some three years ago.

NORWEGIAN GAS

As concerns the reliability of the supplier, there is no doubt that Norway is one of the best potential partners. The current production level (which, since Norway does not consume natural gas corresponds with the export level), varies in the range of 27-28 bcm/y. According to Norway's export commitments, deliveries will rapidly reach a plateau level of 51 bcm/y. In fact, all options for Troll gas (perhaps in the spirit of envisaged gas supply gaps), were exercised by concerned buyers facing an increased gas demand in the next decade. The construction of a fourth export offshore pipeline from Norwegian sector in the North Sea is being seriously discussed. There is no final decision about the landfall which could be Emden (as a third pipe), Zeebrugge (as a second pipe), or even the near French port Calais. Potential buyers from Central and East Europe could probably use the widely known Ruhrgas-BEB-Statoil-Norsk Hydro onshore system, NETRA, designed mainly for the east German company Verbundnetz Gas, but with quite sufficient spare capacity. Another possibility is the Wintershall pressed aim to buy Norwegian gas and pump it into the transit system MIDAL/STEGAL built jointly with Russia. This idea is still opposed by Norwegian producers GFU who wouldn't like to allow middlemen between producers and potential buyers.

NORTH SEA GAS - BRITISH SECTOR - PIPES POLPIPE OR INTERCONNECTOR

The giant field Britannia should be, according to the recent decision of the British government, reserved for UK buyers and needs. If the Interconnector pipeline will be built there is a speculative possibility to use it in the future deliveries from the Continent to the UK.

IRANIAN GAS

Iran disposes of huge gas reserves but for many reasons, such as reliability of Iranian supplies and complicated, distant export routes through unstable regions of the Middle East and Balkan, the real possibility for Iran to enter European gas markets is still far off and unclear. The technical possibilities of how to bring Iranian gas to Europe have been evaluated in many routes and variations.

The last time Iran and Turkmenia tried to reach Europe jointly with their big gas deposits. No final decision was reached. Further development might be very interesting.

YAMAL-EUROPE PIPELINE THROUGH BELARUS AND POLAND

This project should bring up to 67 bcm/y to Europe and is one of the most discussed projects this decade. Nevertheless, some pessimism and doubt still exist about the lead time and even about the

necessity of Yamal gas for Europe. Development of Yamal gas is very expensive in difficult climate conditions and a sensitive ecological area. Accordingly, some estimate sufficient volumes of gas could be economized in Russia, and also deposits in western Siberia could fully cover the demand. Gas from Yamal could be, from our viewpoint, considered as a diversified gas source because of the different export route.

The Czech Republic has ambitious plans for the increase of gas consumption and the level of diversification is estimated at 25%. Not only technical and territorial challenges, but also economic aspects of diversified sources are crucial ones. The costs of new pipeline gas projects, as well as of new LNG projects to Europe, are estimated in the range of 3 and 4 USD/MMBTU, which is much more expensive than the current level. These costly projects could be bearable under the condition that the crude oil price is a minimum of USD 25/bbl and fuel oil USD 35/bbl. This is hardly expected in the near future.

CONCLUSIONS

In order to guarantee reliable deliveries and sufficient volumes of gas, commercial negotiations are held with traditional partners about long-term supply contracts and many projects are evaluated and targeted to potential suppliers. These projects are mainly in preparatory stages and no final decisions have been taken. In any respect, we don't see any problems in further development of natural gas as an excellent and clean fuel and product on the Czech market.

NET ENERGY ANALYSIS - POWERFUL TOOL FOR SELECTING ELECTIVE POWER OPTIONS*

Sy Baron, Associate Director

Brookhaven National Laboratory
Upton, New York, USA

Presented by Romney Duffey

ABSTRACT

A number of net energy analysis studies have been conducted in recent years for electric power production from coal, oil and uranium fuels; synthetic fuels from coal and oil shale; and heat and electric power from solar energy. This technique is an excellent indicator of investment costs, environmental impact and potential economic competitiveness of alternative electric power systems for energy planners from the Eastern European countries considering future options. Energy conservation is also important to energy planners and the net energy analysis technique is an excellent accounting system on the extent of energy resource conservation.

The author proposes to discuss the technique and to present the results of his studies and others in the field. The information supplied to the attendees will serve as a powerful tool to the energy planners considering their electric power options in the future.

Energy and policy planners over the past twenty years have debated the choice of future energy options for growing demand based on such factors as supply, environmental impact, capital investments, and economics. Following the "energy crisis" of the early 1970's the U.S. embarked on an expanded investment in alternate fuels as substitute for imported oil, and encouraged demand side conservation along with improved efficiency and reliability in energy utilization. During the 1970's and 1980's tens of billions of dollars were expended to develop synthetic fuels from coal, demonstrate processes for clean coal utilization, subsidize the production of ethanol from biomass and increase R&D of renewable energy systems based on ocean thermal gradients, solar energy, low head hydroelectric plants, and wind energy. The state public service commissions that regulate the utility rates shifted from traditional approach based on investments in generation to investments in conservation. The state commissions and the U.S. Congress are also encouraging competition from unregulated power producers and requiring the regulated utilities to make their transmission lines available to these power producers so they can compete with the regulated utilities.

In recent years the process for selecting energy options has focused on the use of "externalities" of energy systems which is intended to normalize all the variables such as siting, environmental impact, R&D investments, energy supplies, economics, and risks. Unfortunately the baseline for this approach is neither well established nor consistent and those who have used this approach tend to focus on selected areas¹ which distort the decision making process.

It is important that energy planners from the Eastern European countries make their decisions for selecting energy options based on consistent technical, environmental, and economic factors. Should their government officials select alternate energy options based on political necessities, at least the energy planners and the government will know the price for their choices. The U.S. government policies of the

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¹ Environmental Costs of Electricity, Richard L. Ottinger, TID 195.E4E575, 1990.

1970's and 1980's to invest in synthetic fuels, multiple designs of nuclear reactors, biomass, and subsidies for renewable energy have been costly with doubtful justification. If net energy analysis techniques were applied to these options it would have been an early warning of the high risk and doubtful economics for these approaches.

Many energy analysts² have made extensive studies of net energy analysis for existing electric power plants (natural gas, oil, nuclear, coal) and developing energy options such as advanced reactors, synthetic fuels from coal, biomass and solar energy. For those not familiar with the technique I'd like to review the approach and summarize the results of these analyses so they can be used by energy planners in their decision making process.

The annual rate of energy resource production can be related to the annual rate of energy demand by using net energy analysis. Fundamentally, this energy accounting system totals energy consumed in mining, transporting and processing an energy resource, and energy consumed in materials production, equipment manufacturing and plant construction, and relates this total energy input to output energy in the form of heat, electric energy or synthetic fuels. Operating inefficiencies, such as the power conversion cycle from heat to electric and energy losses consumed in processing a product such as synthetic fuels, are also included in the energy input/output accounting.

A number of net energy analysis studies have been conducted in recent years for electric power production from coal, oil and uranium fuels; synthetic fuels from coal and oil shale; and heat and electric power from solar energy. Figure 1 is an example of a net energy analysis flow diagram for electric power from coal conversion to synthetic fuels. The diagram includes the capital energy and operating energy for all the steps.

A frequent definition in many net energy analyses is payback years, determined by the number of years a plant operates to produce an energy product before that energy product equals the total input energy necessary to build and operate the plant.

For a solar thermal electric power plant, total capital input of energy resources is defined as the sum of electric energy input corrected with a power conversion efficiency of 30% plus the thermal energy resource requirements. Input operating energy is an annually recurring energy resource investment, taken every year over plant operating life.

The payback years of capitalized energy input shown in Table 1 is defined as a multiple of the annual output equivalent to the energy resource necessary to produce the same quality and quantity of energy products. In other words, if we assume that coal is the energy resource used to build a solar electric power plant, payback (see Table 1) is defined as the years the solar electric power plant must operate to produce the same kilowatt-hours as a direct-fired power plant using the same quantity of energy in coal. The input energy resources for synthetic liquids and gases are considered to be supplied by coal. On the other hand, the input energy resources for solar energy system production can be supplied by electric power from coal and nuclear energy, or by a combination of fossil fuels such as oil and natural gas, which are all summed as one total.

Table 1 summarizes the values for the capital and operating energy investments to delivery of synthetic fuels, heat or electric power for various energy conversion systems. The capital energy represents both direct and indirect energy resources consumed in materials production, equipment manufacturing and plant construction for the various energy systems. Coal-and uranium-or plutonium-fueled electric power plants and synthetic fuels process plants (including biomass) pay back capital energy investment in less than 1 year of plant operation.

² For references see S. Baron, Costing Thermal Electric Power Plants, Mech Eng 104, p. 41-47 (1982).

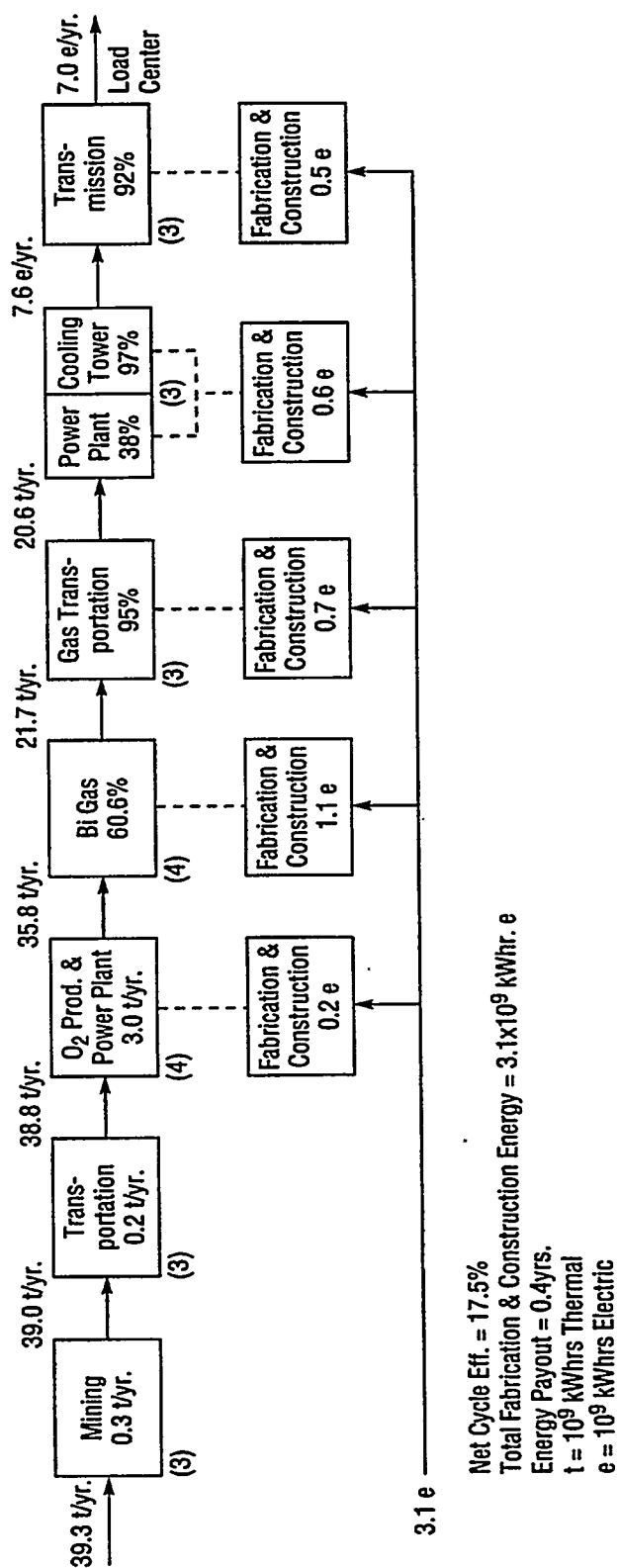


Figure 1. Energy cycle for synthetic natural gas from coal.

TABLE 1

Energy Resource Requirement Input
per Annual Energy Output

Energy Systems	Capital Energy $\left(\frac{\text{Tot. Energy Input}}{\text{Annual Energy Output}} \right)$ Btu/(Btu/yr.)		Operating Energy (Non-fuel) $\left(\frac{\text{Annual Energy Input}}{\text{Annual Energy Output}} \right)$ (Btu/yr.)/(Btu/yr.)	Capitalized Energy Input (Payback, Yrs.)
	Range	Avg.	Avg.	
Oil P.P.	0.3 -0.4	0.4	0.04	1.6
Coal P.P.	0.35-0.40	0.4	0.03	1.3
LWR	0.30-0.36	0.3	0.06	2.1
LMFBR	0.50-0.70	0.6	0.01	0.9
Syn. Liq. from Coal	0.24-0.30	0.3	0.6	18.0+
Syn. Gas from Coal	0.48	0.5	0.6	18.0+
Oil from Oil Shale	0.3 -0.4	0.4	0.5	15.0+
Solar Heating	5.0-10.0	7.0	0.2	11.0
Solar Electric, thermal	5.0-12.0	8.0	0.0	8.0
Solar Electric, photovoltaic	10.0-20.0	15.0	0.0	15.0
Biomass-Ethanol	0.5	0.5	1.25-1.50	37.0-45.0

The operating energy, exclusive of fuel, represents the annual energy consumed in mining, transporting, processing (including distillation), enriching, fabricating, reprocessing, harvesting (biomass), and waste disposal. In the case of synthetic fuels from coal and oil shale, operating energy represents process inefficiencies or the fraction of product consumed as energy to operate the plant. If fuel were included in these cases, the total input/output energy ratio would be 1.5 or 1.6 Btu yr⁻¹ of fossil fuels resource per Btu yr⁻¹ of product energy.

Capitalized energy (see Table 1) is the sum of capital energy and operating energy, whereby operating energy is capitalized by multiplying its annual value by plant life. With the exception of solar heating, which has a 20-year life, all the other energy systems are considered to have a 30-year life. The magnitude of capitalized energy is a measure of the energy resources required over plant life. The large payback periods of capitalized energy for synthetic fuels and solar energy are significantly greater than coal, light water reactor (LWR) and liquid metal fast breeder reactor (LMFBR) energy systems. While more net energy is produced over the life of these plants than is invested in capital and operating energy (with the possible exception of biomass), the high capitalized energy input values signify large energy-resource consumption.

Inhaber³ in studies of material requirements for power plants showed a significant increase in metric tons of material per megawatt-years between conventional fuels (coal, oil, natural gas, uranium) and renewable energy power plants based on wind, solar, and biomass. His studies summarized in Figure 2 show a 10 to 30 fold increase in materials for mining, processing, fabricating and constructing these plants. The capital energy discussed earlier to construct these plants would be even greater since renewable energy have greater percentage content of energy intensive materials such as steel, glass, plastic, aluminum, copper and silicon than conventional plants which are primarily concrete and steel with some copper.

³ H. Inhaber, "Risk of Energy Production", AEACB-119 Rev. 1, p. 28, 1979.

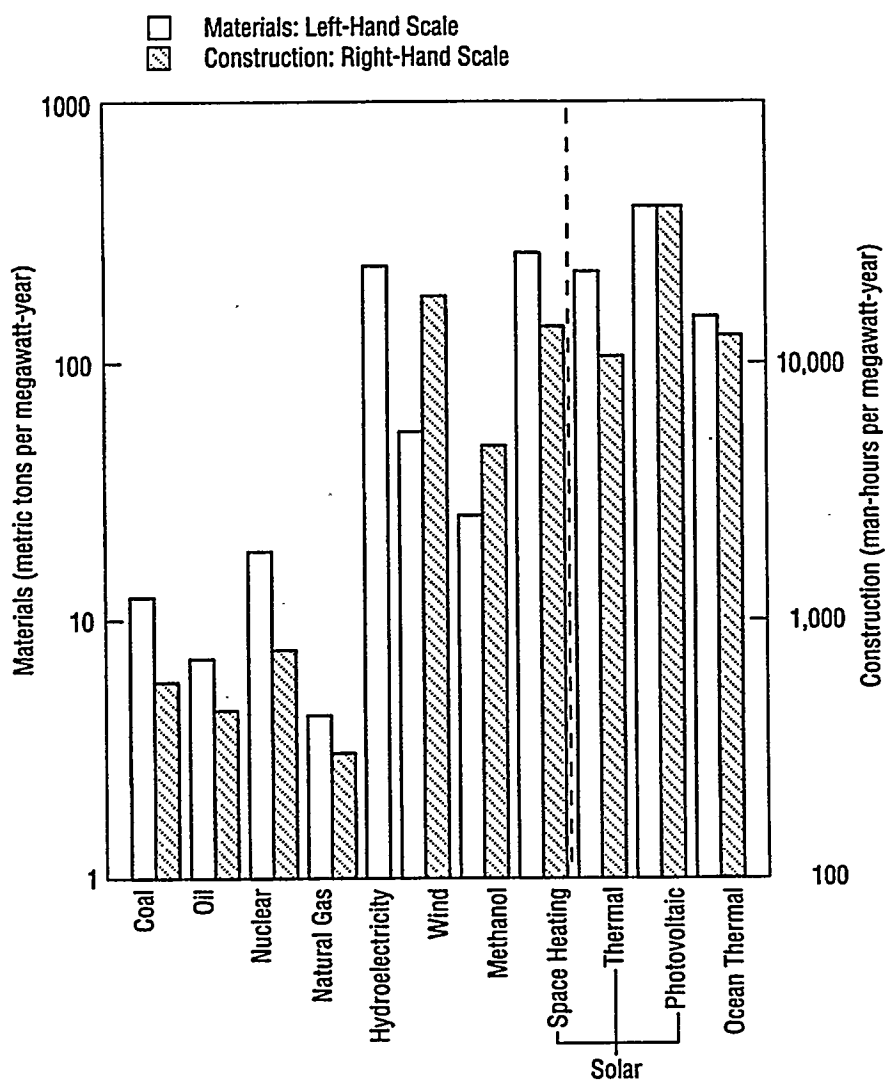


Figure 2. Summary of materials amount and construction man-hours.

Crystalline or amorphous silicon for photovoltaic cells are highly energy intensive. With their low conversion efficiencies (10-20%) and low capacity factors (15-25%/yr) their total energy requirements per megawatt-hour of output is great.

The large dependence of solar energy upon conventional fuels can best be seen by the cost of solar hot water heaters and the cost of photovoltaic cells as these technologies have been perfected over 20-30 years. Figure 3 shows the installed cost of solar hot water heaters from 1962 to 1993^{4,5}. As actual energy costs have risen so has the actual installed cost of solar hot water heaters. The six fold increase in present dollars for solar hot water heaters trend up with the increase in electric power and the increase in natural gas and residual oil prices. As seen in Table 1, the capitalized energy embedded into the U.S. solar hot water heating system is 11yrs. For the South Eastern and South Western part of the U.S. the total solar energy insolation is about 220,000 Btu/ft²/yr. With average energy costs at about \$10/10⁶ Btu (electric power and fossil fuels), the annualized cost of the embedded energy of solar hot water heating would be 220,000 Btu/ft²/yr $\times$ 11/20 $\times$ \$10/10⁶ Btu or \$24/ft² which accounts for 1/3 of the installed cost. Conventional energy costs to mine, process, and manufacture the solar hot water heaters clearly contribute to a major cost component of this system. Solar hot water systems can only be justified where solar insolation is high and the installed costs are subsidized through tax credits and/or low interest rate financing.

The impact of the embedded energy costs for photovoltaic power is even more striking element of the installed costs. From 1970 to early 1980's, the cost of PV units decreased from \$20/peak watt to about \$6/peak watt⁶. By 1991 and 1992 the average price of manufactured PV units has remained unchanged at \$6/peak watt⁷. Assuming 25% for installation costs or \$7.5/peak watt and 25% annual capacity factor, the cost of electric power is about 60¢/kw HR Or 9 fold greater than the conventional electric power at 7¢/kw HR (see Figure 3). The embedded energy cost of PV units from Table 1 is 15 years. If conventional energy costs average \$10/10⁶ Btu (average for natural gas, oil and electric power) for the manufacturing of PV units, the embedded energy costs are \$2-4/peak watts. It is therefore not surprising that the manufactured costs of PV units even thin film have not gone below the \$6/peak watt over the past 10 years. The U.S. stated policy to produce PV units at \$0.5/peak watt is not only elusive but untenable. Applications of PV are likely but only in special cases of high insolation, remote areas with high transmission costs, and with subsidies but not as a viable competitor to conventional fuels.

At the 1992 World Energy Conference the net energy analysis results were reported for small photovoltaic power applications by the Swiss Energy Laboratory for Energy Systems⁸. This study considered not only energy payback years but also environmental payback years. Their results showed energy payback of 6.6 years and an environmental payback of 17 years. The authors concluded that these payback years are too close to the plant life and therefore not a viable option.

⁴ U.S. Department of Energy, "Solar Energy, A Status Report", June 1978 DOE/IET-0062, p. 21.

⁵ Based on discussions with solar energy contractors, Florida Solar Industries Association, Long Island Solar Hot Water contractor, & California Utility.

⁶ S. Baron, "Solar Energy; Economics vs. Energetics", Mechanical Engng Vol. 103, No. 5, May 1981, p.38.

⁷ Solar Collector Manufacturing Activity 1992, DOE/EIA-0174 (92) p. 17.

⁸ Total pollution including "Grey Pollution"; Life Cycle Analysis for the Assessment of Energy Options, R. Frischknecht, P. Hofstetter, I. Knoepfel, P. Suter, World Energy Conference, Madrid Spain, Division 1, T.S./S.T.1.1, papaaer 1.1.02, p. 13-p.32.

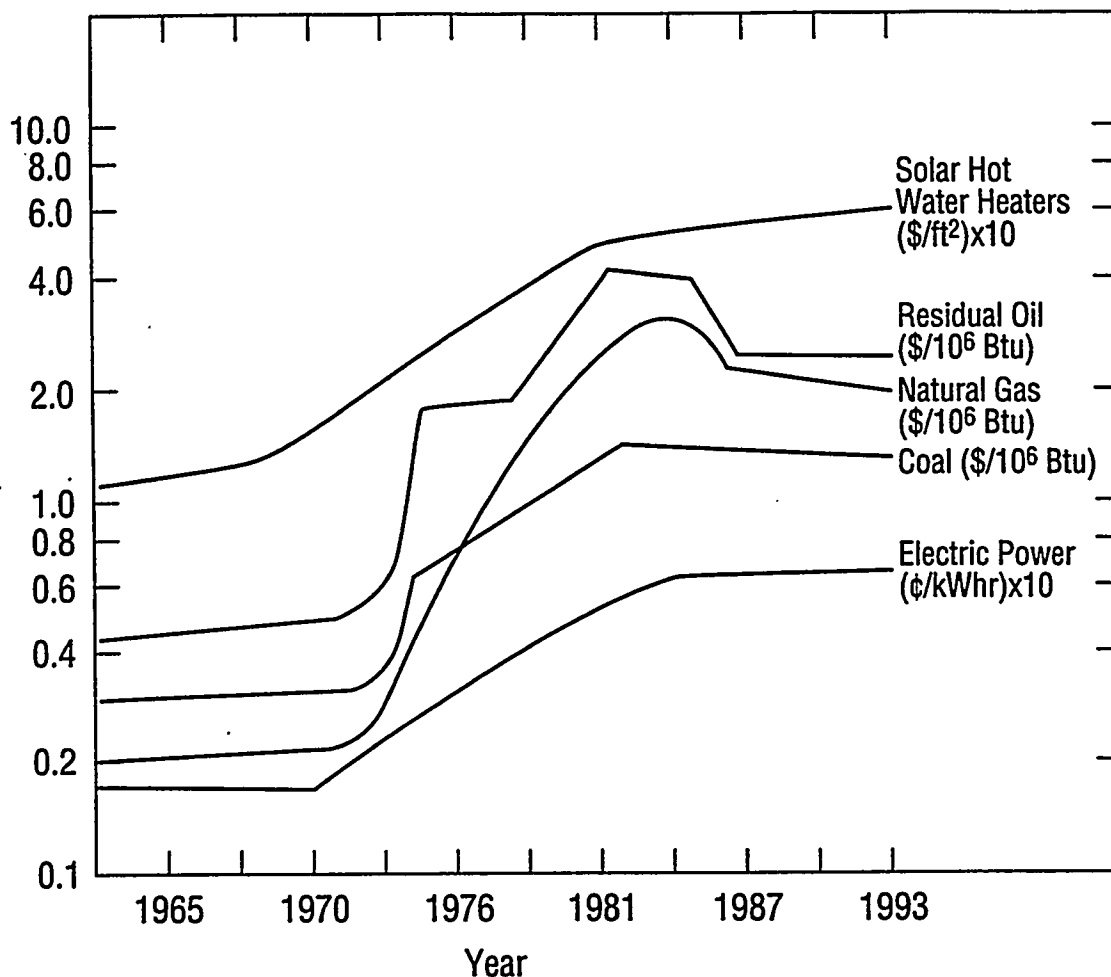


Figure 3. Present day costs of energy and solar heaters.

While the U. S. and many other countries have built synthetic fuel demonstration plants converting coal to high Btu gas or synthetic liquid fuels, the only commercial successful fuels from coal plants are the Sasol plants in South Africa. The drive to build these plants was of strategic importance for the country's survival because of the restrictions during the 1970's and 1980's to trade with South Africa.

Sasol drew upon the early German and U. S. technologies to build its first plants but evolved their own technologies and their Sasol two and three were completed in 1980 and 1983 respectively⁹. These plants best reflect the economic realities of converting coal to synthetic fuels not for competitiveness with alternate available fuels but for necessity of lowest production cost and reliability to supply the fuel needs of the country. The economic break even for the Sasol plants would be equivalent to \$27 per barrel⁹ of crude oil on the world market which is 50 to 100% above the crude oil prices. It is not surprising that the economics is that poor considering the payback of 18 years shown in Table 1.

⁹ 15th World Energy Conference, 1992, Madrid Spain T.S./S.T.2.2, paper 2.2.01, "Utilization of Coal and Neutral Gas for the Production of Synfuels and Chemicals in South Africa". p.4-p.7.

The renewable energy office of the Department of Energy conducted an energy and materials analysis for updated PV central station designs and compared the results with those of a conventional coal plant, a synthetic fuels from coal plant and a nuclear power plant¹⁰ converting the tonnage of finished materials to the energy consumed in their production gives a good basis for comparing the results with those in Table 1. For further comparisons, the materials reported by Inhaber in Figure 2 can also be converted to energy consumption requirements. The results are shown in Table 2 and confirms the significant spread in capital energy requirements between PV central stations and those of conventional designs. The variations amongst the three studies are not significant since the material requirements depend greatly on the degree of detail design and these studies varied greatly but the magnitudes are consistent.

The results of these analyses confirms that the expected economic breakthroughs for PV central plants is still elusive and that synthetic fuels from coal or biomass are not likely to be competitive because of their large operating energy requirements. Investing in synthetic fuels or PV plants to compete with conventional power systems is clearly not a good policy.

There is an old anecdote about three blind men (or women) were asked to describe an elephant by their sense of touch. The blind man who felt the tail thought the elephant was more like a snake. The blind man who felt the trunk compared the elephant to a vacuum cleaner while the blind man who felt the legs compared the elephant to a tree. Clearly one has to feel the total animal to know its size and complexity. Net energy analysis is the tool to see the whole elephant and its impact on the environment.

Capital energy and operating energy are the figure of merits for environmental and economic impact of alternative power options. The greater the capital energy values, the greater the emissions and the capital costs of the power plants. The greater the operating energy values, the greater the emissions and the loss of efficiency in generation. The payback years combines these figures of merits and makes the convincing conclusion that solar energy and synthetic fuels are not competitive to conventional power systems based on economics and emissions.

There are of course special circumstances where by solar energy in remote areas with high solar insolation can be defended particularly with economic subsidies. There are also special circumstances for synthetic fuels where there are no alternatives to coal as in South Africa or where there are subsidies for biomass and for synthetic fuels from coal. Germany during World War II, South Africa in recent years, and the U.S. in the 1970's in a panic response to the middle east oil embargo all moved into the synthetic fuels activity but with no economic justifications.

TABLE 2

Comparison of Capital Energy Requirements for Alternate Power Options			
	Baron Table 1	Doe	Inhaber
	Btu/Btu/yr.	Btu/Btu/yr.	Btu/Btu/yr.
Oil	0.4	-	0.3
Coal	0.4	0.2	0.4
IGCC	0.5	0.2	-
Nuclear	0.3	0.2	0.2
PV	15.0	7.8	25.0

¹⁰ Energy Systems Emissions and Material Requirements, U.S. DOE prepared by the Meridian Corp., Alexandria, VA, 1989, available from PVC Information Resource Center, State House Station 18, Augusta ME # H D9502.U52E53, 1989, See p. 29.

Solar energy suffers from the same problem in that they can be justified only through subsidies and special cases. Supporting these programs by any country has a high financial burden and should only be pursued unless they know the cost to its economy and to its environment.

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IMPORTED RESOURCES – OIL CRUDE OIL PROCESSING IN THE CZECH REPUBLIC AND ITS PROSPECTIVES

Ivan Souček, Manager, Strategic Planning Department
Ivan Ottis, Refinery Manager

Kaučuk
Kralupy nad Vltavou, Czech Republic

ABSTRACT

This paper examines the availability of various crude oils, addressing specifically crude oil pipelines to the Czech Republic, both existing and under construction. Secondly, the economic status of two main Czech refineries is examined in comparison to international trends, technical configurations, and product supply and demand.

CRUDE OIL SUPPLY

Historical Data About Crude Oil Supply to the Czech Republic

The Koncern pro chemický průmysl a zpracování ropy Chemopetrol Praha (Syndicate for Chemical Industry and Crude Oil Processing) was the main representant of the refining and petro-chemical industry in Czech republic in 60's through to 80's. The Syndicate Chemopetrol had been founded in 1965 as refineries affiliation and since 1975 it operated as the syndicate. The only source of crude oil supplies (99.5%) was the oil coming by the pipeline "Družba", and along with Slovnaft, it has been distributed to refineries of Chemopetrol syndicate in Litvínov, Kralupy, Pardubice, and Kolin.

The pipeline "Družba" (operating since 1962) with the annual maximal capacity of 20 mill. tons has been gradually modernized, the pipeline was doubled and the pump stations were gradually updated. The volumes of crude oil transported from the USSR was

5.3 mill. tons in 1965
15.2 mills tons in 1975

The Adria pipeline project was started by Czechoslovakia, Hungary and Yugoslavia. Later on Czechoslovakia withdrew from the construction and the pipeline was completed by the remaining partners only. Pipeline maximum capacity equals to 10 mill.tons per year, 5 mill. of which can be utilized by Czech and Slovak refineries. Adria merges Družba system in Šahy Terminal, Slovakia. Adria was for the first time and unfortunately for the last time as well used to supply crude oil into Czechoslovakia in 1991. In that period there were frequent interruptions in Russian crude supplies. Foreign Trade Companies - Chemapol Praha and Petrimex Bratislava imported 1.8 mill. tons of crude oil at that time. Crude was of Arabian origin namely Iranian Light and Heavy, Saudi Arabian Light, Es Sider and so on. Frankly speaking, due to extremely high transportation tariffs by virtue of which Hungary and Yugoslavia tried to compensate Czechoslovak financial non-participation in Adria construction, this crude became actually non-competitive when compared to Družba Pipeline. Since the war in Yugoslavia began Adria has been out of operation but most likely it managed to maintain its good technical shape.

Volumes of crude oil processed in refineries of Chemopetrol syndicate are stated in Table 1.

The most important partner was Benzina which realised 97% of syndicate's sales of refined products in its retail network.

TABLE 1

Crude Oil Processed in Refineries of the Chemopetrol Syndicate		
Years	Mill. of tons of oil	%
1965	2.90	100.00
1970	4.08	140.00
1975	7.16	247.00
1980	9.48	327.00
1985	8.74	301.00

World Crude Oil Reserves			
	Crude bil.t	Gas bil.t (rop.ekv.)	Gas/Oil
North America	5	6.8	1.37
South America	17.5	6.7	0.39
OECD (Europe)	2.2	5.0	2.27
Other Europe incl. former USSR	8.1	51.0	6.30
Middle East	89.5	39.5	0.44
Africa	8.3	9.0	1.09
Asia	5.9	8.9	1.50
World	136.5	127.0	0.93
OPEC	104.9	51.1	0.49

From the table one can see huge potential resources within Middle East but also in Latin America. On the contrary, countries of Europe and North America are at a position of importers. Czech crude oil and natural gas reserves are very symbolic. Oil and gas exploitation was started in the twenties of this century at the territory of the Czech Republic. In the time between the World War I and II gradual development of geological-prospecting work and growth of hydrocarbons production began. There were 110634 tons of oil and 104050.6 thousand m³ of natural gas exploited in 1993. Regarding crude oil own production covers only 1-2 % of total crude oil demand of Czech Republic.

Crude oil pipelines capacities and utilisation (Družba, Adria, IKL)

The southern branch of the Družba pipeline reaches the Ukraine with 60 cm diameter with separate branches to Lvov and Nadvornaya, then in the area of Uzhgorod it branches off.

The Družba I. pipeline (diam. 50 cm) passes through Slovakia on one hand to supply the Slov- naft Bratislava refinery and on the other hand in the north - west direction it goes up to the towns of Pardubice, Kralupy and Litvínov practically connecting the refineries of Czech Republic (there are plants to build on the pipeline to the area of the German Leuna - Lutzendorf).

The Adriatic pipeline starts out with a diameter of 90 cm from Omishalj - (a port which is capable to accept vessels up to 350 kt dwt.) - then at the Sisak refinery it branches off. Its southern branch supplies the refineries in the towns of Bosansky Brod, Novi Sad and Pancevo, its northern branch before entering Hungary at Virje secures on a side branch connection to the Lednava refinery. The capacity of the pipeline up to Szazhalombatta slightly exceeds 10 mill. tons annually with a diameter of 70 cm. Its terminal is in Slovakia.

The transalpine crude oil pipeline (TAL) starts out from port Trieste and makes a direct connection up to refineries in Karlsruhe. The port can accept vessels with dwt up to 160 kt. At the Austrian Wurmloch a pipeline (AWP) with a 18 inch diameter branches off TAL and provides for the raw material supply of Austria i.e. the Schwechat refinery of OMW.

The diameter of TAL is 100 cm up to Ingolstadt. The name of RDO is also used the section between Ingolstadt and Karlsruhe.

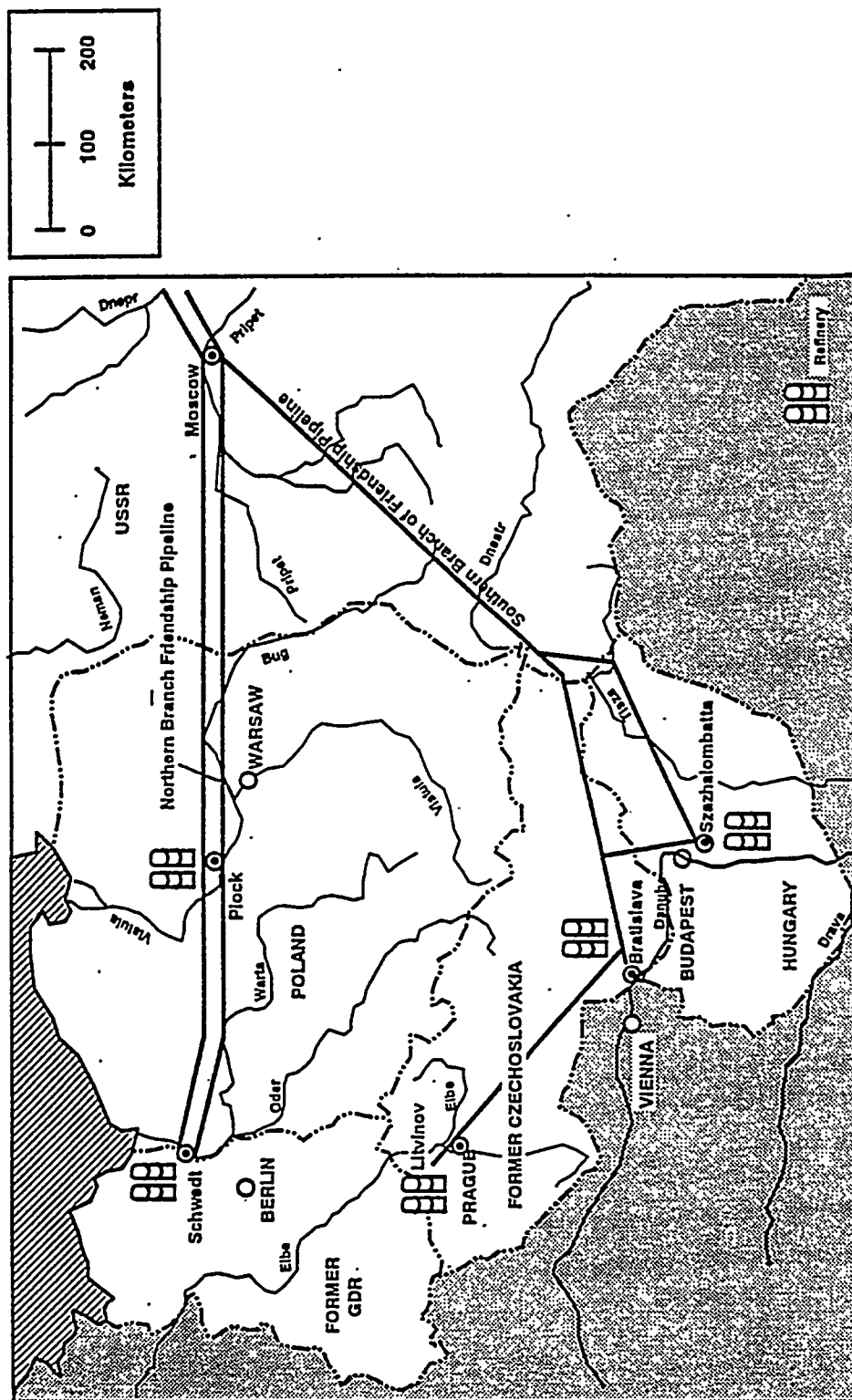
Country	Name of Pipeline	Diameter in mm	Max. capacity Mt/y
Poland	Družba II - branch 1	800	together 35.0
	- branch 2	600	
	Primorski	800	17.0
Hungary	Družba III	500	25.0
	Adria	700	10.0
Slovakia	Družba I	2x500	21.0
	Adria	700	5.0
Austria	TAL-AWP	450,00	10.0
Germany	TAL	1000	25.0
	CEL	450	9.0
	PSE	850+1000	33.0
	NWO - 1	700	15.0
	NWO - 2 (Hamburg)	550	11.5

Capacity of Pipelines to Czech Republic	Mt/y	
Družba (Transpetrol/Petrotrans)	max	21.00
Adria (further through Transpetrol/Petrotrans)	max. realistically	5 2 to 3
MERO - IKL	max. with possible enhancement	10 15

Pipeline capacity utilization		1989	1990	1991	1992	1993	1994 (expect.)
Družba	Mt/y	16.61	13.43	11.31	11.01	10.63	12.13
Utilization rate	%	83.00	7.00	6.00	5.00	51.00	58.00
Adria	Mt/y	0.7-0.8	0.7-0.8	1.10	0.7-0.8	0.00	0.00
Utilization rate	%	14-16	14-16	14-16	14-16	0.00	0.00
Oil for ER	Mt/y	8.72	7.24	6.41	6.71	5.85	7.30

♦Note: There may be used maximally 5 mill. tons/year of total capacity of the Adria pipeline the purposes of Czech and Slovak Republic.

FIGURE VIII.B.1
THE "FRIENDSHIP" PIPELINE NETWORK
CRUDE OIL PIPELINE NETWORK FROM RUSSIA TO EASTERN EUROPE



The Impacts of the Split of ČSFR

The joint stock company Transpetrol, based in Bratislava (almost 80% of shares owned by the Slovak government) was the exclusive crude oil transporter in the former Czechoslovakia. This company was formed by separation of Czechoslovak parts of pipeline Družba and Adria from state company Benzina in 1991.

After the split of ČSFR the company Transpetrol has been divided in two new companies, Transpetrol in Slovakia and Petrotrans in Czech Republic. The state owned joint-stock company Petrotrans manages the part of pipeline Družba on the territory of ČR. The company has an economic independence, so the profit from the activity can be invested in the pipeline on the Czech territory, which was not guaranteed by the Slovak control over the Transpetrol. From the operational point of view, the company will fully depend on Transpetrol, until the Central Tank Station MERO - IKL will be opened and its own investment into measuring of the transported oil will be implemented.

The new company with limited liability Chemopetrol IKL (MERO - IKL), which was founded in the end of 1992 in the Czech Republic, has been assigned to build and operate new pipeline from Ingolstadt, Germany to Nelahozeves near Kralupy nad Vltavou. The pipeline with capacity of 10 mill. tons annually will be connected with the system of west-European pipelines TAL and CEL, respectively. In 1993 companies Transpetrol and Chemopetrol IKL (resp. MERO - IKL) were joint together creating one Czech Company MERO ČR which is occupied in crude oil transportation and new pipeline construction.

The fee of Czech part of Družba pipeline is composed of fixed and variable part and the total represents currently 80,- to 90,- ČK /ton. IKL presumes a rate of 360,- ČK/ton from Trieste to Nelahozeves - Central Crude Oil Storage (hereinafter CCOS) .

New Pipeline Construction

Due to the fact, that the majority of European countries is connected through the network of the previously stated pipelines to marine harbor terminals, these states are supplied from world crude oil resources. The main criteria are price, transportation costs, current processing technology and its adaptability to particular types of crude oil, and the fiscal policy of particular countries.

Central European countries, including Czech Republic, are currently mostly dependent on crude oil supplies from former USSR. Czech Republic makes an effort to solve this disadvantage by building the pipeline MERO - IKL, and to be connected to standard European sources not passing recently unstable regions as soon as possible.

The most important task of Czech crude oil transport system is the construction of the IKL pipeline. The construction should be implemented in 3 phases. The first phase in CCOS - was opened in 1994. The line part including storage in Vohburg and second part of CCOS in Nelahozeves will be opened in the second half of 1995, the third part of CCOS will be opened by the end of 1996. It means, that the capacity of CCOS in Nelahozeves (1. part - 4x50 000 cubic meters will be, approximately 1 year, used for storage of crude oil transported into ČR by the pipeline Družba.

In any case, the increase of crude oil storage capacity by approximately 10 days will decrease the sensitivity to causal interruptions of crude oil supplies from Russia.

To supply the crude oil refineries in Kralupy and Litvínov will be possible after connecting the pipeline IKL and Družba. The supply to Pardubice will be possible after implementation of technical arrangements for drawing the oil from CCOS to Paramo Pardubice.

The implementation of IKL project and its connection to TAL system as an additional resource of supplies of crude oil to Czech Republic will solve the one-side dependence on unstable resources of oil in Eastern Europe. It will also create technical conditions for purchase of higher quality or cheaper types of oil (with low content of sulfur and light crudes or opposite heavy crudes), Arabic, African and others according to needs of Czech refineries.

Crude Oil Trade

Companies engaged in crude oil imports to Czech Republic:

a.s. Chemapol Praha: from historic point of view it is the company dealing with crude oil imports to Czech Republic for the longest period of time. Until 1993 this company enjoyed sovereign monopoly position in oil imports. Recently its share on oil imports is steadily declining, nonetheless it remains the one which imports more than two thirds of all oil amounts needed by Czech refineries.

a.s. Chemopetrol Litvínov: This company has begun to operate oil imports in 1993 exclusively for its own needs. Back in 1993 its imports were of no significance from the point of view of overall oil imports. Beginning from 1994 its share of imports starts to increase gradually. Currently the company is importing about one third of oil required by Czech refineries.

INEKON Ltd Praha: This company is mainly concerned with machinery industries (highly interested in privatisation of ČKD). Its commercial activities within refining-petrochemical industry clearly do not represent its major program. The company has started importing oil in 1992 but its total share is very unstable with the maximum amount being achieved during April to August 1993 (importing about 10% of crude). The share for this year is extremely small.

RTC Praha: The full name of company is "Russian- Czech Trading" which is a joint Russian-Czech Company. Its aim is to penetrate Czech oil marketplace. However, regardless of relatively excellent conditions for obtaining crude oil from Russian Federation the company for the meantime is failing to succeed against more powerful importers on Czech market.

Others: Alongside with the aforementioned companies and trading corporations a series of other firms are emerging within Czech marketplace and these are very eager to do oil imports for Czech refineries. However, all the efforts spent by these small companies are rather overcome by the conditions that other strong importers are able to offer to Czech refineries. Usually, they are private companies with small capital amounts able to supply crude oil based on so called barter trading. In this case oil represents Russian Federation means of payment for goods supplied by these firms to Russian market.

Mechanism of crude oil supply, acceptance:

For oil exports from Russian Federation exporting licences must be issued as a condition. Since the validity of such licences is limited and obtaining new licence is in most cases a lengthy process, the whole system of making contracts with Russian partner is effected by this fact. Owning a licence still does not mean a hundred percent assurance for a respective firm to be able to export oil outside Russian territory. Based on several years of experience a basic document able to provide a survey of companies with a right to export oil, is a so called "Flow- Sheet of Supplies" released by Transnefti Moscow which is a state-owned transportation enterprise. The "Flow-Sheet of Supplies" includes the list of all those companies owning an export licence. Subsequently, based on the prepared "Flow-Sheet of Supplies" the contract may be concluded. Nevertheless, the contracts are made for one month only. Once the contract has been signed (usually during the first days of supply month at the latest) an information is given to transportation organization - a.s. Transpetrol Bratislava which carries out oil acceptance in Budkovce Terminal. The information is given so oil after being supplied to Budkovce Terminal can be identified according importer.

Each oil supply to Budkovce Terminal is subject to quality acceptance procedure. These acceptance procedures can be carried out with no major time loss since the S.E.B (Sojuz Export Blend) oil quality is not changing in a long time range concerning quality parameters, and remains to be the same in all contracts (regardless of type of importer). Should it be that the supplied oil does not meet its quality parameters then the tank containing this crude oil is shut down away from pipeline operations until the claim is solved. In case bad quality oil supplies are long term character the entire pipeline system is to be shut down for a period necessary to cope with the claim.

To cover complexly the trading issue allow me send a few words about Commercial partners in Russia: Trading partners within Russian federation may be divided into two groups. They may either be

constituted by firms and companies trading with oil quotas released by State for the purpose of export (i.e. so called "gosneft" - meaning state owned crude oil). These companies make for about 30 % of all crude exported from Russia. About 40 to 80% of the Czech market requirements are currently purchased from these companies lies in the fact that they have oil always available for clients, and in case of any constraints their supplies can be rescheduled to gain priority. The second group includes those companies exporting oil on the basis of licences the validity of which is limited according to time or amount. Companies like that are trading exclusively with so called "commercial oil". There are six companies exporting state-owned crude oil. The major ones are Neft' Moscow, Mashinoimport (trade companies), also Balcer Trading (Joint Venture), Permneft' and Kombineft' (manufacturers and explorers). There is a greater number of those companies dealing with commercial oil and their number is not stable. Among oil exporters from the former USSR territory are even such corporations like Shell, Total or Chevron.

CRUDE OIL PROCESSING

Existing Czech refineries

Key Industry Players:

Chemopetrol Litvínov
Kaučuk Kralupy
Paramo Pardubice
Koramo Kolín

Chemopetrol Litvínov :

1. Crude oil processing (annual capacity 5,0 Mt) for automobile gasolines, aviation kerosenes, diesels, heating oils, bitumens and liquid gases, raw materials for oil production in Koramo Kolín.
2. Providing the feed for the ethylene unit of petrochemical section of the plant in Litvínov.

Kaučuk Kralupy:

1. Crude oil processing (annual capacity 3.2 Mt) for automobile gasolines, aviation kerosenes, diesels, heating oils and liquid gases.
2. Processing the C4 fraction for production of MTBE (annual capacity 90 kt) and for butadiene production (annual capacity 90 thousand tones) for petrochemical section of the plant in Kralupy.

Paramo Pardubice:

Crude oil processing (annual capacity 1,0 Mt) for diesels, heating oils and bitumens.

Koramo Kolín:

Does not process crude oil currently. Distillation and refinery unit in Koramo Kolín has been subject of reconstruction since 1992. Koramo uses raw material from Chemopetrol for its production of lubricants with capacity approximately 200 000 tons/year.

Geographical Description

Chemopetrol Litvínov is located in Northern Bohemia, near towns Most, Litvínov and Chomutov. Kaučuk Kralupy is located in Central Bohemia, 30 km north-western from Prague, in advantageous position for supplement delivery and distribution of its products. The company has, thanks to its territorial

conditions and secured supply of water and energies, good potential for further development. It is situated in area of the main transport communications.

Capacity Utilization of Kaučuk Kralupy	1989	1990	1991	1992	1993	1994 estimated
Processed crude oil in tons	3130957	2456513	2316727	2359390	2235000	2185000
Utilization rate in %	96.3	75.6	67.6	71.8	61.7	61
MTBE production in tons	63920	57233	44144	46157	38000	48000
Utilization rate in %	71	63.6	50.1	50.5	44.3	55.8
Capacity Utilization of Chemopetrol Litvínov						
Processed oil in tons		4106000	3456000	3811000	3739000	4076000
Utilization rate in %		82.12	69.12	76.22	74.78	81.5
Petrochemical Feed in tons						
% of capacity						
Capacity Utilization of Paramo Pardubice						
Processed oil in tons	526000	456000	451000	450000	450000	465000
Utilization rate in %	52.6	45.6	45.1	45	45	46.5

Future development of refineries

During further development of preparatory work for "bottoms processing" in Kralupy and Litvínov refineries individual alternatives were regarded with respect to their needs for capital expenditure and possible ways of funding these investments. Therefore a concept of using a cheaper conversion technology has been taken into account. A recommended alternative from the year 1991 has been compared with the one using a thermocracker (even though the products do not fully meet expected quality requirements after year 2000). After own elaboration on the matter seven alternatives altogether have been compared in cooperation with ABB Lummus Crest Co. These versions include three basic directions under different construction phasings and links between units including their capacities:

- classical complex refinery (DEA+HDS DEA+FCC VD/DEA Oils) - Litvínov Refinery
- "modern" approach (HDS/HDM AR + FCC AR) - Kralupy Refinery - alt. No 1
- "conservative" approach (TC AR + event. HDS AR) - Kralupy Refinery - alt. No 2.

Conclusions:

- Quality of crude oil is declining steadily, a switch is made to rather more acid and heavier crude. Refinery production worldwide is experiencing a switch from gasoline fractions and fuel oils to medium distillates. However, this tendency is not the same in all regions. Choosing a technological process will mainly depend on regional demand structure for oil products. Such a trend in combination with ecological requirements favours hydrocracking processes instead of cracking ones. Refineries affected by the experience of rapid decline of their profits at the beginning of eighties will be very cautious when investing capital into even less certain projects with high costs incurred due to ecological demands
- Basic criteria for choosing of refinery configuration are:
 - quality of feedstock on conversion unit (utilisation of technology under the risk that higher quality feedstock would not be available versus economical processing or evaluation of residue proportional to the fractional conversion)
- It is highly probable that the development in direction of replacing fuel oil and further lowering of sulphur content in fuels will continue. Therefore refineries will seek new progressive ways like for instance gasification, making use of emulsions etc.

A switch to bottoms processing will become a key point in future development of refinery industries. Simultaneously, under the conditions of developing economies the needs for capital expenditure of a project preferring more simple conversion technologies will be decisive for implementation of technological alternatives.

Czech product demand development (influence to expected quantity of crude oil processed, expected utilisation of each pipeline)

Prospectively one can see a slight demand increase for gasoline (Czech Republic) and medium distillates (Europe) while demand for heavy fractions declines (in Europe much more rapidly than in Czech Republic).

Product quality is an important factor on the market. Concerning the gasoline there is a tendency particularly for reformulation (contents of benzene, aromates, oxygenates and others), in diesel fuel (mainly sulphur content), and in fuel oils (sulphur content in particular).

In Kaučuk Kralupy the trends in production of fuel oils expect substantial production reduction of fuel oils with sulphur content exceeding 3% until 1998, and a complete elimination of sulphured oil production in the year 2003.

Expected global needs for individual products - WORLD

	1973	1990	2000
Light distillates	29.5	35	38
Middle distillates	30	36	40
Heavy products	40.5	29	22

Expected global needs for individual products - Czech Republic

	1995	2000	2003
Light distillates	30	35	38
Middle distillates	36	38	41
Heavy products	34	27	21

Prospects for oil processing and a swift implementation of conversion technologies are not solely effected by production economics but also by disponibility of crude oil and its long term perspectives.

ENVIRONMENTAL ISSUE

Impact of transportation

The environmental damages in European developed countries is estimated 5 to 10% of their GNP.

Companies processing crude oil, oil derivatives respectively, are watched closely to ensure the environmental protection.

The particular arrangements must focus on systematic supervision and on technical equipment of fuel storage capacities and processing units. Small leakage in technological processes, in manipulation with containers, leakage by filling and distribution of fuels and other oil-based waste have a negative impact on condition of underground water resources and working environment quality. Another important issue is emission of gaseous carbon-hydrates and breathing of large-capacity containers during the refilling.

The most damaging are defect of large-capacity containers or product pipeline, which represent a long-term threat to the environment of particular area. It is one of the most important interest of every company to prevent such large scale damages.

Impact of processing and product utilisation (esp. gasolines (Pb content), diesel fuel (sulphur content), heavy fuel oil (sulphur content))

The costs of environmental arrangements will be the most significant issue of refinery industry. Amount of 50 - 100 bill. USD is estimated as a cost for these purposes only in Europe in the next 10 years.

The overview of environmental legislation that will effect a further development of refinery industry in the framework of EC are shown in the following table:

TABLE The status of environmental legislation of EC			
Status	Target of regulations	Main goals	Effective since
Effective	large heating plants (over 50 MW)	- curr. plants 60% depression (compare to 1990) of emissions of SO ₂ until 2003 - new plants: gradual depre- ssion S from 1700 mg/m ³ to 400 mg/m ³ (>500 MW)	11/1988
Effective	content of sulfur in gas oil	- diesel 0.05% S 1996 - - heating oil 0.2% S 1994 0.1% S 1999	3/1991
Proposal	small heating plants	emission S 1700 mg/m ³ (> 1MW) until 2000	1993
Proposal	fuel total	1.0% S for inland 1.5% S for marine bunkers until 2000 1700 mg/m ³ for refinery emissions	1994/95

The following table shows, that the sulfur content increases in all regions, where the Middle Eastern oil will be used. This is in accordance with a presumed reduction of exploitation of sweet oil from Northern Sea.

TABLE
Crude Oil Quality and Presumed Refinery Emissions

Quality	Year	North-Eastern Europe	Atlantic	Mediterranean
Sulfur content in oil (mass %)	1990	1.12	0.96	1.3
	2000	1.14	1.02	1.44
	2010	1.20	1.13	1.48
Average emission SO ₂ (mg/m ³)	1990	1.42	2.80	1.44

The table shows also the level of refinery emissions of SO₂. This level is lowest in North-Eastern Europe where strict environmental regulations are in effect.

The impact of environmental regulations on refinery products quality assessed based on sulfur content is stated in the following table.

TABLE
Quality of Refinery Products (Content of Sulfur)

Product	Sulfur limit (%hm.)	Area	Expected effectiveness	Czech Regulation
Gasoline	0.05	EC	1998	0,05 - 1990
Aviation gasoline	0.10	EC	1996	
Heating diesel	0.10	EC	1999	
Heating oil (inland)	2.00	EC	1995	
Marine bunkers: gas oil (MGO)	0.1	EC	1999	
engine diesel (MDF)	0.50	EC	2000	
heavy fuel				
alternative 1	1.50	world	2000	
alternative 2	1.0 2.0	world - coast world - open sea	2000 2000	
alternative 3	1.0 3.5	EC - coast world	2000 present	3.0 - present

Further environmental requirements are focused on benzene content in gasolines. The current maximum content in Europe is 5%. The effort for its reduction is based on its cancerogene impact.

Many isomerating units have been built recently and further increase of isomerating and alkylating capacities is planned. It is estimated that the limit of benzene should decrease to 1% by the year 2000.

Reduction of CO₂ content in emissions is the important issue not only for the refinery industry. The EC committee prepared regulation, suggesting to tax the energies. 50% of this tax would be created by the CO₂ emission. This tax means 3 USD/bbl, with gradually increased rate of 1 USD/year, until 2000, when the rate reaches 10 USD (for coal the estimate is 14 USD and for gas 7 USD).

The depression of SO₂ in smoke gases is very discussed issue. The following table states suggested limits of SO₂ in smoke gases for refineries and heating plants:

TABLE
Emission Limits in Smoke Gases

	Limit mg/m ³ SO ₂ in smoke gases	Country	Expect. effect. since
Refineries (current and new)	2000	EC	1996
	1700	EC	2000
	1000	EC	2000
Heating plants	3400	EC	1996
	1700	EC	2000

IMPORTED RESOURCES – GAS/OIL

Károly Jakob, Director

MOL Hungarian Oil and Gas Company
Budapest, Hungary

INTRODUCTION

The goal of this presentation is to provide information on issues of crude oil and natural gas supply at a conference addressing the problems of energy in Eastern and Central Europe. Although this can inevitably be performed through the "binoculars" of the petroleum sector of my country, I will try to present the issues and challenges that are thought to be characteristic in general for the region.

SUPPLY AND TRADING EXPERIENCE IN DEVELOPING A MARKET ECONOMY IN HUNGARY

Transition from the centrally planned economic system to a market-oriented economy has emerged several positive and negative implications. Refining and marketing in the region are now in a fierce competition. Market is still more or less liberalised in these countries but the regulations, protection of domestic petroleum sector, Governmental intervention, system of customs and prices and the pricing mechanism varies from country to country.

It would be too general to say, I think, that liberalisation in each country was followed by legal regulation of control and rigorous enforcement with some delay. Such factors and the changing taxation and customs regulations almost "invite" opportunities for abuses, semi-legal or illegal manoeuvres to find ways around the taxation and customs system and thus obtain "competitive advantages" against decent companies with fair operations. Organized crime has also appeared - why just the criminal underworld would have been left out from the extremely rich oil business. Fortunes have been created as a result of violating or simply evading the regulations, huge amounts of money are washed and even levels of supervising, enforcement and decision making bodies have been attacked and penetrated. 20 billion HUF budgetary loss was estimated for 1992.

The oil product market in Eastern/Central Europe is a supply-driven market. If we look at the three sophisticated refineries in the region that operate quite close to one another, i.e. Schwechat, Bratislava and Százhalombatta, including the fourth at Sisak, though somewhat further down on the map. Each is modern, complex asset and their aggregate capacity is exceeding for mid-term the realistic demand. In addition to that there are some other smaller refineries to increase the surplus capacity. These refineries are already in rigorous competition. One of the key factors in such competition is the crude supply, one of the issues to be covered by my presentation.

HUNGARY'S ENERGY STRUCTURE, THE ROLE OF PETROLEUM AND NATURAL GAS IN ENERGY SUPPLY

The energy utilization structure of Hungary can be considered favourable if compared with the average of Western countries and Eastern Central European countries. Since the share of natural gas is over 30% and petroleum is almost 30%, hydrocarbons form almost 60% of primary energy utilization, and due to the one nuclear power plant, the share of nuclear power is 12%. (The primary energy distribution of Hungary and OECD countries is shown in the slide.)

CRUDE OIL SUPPLY OPPORTUNITIES FOR THE REGION

Hungary is directly connected to Russia with Friendship II pipeline through Ukraine, and, indirectly with Friendship I. pipeline that first enters to Slovakia. Nominal capacity of Friendship II. pipeline is 10 Mt/y, i.e. it will be able to secure the total crude supply for Hungary also for long term.

Adria Pipeline connects the Omisalj terminal at Krk island in Croatia, near Rijeka to the refinery at Százhalombatta. Crude can also be transported further to Bratislava through Friendship I. pipeline. Adria also supplies the refineries at Rijeka and Sisak in Croatia, Lendava in Slovenia and Bozanski Brod in Bosnia (this was knocked out of operation) and Novi Sad and Pancevo in Serbia.

The diameter of the Hungarian section of Adria Pipeline - that was commissioned in 1978 - is 600 mm with a nominal capacity of 10 Mt/y. The maximum volume of crude to be transferred to Slovakia was defined in the original agreement as 5 Mt/y. The pipeline was "dry" for 18 years, then from 1987 it was used in the reverse direction as crude was transported to Yugoslavia. It resumed the original operation only in 1990 and crude oils from the Middle East and Africa were then transported.

The transportation capacity of the pipeline can be upgraded to 14-15 Mt/y with the expansion of certain servicing equipment and the Croatian section is also capable of catching up with such development. It means that as an extreme case, the total crude oil requirement of both mentioned countries could, in principle, be secured from either direction, i.e. through Friendship or Adria pipeline, even if only one of them is serviceable. If we look at the present situation, Hungary is unilaterally dependent on the Russian supplies.

Regulations for sulphur content of oil products are increasingly more and more rigorous in Western Europe and this is solved through processing low sulphur crude grades. Grades from the North sea and some crude from North and West Africa belong to this category. Should both pipelines be operational, Hungary's import would be shared between the two options depending on price, net-back value and environmental considerations. The situation in Slovakia is supposedly the same.

During the two years when MOL could use Adria pipeline nearly 15 % of the total import was sweet in 1990 and 24 % in 1991, respectively.

The Adria was closed down at the end of 1990. The pipeline itself is technically operational, as information revealed, but between Omisalj and Sisak a nearly 50 km section in the so-called Crayina Area is under military control and is kept shut down due to the un-settled difficulties between Croatia and Serbia.

There has been no supply crisis neither in Hungary nor in any of the East Central European countries dependant on the Friendship pipeline. Eventual supply irregularities occurred mostly for technical reasons or issues related to quota interpretation and these were settled shortly after being clarified. This was obviously and hopefully motivated by mutual interests. Hungary is a fair and reliable business partner, paying in time in hard currency, and so are the other countries in the region. The regular currency revenues that arrive to Russia against the purchases made by countries, as good debtors, that are connected along the existing pipeline system should represent a vital interest also for the Russian economy and for companies with export quota. This is also reflected by the fact that Russia, making use of falling domestic demand, can still increase its export though its oil production has been declining.

Diversification of unilateral supply is a natural drive for each country, particularly if events of crisis can easily emerge in any existing supply zones. This endeavour is extremely justified if a refinery can only be supplied through one single pipeline. This makes the decision of the Czech Republic to connect its refineries at Litvinov and Kralupy to TAL system so rational. The idea to extend this pipeline up to Leuna has time-to-time emerged. The proposed extension of AWP pipeline up to Bratislava seems also quite feasible due to the short distances but this will obviously be subject to the relations between ÖMV and SLOVNAFT. As far as Hungary is concerned we have also investigated the reality and risk factors of a third supply pipeline that would cross a region with lower political risks. The nearest pipeline, i.e. AWP has only a limited available free capacity and the construction of any other pipeline would imply - due to

the large distance - extremely high expenditures. Hungary thinks that risks have not reached the level that would justify the high cost of construction of a third pipeline.

Crude oil (and oil product) import is fully liberalised in Hungary. In most cases it is subject to an import license but it is granted to any applicant who meets the legal requirements specified for foreign trading activities, i.e. no caution is required. During the years of centrally planned economic system MINERALIMPEX enjoyed monopoly rights for import of crude oil and natural gas. Nowadays MOL also imports itself and e.g. in 1993 7 other companies imported crude oil (and 70 companies imported oil products).

NATURAL GAS SUPPLY OPPORTUNITIES FOR HUNGARY

Nearly half of natural gas resources are produced in Hungary, the other half is imported. According to forecasts, the demand for natural gas is going to increase in the future and on the long run also: it may increase from 10.5 billion to 13 billion m³ in 2000. As Hungarian natural gas production is decreasing since the peak of 7.5 billion m³ in 1985., it was 4.9 billion m³ in 1990. and will be 2.5 billion m³ in 2010., the share of import will increase in accordance and by the turn of the century, it may be many times higher than domestic production.

The source of natural gas supply is still fully dependent of a unilateral direction, all imported gas arrives from Russia. Hungary imports gas primarily on the basis of previous long term contracts, which are known as the Yamburg and Orenburg gas contracts concluded as a mode of re-paying Hungary's contribution to projects in the former Soviet Union. The former will remain valid until 1997 and may be renewed for another 10 years and secures the supply of 2 bcm/y from Yamburg in North Western Siberia.

The latter provides 2,8 bcm/y gas from Orenburg in Southern Siberia and will expire in 1998., but this may also be renewed in principle. In addition Hungary has trade agreements that are annually re-negotiated and renewed.

Russian natural gas arrives to Hungary through the Hungarian side-line branching off from the trunk line in Ukraine. The nominal capacity of the line operating at 64 bar pressure is 11.0 bcm. Prior to the Yugoslav crisis, it was also used for transit transportation in addition to Hungarian requirements.

The slide shows the existing and some possible gas lines which supply the East Central European Region.

Completion of HAG (Hungarian-Austrian Gas pipeline) project, i.e. construction of a gas pipeline connection between Győr in Hungary and Baumgarten in Austria will be a major step forward to logistically diversify Hungary's supply position as it will connect Hungary to the West European gas network. The pipeline will have a diameter of 700 mm and a distance of 116 km, the nominal capacity is planned as 4.5 bcm/y. Construction has commenced and completion date is October 1996.

Hungary has a favourable geographical location for potential transit services for several trans-continental or trans-regional pipeline. These are presently only in the form of concepts or ideas, decisions are not yet reached and preparations are mostly in a very initial phase. Such concepts include 1) the pipeline that could arrive from Iran through Turkey and heading towards Western Europe, 2) or extension of the Transmed pipeline arriving from Algeria with parallel lines with an extension to the East Central European region, 3) transportation of LNG from Algeria arriving through a terminal to be constructed at the Adriatic coast up to Slovakia, 4) a pipeline from Norway, through Denmark and Germany to the East Central European countries, and 5) LNG from Norway, gassed at a terminal in Gdansk, Poland and transported in a pipeline to Hungary.

All of the above assumes the common interest and cooperation of several countries and also the willingness of the companies of the supply and transit countries to supply gas on the basis of a long term contract is required. These investments are not likely to be realized before the turn of the century.

Since the average daily demand is 2.5 times higher in the winter season than in summer and further increase of this difference can be anticipated, storage of natural gas is very important, which provides protection against supply difficulties in addition to seasonal storage facilities. At present 1.88 bcm natural gas can be stored in underground storage vessels in three sites. The capacity of such storage facilities is being developed and new storage areas are being constructed and explored. A new facility with 600 mcm storage capacity is being commissioned and we see the possibility for further development.

MOL in the time being has exclusive right to sell natural gas in Hungary and MOL owns the high pressure domestic pipeline network. Natural gas is distributed to the customers by gas distribution companies, one operating in Budapest and five in the country. These companies are responsible for constructing the low pressure supply pipeline systems and connection of settlements into the gas network. These companies are partly privatized and full privatization is anticipated, and it seems that large West European gas companies are interested in this area.

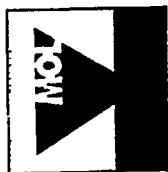
At the same time, diversification of natural gas purchase can be expected in a different direction, because we hope that companies interested in the privatization of gas distribution companies will also be involved in purchasing gas.

A fundamentally new situation has recently emerged in Hungary's gas supply business. A Russian-Hungarian joint venture has been established with the participation of GAZPROM - the Russian giant gas company. The name of the new venture is PANRUSGAZ Co. Ltd with an initial share capital of HUF 120 million. The company's shareholders are Interprocom, one of GAZPROM's exporter businesses with a shareholding of 50 %, from the Russian party, and MOL Rt with 30 % and MINERALIMPEX with 5 % and DKG EAST Co. (a Russian-Hungarian joint venture) with 15 %. The new trading house will have a dominant role in safety of gas supply of Hungary and increasing the volume of gas import. Activities of Panrusgaz will however not be limited to natural gas import as it is interested in promoting any form of trading relations between Russia and Hungary and it will evidently have transit objectives.

Pricing in Hungary is certainly part of this picture. Unlike for prices of crude oil and oil products gas prices are set by the Government, which is actually lower than that of the imported gas. MOL therefore has no choice but "selling" the gas to the gas distribution companies at a price 3 forints lower per cubic meter than it pays for the import gas.

Also the price structure is different from that of the traditionally market oriented countries: the price of household gas is the lowest, HUF 26.1/MJ, while the highest price is paid by general industrial users for firing, which is HUF 33.1 and gas used by the electric and chemical industry is between the two: HUF 28.0/MJ.

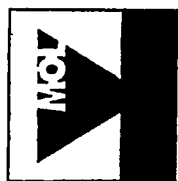
The solution of the awkward situation is now being forced due to the new Gas Act, enacted in 1994. This has provided that natural gas price should be settled latest by 1 January 1997 so that all operation and other costs of the companies engaged in supply, transportation, storage and distribution of natural gas can be fully recovered, including a fair profit and the margin can provide coverage for the developments required. To establish a price level covering the expenses of MOL and the gas distributing companies, a significant price increase would be justified. A new office was established simultaneously with the new Law, namely the Hungarian Energy Agency. It will be responsible for supervision and control of prices and submit proposals with this respect. The Government has recently decided to increase the prices in one single step at the beginning of 1995. This move will primarily affect the household gas prices as this is the category where only a 100 % rise can eliminate one of the last factors remaining from the former centrally planned system, i.e. "low wages - subsidised (distorted) prices". The Government will therefore carefully develop a solid system for compensation to help the population to tackle with this unbearable burden.



Primary energy supply in Hungary, Mtoe

	1985 ¹		1990 ¹		1993 ¹		2000 ²	
	Domest.	Imp.	Domest.	Imp.	Domest.	Imp.	Domest.	Imp.
Coal	7.9	0.7	6.3	0.3	4.2	0.2	5.4	0.1
Oil	7.2	2.4	6.0	2.2	6.0	2.0	8.1	2.0
Gas	7.8	1.1	7.5	1.4	7.0	1.6	8.3	1.8
Nuclear	3.6	-	3.6	-	3.6	-	3.6	-
Electr.imp.	-	1.0	-	1.0	-	0.2	-	0.2
Total	26.5	5.2	23.4	4.9	20.8	4.0	25.4	4.1

Sources: 1. State Authority for Energy Management and Safety (ÁEEF)
2. The Hungarian Energy Policy, 1993



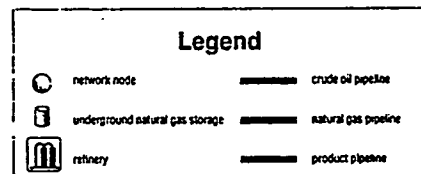
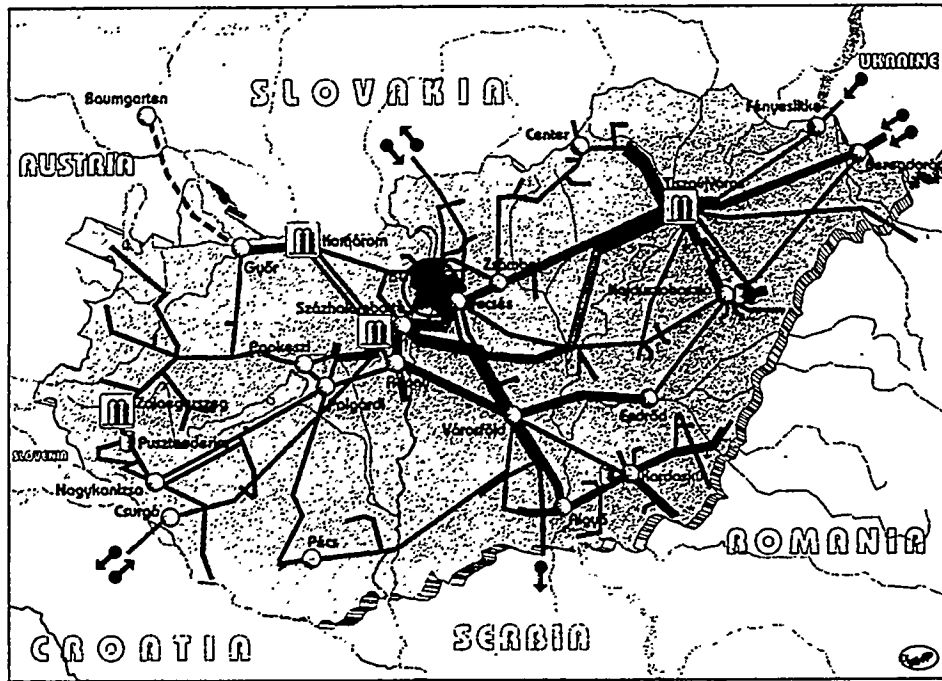
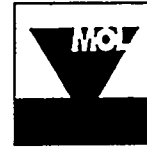
Crude oil quality

	Hungarian		Imported	
	Algyő	Nagylengyel	SEB	Bonny Light
API	45	16.5	32	37
% S (wt)	0.2	3.5	1.4	0.1
Pour pt. (°C)	0	0	-25	-15
Fuel oil				
% S (wt)	0.9*	2.6	2.6	0.4
Metals (ppm)	20*	...	200	17

* Short residue

HUNGARY

MOL'S CRUDE OIL, GAS AND PRODUCT PIPELINES



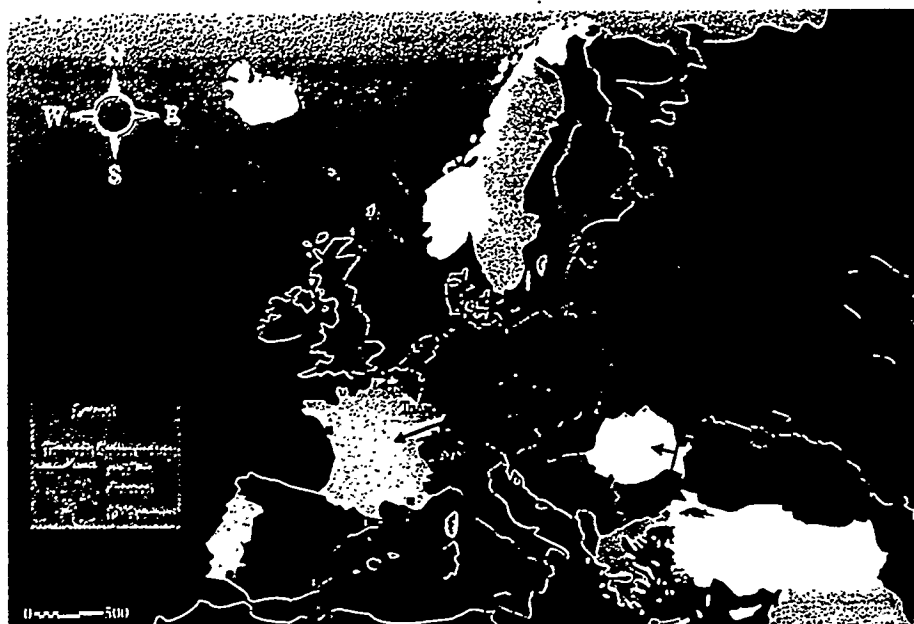


European crude oil pipeline network





European natural gas delivery systems



Environmental Economics: Perception and Reality in Conflict

Session B6

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Centre for Environmental Scholarship
Charles University
Prague, Czech Republic*

QUANTIFYING THE ECONOMIC VALUE OF ENVIRONMENTAL QUALITY

Jeff Sletten

Custom Coals Corporation
Pittsburgh, Pennsylvania, USA

Information not available at time of publication.

MAKING DIFFICULT ENVIRONMENTAL AND ECONOMIC CHOICES IN A MARKET ECONOMY

Josef Vavroušek, Chairman

Society of Sustainable Living
Prague, Czech Republic

Information not available at time of publication.

STREAM C

POSTERS

*Coal Conversion/
Coal Science*

Session C1

CO-PYROLYSIS OF COAL WITH ORGANIC SOLIDS

Pavel Straka, Scientific Worker
Jaroslav Buchtele, Head of the Department of Caustobioliths

Institute of Rock Structure and Mechanics
Academy of Sciences of the Czech Republic
Prague, Czech Republic

ABSTRACT

The co-pyrolysis of high volatile A bituminous coal with solid organic materials (proteins, cellulose, polyisoprene, polystyrene, polyethylene-glycolterephthalate-PEGT) at a high temperature conditions was investigated. Aim of the work was to evaluate, firstly, the changes of the texture and of the porous system of solid phase after high temperature treatment in presence of different types of macromolecular solids, secondly, properties and composition of the tar and gas.

Considered organic solids are important waste components. During their co-pyrolysis the high volatile bituminous coal acts as a hydrogen donor in the temperature rank 220-480°C. In the rank 500-1000°C the solid phase is formed. The co-pyrolysis was carried out at heating rate 3 K/min. It was found that an amount of organic solid (5-10%) affects important changes in the optical texture forms of solid phase, in the pore distribution and in the internal surface area. Transport large pores volume decreases in presence of PEGT, polystyrene and cellulose and increases in presence of proteins and polyisoprene. (Image analysis measurements show that the tendency of coal to create coarse pores during co-pyrolysis is very strong and increases with increasing amount of organic solid in blend). An addition of considered materials changes the sorption ability (methylene blue test, iodine adsorption test), moreover, the reactivity of the solid phase.

The gases and tars obtained were analyzed and their composition and physical properties were determined and discussed.

INTRODUCTION

Both industrial and household wastes contain considerable amounts of solid organic substances. Organic wastes of biological origin may be efficiently processed into fodder pastes or composted. However, the organic wastes from the industry of plastics, leather, the production of tires, the processing of wood, etc., must be utilized in other ways, among which pyrolysis is of a great importance. Pyrolysis of plastic wastes, wood and biomass provides unstable unsaturated oils of low utility value which, however, may be further processed and applied, and phenol for the production of phenol formaldehyde resins /1/. By pyrolysis of the combustible organic fraction of wastes by the PKA, (Pyrolyse-Kraftanlagen GmbH Aalen, FRG), procedure /2/ at 550°C a solid pyrolytic residue and pyrolytic gas are obtained; both products are utilized further. Pyrolytic installations exhibit lower investment costs than incineration installations and they give satisfactory yields of useful products such as oils, phenols, pyrolytic gas or electric energy.

The utility value of the products of pyrolysis of solid organic wastes may be further increased by conversion in the presence of coal, by co-pyrolysis where coal acts as a hydrogen donor and the solid organic wastes as a hydrogen acceptor. The marginal bituminous coals with a high content in volatile (combustible), matter act as a hydrogen donor /3,4/ and may represent an interesting and inexpensive hydrogenation agent for suitable solid organic wastes.

Typical solid organic wastes are plastics, cellulose, proteins and polyisoprene. Co-pyrolysis was therefore aimed at wastes corresponding to the character of these substances.

In the case in question co-pyrolysis of marginal bituminous coal with organic wastes was framed as a high-temperature procedure. The main product is coke with low ash content. Side products are tar and pyrolytic gas exhibiting a high value of combustion heat.

The aim of this paper is to evaluate the products of high-temperature co-pyrolysis of solid organic wastes with marginal coal with a high content in volatile (combustible) matter with the following organic wastes: polyethylene glycol terephthalate, polystyrene, wood sawdust, leather and rubber and from the parameters determined to evaluate the suitability of the suggested method for the conversion of the wastes in question.

EXPERIMENTAL

Samples with the mass of 0.5 kg, where 90% of grains were of a size below 3mm, containing a mixture of bituminous coal and solid organic waste (5-10%) were co-pyrolyzed in a quartz reactor in a vertical tube furnace with electric heating. The mixture was warmed up with the heating rate of 3K/min from the room temperature to the final temperature of 1020°C, with a dwell of 60 minutes at the final temperature. The volatile products of pyrolysis were transferred from the reactor into coolers cooled to the temperature of -30°C with a mixture of ethanol and solid carbon dioxide. Tar and water, separated from the stream of raw gas, were trapped in a receiving flask. The pyrolytic gas obtained was collected in a gasometer with the volume of 200 dm³. Water was separated from the tar by esotropic distillation with n-hexane. The water formed by pyrolysis was determined from the difference of the total water determined and the water originally present in the sample. The composition of the pyrolytic gas accumulated in the gasometer was determined by chromatographic methods. From the composition of the gas the combustion heat, the density and the relative density were calculated.

For the experiments gas bituminous coal from the mining district of Ostrava-Karviná was used with the content of volatile matter $V^{daf} = 30.3\%$, swelling index = 3 and total dilation = 0. The coal used contained 86.8% C^{daf} , 5.0% H^{daf} , 1.3% N^{daf} , 0.4% S^{daf} , and 6.5% O^{daf} .

The co-pyrolyzed samples contained 1.3 - 2.3% of moisture, 7.0 - 11.1% of ash matter and 0.4% of total sulphur. The following organic wastes were subjected to co-pyrolysis: polyethylene glycol terephthalate waste granulate, crushed polystyrene waste, wood sawdust, waste natural leather and rubber from the production of tires.

RESULTS AND DISCUSSION

Primarily the yields of the products (the mass of the co-pyrolyzed sample = 100 mass %), were determined. By co-pyrolysis 69.7 - 72.8% of coke, 6.6 - 8.0% of pyrolytic (reaction) water were obtained. The losses amounted to 2.7 - 3.5%. Co-pyrolysis thus resulted in acceptable yields of both the main and the side products with quite low mass losses. It is probably that similar yields would be obtained also with pyrolysis performed on a larger scale.

Above all the utility properties of the obtained cokes, tars and gaseous mixtures were evaluated. The samples of coke contained 10.3% of ash and 0.4 - 0.5% of total sulphur with moisture content of 0.6 - 1.0%. It was found that the addition of solid organic waste may markedly affect the porosity of the coke obtained. For example, when coke from the used coal alone had the porosity of 43.8%, then the presence of 5% of polyethylene glycol terephthalate in the charge caused the decrease in the porosity of the coke obtained to 38.6% and the presence of 10% of polyethylene glycol terephthalate led to a further decrease to 34.9%. On the other hand, the presence of 10% of wood sawdust in the charge caused an increase in the porosity of the coke to 53.0%. With regard to the data given in the communication /5/ we may say that the presence of solid organic wastes in the charge influences especially the apparent density of the coke, further on the true density of the coke, the distribution of pores and thus also the porosity. This fact is important for the possibility of using the coke from co-pyrolysis as a smokeless fuel, as the porosity affects significantly the reactivity of coke.

In the optical texture of cokes formed by co-pyrolysis, changes in comparison with the texture of coke from the applied coal alone were observed. The presence of 5% of polyethylene-glycol terephthalate or sawdust or polystyrene in the charge caused practically no changes in the texture of the coke, but the presence of 5% of leather caused a high relative ratio of all types anisotropy at the costs of the isotropic texture component and the presence of 5% of rubber in the charge resulted in an important increase in fine grained mosaic up to medium grained mosaic anisotropy at the costs of the isotropic component. With the component of 10% of ethylene glycol terephthalate already three anisotropic phases were observed: the prevailing fine grained mosaic component, with pores, the less abundant medium grained mosaic up to coarse grained mosaic component and the scarcely abundant domain up to layer component, strongly porous. A pronounced anisotropy was observed also with coke samples from the charge with 10% of sawdust. These observations are of importance when also applications of the coke from co-pyrolysis other than as a smokeless fuel are considered, e.g., as a sorbent. The sorption capacity of coke is influenced not only by the inner surface and the distribution of pores but it may also be affected by the character of the texture of the pore walls.

The sorption capacity of the cokes from co-pyrolysis was evaluated and compared by tests with methylene blue and iodometrically by the iodine adsorption number. The results are presented in Table 1.

TABLE 1

Sorption capacity of the cokes obtained by co-pyrolysis of bituminous coal with solid organic wastes. MB means the quantity of methylene blue (in mg) sorbed by 1 g of coke. I (the iodine adsorption number) means the quantity of iodine (in mg) sorbed by 1 g of coke.

Coke from the charge	MB (mg/g)	I (mg/g)
coal + 10% of polyethylene glycol terephthalate	2.58	43.05
coal + 10% of wood sawdust	2.78	62.57
coal + 5% of leather	2.22	35.65
coal + 5% of polystyrene	2.80	56.25
coal + 5% of rubber	2.57	41.18
coal without organic wastes	1.90	44.95

From the results presented in Table 1, it follows that the sorption capacity of cokes from co-pyrolysis is low and for the application for purification, e.g., treatment of waste water, an activation of the cokes would be necessary.

With a significantly higher content in the solid organic wastes in the charge, e.g., 40- 50%, the obtained solid pyrolytic residue may be probably activated by abrupt cooling in water after termination of the carbonization, similarly as it is the case in the PKA procedure /2/.

The pyrolytic gas obtained by high-temperature co-pyrolysis with the solid organic wastes given above had a combustion heat of 21 - 22 MJ/m³. This value represents a high usable energy. The gas may be used partly in the heating of the co-pyrolytic units and partly, after purification, in the production of electric energy by combustion in a gas engine coupled with a generator of electric energy.

With the tars from the co-pyrolysis their ash content, density, combustion heat and heating value were determined. The results are summarized in Table 2.

TABLE 2

The parameters of tars obtained by co-pyrolysis of solid organic wastes with coals. A^d - ash content, d - density, Q_s^d - combustion heat, Q_i^d - heating value.

Tar from the charge	A^d (%)	d (g/cm ³)	Q_s^d (MJ/kg)	Q_i^d (MJ/kg)
coal + 10% of PEGT	0.17	1.07	34.72	33.14
coal + 10% sawdust	0.25	1.02	38.42	36.48
coal + 5% of leather	0.14	0.96	38.58	36.55
coal + 5% of polystyrene	0.09	0.99	39.83	37.93
coal + 5% of rubber	0.11	0.97	40.18	38.19

From the values presented in Table 2, it is clear that the tars from co-pyrolysis or their mixtures may be used as a substitute for deficient heating oils. For this application speaks also the favorable yield of tar and raw benzol, i.e., 7 - 8%. Of course, the composition of the tar will change considerably with the character of the solid organic waste in the charge, e.g., 40- 50%, the composition of the resulting tar may be purposely changed by adding a certain organic waste. On the other hand, we must take into account the decrease in the values of the combustion heat and the heating value of the tar with the increasing content in organic waste in the charge. For example, with the increase in the content of polyethylene glycol terephthalate in the charge from 5 to 10%, the value of combustion heat decreased from 36.94 to 34.72 MJ/kg and the heating value from 35.24 to 33.14 MJ/kg.

The yields and parameters of the products of co-pyrolysis of solid organic waste with coal show that this solution is a suitable variant of the processing of wastes by thermochemical conversion. (A review of the processes of wastes by thermochemical conversion of solid organic wastes aimed at pyrolysis, liquefaction at increased pressure and refinement of the oils obtained, including the technical-economic data, is given in the paper /6/). It represents a more suitable method of conversion of wastes than incineration as it results in the products of high utility values - a smokeless fuel or sorbent, a substitute for heating oil and agas rich in energy, or, as the case may be, in electric energy. Pyrolytic installations exhibit lower investment costs than incineration installations which always represent solutions of the disposal of organic waste which are exacting from the point of view of both investment and operation, with a costly maintenance and short renovation cycles.

CONCLUSION

The high-temperature co-pyrolysis of solid organic wastes with marginal bituminous coal with a high content in volatile (combustible) matter, performed at a low heating rate (3 K/min), represents a suitable variant of the treatment of solid organic wastes. The yields of the products - heating coke (smokeless fuel), sorbent, liquid hydrocarbons mixture (heating oil) and pyrolytic gas (production of electric energy) are satisfactory - the same is valid for the utility properties of the products. Besides that, it is necessary to investigate also the co-pyrolysis of mixtures with a high content in organic wastes as well as the co-pyrolysis with brown coal.

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ROSEBUD SYNCOAL PARTNERSHIP SYNCOAL® DEMONSTRATION- TECHNOLOGY DEVELOPMENT UPDATE

Ray W. Sheldon

Rosebud SynCoal Company
Billings, Montana, USA

Steven J. Heintz

U.S. Department of Energy
Pittsburgh Energy Technology Center
Pittsburgh, Pennsylvania, USA

Presented by:
Thomas Niquette

Horizon Coal Services, Inc.
Butte, Montana, USA

INTRODUCTION

Rosebud SynCoal® Partnership's Advanced Coal Conversion Process (ACCP) is an advanced thermal coal upgrading process coupled with physical cleaning techniques to upgrade highmoisture, low-rank coals to produce a high-quality, low-sulfur fuel.

The coal is processed through two vibrating fluidized bed reactors where oxygen functional groups are destroyed removing chemically bound water, carboxyl and carbonyl groups, and volatile sulfur compounds. After thermal upgrading, the SynCoal® is cleaned using a deep-bed stratifier process to effectively separate the pyrite rich ash.

The SynCoal® process enhances low-rank western coals with moisture contents ranging from 25-55%, sulfur contents between 0.5 and 1.5 %, and heating values between 5,500 and 9,000 Btu/lb. The upgraded stable coal product has moisture contents as low as 1 %, sulfur contents as low as 0.3%, and heating values up to 12,000 Btu/lb.

Construction of the 300,000 ton per year (tpy) demonstration project adjacent to Western Energy Company's Rosebud mine unit train loadout facility near the town of Colstrip in southeastern Montana was completed in 1992. An extended startup and shakedown period lasted until August 1993. The facility has produced nearly at-design capacity since January 1994. Rosebud SynCoal's demonstration plant is sized at about one-tenth the projected throughput of a multiple processing train commercial facility. The next generation of facilities are expected to become standardized 100 TPH process trains.

Demonstration operations and testing began in April 1992 and are continuing. Initial operations discovered the normal variety of equipment problems which delayed operational and process testing. As operational testing has proceeded, the product quality issues that have emerged are dustiness and stability. The SynCoal® product has met the BTU, moisture and sulfur specifications. The project team is continuing process testing and is working toward resolution of the operational and process issues in response to market requirements.

The ACCP Demonstration Facility is a U. S. Department of Energy (DOE) Clean Coal Technology Program Project with 50% funding from the DOE and 50% from the Rosebud SynCoal Partnership through the end of the original \$69 million project. DOE and Rosebud recently agreed to extend the

project until November 1997 with total funding increasing to \$105.7 million and DOE's contribution increased to a total of \$43.125 million.

The Rosebud SynCoal Partnership is a venture involving Western SynCoal Company and Scoria Inc.. Western SynCoal is a subsidiary of Western Energy Company (WECO) which is a subsidiary of Entech Inc., Montana Power Company's non-utility group. Scoria Inc is a subsidiary of NRG Energy Inc., Northern States Power's non-utility group.

STATUS OF DEVELOPMENT

Much of the early ACCP development was performed using a small, 150 pound per hour pilot plant located at the Mineral Research Center, south of Butte, Montana. Up to 100 ton lots were produced to assess shipping and handling stability as well as chemical characteristics. A variety of coals and process conditions were tested to determine the process capabilities.

Development is continuing as construction and startup has been completed and demonstration operation is continuing at the 300,000 ton per year demonstration plant at Western Energy's Rosebud Mine near Colstrip, Montana. The demonstration facility has operated nearly at full design capacity during 1994, reaching as much as 115 percent of design on an hourly basis for short periods of time. Rosebud SynCoal is developing facility designs and equipment concepts around 100 TPH process units that can be added in multiples to make facilities at virtually any production capacity desired. A listing of the most significant events in the history of the ACCP development is provided in Appendix A.

PROCESS DESIGN DESCRIPTION

In general, the ACCP is a low rank coal upgrading and conversion process using low pressure, superheated gases to process coal in vibrating fluidized beds. Two vibratory fluidized processing stages are used to heat and convert the coal followed by a water spray quench and a vibratory fluidized stage to cool the coal. The solid impurities are then removed from the dried coal using pneumatic separators. Other systems servicing and assisting the coal conversion system are:

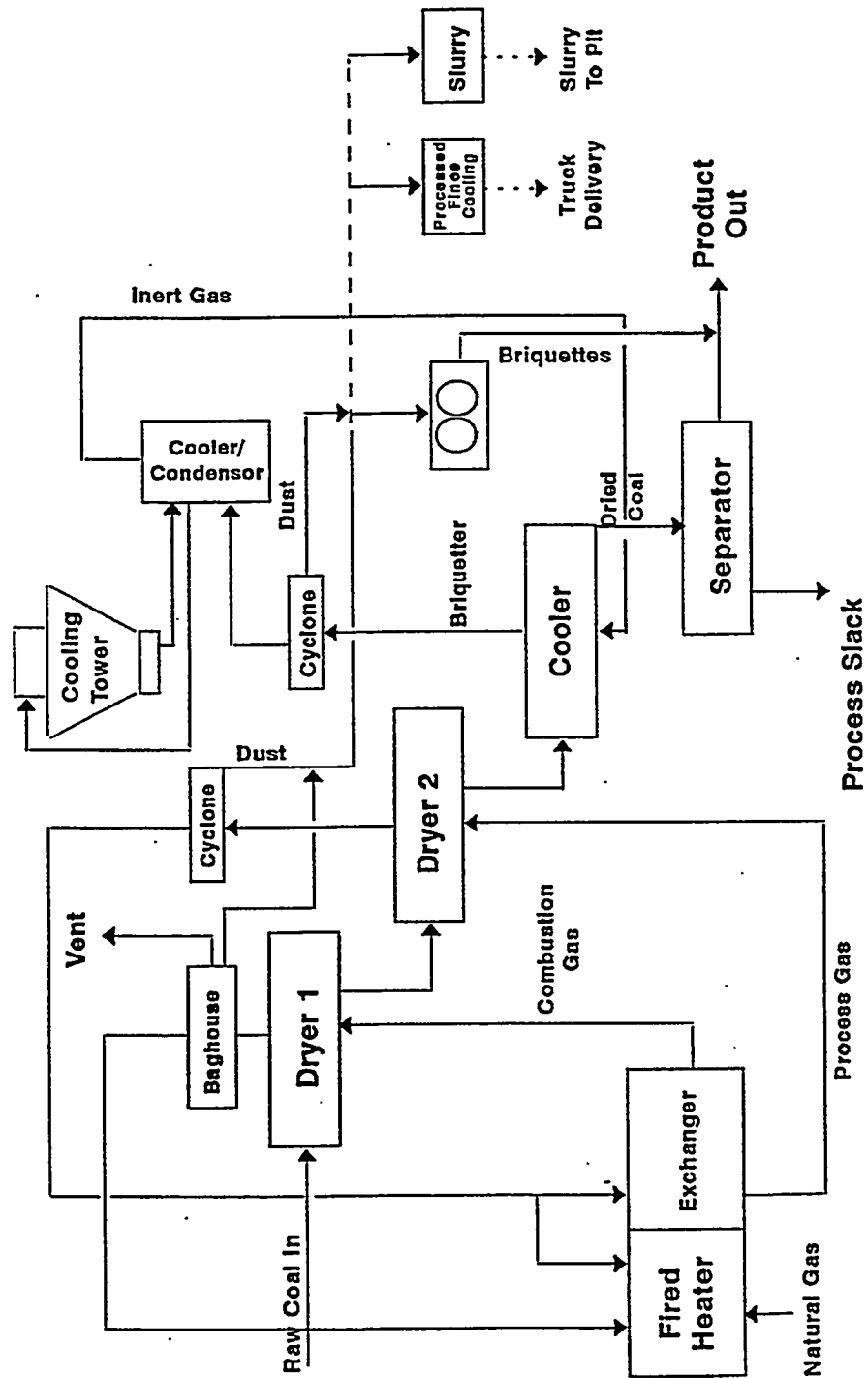
- Product Handling
- Raw Coal Handling
- Emission Control
- Heat Plant
- Heat Rejection
- Utility and Ancillary

The nominal throughput of the demonstration plant is 450,000 tpy (1,640 tpd) of raw coal, providing 242,000 tpy (886 tpd) of coarse SynCoal® product and 66,000 tpy (240 tpd) of SynCoals fines (minus 20 mesh). The fines are to be collected and sold, giving a combined product rate of 308,000 tpy (1,126 tpd) of high-quality, clean SynCoal® product. The central processes are depicted in Figure 1, the Process Flow Schematic.

Coal Conversion

The coal conversion is performed in two parallel processing trains. Each consists of two 5-feet wide by 30-feet long vibratory fluidized bed/reactors in series, followed by a water spray quench section and a 5-feet wide by 25-feet long vibratory cooler. Each processing train is fed 1,139 pounds per minute of sized coal.

Process Flow Diagram



In the first-stage dryer/reactors, the coal is heated using recirculated combustion gases, removing primarily surface water from the coal. The coal exits the first-stage dryer/reactors, at a temperature slightly above that required to evaporate water, and is gravity fed into the second-stage reactors. Here the coal is heated further using a superheated gas stream, removing water trapped in the pore structure of the coal, and promoting the thermal destruction of the oxygen functional groups, such as hydroxyls, carbonyls and carboxylate that are normally prevalent in lower rank coals. The superheated gases used in the second stage are actually produced from the coal. The make-gas from the second stage system is used as an additional fuel source in the process furnace, incinerating all the hydrocarbon gases produced in the process. The particle shrinkage that liberates ash minerals and imparts a unique cleaning characteristic to the SynCoal® also occurs in the second stage. As the coal exits the second-stage reactors, it falls through vertical quench coolers where process water is sprayed onto the coal to reduce the temperature. The water vaporized during this operation is drawn back into the second-stage exhaust gas. After quenching, the SynCoal® enters the vibratory coolers where the SynCoal is contacted by cool inert gas. The SynCoal® exits the cooler at less than 150 degrees Fahrenheit (F) and is conveyed to the pneumatic cleaning system. The cooler exit gas is cooled by direct contact with water prior to returning to the vibratory fluidized coolers.

Coal Cleaning

The SynCoal® entering the cleaning system is screened into four size fractions: plus 1/2 inch, 1/2 by 1/4 inch, 1/4 inch by 6 mesh, and minus 6 mesh. These streams are fed in parallel to four deep-bed stratifiers (stoners), where a rough specific gravity separation is made using fluidizing air and a vibratory conveying action. The light (lower specific gravity) streams from the stoners are sent to the product conveyor; the heavy streams from all but the minus 6 mesh stream are sent to gravity separators. The heavy fraction of the minus 6 mesh stream goes directly to the waste conveyor. The gravity separators, again using air and vibration to effect a separation, each split the coal into light and heavy fractions. The light stream is considered product; the heavy or waste stream is sent to a 300 ton storage bin to await transport to an off site user or alternately back to a mined out pit disposal site. The dry, cool, and clean product from coal cleaning enters the product handling system.

Product Handling

Product handling conveys the clean product coal to two 6,000 ton capacity concrete silos and allows unit train loading with the mine's tippie loadout system. SynCoal® fines are collected from the process baghouses and cyclones using screw and chain conveyors. The SynCoal® fines are conveyed to an indirect cooler that uses water cooled plates to reduce the temperature of this product to safe levels. The fines are then conveyed to a 250 ton truck loadout for sale.

Raw Coal Handling

Raw sub-bituminous coal from the existing Rosebud Mine A/B stockpile is screened to provide 1-3/4 x 3/8 inch feed for the ACCP process. Coal rejected by the screening operation is conveyed back to the active stockpile. Properly sized coal is conveyed to a 1,000 ton raw coal storage bin which feeds the process facility.

Emission Control

The fugitive dust from the coal cleaning system is controlled by placing hoods over the generation sources and conveying the dust laden air to fabric filter(s). The bag filters can remove 99.99 percent of the coal dust from the air before discharge. All fines report to a fines handling system than can briquette or cool the fines for product sales or make a slurry for disposal.

Sulfur dioxide emission control philosophy was based on injecting dry sorbent (sodium bicarbonate) into the ductwork to minimize the release of sulfur dioxide to the atmosphere. Testing has shown very low SO₂ emissions occur inherently from the process, less than one-fifth the level expected with the emission control; therefore, the dry sorbent injection is not being used.

Heat Plant

The heat required to process the coal is provided by a natural gas fired process furnace. This system is sized to provide a heat release rate of 58 MM BTU/hr. Process gas enters the furnace and is heated by radiation and convection from the burning fuel. Process make gas from coal conversion is used as fuel in the furnace. A commercial scale plant would most likely use a coal fired process furnace due to the much lower energy cost of coal.

Heat Rejection

Heat rejection from the ACCP is accomplished mainly by releasing water and flue gas to the atmosphere through the exhaust stack. The stack design allows for vapor release at an elevation great enough that, when coupled with the vertical velocity resulting from a forced draft fan, maximize the dissipation of the gases. Heat removed from the coal in the coolers is rejected using an atmospheric induced-draft cooling tower.

Utility and Ancillary Systems

The coal fines that are collected in the conversion, cleaning and material handling systems are gathered and conveyed to a surge bin. The coal fines are then briquetted and returned to the product stream.

The common facilities include a plant and instrument air system, a fire protection system, and a fuel gas supply and distribution system.

The power distribution system includes a 15 KV service, a 15 KV/5 KV transformer, a 5 KV motor control center, two 5 KV/480 V transformers, two 480 V load distribution centers, and six 480 V motor control centers. An uninterruptible power supply (UPS) was added to provide minimal power for control and emergency functions in the event of power interruptions.

Control of the process is fully automated including dual control stations, dual programmable logic controllers, distributed plant control, and data acquisition hardware.

PRODUCT CHEMISTRY

Rosebud SynCoal's Advanced Coal Conversion Process yields a synthetic solid fuel that represents an evolutionary step in the coalification process. Western U.S. lignite and subbituminous coals are converted by the thermal environment of the ACCP to a higher rank fuel.

The ACCP changes the chemical composition and structure of the coal feedstock. The changes include:

- Increased higher heating value;
- Increased aromaticity;
- Increase fixed carbon;
- Increased carbon to hydrogen ratios;
- Increased carbon + hydrogen to oxygen ratios;
- Decreased moisture content;
- Decreased sulfur content per million Btus;

- Decreased ash content per million Btus; and
- Decreased oxygen functional groups.

The above changes are the result of the thermo-chemical reactions induced by the ACCP and the enhanced ability to remove the pyritic and ash forming minerals resulting in the upgraded synthetic coal product.

The demonstration project has allowed the SynCoal organization to test North Dakota lignite and Wyoming sub-bituminous coals as well as the regular Rosebud sub-bituminous feedstock.

The average analyses of the coal feedstocks and upgraded products from the demonstration plant are shown in Table 1. The first section of the table shows standard proximate and ultimate coal analyses of the coal feedstock and the synthetic coal product. The second section of the table shows additional analyses showing the coal upgrading by the process.

Moisture is essentially eliminated from the coal during the ACCP. This moisture removal is due to thermal dehydration of the coal particle both physical and chemical, and the chemical condensation reactions which the feedstock experiences during its residence in the high temperature environment of the second-stage reactor bed.

The moisture-free analysis of the feedstock and the upgraded product also show that, to a large extent, both the volatile matter and the fixed carbon content is retained in the SynCoal product. This phenomenon is significant and desirable, because normally raw coal, when subjected to the temperatures of the ACCP, would undergo devolatilization and substantial gasification. The ACCP products are much more desirable fuels because of their extremely good ignitability and complete combustion causing many observers to comment that it "burns like natural gas" except the opaque flame provides more radiant heat providing an additional benefit to direct fired kiln operations.

The reduction in total sulfur is due primarily to the mechanical removal of pyrites during the cleaning step. However, the ability to remove these pyrites is a result of the chemical repolymerization and consequent shrinkage of the organic components of the coal, which causes fracture release of the ash or mineral components. A small amount of organic sulfur is volatilized from the coal in the form of hydrogen sulfide (H_2S) during the upgrading process.

PROJECT STATUS

Construction of Rosebud SynCoal's ACCP Demonstration Facility was completed during the first quarter of 1992 at a total cost of approximately \$35 million. Initial equipment startup was conducted from December 1991 through March 1992. Initial operations discovered the normal variety of equipment problems. The project's startup and operations groups worked together to overcome the initial equipment problems and achieve an operating system. The fines handling equipment was undersized originally and required a significant modification to expand the capability of this system. This modification was completed in August 1993. The lack of fines handling capacity prevented the facility from achieving full production rate and limited operating hours due to frequent fines handling equipment failures. The new fines handling system has expected to allow full production and more reliable operations. Table 2 shows the improved operations since September 1993.

The SynCoal® product has displayed a tendency towards self heating that was not expected. The project's technical and operating team has conducted an extensive process testing program in order to determine the cause of the product's lack of stability. A number of approaches have been partially successful; however, to date, the demonstration product has not met the level of resistance to spontaneous combustion that was apparent in the earlier pilot plant work. This has reduced the storage life and as a result delayed the full-scale test burn program. An initial test burn program has been conducted at Montana Power's Corette station. A significant amount of handling and storage testing was conducted in preparation for the anticipated full-scale test burn program.

TABLE 1 - Syncoal Quality Comparisons - Raw Feedstocks vs. Products

	Rosebud Syncoal				Center Syncoal				Powder River Syncoal			
	Feedstock and Coal Product Analysis		Feedstock and Coal Product Analysis		Feedstock and Coal Product Analysis		Feedstock and Coal Product Analysis		Feedstock and Coal Product Analysis		Feedstock and Coal Product Analysis	
	Raw Coal Feedstock	Rosebud Syncoal	Rosebud Syncoal Fines		Raw Coal Feedstock	Center Syncoal	Center Syncoal Fines		Raw Coal Feedstock	Powder River Syncoal	Powder River Syncoal Fines	
Proximate Analysis												
% Moisture	25.24	2.21	5.59		36.17	7.35	10.26		28.11	4.51	6.22	
% Volatile Matter	29.16	36.98	35.32		27.13	39.39	36.33		31.78	41.4	39	
% Fixed Carbon	36.69	51.19	49.65		30.16	46.74	43.92		35.25	47.48	48.48	
% Ash	8.92	9.2	9.44		6.54	6.52	9.49		4.86	6.61	6.3	
% Sulfur	0.74	0.56	0.87		1.07	0.77	1.06		0.34	0.45	0.48	
BTU/lb	8634	11785	11194		7064	10799	9914		8727	11805	11339	
SO ₂ /MMBTU	1.71	0.95	1.55		3.03	1.43	2.14		0.78	0.76	0.85	
Ash/MMBTU	10.3	7.8	8.4		9.3	6.0	9.6		5.6	5.6	5.6	
Equilibrium Moisture	24.9	14.7	20.2		34.98	20.12	21.92		28.38	14.04	20.2	
Ultimate Analysis												
% Carbon	50.54	68.16	64.8		42.25	64.15	59.17		49.7	66.96	64.89	
% Hydrogen	3.33	4.7	4.37		2.62	4.11	3.74		3.69	4.93	4.56	
% Oxygen	10.47	13.52	13.83		10.76	16.22	15.35		12.52	15.39	16.48	
% Nitrogen	0.76	1.23	1.1		0.59	0.88	0.93		0.78	1.15	1.07	
C:H Ratio	15.18	14.50	14.83		16.13	15.61	15.82		13.47	13.58	14.23	
(C+H):C Ratio	5.15	5.39	5.00		4.17	4.21	4.10		4.26	4.67	4.21	
Petrographic Analysis												
% Huminite by volume	68.1	69.4	68.7		73.4	85.1	74.5		73.4	85.1	74.5	
% Liptinite by volume	7.8	6	4.4		4.2	4.4	5.2		4.2	4.4	5.2	

TABLE 2 - Syncoal Demonstration Operating Statistics

Month	Production Availability	Forced Outage Rate	Tons Processed	Capacity Factor	Shipments
Sept 1993	73%	18%	14,371	65%	3,545
Oct 1993	76%	11%	23,528	63%	12,753
Nov 1993	85%	14%	27,930	74%	14,349
Dec 1993	74%	9%	26,009	69%	16,951
Jan 1994	73%	17%	34,979	93%	18,754
Feb 1994	67%	25%	29,280	85%	7,369
March 1994	82%	13%	41,891	112%	24,351
April 1994	72%	26%	34,438	92%	15,022
May 1994	76%	17%	39,440	105%	26,355
June 1994	77%	23%	36,657	98%	18,772

A test program was initiated March 1, 1994 at the J.E. Corette power plant using a 50/50 blend of raw sub-bituminous and DSE Conditioned SynCoal®. Testing has continued into the summer with some variations in plant loads and blend ratios. The results are still being evaluated, but the immediate indications include significantly improved boiler cleanliness, efficiency and operations capacity while the SO₂ emissions decreased with no noticeable effect on NO_x. With the higher SynCoals® blends SO₂ emissions decrease by as much as 43 % and the plant could hold a 170 MWe load which is well above the normal 160 MWe load. The boiler efficiency increased from 84.9% to 85.7% with the 50/50 blend and to 86.2% with a 75/25 blend. The corresponding decreases in net unit heat rate were 130 Btu/kWh and 181 Btu/kWh respectively.

Additional testburning is anticipated later this year in a variety of facilities. The primary marketing focus this year has been expanding the industrial market applications of SynCoal®. This market niche is the most lucrative for SynCoal since it can take better advantage of the specific benefits of SynCoal®, adapts quickly and will pay for the additional benefits.

PROJECTIONS FOR THE FUTURE

The Rosebud Syncoal Partnership intends to commercialize the process by both preparing coal in their own plants and by licensing to other firms. The target markets are primarily the U.S. utilities, the industrial sector and Pacific Rim export market. Current projections suggest the utility market for this quality coal is approximately 60 million tons per year with potential industrial markets of 38 million tons per year. The Partnership is currently working on three potential semi commercial projects tentatively located in Wyoming, North Dakota and Montana. Each project represents significant enhancements toward the ultimate goal of a standardized process train and modular commercial design that will allow development of future facilities sized to match the needs of the specific markets anywhere from 500,000 to 5 million tons per year.

The Wyoming project is a stand alone mine mouth design. The North Dakota project is integrated into a mine mount power plant with the product sales offsite to regional markets. The Montana project is designed either as an integration into a power plant and fuel user or an expansion of the existing demonstration facility.

CONCLUSION

The ACCP is a relatively simple, low pressure, medium temperature coal upgrading and conversion process. The synthetic upgraded coal product exhibits the characteristics of reduced equilibrium moisture level, reduced sulfur content and increased heating value. The SynCoal product retains a majority of its volatile matter and demonstrates favorable combustion characteristics.

Although some difficulties have been encountered, SynCoal's technical and operating team are resolving the issues and SynCoal marketing is starting to expand rapidly. The ACCP Demonstration program is continuing with a complete team effort involving all three of the major participants. It is expected that the ACCP demonstration will continue to produce test results and technology development through the extended demonstration resulting from DOE's expanded funding and time schedule and the continued efforts of the Rosebud SynCoal Partnership.

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SynCoal® is a registered trademark of the Rosebud SynCoal Partnership.

APPENDIX A

ADVANCED COAL CONVERSION PROCESS SIGNIFICANT EVENTS

- | | |
|----------------|---|
| September 1981 | Western Energy contracts Mountain States Energy to review LRC upgrading concept called the Greene process. |
| November 1984 | Initial operation of a 150 lb/hr continuous pilot plant modeling the Greene drying process at Montana Tech's Mineral Research Center in Butte, Montana. |
| December 1984 | Initial patent application filed for the Greene process, December 1984. |
| January 1986 | Initiated process engineering for a demonstration-size Advanced Coal Conversion Process (ACCP) facility. |

October 1986	Completed six month continuous operating test at the pilot plant with over 3,000 operating hours producing approximately 200 tons of SynCoal@.
October 1986	Western Energy submitted a Clean Coal I proposal to DOE for the ACCP Demonstration Project in Colstrip, Montana, October 18, 1986.
November 1987	Internal Revenue Service issued a private letter ruling designating the ACCP product as a "qualified fuel" under Section 29 of the IRS code, November 6, 1987.
February 1988	First U.S. patent issued February 16, 1988, No. 4, 725,337.
May 1988	Western Energy submitted an updated proposal to DOE in response to the Clean Coal II solicitation. May 23, 1988.
December 1988	Western Energy was selected by DOE to negotiate a Cooperative Agreement under the Clean Coal I program.
March 1989	Second U.S. patent issued March 7, 1989, No. 4, 810,258.
September 1990	Signed Cooperative Agreement, after Congressional approval, September 13, 1990.
September 1990	Contracted project engineering with Stone & Webster Engineering Corporation. September 17, 1990.
December 1990	Formed Rosebud SynCoal Partnership, December 5, 1990.
December 1990	Started construction on the Colstrip site.
March 1991	Novated the Cooperative Agreement to the Rosebud SynCoal Partnership, March 25, 1991.
March 1991	Formal ground breaking ceremony in Colstrip, Montana March 28, 1991.
December 1991	Initiated commissioning of the ACCP Demonstration Facility.
April 1992	Completed construction of the ACCP Demonstration Facility and entered Phase III, Demonstration Operation.
June 1992	Formal dedication ceremony for the ACCP Demonstration Project in Colstrip, Montana, June 25, 1992.
July 1992	Identified a variety of mechanical and process issues June 1993 Initiated deliveries of SynCoal under a contract with industrial customer.
August 1993	State evaluated emissions, and the ACCP process is in compliance with air quality permit. ACCP Demonstration Facility went commercial on August 10, 1993, having resolved major mechanical issues.
October 1993	Tested North Dakota lignite as a potential process feedstock, achieving nearly 11,000 Btu/lb heating value and substantially reducing the sulfur content in the resultant period.
December 1993	Signed a Letter of Intent with Minnkota Power Cooperative to attempt development of a SynCoals facility at M.R. Young plant site near Center, ND.
May 1994	Tested Wyoming Powder River sub-bituminous coal as a potential process feedstock, achieving 11,800 Btu/lb heating value in the resultant product.

**WORLDWIDE COAL-RELATED ACTIVITIES OF THE
U.S. GEOLOGICAL SURVEY**

P.D. Warwick
E.A. Landis
S.B. Roberts
E.A. Johnson

U.S. Geological Survey
Reston, Virginia, USA

Presented by:

Hal Gluskoter

United States Geological Survey
Department of the Interior
Reston, Virginia, USA

Abstract and paper unavailable at time of publication.

THE EVALUATION OF PROPERTIES OF COAL MASS FROM THE VIEWPOINT OF ENVIRONMENT

Rudolf Foniok
Michal Lukeš

Research Mining Institute
Ostrava-Radvanice, Czech Republic

ABSTRACT

This paper deals with the evaluation of several various coal kinds from the Czech coalfields from the viewpoint of the development of thermal processes in coal mass due to their tendency towards self-ignition during storing.

In such a case that no self-ignition during storing occurs, gaseous products are liberated into air, the quantity and composition of which depend upon fuel type and its temperature as well. From the environmental viewpoint, substances washed from stored coal are of a certain interest, too. In accordance with this fact, the importance of measures against self-heating of stored coal mass and the importance of a detailed observation of coal quality are concluded.

The tables, which compare various coal kinds from the viewpoint of their behavior at self-ignition processes, are the integral part of this presented paper.

Our greatest attention is paid to both the quantity and composition of gases being liberated in dependence upon the temperature of coal mass, and at its crushing with regard to selected methods and means of milling circuits before and explosion. Oxygen sorption by means of coal mass is also observed, being of a great importance for self-inertization of closed tanks. All the above-mentioned processes are demonstrated in form of graphic plots.

Qualitative signs of coal mass are the basic means for its assessment from the viewpoint of emissions at burning/combustion, and the evaluation of explosive properties. A great attention is paid to explosion-proof means being produced in the Czech Republic. These means can be used for protection of milling circuits of power plants and heating plants or for safety systems of combustion chamber by means of insulation to secondary air main. Explosion-proof quici-acting valves, a special type of safety membrane and device for explosion suppression nip in the bud do represent the latest explosion-proof means.

At the very conclusion, the paper deals with a brief description of the main activities of Testing Authority and with its selected accredited industrial laboratories.

Paper unavailable at time of publication.

PROBLEMS WITH THE QUANTITATIVE SPECTROSCOPIC ANALYSIS OF OXYGEN RICH CZECH COALS

Helena Pavlíková
Vladimír Machovič
Jaroslav Černý

Institute of Chemical Technology
Prague, Czech Republic

Eva Šebestová

Institute of Rock Structure and Mechanics
Prague, Czech Republic

ABSTRACT

Solid state NMR and FTIR spectroscopies are two main methods used for the structural analysis of coals and their various products. Obtaining quantitative parameters from coals, such as aromaticity (f_a) by the above mentioned methods can be a rather difficult task. Coal samples of various rank were chosen for the quantitative NMR, FTIR and EPR analyses. The aromaticity was obtained by the FTIR, ^{13}C CP/MAS and SP/MAS NMR experiments. The content of radicals and saturation characteristics of coals were measured by EPR spectroscopy. The following problems have been discussed: 1. The relationship between the amount of free radicals (N_g) and f_a by NMR. 2. The f_a obtained by solid state NMR and FTIR spectroscopies. 3. The differences between the f_a measured by CP and SP/NMR experiments. 4. The relationship between the content of oxygen groups and the saturation responses of coals. The reliability of our results was checked by measuring the structural parameters of Argonne premium coals.

INTRODUCTION

Technological evaluation of coal is based on the use of parameters characterizing organic as well as inorganic part of the coal. The evaluation of the inorganic part is done with the use of moisture and ash content, eventually composition of ash and its melting point. Among the parameters which characterize the organic part of coal one can include volatile matter content, heating value and calorific value, elemental analysis, sulfur amount and its forms, petrographical analysis, etc. For technological assessment of coal behavior, namely coking properties, combustion reactivity, self-ignition properties are of interest.

The generally used characterization parameters do not usually give enough information especially about the structural characteristics of coals. Furthermore, their determination is usually time consuming. That is the main reason why some spectroscopic methods are very often used not only in laboratories, but also in the coal industry. Typical example can be the FTIR and DRIFT spectroscopy, which can be used for the automatic characterization of coal samples. DRIFTS can be used for an assessment of a number of coal properties, such as elemental analysis, volatile matter, ash, moisture, petrographic properties, grind ability, and coking properties (1).

Valuable structural data on coal can be obtained from NMR in solid phase. For many years, especially the ^{13}C CP/MAS NMR technique has been used for such purpose. Besides characterizing coal samples, valuable information can be obtained about the chemical changes of coal and coal products taking place during various technological processes (2 - 4). The solid ^{13}C NMR spectra can also be quantitatively evaluated and valuable structural parameter - the so called aromaticity (f_a) can be determined. The CP/MAS is relatively very rapid technique, but in case of measuring heterogeneous material such as coal one is dealing with problems concerning the quantitative obtaining and evaluation of the NMR spectra. The main reasons of these difficulties have been discussed in many papers, e.g. (5 -

9), and lately the technique SP/MAS has been recommended for the quantitative evaluation instead (5). However, the SP technique is rather time-consuming, and, in addition, the spectra are of lower sensitivity than the CP ones. Therefore, the determination of the validity of the aromaticity from the CP technique would be a valuable information.

For this work, naturally oxidized coals of various degree of coalification were chosen. The main reason for studying such coals were differences in aromaticities obtained by the CP and SP NMR techniques in our recent work (10). The coals are known to contain a relatively high amount of unpaired electrons in form of either organic free radicals or paramagnetic inorganic ions. The interaction between the ^{13}C nuclei and electrons may cause an increase in the width of the resonance signals, which it may even be shifted out from the ^{13}C spectral region. Thus, a high percentage of carbon atoms may not be seen in the NMR spectra. As the chosen coal samples contained a high amount of oxygen, the role of mainly inorganic radicals is to be expected (11). Therefore, the EPR method was used to determine the concentration and types of radicals in the oxidized coals. A correlation between the aromaticities obtained by NMR and the other spectroscopic techniques was made and discussed.

EXPERIMENTAL

Samples

Czech bituminous coals come from the locality of the Northern Moravia district and belong to the post-sedimentary oxidized coals characterized as oxihumolites or pseudoanthracites (12). The subbituminous coals are from the Northern Bohemian locality. The number of coals was completed by one peat sample. Some of the samples were recently characterized by Sýkorová et al. (13,14). The reliability of our results was checked by measuring the structural parameters of Argonne premium coals - Illinois 6 (BCILL6) and Beluah Zap (LBZ).

EPR spectroscopy

The EPR spectra were obtained at room temperature using an ERS-220 (AW DDR) spectrometer operating in the X-band (9.1 GHz) with a 100 kHz magnetic field modulation at 1 mW microwave power. The saturation behavior was examined by varying the microwave power from 0.1 to 20 mW. The concentration of radicals was computed by double integration of the first derivative of the absorption spectrum, and by comparing it to the internationally calibrated coal standard (15). A ruby crystal permanently placed in the resonator was used as a secondary spin concentration standard. The spectra were taken in an air atmosphere.

^{13}C CP/MAS and SP/MAS NMR

^{13}C CP/MAS NMR spectra were measured using a Bruker MSL 200 spectrometer operating at 50.32 MHz. The spectra were obtained with the following parameters: 1 ms contact time, sweep width of 29 kHz, 75 Hz line broadening, and 5 kHz spinning speed. The SP/MAS spectra were obtained with the puls delay of 100 s. The number of accumulations was from 900 to 3600. Aromaticity f_a was estimated as the ratio of the integrated area of aromatic carbons (approx. 90-165 ppm) to the integrated area of all carbons in the spectrum. The integrated intensities of the aromatic spinning sidebands were added to those of their parent peak, and the intensities of aliphatic spinning sidebands were added to the total intensity.

Drifts

The diffuse reflectance (DRIFT) spectra were measured on a Nicolet 740 Fourier-transform infrared spectrometer equipped with a TGS detector. Approximately 50 mg of samples in neat form were measured with a diffuse reflectance accessory (Spectra Tech). Each sample spectrum averaging 512 scans per sample required three minutes of total measuring time. All spectra were recorded at a resolution of 2 cm^{-1} . Spectral manipulation (blank, smoothing, baseline correction) was performed by using Omnic Nicolet software. The Jandel Scientific PeakFit curve-fitting software was used for curve resolution.

of the aliphatic and aromatic C-H stretching modes between 3100 - 2700 cm^{-1} and of carbonyl and skeletal vibrations between 1800-1500 cm^{-1} . Voigt profiles were used in the curve-fitting. The relative integrated peak intensities of the aromatic C=C (1600 cm^{-1}), aliphatic C-H (3000 - 2800 cm^{-1}) and carbonyl C=O (1700 cm^{-1}) were normalized to 100 %.

RESULTS AND DISCUSSION

The elemental and technical analysis data of the coals studied are given in Table 1. Bituminous coals with a high amount of oxygen (BCOX1-8) were chosen for our study. Two other bituminous coals (BC1, BC2) had the content of O_{daf} below 10%. The subbituminous coals SBC1 - 9 are from the Northern Bohemian locality. Three of them (SBCOX, SBC1 and SBC3) were previously studied as potential sources of humic acids, and a relatively high difference between the aromaticities from the CP and SP techniques was obtained for oxihumolite SBCOX (10). The peat sample was label as P.

TABLE 1

Elemental and technical analysis									
Sample	W ^a	A ^d	V ^{daf}	C ^{daf}	H ^{daf}	N ^{daf}	S ^{daf}	O ^{daf}	(H/C) _d
P	13.39	2.78	67.36	60.34	6.02	2.49	0.17	30.98	1.20
SBCOX	28.00	24.00	56.30	65.20	5.10	1.00	0.80	27.90	0.94
SBC1	27.00	13.00	54.30	73.00	5.80	1.10	1.10	19.00	0.95
SBC2	12.58	16.16	52.42	70.62	6.60	1.18	1.26	20.34	1.12
SBC3	20.00	21.00	56.50	69.50	5.90	1.10	1.20	22.30	1.02
SBC4	n.d.	4.13	50.32	72.46	5.62	1.03	0.45	20.44	0.93
SBC5	n.d.	15.65	49.75	67.92	5.37	1.29	1.37	24.05	0.95
SBC6	n.d.	8.59	48.23	71.65	5.55	1.19	0.97	20.64	0.93
SBC7	n.d.	3.37	47.91	72.14	5.37	0.95	0.67	20.87	0.89
SBC8	n.d.	18.99	49.07	69.90	5.46	1.31	1.09	22.24	0.94
SBC9	n.d.	5.65	48.26	70.71	5.30	1.05	0.30	22.64	0.90
LBZ ²	n.d.	10.00	n.d.	73.00	4.80	n.d.	0.80 ¹	20.00	0.79
BCILL6 ²	n.d.	15.00	n.d.	78.00	5.00	n.d.	4.80 ¹	14.00	0.77
BC1	1.20	10.39	n.d.	84.97	5.06	1.33	0.27	8.37	0.71
BCOX1	21.50	24.82	n.d.	70.83	2.72	2.43	0.25	23.77	0.46
BCOX2	27.43	28.10	n.d.	72.98	2.80	2.43	0.13	21.66	0.46
BCOX3	17.37	12.89	n.d.	74.90	2.60	1.78	0.19	20.53	0.42
BCOX4	14.18	45.53	n.d.	66.78	3.86	1.84	0.10	27.42	0.69
BCOX5	15.17	41.52	n.d.	67.95	3.10	1.94	0.44	26.57	0.55
BCOX6	16.44	44.38	n.d.	65.86	3.14	2.47	0.56	27.97	0.57
BCOX7	15.02	15.80	n.d.	73.28	1.87	3.03	0.45	21.37	0.31
BCOX8	15.10	20.28	n.d.	71.68	2.07	4.28	0.52	21.45	0.35
BC2	7.12	11.51	n.d.	87.32	1.99	1.29	0.32	9.08	0.27

¹On dry basis (16), ²Data from (16), n.d. - not determined

The NMR data were measured on 200 MHz spectrometer. In the spectra from a spectrometer with higher external magnetic field one has to deal with spinning sidebands of relatively high intensity. Various techniques exist for the suppression of sidebands, some of them are described in paper (17). However, in numerous papers authors doubt the quantitative character of data from such an experiment (5,9). There is another possibility of avoiding spinning sidebands - application of magic-angle hopping (MAH) technique. It has, however, some disadvantages, e.g., poor sensitivity (5) which are especially not suitable for the SP measurements. Therefore, in this work experiments without the sidebands suppression were used.

The CP/MAS NMR experiments were performed on all samples studied, the SP/MAS NMR experiments then only on a selected number of samples, i.e., with higher and lower content of paramagnetic species. The aromaticities calculated from both techniques were correlated with the atomic H/C ratio (see Figure 1).

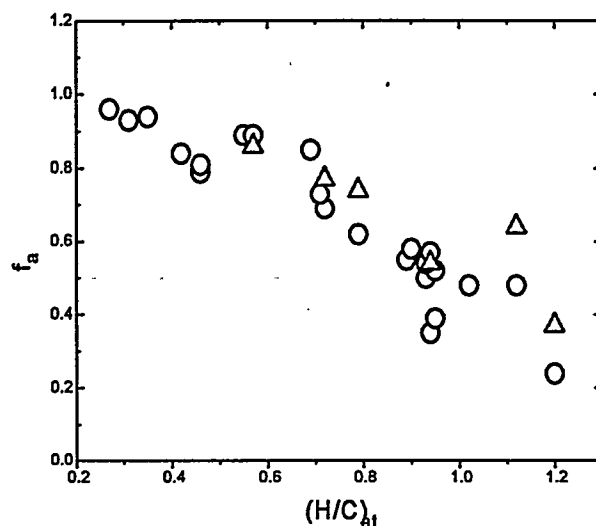


Figure 1. Plot of f_a from CP (circle) and SP/MAS NMR (triangle) vs. $(H/C)_{at}$

It seems that some relation between these two parameters exists even though the aromaticity values from both NMR techniques considerably differed in numerous cases. Similar correlation was found by Axelson (18) and Furimsky et al. (19), but, on the other hand, Yoshida et al. (20) found the plot of aromaticity versus atomic H/C ratio highly scattered. According to Derenne et al. (21), an increase in f_a is always observed when the H/C atomic ratio decreases, but this correlation should not be used as a mean of detection of the limit of the reliability of f_a . The correlation between the aromaticity and fixed carbon has been proposed instead (21). However, it can be seen from the Figure 2, that aromaticities measured by both CP and SP techniques fall into one approximately linear relationship. They did not create two independent plots, as could be expected for differences between them far from experimental errors.

As can be seen in Figure 2, an interesting dependence was obtained between the aromaticities obtained by the CP and SP techniques. From these results one could estimate, that a greater difference between the aromaticities from CP and SP could be obtained for lower rank coals. Similar suggestion can be found in Botto (11). However, to make any further deduction from the relation, much more SP measurements will have to be made.

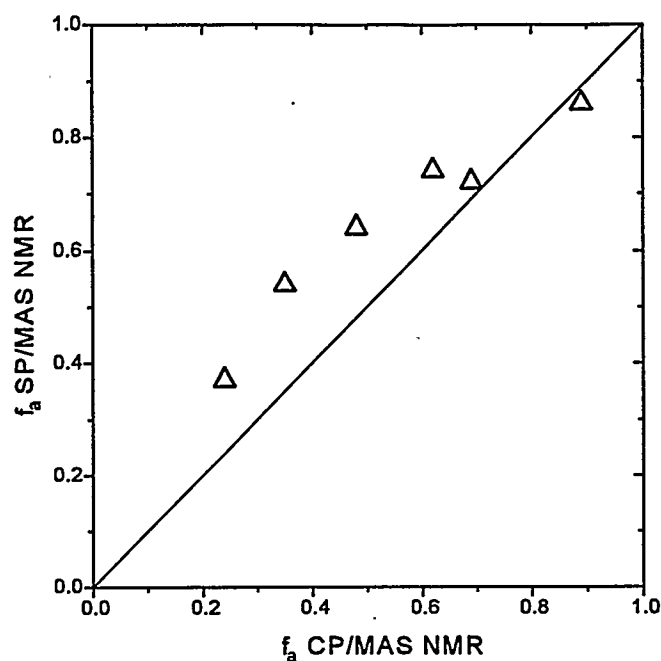


Figure 2. Plot of aromaticities from CP/MAS vs. SP/MAS NMR experiments be found in the work of Silbernagel.

Oxygen rich coals are expected to contain various amount of paramagnetic species, the higher rank coals in addition higher content of organic free radicals. Therefore, the EPR spectroscopy was applied. The dependence between the aromaticities of coal and peat samples and the amount of organic free radicals in Figure 3 is ambiguous. Usually, an increase in the aromaticity and the concentration of organic free radicals can be seen with increased coal rank. In the case of our extremely oxidized samples, the relation is not so pronounced, probably due to the consumption of radicals during natural oxidation process.

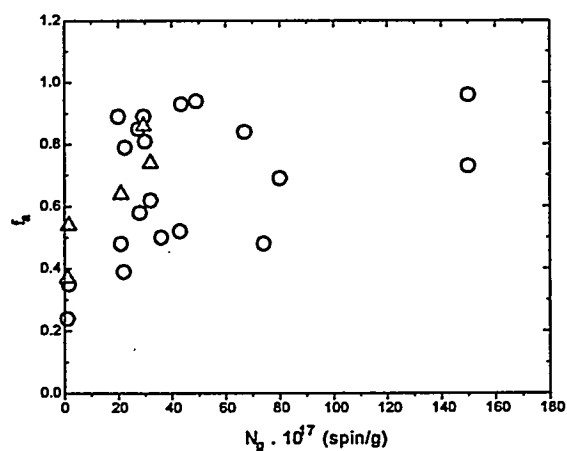


Figure 3. Relation between the CP (circle) and SP/MAS NMR (triangle) aromaticities and amount of free radicals N_g (EPR)

According to (5) a percentage of carbon atoms not observed in the NMR spectra can be estimated from the amount of unpaired electrons in the sample. The influence of organic free radicals in all our samples was small and not exceeding 10%, even in the case of high rank coal with the lowest content of oxygen (BC2) (see Table 2). According to EPR spectra, our coal samples contained at least two forms of paramagnetic inorganic ions (see Figure 4). The asymmetrical line centered at g factor of 4.2 is consistent with Fe^{3+} ions bound to functional groups in tetrahedral or octahedral sites with highly rhombi symmetry (22). Concentration of unpaired electrons arising from this absorption is comparable with free radical content (see Table 2). Broad absorption centered around $g = 2.4$ is consistent with pairs of Fe^{3+} ions in the coal (23). For our coals, it is hard to distinguish this latter signal from another broad signal centered at about $g = 2$. This broad signal consists of several superimposed lines arising from extended spin-spin couplings between various paramagnetic metal ions. The prevailing one is from spin coupling of neighboring high-spin Fe^{3+} ions (22). Only in the spectrum of Illinois No. 6 an isotropic pattern consisting of 6 lines can be seen (see Figure 4). The g factor of these signals is around 2 and is typical for Mn^{2+} ions (22). In some of our samples the amount of the unpaired electrons in this area of the EPR spectra is very high around 10^{20} (see Table 2). Such concentration of unpaired electrons is too high for application of Botto's equation (5) for the estimation of percentage of unobserved carbon in NMR spectroscopy. According to the literature (5), the paramagnetic inorganic ions have an influence on the aromaticities from both CP and SP/MAS measurements. We expected that paramagnetic ions might affect the results from CP in a greater deal than those from the SP. Furthermore, some regularity in differences between aromaticities obtained by CP and SP, resp. and the concentration of unpaired electrons were expected. However, due to a limited number of samples, the latter proposal cannot be confirmed. The differences in aromaticities from CP and SP experiments can also be affected by the differences in EPR

TABLE 2

Spectroscopic analysis									
Sample	f_a CP NMR	f_a SP NMR	N_g spin/g 10^{17}	$N_{Fe2.4}$ spin/g 10^{16}	$N_{Fe4.2}$ spin/g 10^{17}	C_{unobs} %	C_{HAl} DRIFT	C_{Car} DRIFT	C_{CO} DRIFT
P	0.24	0.37	1.1	410	32	0.05	34.25	18.03	47.72
SBCOX	0.35	0.54	1.6	220	21	0.08	18.13	34.95	46.96
SBC1	0.39	n.d.	22.0	70	10	1.10	28.30	21.59	50.11
SBC2	0.48	0.64	21.0	670	15	1.05	30.19	23.91	45.90
SBC3	0.48	n.d.	74.0	420	14	3.70	29.77	24.61	45.62
SBC4	0.50	n.d.	36.0	1	21	1.80	23.45	28.39	48.16
SBC5	0.52	n.d.	43.0	n.d.	n.d.	n.d.	29.25	26.14	44.61
SBC6	0.54	n.d.	n.d.	0	7	2.15	32.37	29.01	38.62
SBC7	0.55	n.d.	n.d.	n.d.	n.d.	n.d.	31.80	23.41	44.79
SBC8	0.57	n.d.	n.d.	n.d.	n.d.	n.d.	34.70	21.30	44.00
SBC9	0.58	n.d.	28.0	10	16	1.40	31.41	24.25	44.34
LBZ	0.62	0.74	32.0	780	5	1.60	18.51	36.29	45.20
BCILL6	0.69	0.72	80.0	430	3	4.00	40.79	38.80	20.42
BC1	0.73	n.d.	150.0	n.d.	n.d.	7.50	41.67	32.13	26.21
BCOX1	0.79	n.d.	22.5	n.d.	n.d.	1.13	3.99	48.79	47.22
BCOX2	0.81	n.d.	30.0	150	31	1.50	0.22	60.10	39.68
BCOX3	0.84	n.d.	67.0	n.d.	n.d.	3.35	4.45	51.06	44.49
BCOX4	0.85	n.d.	27.5	n.d.	n.d.	1.38	1.26	59.85	38.89
BCOX5	0.89	n.d.	29.5	n.d.	n.d.	1.48	1.90	57.90	40.19
BCOX6	0.89	0.86	20.0	310	33	1.00	0.43	60.09	39.47
BCOX7	0.93	n.d.	43.5	n.d.	n.d.	2.18	0.28	60.14	39.57
BCOX8	0.94	n.d.	49.0	n.d.	n.d.	2.45	n.d.	n.d.	n.d.
BC2	0.96	n.d.	150.0	n.d.	n.d.	7.50	18.36	53.76	27.88

n.d. - not determined

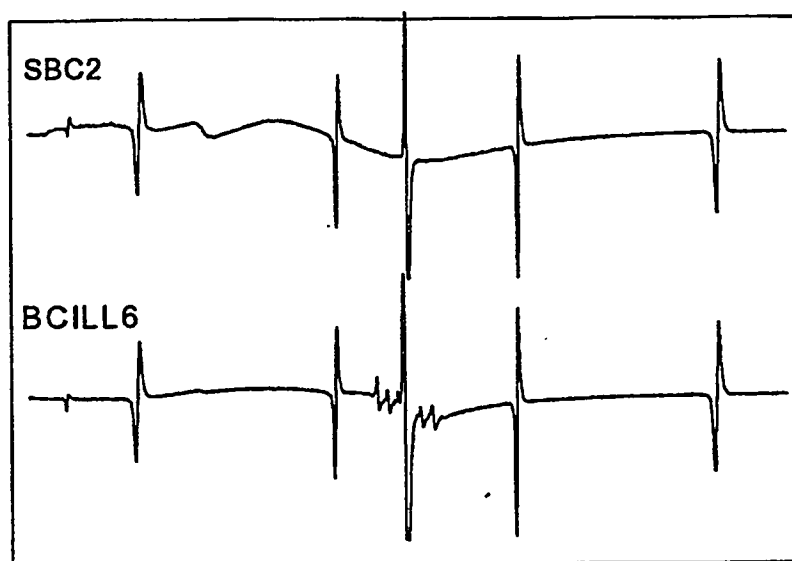


Figure 4. EPR spectra of SBC2 and BCILL6 taken at 20 mW microwave power
SW = 5000

saturation behavior of some our samples expressed by the microwave power $P_{1/2}$ - see Figure 5 (23). This problem will further be studied.

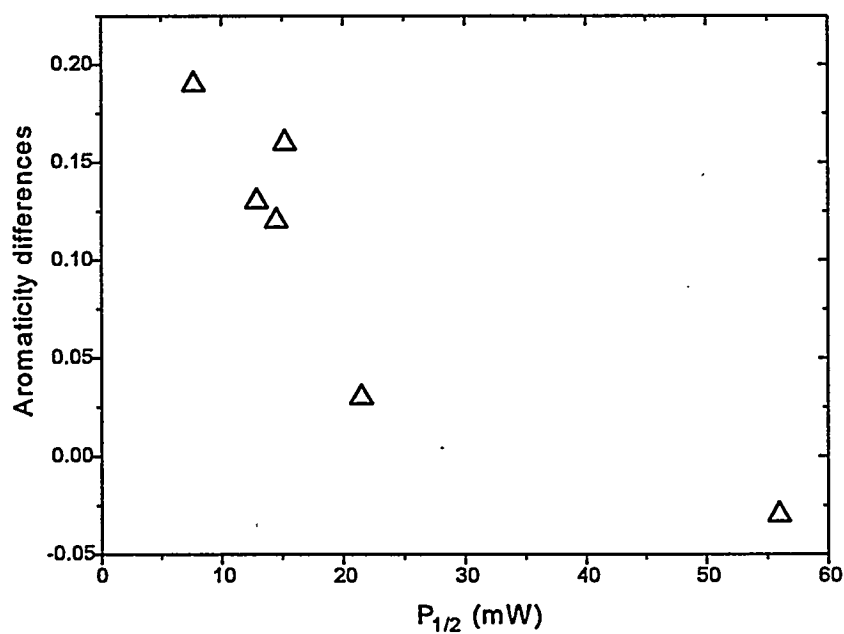


Figure 5. Relation between microwave power $P_{1/2}$ and differences between SP and CP/MAS NMR aromaticities

To check the reliability of our results, two Argonne coal samples were measured by both the CP and the SP techniques, and the aromaticities were compared with some data already published. As can be seen from the Table 3, an excellent agreement was found between the aromaticity values from various papers and our own for Illinois No. 6 coal sample. Noticeably larger differences can be seen for the CP aromaticity of Beluah Zap lignite. A possible explanation can be in the integration limits taken for the evaluation of the aromaticity. In our case, an attempt was made to differentiate carboxyl and carbonyl carbons from the aromatic sideband peak. This was a rather difficult task in case of Beluah Zap lignite as the content of oxygen bonded carbon is relatively high, and it was hard to make a line between the aromatic sideband and the mentioned carbon.

TABLE 3

Aromaticities from the CP/MAS, SP/MAS and 3p MAT NMR spectra of Illinois No 6 and Beluah Zap coal samples

Sample	CP	CP	CP	CP	CP	CP	SP	SP	SP	3p MAT
BCILL6	0.72	0.72	n.d.	0.72	0.70	0.72	0.75	0.76	0.74	0.72
				0.72	0.73		0.72	0.78		
				0.72			0.70			
				0.73						
LBZ	0.66	0.68	0.68	n.d.	n.d.	0.62	n.d.	n.d.	0.76	0.67
Lit	24	25	7	26	27	a	26	27	a	28

a - this paper

Diffuse reflectance spectroscopy provides useful information about the coal structure. For example a method has been developed for the determination of coal alteration degree of in situ oxidized and fresh coals from Ostrava-Karviná basin (12). For quantitative evaluation, three coalification indexes were determined from DRIFT spectra. The $C-H_{al}$ parameter was determined from bands areas between $3000 - 2800\text{ cm}^{-1}$. The $C=C_{ar}$ was calculated from the sum of the aromatic areas near 1600 cm^{-1} and the $C=O$ parameter was determined from the carbonyl and carboxyl contributions above 1620 cm^{-1} . From the $C-H_{al}$ indexes (see Table 2) a very low content of aliphatic C-H bonds can be seen for the temperature and oxidatively alternated coals BCOX1 - BCOX7. High values of $C=O$ index agree with high content of oxygen determined by elemental analysis (see Table 1). In Figure 6 a good relation between the aromaticity from NMR (both CP and SP techniques) and the amount of $C=C_{ar}$ bonds from DRIFTS is shown.

CONCLUSIONS

Solid state NMR, FTIR and EPR spectroscopies are useful methods for the structural analysis of coals and their various products. Obtaining quantitative parameters from coals by the above mentioned methods can be a rather difficult task. Some difficulties in the characterization of highly oxidized coals were discussed. The differences in aromaticities from CP and SP/MAS NMR experiments can be affected by the differences in EPR saturation behavior expressed by the microwave power $P_{1/2}$. The correlations between atomic H/C ratio, DRIFT aromaticity and NMRaromaticity were shown. The reliability of our results was checked by measuring the structural parameters of Argonne premium coals.

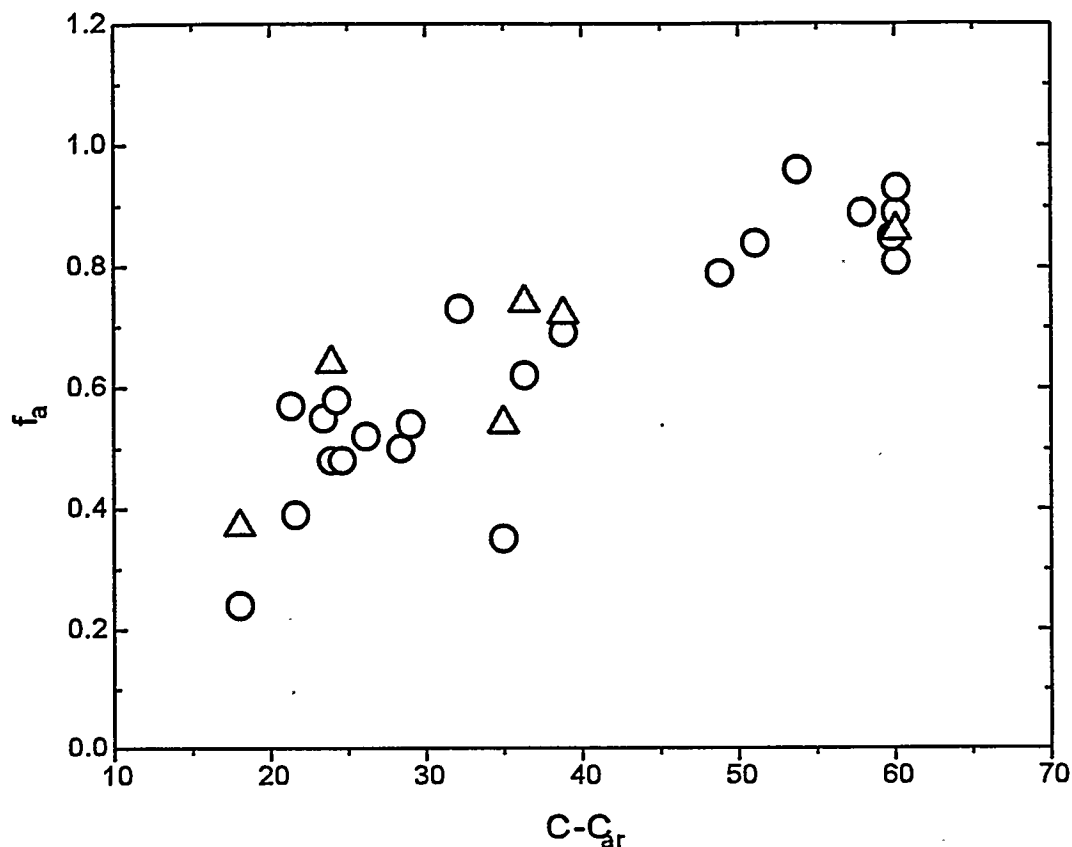


Figure 6. Relation between content of C-Car bonds (DRIFTS) and CP (circle) and SP/MAS NMR (triangle) aromaticities

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LIGNITE AIR-STEAM GASIFICATION IN THE FLUIDIZED BED OF IRON-CONTAINING SLAG CATALYSTS

Boris N. Kuznetsov
Maxim L. Shchipko
Yu Golovin

Institute of Chemistry of Natural Organic Materials
Siberian Division of Russian Academy of Sciences
Academgorodok, Krasnoyarsk, Russia

ABSTRACT

The influence of fluidized bed of iron-containing slag particles on air-steam gasification of powdered Kansk-Achinsk lignite in entrained flow was studied in pilot installation with productivity about 60 kg per hour. Slag of Martin process and boiler slag were used as catalytic active materials until their complete mechanical attrition. Two following methods of catalytic gasification of lignite were compared: the partial gasification in stationary fluidized bed of slag particles with degree of fuel conversion 40-70% and complete gasification in circulating bed of slag particles. In the first case only the most reactive part of fuel is gasified with the simultaneously formation of porous carbon residue with good sorption ability.

It was found the catalytic fluidized bed improves heat transfer from combustion to reduction zone of gas-generator and increases the rate of fuel conversion at the temperature range 900-1000°C. At these temperatures the degree of conversion is depended considerably on the duration time of fuel particles in the catalytic fluidized bed.

The influence of catalytic fluidized bed height and velocity of reaction mixture on the temperature profiles in the gas-generator was studied. The optimal relationship was found between the fluidized bed height and velocity of flow which makes possible to produce the gas with higher calorific value at maximum degree of fuel conversion.

INTRODUCTION

The gasification of solid fuels makes possible to decrease the negative influence of coal energetics on the environment. The technology of air-steam gasification of coal is remarkable for less capital investments and exploitation costs as compared to the others gasification processes [1,2]. Air-steam gasification technique was used for the elaboration of the combined energetic cycle with partial gasification of low-rank coal [3,4]. The apparatus with circulating bed are used for coal gasification and combustion in the above-mentioned energetic cycle.

The gas generator with circulating bed has vertical reactor where the lignite-gaseous reagents mixture moves upwards. The using of fluidized of bed makes possible to intensify the diffusion of reagents and to increase the heat transfer from the combustion to the reduction zone of gas generator. Some data were obtained for Kansk-Achinsk lignite combustion in apparatus with circulating fluidized bed [5] but there is no information about this lignite gasification at this conditions.

Among different methods suggested for increasing the effectiveness of coal gasification the catalytic gasification has considerable potentialities for elaboration of effective and environmentally friendly process of energy production from solid fossil fuels. But the catalyst application in coal gasification results to some additional technological problems connected with the proper catalyst preparation, its stability, re-using e.a. These shortcomings are absent when the process of coal gasification is carried out in fluidized bed of disposable catalyst particles.

In this paper some data of the study of Kansk-Achinsk lignite gasification by air-steam mixture in the reactor with conventional fluidized bed and with circulated fluidized bed of catalytically active slag particles are presented.

EXPERIMENTAL

The scheme of pilot installation for air-steam gasification of lignite is given on Fig.1. The gasification reactor was applied with vertical rectangular tube made from the stainless steel with the inner size 0.22 x 0.22 m and the height 4.2 m. In the lower part of reactor the air-distributive grating with the free cross section on 3% was placed. The technological steam with the temperature of 150°C and air were fed under the distributive grating. The powdered lignite-air mixture was injected above the distributing grate. Two regimes of lignite gasification process were studied. According to the one of them the dust from the gas generator was separated from gaseous products in the cyclone 16, collected in the collector 17 and periodically removed from the process. In the other regime the dust material from the collector 14 was recirculated into the combustion zone of the gas generator due to the gravity action.

The lignite from Irsha-Borodinsky pit with the following characteristics: total moisture content - 9.6%, ash content - 8.7%, volatile matter - 39.2%, carbon content - 57.8%, hydrogen content - 3.9%, nitrogen content - 0.8%, sulphur content - 0.25%, oxygen content - 19.0% was used. The particle sizes of powdered lignite were the same as those used in industrial energetic combustors: the residue on 0.2 mm sieve made up 34.1% and on 0.09 mm sieve - 66.0%.

The amount and composition of solid gaseous and liquid products of lignite gasification process were studied. Gases were analyzed using LHM-80 chromatograph with the thermal conductivity detector (temperature of 200°C) and argon as gas carrier. The analyses of gas mixture was performed on columns with molecular sieves CaX and polysorb-1. In the first case H_2 , O_2 , N_2 , CH_4 and CO were detected, in the latter - CO_2 and hydrocarbons. The amount of unreacted steam was evaluated by freezing out from gas sample.

The obtained data made possible to calculate material balances of experiments relative to carbon and hydrogen and to obtain the technical parameters of gasification process.

The catalytic activity of slag materials was measured in the reaction of CO oxidation by air. The reaction mixture of stoichiometric composition was used. Experimental data were obtained in quarts reactor with the inner diameter 0.015 m and the length of 0.15 m at temperature 400°C and volume velocity $2 \times 10^3 \text{ m}^3/\text{h}$. The catalyst loading was 10 cm^3 and catalyst particles sizes 0.5-3.0 mm. The concentration of carbon monoxide was measured before and after catalytic reactor using gas chromatography technique.

The mechanical strength and abrasive ability of catalyst samples were tested in rotatory drum with inner diameter 0.18 m and the length 0.17 m. The drum was loaded by 200 cm^3 catalyst and by 5 cylinders from steel (with diameter 0.012 m and length 0.024 m) and rotated 4 hours with the speed 1110 revolutions per hour. The sample firmness (F) was estimated as: $F = (W/W_i) \times 100\%$, where W - the weight of sample particles which keep on sieve 0.5 mm after experiment, W_i - the weight of initial sample.

The sample abrasive ability was estimated as: $A = [(W_i - W)/W_i] \times 100\%$, where W - the weight of 5 steel cylinders after experiment, W_i - their initial weight.

Some results of catalyst testing are shown in Fig.2. Open-hearth furnace slag was chosen as a catalyst for lignite gasification taking into account the high level of catalytic activity and its increased mechanical firmness.

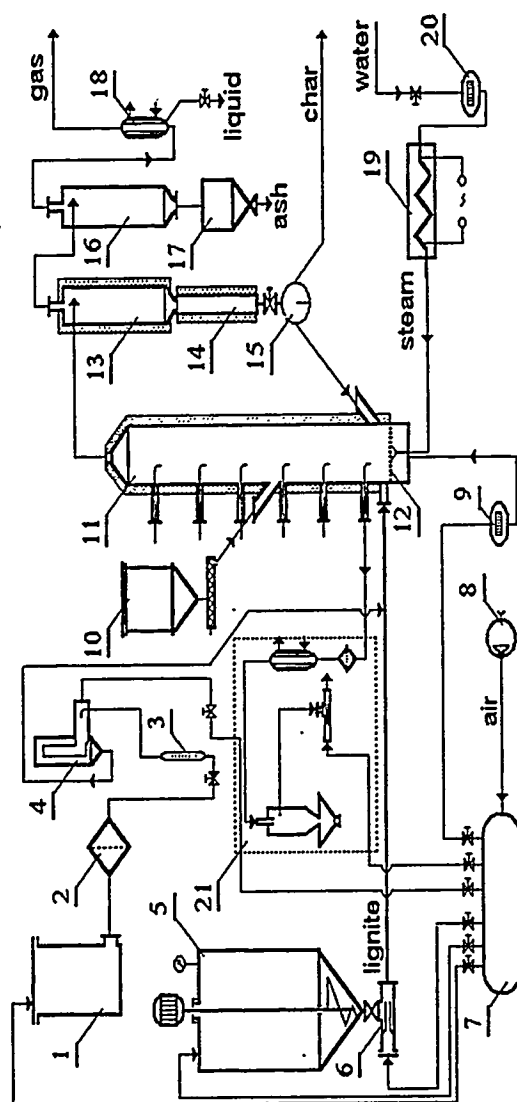


Figure 1. The scheme of pilot installation with fluidized bed

1 - mazut tank, 2 - filter, 3 - rotameter, 4 - smoke gases generator, 5 - bunker with powdered lignite, 6 - injector, 7 - reciver, 8 - compressor, 9 - gas counter, 10 - bunker for granular fuel, 11 - reactor with fluidized bed, 12 - air distributive grating, 13 - "hot" cyclone, 14 - capacity for unreacted particles of fuel, 15 - switch, 16 - secondary cyclone, 17 - ash collector, 18 - condenser, 19 - electric boiler, 20 - water counter, 21 - sampling device (dotted line): consist from cyclone, injector, condenser, filters and from set of sampling placed along the reactor height. A - solid carry-over removal from the unit at operation without recycling, B - direction of solid carry-out recycling. The open-hearth furnace slag particles of two fraction 0.8-1.2 mm and 0.10-0.25 mm was used as fluidized bed material. Slags major components are (%): SiO₂ - 19.4, CaO - 38.6, MgO - 14.3, MnO - 5.7, Fe - 6.7. This material is cheap, easily available, has high thermal and mechanical resistance. In addition several slag components are known as catalysts of some reactions (oxidation, methanization etc.) which can proceed during gasification process.

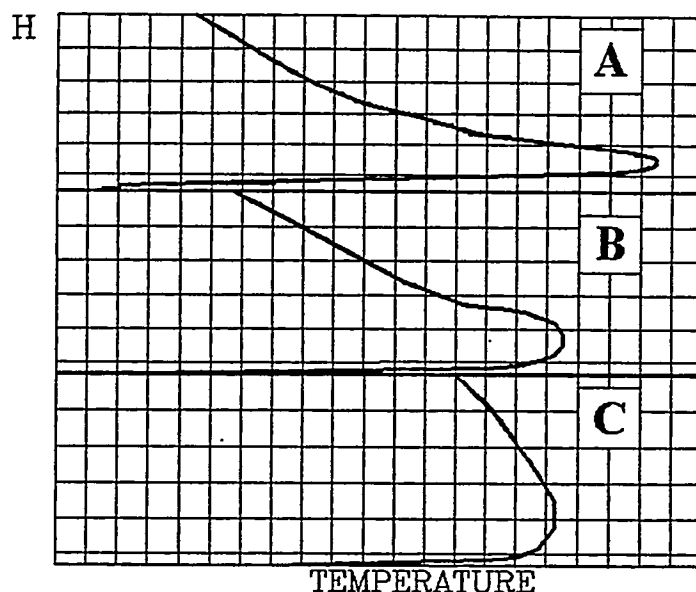


Figure 2. The distribution of temperature along the gas generator height during the process of powdered lignite gasification by air-steam mixture : in entrained flow (a), entrained flow and fluidized bed of slag particles (B), entrained flow and circulating bed of slag particles (C) conditions.

RESULTS AND DISCUSSION

Fig.3 shows observed for the distribution of temperature which different gasification processes. In the first case, the process was carried out in the entrained flow (without fluidization of the bed). After gas generator heating by the outside heating source, air, steam and coal were fed into reactor.. The velocity of initial reagents flow was 1.74 m/s and their initial concentrations were: O_2 - 16.6%, H_2O - 20.9%, lignite powder - 0.29 kg/kg (kg of lignite per kg of reaction mixture). In this set of experiments the formation of comparatively narrow front of flame was observed. The temperature about 1000°C was recorded inside the gas generator on the height of approximately 0.5 m above air-distributive grating. After the adding of 12 litres of open-hearth furnace slag particles (the fraction 0.8-1.2 mm) into the reactor the distribution of temperatures corresponded to that presented in Fig. 3B. The maximal temperature in gas generator was 930°C. The extension of this high temperature zone is increased along several times by the reactor height as compared to that observed in the absence at slag particles. The degree of lignite conversion was increased from 40 to 67% (relatively to carbon content) after slag particles addition into reactor.

As it has been already noted, the using of fluidized bed should promote the reagents mixing and intensify the heat transfer from combustion to the reduction zone of gas generator. The change in the temperature distribution along the height of the gas generator is confirmed this preposition. In the conventional entrained flow regime of lignite gasification (see experiment, presented in Fig.3A) fuel particles are moved straightfoward. But in the presence of larger slag particles (see Fig.3B) their tracks become winding. Due to this effect the residence time of fuel particles in the reaction zone is increased. The velocity of fuel particles transfer in the fluidized bed in the vertical direction was calculated according to the equation [6]:

$$U_v = 0.15 (U_e - U_{cv})^{0.15} \quad (1)$$

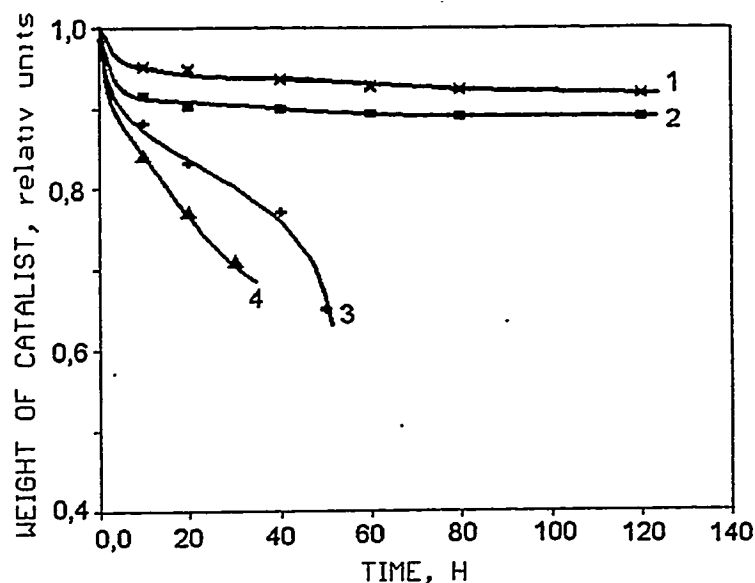


Figure 3. The decreasing of catalysts weight as a result of their attrition in fluidized bed. 1 - Al-Cu-Cr catalyst, 2 - open-hearth furnace slag, 3 - boiler slag from lignite combustion, 4 - chamotte.

were U_g - gas velocity in the fluidized bed of slag particles, U_{cv} is the critical velocity of fluidizing coal particles. The height of fluidized bed was determined by the equation $H = H_0(1 - E_0)/(1 - E)$. The values of the bed height in fixed state (H_0) and the bed porosity (E_0) were determined experimentally. The porosity of bed in the fluidized state (E) was calculated according to the usually accepted equations [6] and the fuel particles residence time in the bed $t_s = H/U_g$ was determined. The fuel particles residence time above the fluidized bed was accepted equal to the residence time of gaseous mixture.

The experimental measurement the residence time of lignite particles in the fluidized bed was conducted on cold reactor model with the dimensions which are identical to those of the gas generator. The experiment runs carried out in the interval of Reynolds numbers, corresponding to the lignite gasification process under investigation have confirmed satisfactory the accuracy of the equation (1).

The main reasons of the increasing of lignite conversion degree in the fluidized bed of slag particles are apparently connected: with the growth of fuel particles residence time in high temperature zone, with intensification of reagents mixing and with the promoting of heat exchange between combustion and reduction zones of gas generator. It is known the complete mixing of reagents is achieved at the fluidized bed height 50-100 mm above the powdered lignite injection point [6]. Therefore at the increasing the bed height from 400 to 700 mm (see experiments given in Table 1 and Fig.4) only the increase of fuel particles residence time and the intensification of heat exchange between combustion and reduction zones of gas generator should be taken into account as main reasons of the growth of the lignite conversion degree.

In the investigated range of gasification process parameters the degree of lignite conversion has good correlation with the time of fuel particles duration in the fluidized bed of slag particles. Since the gasification of char of Kansk-Achinsk lignite by air-steam mixture proceeded with detectable rate already at 400°C [7] one can expect that at the temperature about 900°C the gasification process is limited by diffusion. This conclusion is supported by the fact that the change of temperature from 890 up to 960°C has no strong influence on the degree of lignite conversion.

TABLE 1

Parameters of powdered lignite gasification by air-steam mixture
in fluidized bed of open-hearth slag particles.

Indices of parameters	Experiment No					
	1	2	3	4	5	6
Composition of initial reaction mixture:						
- lignite, kg/kg	0.21	0.26	0.27	0.27	0.32	0.32
- oxygen, %	14.6	19.7	16.7	18.3	16.7	19.7
- steam, %	30.4	5.9	20.3	12.8	20.5	6.0
Height of fluidized bed, m	0.45	0.68	0.47	0.70	0.58	0.40
Gaseous reagents velocity in empty reactor, m/c	1.76	2.78	1.67	2.75	1.56	2.53
Temperature (°C) at different height in the reactor, m						
- 0.2	870	970	950	920	870	890
- 0.6	860	1060	930	980	860	950
- 4.2	520	680	560	610	510	580
Stoichiometric ratio air/lignite	0.44	0.41	0.35	0.37	0.27	0.30
Calorific value of produced dry gas, MJ/m ³	2.30	3.06	2.46	3.28	2.49	3.35
Fuel conversion, %	59.0	57.5	67.0	55.2	47.3	48.1

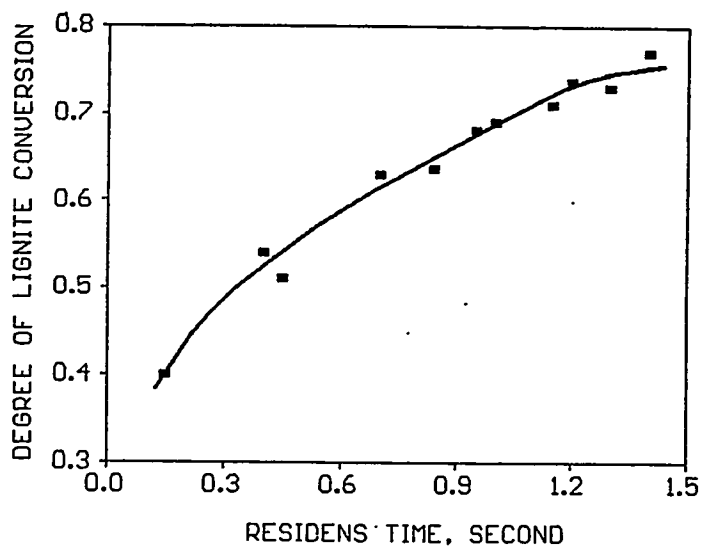


Figure 4. The degree of lignite conversion as a function of residence time of fuel particles in reactor zone of gas generator

There is the obvious correlation between the velocity of reagents flow through the gas generator and the calorific value of produced gas (see Table 1). Thus in the runs 1, 3, 5 the average velocity of reagents flow made up 1.66 m/s and the calorific value of reduced gas was equal to 2.42 MJ/m³. At the higher velocity (runs 2, 4, 6 in Table 1) calorific value of produced gas is increased up to 3.23 MJ/m³. There are two main sources of combustible gases formation: one of them is volatile compounds produced during the pyrolysis of lignite particles. The concentration of volatile compounds is rather high in the gas mixture because the content of volatile matter in lignite makes up 50% on dry ash-free matter. The other way of combustible gases formation is the char gasification by steam and carbon dioxide. These two ways of combustible gases production are accompanied by secondary reactions of initial gaseous compounds transformation (oxydation, metanation, CO-H₂O shift etc.). In all runs practically the complete amount of oxygen is consumed during gasification process and O₂ concentration in gases at the exit from the gas generator does not exceed 0.6%. The first way of gas formation is preferable for producing of combustible gases since the calorific value of pyrolysis gases is usually higher than that of gases produced by char gasification by air-steam mixture. One can expect that the amount of volatile compounds reacted with oxygen, will change with the variation of the velocity of reaction mixture flow. At higher velocities of gas flow the faster removal of volatile compounds from lignite particles takes place. This effect facilitates the oxygen diffusion to the fuel surface and accelerates the process of char oxidation. As a consequence the amount of oxygen reacted with pyrolysis gases is decreased and this results to formation of gas mixture with higher calorific value.

In order to achieve the more uniform distribution of temperature along the height of the gas generator the recirculation of open-hearth furnace slag particles was used as it is shown in Fig.3C. In this case the gas generator worked in fluidized bed regime. The velocity of slag particles circulation was calculated as the amount of solid material, passing the cross section of recycling line per second. The parameters of slag particles circulation were regulated by the change of the diameter of recycling pipeline. The major parameters of lignite gasification process in the gas generator with circulating bed of slag particles are presented in Table 2. One can expect that in experiments with circulated bad of slag particles the height of fluidized bed is equal to the whole height of the reactor (4.2 m). This assumption is indirectly confirmed by the data of temperature distribution along the reactor height. In the runs with fluidized bed without circulation of slag particles the temperature at the exit from the reactor is ussially on 250-300°C lower than that in the combustion zone of gas generator. This difference in temperatures was 3-4 times less for circulating bed reactor.

The increase of high-temperature zone extension results in the considerable growth of lignite conversion degree. It was found when the velocity of reaction reagents flow is increased by 2-3 times, the degree of lignite conversion growth approximately by 1.5 times. It is important to note that the different dependences between the velocity of gaseous reagents and the calorific value of produced gas were observed for conventional fluidized bed (see Table 1) and for circulating bed (see Table 2). In the latter case the critical value of gaseous reagents velocity apparently exists. The relationship between the calorific value of gases produced by lignite gasification in both series of runs and the velocity of gasifying agents flow (1/w) is illustrated by Fig.5. Judging from the present data the gas with the most high calorific value is obtained in the region of flow velocity 0.3-0.4 l/w (2.5-3.3 m/c).

CONCLUSION

The process of powdered lignite gasification in entrained upstream flow reactor proceeds in highly non-isothermal conditions. This results to unefficient utilization of fuel in the upper reactor part, were the temperature is comparatively low. The uzing of fluidized bed of open-heath furnace slag favoures the uniform temperature distribution along the reactor height, intensifies mass and heat transfer processes and increases the residence time for lignite particles in the reaction zone. The last two factors are of special importance for highly reactive Kansk-Achinsk lignite, for which the gasification process in 850-1050°C temperature range is limited not only by chemical conversions but also by diffusion phenomena.

The application of circulating bed of open-hearth furnace slag particles results in more uniform distribution of temperature along the gas generator height as compared to conventional fluidized bed. As a consequence the considerable increase of the extension of the reaction zone in the gas generator

TABLE 2

Parameters of powdered lignite gasification by air-steam mixture
in circulated bed of open hearth slag particles.

Indices of the processes	Experiment No							
	1	2	3	4	5	6	7	8
Composition of initial reaction mixture:								
- lignite, kg/kg	0.18	0.19	0.19	0.20	0.20	0.21	0.27	0.18
- oxygen, %	19.3	19.8	19.3	19.1	19.3	18.4	18.9	31.7
- steam, %	8.0	5.8	8.8	9.2	8.0	12.2	9.9	10.8
Gaseous reagent velocity in empty reactor, m/c	3.82	5.23	3.72	5.52	3.74	3.92	3.15	2.87
Temperature (°C) at different height in the reactor (m)								
- 0.2	925	905	905	960	890	900	945	945
- 0.6	945	940	930	975	895	905	945	945
- 4.2	860	850	860	920	830	820	890	890
Composition of produced gas, %								
H ₂	6.9	4.6	5.4	7.1	5.9	5.4	9.7	12.1
CO	5.6	6.1	4.4	8.2	5.4	6.7	11.0	13.4
CH ₄	1.1	1.4	0.9	1.4	1.0	1.2	2.0	3.5
N ₂	58.9	58.9	59.2	55.5	59.0	55.6	50.7	46.1
H ₂ O	13.2	13.6	14.8	14.3	14.8	16.7	12.5	11.7
O ₂	1.9	2.3	1.4	1.5	2.5	1.6	0.8	0.8
Calorific value of produced dry gas, MJ/m ³	2.11	2.06	1.70	2.70	1.99	2.52	3.62	4.83
Slag particles recycling velocity, kg/s	0.110	0.167	0.110	0.167	0.069	0.069	0.125	0.125
Fuel conversion, %	69.4	75.7	68.0	78.1	58.2	60.5	70.5	69.7

takes place. It makes possible to raise by 2-3 times the velocity of gaseous reagents flow and consequently to increase the gas generator productivity. In order to obtain from lignite the fuel gas with high calorific value it is reasonable to keep the definite value of gases velocity. It was experimentally found that the optimum gases velocity for air-steam gasification of Kansk-Achinsk lignite in the reactor with circulated bed of slag particles is 2.5-3.5 m/s.

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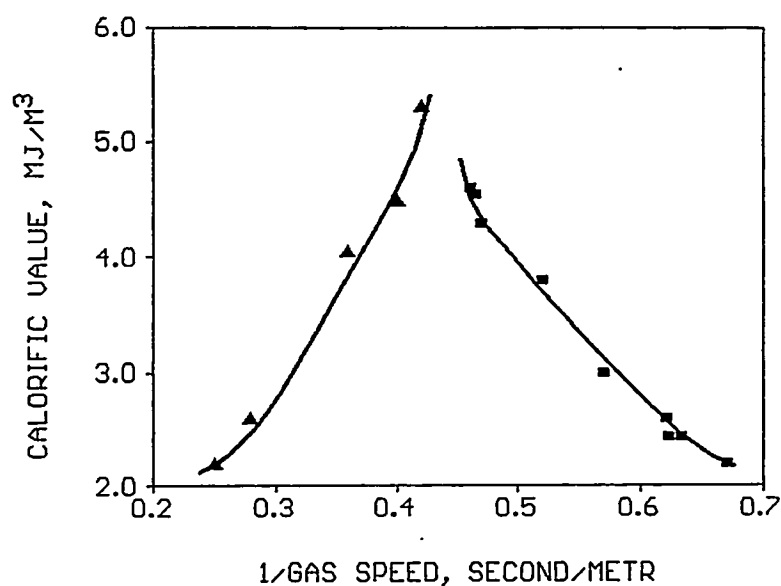


Figure 5. The influence of gaseous reagents velocity on the calorific value of produced gas.

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CHEAP CARBON SORBENTS PRODUCED FROM LIGNITE BY CATALYTIC PYROLYSIS

Boris N. Kuznetsov
Maxim L. Shchipko

Institute of Chemistry of Natural Organic Materials
Siberian Division of Russian Academy of Sciences
Akademgorodok, Krasnoyarsk, Russia

ABSTRACT

Some data are presented describing the new technology of carbon sorbent production from powdered lignite in the installation with fluidized bed of catalyst. It was shown the different types of char products with extended pore structure and high sorption ability can be produced from cheap and accessible lignite of Kansk-Achinsk coal pit in pilot installation with fluidized bed of Al-Cu-Cr oxide catalyst or catalytically active slag materials. In comparison with the conventional technologies of pyrolysis the catalytic pyrolysis allows to increase by 3-5 times the process productivity and to decrease significantly the formation of harmful compounds. The latter is accomplished by complete oxidation of gaseous pyrolysis products in the presence of catalysts and by avoiding the formation of pyrolysis tars - the source of cancerogenic compounds.

The technology of cheap powdered sorbent production from lignites makes possible to obtain from lignite during the time of pyrolysis only a few seconds char products with porosity up to $0.6 \text{ cm}^3/\text{g}$, and specific surface area more than $400 \text{ m}^2/\text{g}$.

Some methods of powdered chars molding into carbon materials with the different shape were proved for producing of firmness sorbents. Cheap carbon sorbents obtained by thermocatalytic pyrolysis can be successfully used in purification of different industrial pollutants as one-time sorbent or as adsorbents of long-term application with periodic regeneration.

INTRODUCTION

Carbon sorbents are widely used for purification of pollutant from different types of contaminations. But sorbents obtained by conventional technologies are usually expensive and therefore needed the regeneration procedure for their re-using in purification process. The application of cheap materials like lignites or wood wastes along with simple technology of their pyrolysis makes possible to produce some sorbents with low cost. Cheap carbon sorbents can be used without regeneration. This gives new possibilities for their big scale application in industry and energetics.

The simple and effective method of powdered raw material pyrolysis was suggested in [1-2]. It is based on realization of oxidative pyrolysis of air-powdered solid fuel in fluidized bed of catalyst. As a result of heat evolution during catalytic oxidation of volatile compounds, derived from solid particles of raw material, the pyrolysis process goes autothermally without external heat supply. Finally a set of different steps: heat evolution, raw material pyrolysis and char activation by gaseous products of pyrolysis takes place simultaneously in the same reactor unit.

Some experimental data obtained in the Institute of Chemistry of Natural Organic Materials in the field of new thermocatalytic technologies of cheap carbon sorbent production from Kansk-Achinsk lignite are presented in this paper.

THE SCHEME OF PILOT INSTALLATION WITH FLUIDIZED BED OF CATALYST

The scheme of pilot installation for pyrolysis in fluidized bed of catalyst is given on Fig.1. Two different types of pyrolysis reactor were applied. For both "short" and "long" reactors the height of first section was 0.6 m and its inner diameter 0.3 m. This section is filled up by fluidized bed of catalyst particles during pyrolysis process. The second section has the inner diameter 0.3 m, the length of 1 m for "short" reactor and 2.8 m for "long" reactor. The latter has also the third section with height 0.8 m and the inner diameter of broad part section 0.6 m. The variation of height and diameter of reactors makes possible to regulate the time of raw material thermal treatment without changing the expenditure of reagents. The mixture of air with water steam heated to 250°C was used as fluidizing agent.

Char particles with size less than 0.2 cm, gaseous mixture of CO_2 , H_2O , H_2 , CO , CH_4 , N_2 and tar were main products of lignite pyrolysis in reactor (1). The cyclone (7) separates most big char particles from gaseous products. Therefore about 85% of char particles trapped in bunker (8) have the size 0.01-0.2 cm. Char particles with less sizes were accumulated in multi cyclone (10) and in hose filter (11). For warming the pyrolysis reactor (1) at the starting period of time the furnace (15) working on diesel fuel and electric heater (16) were applied. The combustion of 1-2 kg of lignite with particles sizes 0.01-0.05 cm was needed to reach the study-state pyrolysis process with productivity up to 60 kg of raw material per hour.

Oxide Al-Cu-Cr catalyst with 5.9% of CuCr_2O_4 on $-\text{Al}_2\text{O}_3$ (surface area 160 m^2/g) and the set of disposable slag materials of high temperature industrial processes were used for catalytic pyrolysis in fluidized bed. The average particles size of catalyst was 0.2-0.25 cm.

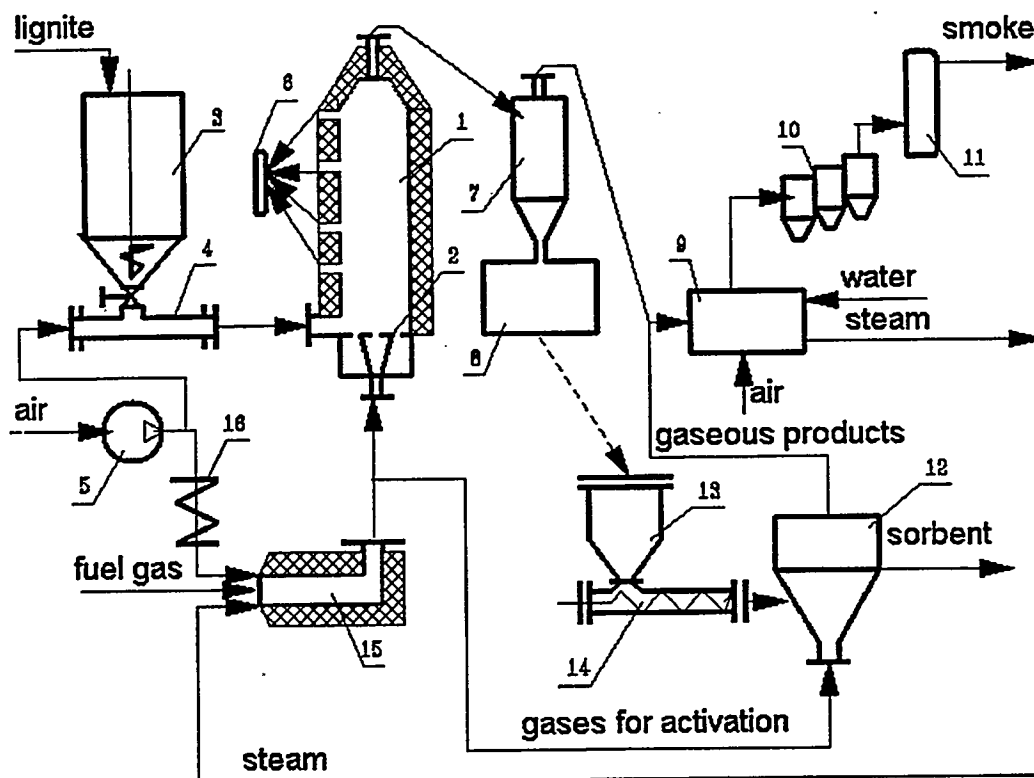


Figure 1. The scheme of pilot installation for char production from lignite.
 1 - reactor with fluidized bed, 2 - air distributed grating, 3 - bunker for lignite, 4 and 14 - feeders, 5 - compressor, 6 - sampling device, 7 - cyclone, 8 and 13 - bunkers for char product, 9 - economizer, 10 - multi cyclone, 11 - hose filter, 12 - reactor for char activation, 15 - furnace, 16 - electric heater.

The following procedure of lignite thermal treatment was used in accomplished experiments [3]. The powdered lignite was fed by air flow to the lower part of fluidized bed of slag particles. Passing through reactor lignite particles were pyrolyzed with formation of gaseous and solid products. The latter were recovered in cyclones and cooled to room temperature. The final purification of pyrolysis gases was carried out after their cooling up to 150-170°C.

The composition of gaseous products of pyrolysis was analyzed by gas-chromatographic technique. The total porosity of lignite and products of its thermal treatment was measured by kerosene sorption on the sample. The more detailed information about carbon products texture (specific surface area, volume and ratio of micro- and mesopores) was obtained from isotherms of N₂ adsorption, recorded at -196°C by automatic adsorption apparatus ASAP-2400 Micromeretics Company. The surface area value was calculated by BET method with the using of standard sample. The analysis of meso pores distribution in the interval of diameters 3-100 nm was made from desorption branch of isotherm by Broekhoff-de Boer method taking into account the adsorption potential in framework of cylinder-type pore model. For X-ray diffraction analysis of char samples the apparatus DRON-2 with K monochromatic was used. The half width of band 002 was chosen as a degree of structural regularity of char material.

The ability of solid carbon products for adsorption of oil impurities was tested using of mazut-water mixture with mazut concentration 1 g per liter. The experimental procedure included first the mazut-water mixture preparation, its stirring during 2 hours at 50°C by magnetic mixer and cooling up to the temperature 20°C. Than 1 gram of carbon sorbent was added to solution and was kept during some period of time without agitation. The time of adsorption (during 2 minutes) was chosen taking into account the condition of sorbent using in industrial reactor. The amount of adsorbed mazut was determined from the difference of its concentration in initial solution and in solution, treated by char. The mazut concentration in water was measured by UV-technique. The experimental procedure included the extraction of mazut-water emulsion by hexane. The comparison of UV-spectra intensity in standard and studied samples was used for calculation of mazut concentration.

CARBON SORBENTS PRODUCTION

Lignite of Kansk-Achinsk coal pit was used as initial raw material for char production. After drying it contains 9-12% of water, 7% of ash (on dry matter) 49% of volatile substances (on dry ash free matter). The composition of dry ash free matter of lignite: C - 70.5%, H - 5.1%, N - 0.9%, S - 0.2%, the rest - oxygen. The lignite porosity is 0.18 cm³/g, specific surface area - 2.5 m²/g, pores with size less than 100 nm are practically absent.

Typical parameters of powdered lignite pyrolysis in fluidized bed of catalytically active open-hearth furnace slag are listed in Table 1. The calculated time of lignite particles thermal treatment in conformity with [4] is 0.3-0.4 sec. in "short" reactor and 1.2-2.6 sec. in "long" reactor. The carbon products, produced in "long" reactor, have higher surface area and increased sorption ability as compared with ones obtained in "short" reactor (see Table 1). The explanation of these experimental fact can be suggested taking into account two main stages of studied pyrolysis process [5-10]. At the first stage lignite particles undergo to flash pyrolysis in heated fluidized bed of catalyst particles.

One can expect that in conditions of flash-pyrolysis the intensive emission of gaseous products from lignite particle causes the pressure increasing inside particles with sizes 0.05-0.5 mm. This phenomena should prevent the decreasing of lignite particles volume during pyrolysis process. Above mentioned hypothesis was checked in experiments with lignite pyrolysis at different rates of heating in quarts reactor up to the temperature 700°C. It was found the 25-30% decreasing of sample volume at the rate of heating 0.3-0.4°C per second. The porosity of sample practically did not change during pyrolysis and its value remains about 0.18 cm³/g. But the heating of sample with high rate (10³-10⁴°C per second) results to formation of char with porosity 0.5-0.6 cm³/g, according to data of Table 1 for "long" reactor. Since, the char interaction with gaseous reagents in "short" reactor has short time duration the increasing of porosity and surface area of char from 0.18 cm³/g up to 0.23-0.4 cm³/g and from 6 m²/g up to 130-190 m²/g, accordingly, takes place in the first stage of thermal treatment - flash pyrolysis of lignite particles.

TABLE 1

Typical parameters of lignite pyrolysis process and properties of char products.
Type of reactor

	short		long	
	1	2	3	4
Lignite expenditure, kg/h	29.1	38.4	27.8	58.7
Air expenditure, m ³ /g	52.8	51.6	52.2	94.6
Steam expenditure, kg/h	10.8	18.6	10.8	18.6
Temperature of fluidized bed of catalyst°C	930	930	960	960
Calculated time of lignite treatment, sec.	0.4	0.3	2.6	1.2
Yield of char, kg/h	8.4	10.4	6.7	29.7
Properties of char:				
Ash content, %	29.6	30.4	43.2	18.9
Content of volatiles, %	8.6	9.7	6.1	6.4
Porosity, cm ³ /g	0.41	0.23	0.39	0.61
Micro pores volume, cm ³ /g	0.15	0.09	0.13	0.19
Specific surface area, m ² /g	190	127	402	419

The second stage is connected with the interaction of solid and gaseous products formed at the first stage of pyrolysis process. Since gasification reactions at studied temperatures proceed essentially slowly than pyrolysis ones, the second stage of the process is takes place only in "long" reactor. The increasing of time of char gasification by CO₂ and H₂O in "long" reactor as compared with "short" one results to increase the surface area of solid carbon products. It should be considered that at the stage of char activation by gaseous products micro- and meso pores are mainly formed. This conclusion is confirmed by the data for micro- and meso pores distribution which show that pores is diameter up to 90 nm are mainly produced during lignite pyrolysis in "long" reactor. Just the same samples have higher capacity in mazut adsorption.

It was found the variation of heating rate results also to the changes in the degree of structural regularity of carbon products of lignite pyrolysis. These data were obtained using γ -ray diffraction technique. It is known the half-width of band 002 is connected with the degree of carbon network regularity and this parameter can be used for calculation of the size of carbon crystallites (L_c). It was found that char of flash pyrolysis has less structural regularity as compared with char of slow pyrolysis process. As it was found earlier the char obtained by flash pyrolysis of lignite in fluidized bed of oxidation catalyst has the best reactivity in water steam gasification process among carbon products of different pyrolysis processes [11]. This fact can be explained taking into account the high reactions ability of sides and edges of carbon crystallites toward interaction with gasification reagents like water steam and CO₂ [9]. The essential increasing of the number of these active sites in carbon micro crystallites formed during lignite flash-pyrolysis results to increasing the activity of char in gasification reactions.

The obtained data make possible to suggest the process parameters for producing of char with good sorption ability by oxidative pyrolysis of Kansk-Achinsk lignite in fluidized bed of catalytically active slag material. The following main stages of the process should be considered. At the first stage (proceeds in lower part of reactor) the pores and highly reactive char is formed during period of time about 0.3 sec as a result of flash pyrolysis of lignite particles. Than at the second stage (proceeds in top part of reactor) the partial char gasification is accomplished during the time 1-2 sec with the formation of extended system of micro- and mesopores. Finally the cheap carbon sorbents with porosity up to $0.6 \text{ cm}^3/\text{g}$, specific surface area more than $400 \text{ m}^2/\text{g}$ and mazut adsorption ability 0.9 g/g are produced during the period of time about 3 seconds.

APPLICATION OF CARBON SORBENTS FROM LIGNITE

Sewage purification

Commercially produced carbon sorbents have as a rule the high amount of pores with sizes less than 4 nm . Since oil and mazut drops in sewages have more high sizes it is reasonable to use sorbents with meso-pores size $4\text{-}10 \text{ nm}$ [12]. The carbon product with extended meso-pores structure was produced from Kansk-Achinsk lignite by catalytic pyrolysis using the parameters of experiment 4 (Table 1). The initial lot of this carbon product was 0.6 tonn . It has the following properties: ash content - 18.3% , volatile substances - 9.3% , I_2 sorption ability - 38% , mazut sorption ability - 0.8 g/g for 2 min. The experimental testing of sorbent was carried out on purification facilities of Krasnoyarsk Heat Plant-2. The scheme of the latter is given in Fig.2. The common procedure of this purification facilities operation

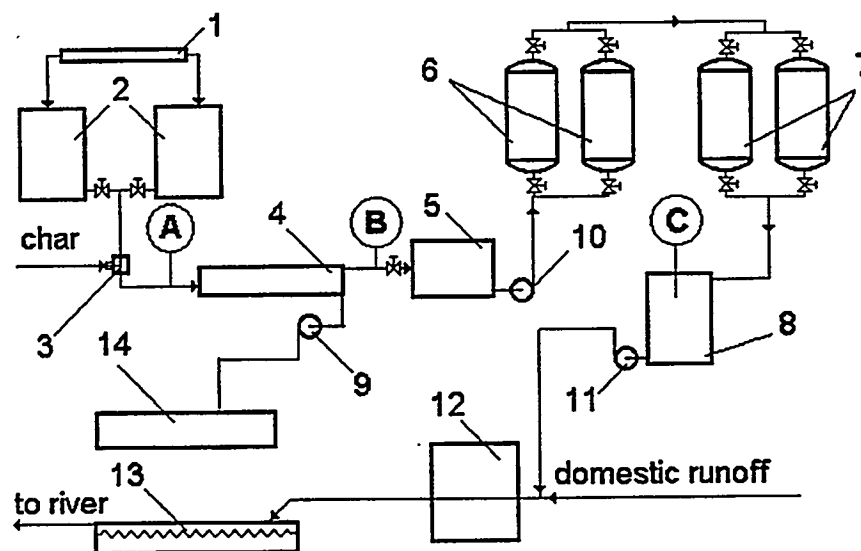


Figure 2. The scheme of purification facilities of Krasnoyarsk Heat Plant-2.

1 - collector, 2 - settler bunkers, 3 - char feeder, 4 - oil trap, 5 - collector bunker, 6 - sand filters, 7 - filters with carbon sorbent, 8 - bunker, 9, 10, 11 - pumps, 12 - mixing tank, 13 - settler pond, 14 - coal storehouse.

includes the collection of sewage highly contaminated by mazut into two bunkers (2). Each of them has volume 300 m³ and they work by turns. After the settle during 1.5-2 hours the contaminated water is feed to oil trap (4) with volume velocity about 50 m³/g. After oil trap the sewage goes to intermediate bunker (5) and than it pumps on mechanical filters (6), filled by anthracite. The fine purification of water is carried out by active carbon on filters (7). The mazut concentration in water is 10-50 mg/l after oil trap and 0.3-3.0 mg/l after carbon filters. The mazut concentration in purified sewage which is thrown to open reservoir is restricted by law as value 0.05 mg/l. This value of mazut concentration in contaminated water is reached by its further dilution. Purified and diluted sewage passes first through precipitation tank (12), than through the pond (13) and goes into Yenisey river. In experiments with char produced from lignite by catalytic pyrolysis the char feeders (3) was placed before oil trap (4). The char from lignite was mixed with mazut contaminated water. In the process of char moving along oil trap the mazut impurities were absorbed by char particles. The latters are settled on the oil trap bottom and than removed by special pump. After drying on the open air the char contaminated by mazut was mixed with powdered lignite and than was burned in boilers of Heat plant. Results of experimental testing of char product from lignite in purification on mazut containing sewage of Krasnoyarsk Heat Plant-2 are given in Table 2. During the time 4 days the amount 1200 m³ of sewage was purified. Data of table 2 show that the degree of purification in oil trap at common conditions is 9.2% at mazut concentration 2.7 mg/l and 27.3% at mazut concentration 12.3 mg/l. The addition of char from lignite increases the degree of purification more than 3 times at char expenditure 1 kg/m³. In the interval of mazut concentration 10.8-17.3 mg/l the oil trap works with average degree of purification 23.7% (see table 2) and the addition of char results to 3 times increase of this value. The amount of mazut adsorbed by char is ranged from 0.9 g/kg up to 33.5 g/kg. The content of adsorbed mazut in increased with the growth of its concentration and with decreasing of char expenditure. It should be noted that used experimental conditions are far from optimal one's. Nevertheless the char introducing to oil trap in the amount 0.5 kg per 1 m³ of sewage with mazut concentration 5-22 mg/l results to purification degree 60-80%. The affectivity of sewage purification can be significantly increased with the growth of mazut concentration according to data of table 2.

TABLE 2

Results of experimental testing of powdered char from Kansk-Achinsk lignite in purification of water from oil impurities the sewage of Krasnoyarsk Heat Plant-2

Concentration of oil products in water, g/liter x 10 ³		Degree of purification, %
before oil-trap	after oil-trap	
1	2	3
Experiments without char		
2.70	2.45	9.3
12.34	9.42	23.7
•Experiments with char expenditure 1 kg/m ³		
2.70	1.80	33.3
8.44	2.90	65.6
9.26	3.25	64.9
8.24	2.16	73.8
17.25	4.50	73.9
Experiments with char expenditure 0.5 kg/m ³		
10.81	3.14	71.0
20.89	4.23	79.8
22.15	5.40	75.6
5.22	2.00	61.7
8.28	1.46	82.4

NO_x adsorption by char from lignite

Carbon sorbents are used in grow scale for purification of smoke gases. It is known the char from lignite is produced in Germany for this aim. The NO_x adsorption ability of char produced from Kansk-Achinsk lignite by oxidative pyrolysis in fluidized bed of slag catalyst was studied by us. The testing of char sorbents was carried out in dynamic regime by using glass column. The gaseous mixture: air - NO₂ - NO with NO₂: NO ratio 40:60 was passed through the charge of char with length 0.1 m and char volume 20 cm³, with the volume velocity 1 c⁻¹. The nitrogen oxides content in gases was measured before and after the charge of carbon sorbents. The ability of char from lignite produced in conditions of experiment 1 (Table 1) to NO_x absorption was compared with the ability of commercial adsorbent CKT. Data of Fig.3 show that degree of NO_x purification by char adsorbent from lignite is comparable with the commercial sorbent.

The adsorbent capacity of char sorbent is higher as compare with the commercial one (see Fig.4). Obtained data show that cheap carbon sorbents produced from lignite by catalytic pyrolysis are of interest for using in purification of gases from nitrogen oxides.

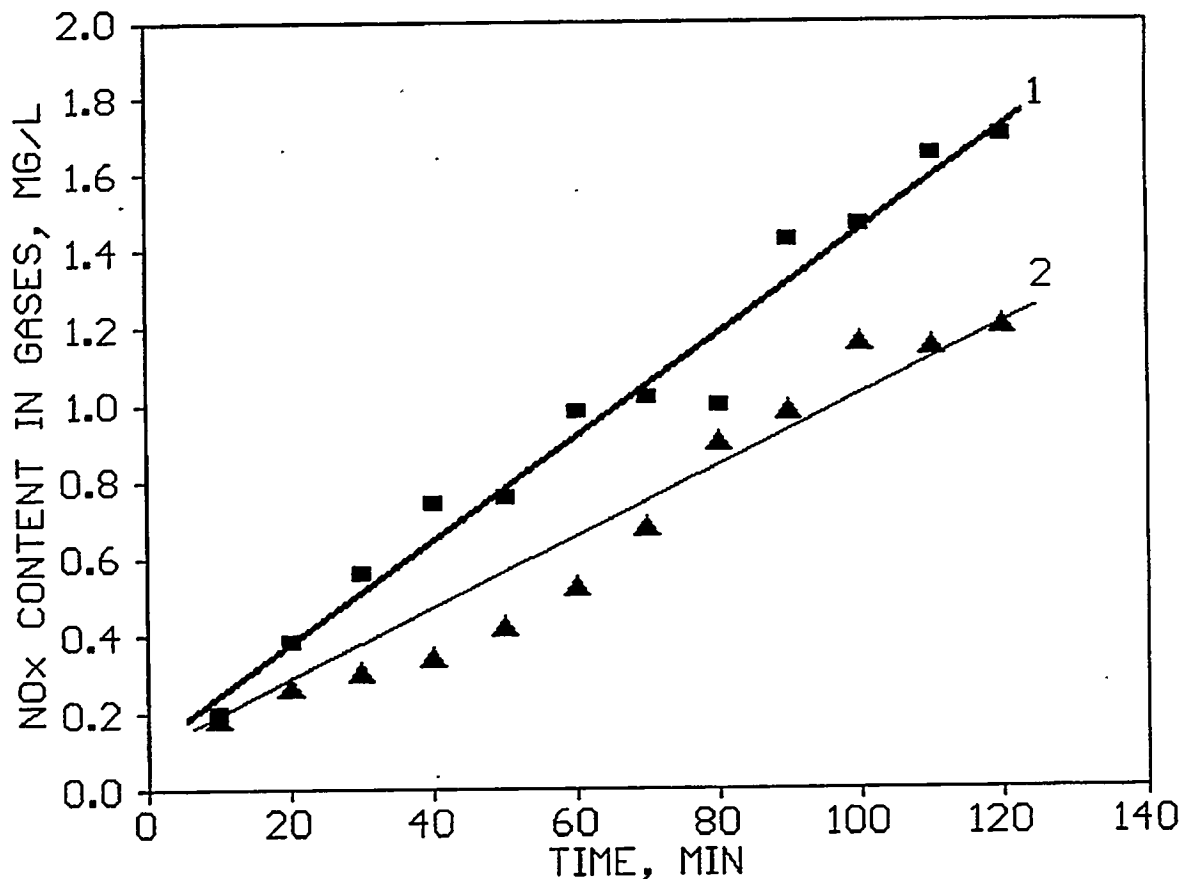


Figure 3. The time dependence of the content of nitrogen oxides in gases after purification by char sorbent from lignite (curve 1) and commercial carbon sorbent CKT (curve 2) at the gas volume velocity 1 c⁻¹. The gaseous mixture composition: air - NO₂ - NO with NO₂/NO ratio 40:60.

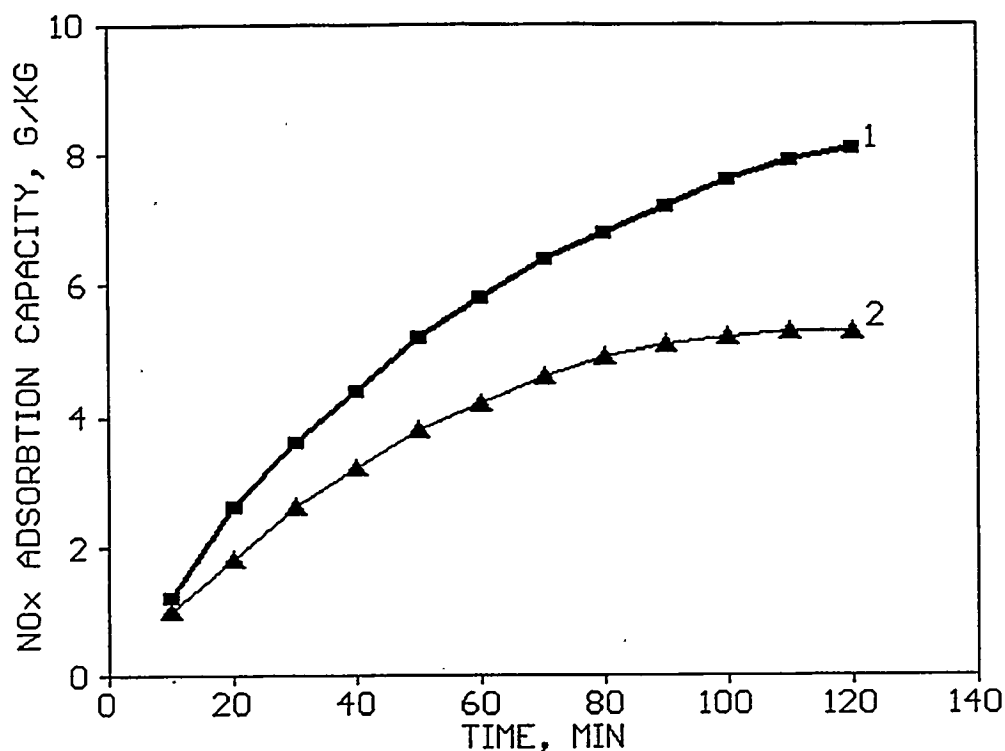


Figure 4. The time dependence of NO_x adsorption capacity of char from lignite (curve 1) and commercial carbon sorbent CKT (curve 2). The adsorption condition are the same as in Fig.3.

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THE PRODUCTION OF HIGH LOAD COAL-WATER MIXTURES ON THE BASE OF KANSK-ACHINSK COAL BASIN

Y. Demidov
G. Bruer
S. Kolesnikova

Research and Design Institute for Problems of
Development of Kansk-Achinsk Coal Basin (KATEKNIllugol)
Krasnoyarsk, Russia

ABSTRACT

The results of the "KATEKNIllugol" work on the problems of high load coal-water mixtures are given in this article. General principles of the mixture production, short characteristics of Kansk-Achinsk coals, the experimental results of the coal mixture production on a test-industrial scale, the suspension preparation on the base of coal mixtures, technical-economical indexes of tested coal pipeline variants based on Kansk-Achinsk coals are described.

PREFACE

Nowadays high load coalwater mixtures (HSC\EM) are qualified as an alternative fuel instead of coal and heavy fuel oil burnt in boiler units of power stations. The production of HLCM4; on the base of bituminous coals are carried out on an industrial scale. At present industrial coal pipeline transmits the mixture prepared on the base of Kusbass coals from Inskaya (Belovo city, Kemerovo Territory) to Electric Power Station-5 in Novosibirsk. It's length is 260 kilometers and productivity capacity is near 3 mln t annually in terms of dry coal.

Japan-Chinese joint venture company, YANRI CWM CO., LTD, constructed in 1992 a 250 000 tons/year CWM manufacturing plant in China, Shandong Province, Rizhao construction site /1/. But the problem of mixture preparation on the base of brown coals still exists. The most difficult task is the production of fluid suspension based on brown coal of higher concentration and having demanded technological characteristics~ Run-of-mine brown coal of Kansk-Achinsk coal basin (KACB) has the moisture 33-40%, the calorific value - 12.6 - 16.3 MJ/kg.

Brown coal of Kansk-Achinsk coal basin is of great interest because of its reach reserves, first of all, and low prime cost of output. Geological reserves of coals easy of industrial access make 600 million tons including 140 million tons good for the cheapest open-cast mining. Low ash content of Kansk-Achinsk coal (8-12%), the absence of harmful elements including natural radio nuclides, relatively high calorific value make it possible to use such coals for heat and power production /2,3 /.

However, there is no practical commodity market in the region of coal output. The fuel transportation is connected with great difficulties, in particular it is necessary to increase the carrying capacity of some railway sections. Besides, long-distance transportation requires substantial expenditures, exceeding the coal cost. The coal pipeline construction for coal transportation in a coal-water mixture state can serve as an alternative variant.

KATEKNIllugol worked out the technology of coal-water mixture preparation based on Kansk-Achinsk coals. There are four kinds of mixture / 3 / produced under different conditions of preparation:

- based on run-of-mine coal with the initial moisture 33% treated in ball and rod mills with subsequent homogenization and concentration 42-48% in terms of dry substance, specific calorific value - 9.2-10.2 MJ/kg;

- on the base of dried coal with the moisture 10-15% and the following treatment on the same technology with the concentration in terms of dry substance 56-58%, ~ and specific calorific value 12, 6-13, 4 MJ/kg;
- on the base of steam-and-pressure cured coal and the following treatment on the technology of the Institute of Solid Fuel Dressing with the ultimate moisture 15-18%, the concentration in terms of dry substance 56-58% and specific calorific value 12,6-1398 MJ/kg;
- on the base of thermocoal and semi-coke prepared from Kansk Achinsk coals on the Combustible Resources Institute's technology and on the technology of the Krzhizhanovsky Power Institute with the concentration in terms of dry substance 62-67% and specific calorific value 15, 5-16.7 MJ/kg.

Experimental-industrial tests of coal-water mixture production were carried out only on the base of Kansk-Achinsk coals prepared according to the first variant.

MIXTURE PREPARATION ON THE BASE OF BROWN COAL

Pilot plant for high load coal-water mixture production was mounted in an experimental shop of Alumina Integrated Works in Achinsk (AAIW) on the base of operating grinding equipment with the productivity of 4-21 t/h / 4 /. The scheme of the pilot plant is shown on Fig. 1. Coal from the store-room is brought with a grab crane to the bunker, out of which to the Jaw crusher by means of an apron feeder. Then it moves with belt conveyers to the cone-type crusher, out of which with the help of belt and reverse conveyers it moves to the bunker. After that coal through the reciprocating plate feeder and belt weight meter is brought to the ball mill, water and plasticizing agent solution from the measuring tank through the dosimeter are brought there simultaneously. Then mixture passes to the tank with a mixer, out of which it is pumped to the rod mill and then to the reservoirs equipped with a mixing facility and at last to the user. The plasticizing agent solution is brought to the rod mill from the measuring tank.

For the mixture production brown coal from the coal basin "Beryozovsky" was used, its physical-chemical characteristics are represented on the Table 1. Sample selection and coal and CWM analysis were carried out due to standard technique. Rheological parameters of mixture were estimated on the base of structural viscosity (M_c) and yield point (T_o) using the rotary viscometer "Reotest-2" in a shift speed range from 0.3 to 145.8 9-1. The technology of coal-water mixture production according to the scheme of two-stage grinding was optimized on the pilot plant. On the first grinding stage coal was previously crushed to 40 mm lump size in the ball mill. For the mixture production usual water from common water-line was used. The coal output of the ball mill in the operating process was 4-12 t/h, Ball mass in the mill was constant and made up 9 t. Ball loading assortment: 0 400 mm - 0.2 t; 0 50 mm - 7.2 t; 0 60 mm - 0.5 t; 0 70 mm - 0.5 t; 0 80 mm - 0.5 t; 0 90 mm - 0.1 t.

With the increase of the mill output from 4 to 12 t/h coal classification yield less than 50 mm was reduced from 50 to 20 % but the yield of larger coal classifications grew (Table 2).

On the second grinding stage the mixture was brought to the rod mill. The yield of finely dispersed classifications increased from 48 to 83 % while the rod mill output simultaneously decreased from 21 to 6 t/h (Table 3).

When the pilot plant output was 9-10 t of the mixture per hour (5-6 t of coal per hour) the mixture had viscous-flow properties providing its prolonged storage and pumping. The solid phase content in the mixture was 39-44%, finely dispersed fraction content (C 50/mm) -70-78%.

Under pilot conditions as a plasticizing agents were used technical lignin-base sulphonate (LBS) of Permsky Pulp-and-Paper Plant, complex alkaline agents on the base of modified lignin-base sulphonates (MLBS) and coal-alkaline reagent (CAR). At the pilot run-of-mine coal output 6t/h the consumption of plasticizing agents constituted:

LBS - 0.5 %; MLBS + NaOH - 0.3 %; CAR + NaOH - 0.6 %.

Water feed was 3,5-4,0 m³/h. Sodium hydroxide was introduced on the first grinding stages other agents - on the second one. Modified lignin-base sulphollates made the viscosity of the mixture higher from 1.5 to 4.5 Pa.s. CAR addition made the mixture stabilized but its viscosity increased a little. Lignin-base sulphonate LBS showed good dilution properties making the structural viscosity lower from 1.5 to 0.1 Pa.s, and ultimate shear rate - from 20 to 9 Pa keeping satisfactory stability.

For the purpose of dynamic properties determination of HLCWM a special installation was constructed on the territory of AAIW. It represented a small test ring with the length of 120 m (Fig.2) consisting of pipes 100, 150, 200 and 400mm in diameter. The length of every test section was 28m.

HLCWM with the concentration of 40.9% was subjected to the hydraulic measuring. The mixture was transported through the test section by turns. Pressure drop on the control section with the pipes 100, 150 and 200 mm in diameter was measured by OEM1-160 manometers, with the pipes 400 mm in diameter - by water differential manometer with the 0-1500 of water column scale. The mixture consumption was measured by the flowmeter IR-61.

The relationship between pressure loss and the mixture flow speed in the pipes of different diameters is shown on Fig.3.

The regime of the mixture flow after its prolonged storage at rest state was tested on the pilot plant, that is the possibility of pipeline actuation after its long outage was examined. At rest state definite structure is being built in the mixture (thixotropy property). Under the action of applied pressure when velocity gradient starts to change, inner structure destroys. Being tested, the mixture stayed at rest in the pipe 200 mm in diameter during 27 days, then it was pumped through the 5-th - 2-nd rings section (Fig. 2) for three hours. The mixture viscosity before the test was 0.22 Pa.s, at the end of the test - 0.15 Pa.S.

Under the action of applied pressure when the velocity gradient starts to change inner mixture structure destroys. The flow regime of the mixture with demidestroyed structure will be in the field of pseudolaminary regime at low speed.

Thus, on this pilot plant with the productivity 6-21 t of the mixture per hour the technology of HLCWN. with the concentration 39-44 % (dry mass) was optimized on the base of "Beryosovsky" coals. The produced suspension (1200 t) was used in the technological process of AAIW. Mixture storage during 30 days and more showed that there were no separation and sediment.

When the dynamic stability of the mixture was tested while being transported through the pipes 120 mm in diameter at a speed of 0.1-2.5 m/s, it was found that there was no sufficient sedimentation of coal particles at the pumping and after pipeline outage for 27 days.

The usage of technical lignosulphonate as a plasticizing agent was the most effective.

Power expenditures for the mixture production due to the scheme of two-stage grinding in the ball and rod mills don't exceed 25 kW.h/t.

COAL - WATER MIXTURE PRODUCTION ON THE BASE OF COALS MIXTURE

Laboratory tests showed that the mixture produced on the base of bituminous and brown coals mixture with the concentration up to 55% has satisfactory rheology characteristics for its transportation and long storage.

Bituminous and brown coals grinding gives bimodal coal particles relation, that makes it possible to encrease the concentration of HLCWM. As the fuel reactivity increases, it ignites at lower temperature and burns up quicker. At the expense of high content of calcium and magnium oxides, sulphur oxides of bituminous coals can be bound in the ash-producing process preventing their effluent into the atmosphere.

Taking into account the advantages of the fuel on the base of bituminous and brown coals mixture pilot tests / 5 / for its production were carried out in KATEKNIlugol (Fig. 1).

In this process three types of coals were used: bituminous coal from the mine "Inskaya" with high ash content, on the base of which bituminous coal mixture was produced; Bituminous coal from the same mine with low ash content; and brown coal from the coal basin "Beryosovsky". On the base of these coals mixture in proportion 80:20 coal-water mixture was produced (Table 4). As a plasticizing agent the diluent S-3, put into practice on the coal-pipeline "Belovo-Novosibirsk", was used. Its quantity was 1%.

While preparing the mixture on the base of bituminous coal bimodal particles distribution was not obtained, though at the productivity of the pilot plant 6 t/h the mixture with parameters necessary for its storage and transportation was prepared. (Table 5).

When the mixture on the base of brown and bituminous coals was tested, it was found that at the pilot plant output 8 t/h the mixture with bimodal coal particles distribution was obtained, Table 6). At such output 40 t of mixture on the base of brown and bituminous coals were prepared. Solid dry residue content in the mixture constituted 54%; coal classes less than 50 μm - 58 %, more than 200 μm - 3%. Structural viscosity was 0.74 Pa.s; yield point - 9 Pa; ash content in HLCWM - 17.5 % ; low heat value for operating moisture - 9.5 MJ/kg; high heat value for dry ashless mass 30.7 MJ/kg.

For the experimental burning the prepared mixture was transported (200 km) in highway tank trucks to the Krasnoyarsk Power Station - 2. After the transportation all the characteristics of the mixture were the same, had no deviations.

INDUSTRIAL TESTS OF HLCWM PRODUCTION TECHNOLOGY

To examine the high load coal water mixture production technology on the base of brown coals the tests were carried out on the industrial equipment in AAIW. The principle scheme of HLCWM production on the base of brown coals is given- on Fig.4, 5, 6 . From the storeroom coal is fed with a clamshell crane through a reciprocating plate feeder and belt conveyor to the primary crushing crusher, then with the help of a belt conveyor to the cone type crusher for fine crushing. After crushing coal is fed to the bunker then through the belt weigher and reciprocating plate feeder - to the ball mill for the first grinding stage. Simultaneously water is fed to the mill through the weigher. From the ball mill the mixture is fed to the reservoir with a mixing device, from which it is pumped with a centrifugal pump to the rod mill for the second grinding stage, after which it comes to the reservoir with a mixing device and then it is pumped through the pipe-line to the correction pond .

For the HLCWM production brown coal of "Beryosovsky" coal basin was used. It was of the following characteristics: $W_r = 33 \%$; $A_d = 5.9 \%$ and $Q_r = 16.2 \text{ MJ/kg}$. The coal output of the ball mill constituted 90-150 t/kg, water consumption 65-110 m³/h, real ball loading of the mill - 216 t. Installation productivity was limited by the pump used for the mixture evacuation. The mixture produced in the ball mill had not very high concentration - up to 42%, low viscosity - 0.3 Pa.s and yield point - 2-7 Pa (Table 7).

From the ball mill the mixture was centrifugally pumped to the rod mill with the productivity 400 t/h. Rod mill loading constituted 150 t. The output of coal class less than 50 μm was 66-79% mixture viscosity didn't exceed 0.5 Pa.s and yield point became higher - up to 27 Pa (Table 8).

Acceptable values of rheological characteristics and granulometer composition were obtained at the installation productivity 225 t of mixture per hour (145 t/h of coal). 1260 t of the mixture were prepared under such conditions, 1160 t of which were left in a correction pond. Averaging of the mixture in the pond was realized while mixing by means of air bubbling, the air consumption was 1500 m³/h under the pressure 4-5 atm. After mixture averaging solid concentration in terms of dry mass constituted 37.6% $M_c - 0.11 \text{ Pa.s}$; $t_0 - 5 \text{ Pa}$; density - 1125 kg/m³.

The examination of statistical stability of HLCWM in a correction pond was carried out for 15 days. The mixture samples were selected from the low part of the pond. As a result it was defined that the rheological characteristics and granulometer composition of the mixture didn't significantly change during

the whole storage period, though in the upper part of the pond there was unimportant separation (Table 9). When the time of the storage expired, the mixture was used in the technological process of cement production.

During the tests the following consumption indicators were defined: grinding balls - 0.37 kg/t, rods - 0.3 kg/t, specific power expenditures at the installation productivity 225 t/h 24.9 kW.h/t.

So, industrial tests proved that such technological scheme provided reliable production of high load coal-water mixture on the base of brown coals with the concentration not less than 42 % in terms of dry mass at the installation productivity 200- 225 t/h. It may be recommended for the industrial usage on the coal basin "Beryosovsky". It is also recommended to include homogenizer into the technological scheme after the second grinding stage to make HLCWM stability higher. The productivity of a single line will constitute annually 1.5 mln t of mixture or 1 mln t of coal.

THE CHOICE OF PRIMARY OBJECT OF INCULCATION

To solve the problems of transportation, storage and burning of high load coal-water mixture on the base of coals of Kansk-Achinsk coal basin it is necessary to build experimental coal pipeline, which would justify expenses / 7 /. For the technical-economical ground five variants of pilot plants were examined:

- coal pipeline "Beryosovsky" coal basin - Beryosovskaya Power Station 2" with the capacity 6400 MW and length -200 km (variant 1);
- coal pipeline "Beryosovsky coal basin - Beryosovskaya Power Station 1" with the capacity 800 MW and length -15 km (variant 11);
- coal pipeline "Borovsko-Sobolevsky coal basin - Achinsk Alumina Integrated Works (AAIW)" with the annual coal consumption 1.5 mln t and the length - 40 km (variant 111)
- coal pipeline "Borovsko-Sobolevsky coal basin - AAIW" with the annual coal consumption 7.5 mln t and the length - 40 km (variant V);
- coal pipeline "Beryosovsky coal basin - AAIW" with the annual coal consumption 7.5 mln t and the length - 140 km (variant V).

Considered coal pipelines of small length have a common leading station (CLS) without intermediate ones. The operating regime of a coal pipeline is continuous, twenty-four hour (7000 hours a year).

Coal from the coal basin is subjected to two-stage grinding up to lump size 0.3 mm. Crushed coal together with waters plasticizing agent, anticorrosive reagents and others is fed to the mill, where the high-load coal-water mixture production takes place. HLCWM is accumulated in reservoirs and then is pumped through the coal pipeline to the storeroom of the user. The main characteristics of coal-water mixture produced at the pulp preparing complex:

- solid content (in terms of dry coal mass) - not less than 42%;
- low specific heat value of a combustible - not less than 2200 kcal/ kg;
- granulometer composition of solid phase: up to 50 um - 75 %; up to 200 um, - up to 98% up to 1 mm - 100%;
- statistical mixture stability - not less than 30 days
- initial shear rate-9 Pa, structural viscosity - 0.6 Pa.s.

The type and number of pipeline pumps are defined proceeding from the pipeline productivity and specific losses of pressure. At high pressure reciprocating pumps of Sumsky Scientific-Industrial Complex, at low pressure - centrifugal multi-stage pumps of "Nasosenergomash" Scientific-Industrial Complex are used.

Pipeline construction is carried out due to the method of penetration lower than the freezing level. Reservoir parks for the mixture are formed from the vertical steel oil-type reservoirs of an individual capacity 5, 10, 20 and 50 thousand m³. The reservoir capacity is considered equal to 2-3 days productivity of the pipeline.

The economical indexes calculation of coal pipelines is carried out for flat-hilly route and includes all the expenditures together with route preparation, digging and filling up trenches, pipeline and reinforcement mounting, electric power supply, communication, environment protection and hydrostatic tests.

Extended indexes of pump station building are taken in accordance with pipeline capacity regarding for the buildings, constructions and equipment except the cost of main pumps and reservoir parks, which are regarded separately. Exploitation expenditures are defined due to expenditure items: amortization, salary, electric-power expenditures and others. The service staff number on the CES is 49, including the maintenance staff and the staff of emergency post - 100 persons.

The evaluation of the capital investments of the pulp preparing station was generalized because of the absence of a contractor design. Two power station modules were examined: of the productivity 225 t/h (1.75 mln t/year) and 400 t/h (3.12 mln t/year).

The structure of industrial prime cost includes: raw and other industrial materials, the service, electric power, salary, amortization, social insurance assignment and etc. Full prime cost includes industrial prime cost, unindustrial and centralized expenditures..

Comparative technical-economical evaluation of design solutions of examined coal pipelines shows that the most preferable is the first variant meaning both specific capital investments and exploitation expenditures. It is the most productive and less at length. However this variant can't be qualified first and foremost as the project of "Beryosovskaya" Power Station - 2 has already finished.

The most realistic are the second and the fourth variants. They are of slight difference as far as specific capital investments and exploitation expenditures. But due to the second variant it is necessary to design a boiler unit for the mixture burning on "Beryosovskaya" Power Station-1, that is why it is impossible to use the second variant as the first and foremost.

The third variant of coal pipeline has the lowest specific indexes, minimum construction expenditures and besides, long-term opportunity to enlarge the capacity up to the fourth variant level. In this connection this variant is the most probable for the first coal pipeline construction.

CONCLUSION

The investigations of Scientific-Industrial Complex "Hydrotruboprovod", Design-and-Research Institute "KATEKNugol", Scientific-Industrial Complex "Ugleprovod" and others show the expediency to build large-scale high load coal-water mixture preparing plant. New fuel introduction into power engineering instead of run-of-mine coal improves exploitation and ecological conditions owing to reduction of dust, sulphur and nitrogen oxides pollution, to power station disperse at ecologically safe distances, to the usage of dirty mine, quarry and common flows for the mixture preparation; it makes it possible to maintain the steady rhythm of fuel supply having a stable design quality under season and day conditions; to exclude the coal losses and self-ignition during its storage and transportation; to provide full automation of technological processes of production, transportation and fuel usage even in small boiler-rooms and dryers in municipal service, in agriculture and light industry; to improve labour conditions of staff on transport and power station; to improve considerably technical-economical indexes; and the most important to find commodity market for Kansk-Achinsk coals in other regions, that makes it possible to

increase considerably coal output and consequently to enable fuel cost reduction in national economy and to improve ecological conditions in number of regions.

The burning of coal-water fuel instead of coal makes dust pollution of power station 3-4 times lower, nitrogen oxides pollution - 4 times lower, The cost of nitrogen and sulphur oxides pollution reduction in burning process is much more less than of dry coal and heavy fuel oil.

Industrial tests of HLCWM production technology on the base of brown coals prove that it provides reliable mixture production with the concentration not less than 42% at the installation output 200-225 t/h and can be recommended to the inculcation on the coal basin "Beryosovsky".

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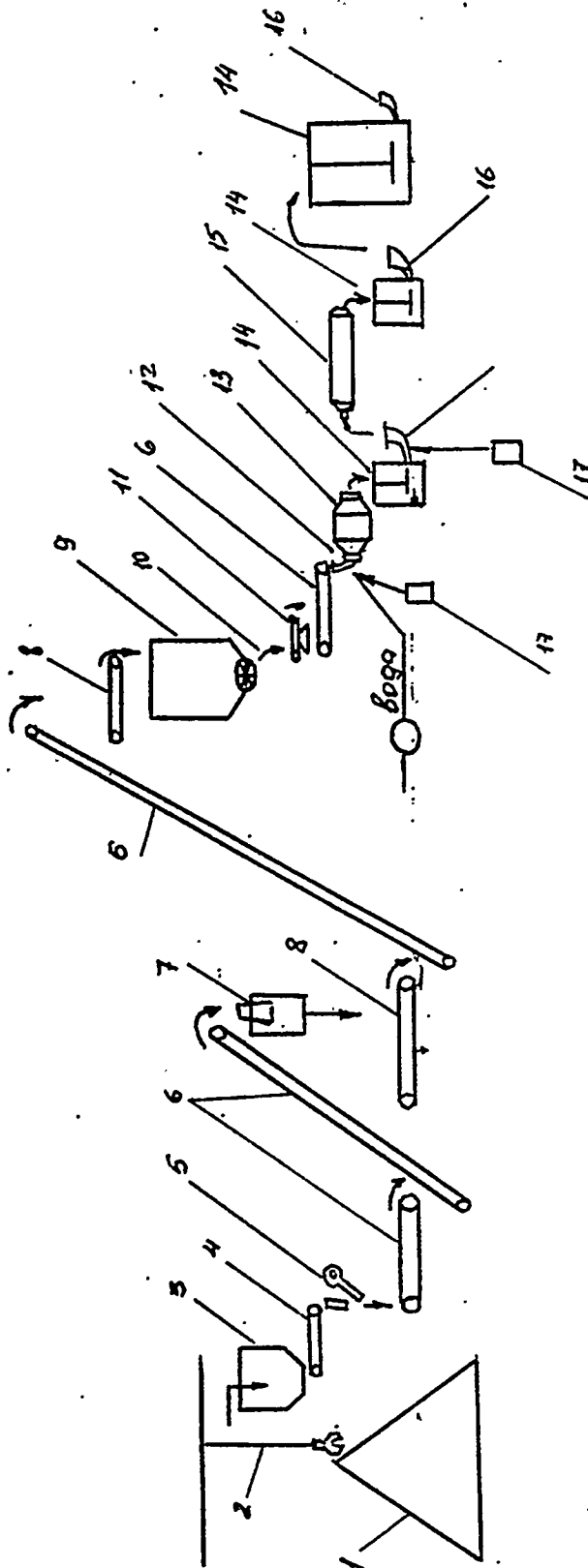


FIGURE 1 TECHNOLOGICAL SCHEME OF HLCWM PRODUCTION AT THE PILOT PLANT

1 - store-room; 2 - clamshell crane; 3 - bunker; 4 - apron feeder; 5 - jaw crusher; 6 - belt conveyor; 7 - cone-type crusher; 8 - shuttle conveyor; 9 - bunker; 10 - reciprocating plate feeder; 11 - belt weight-meter; 12 - water consumption register; 13 - ball mill; 14 - mixer; 15 - rod mill; 16 - pump; 17 - measuring tanks for admixtures.

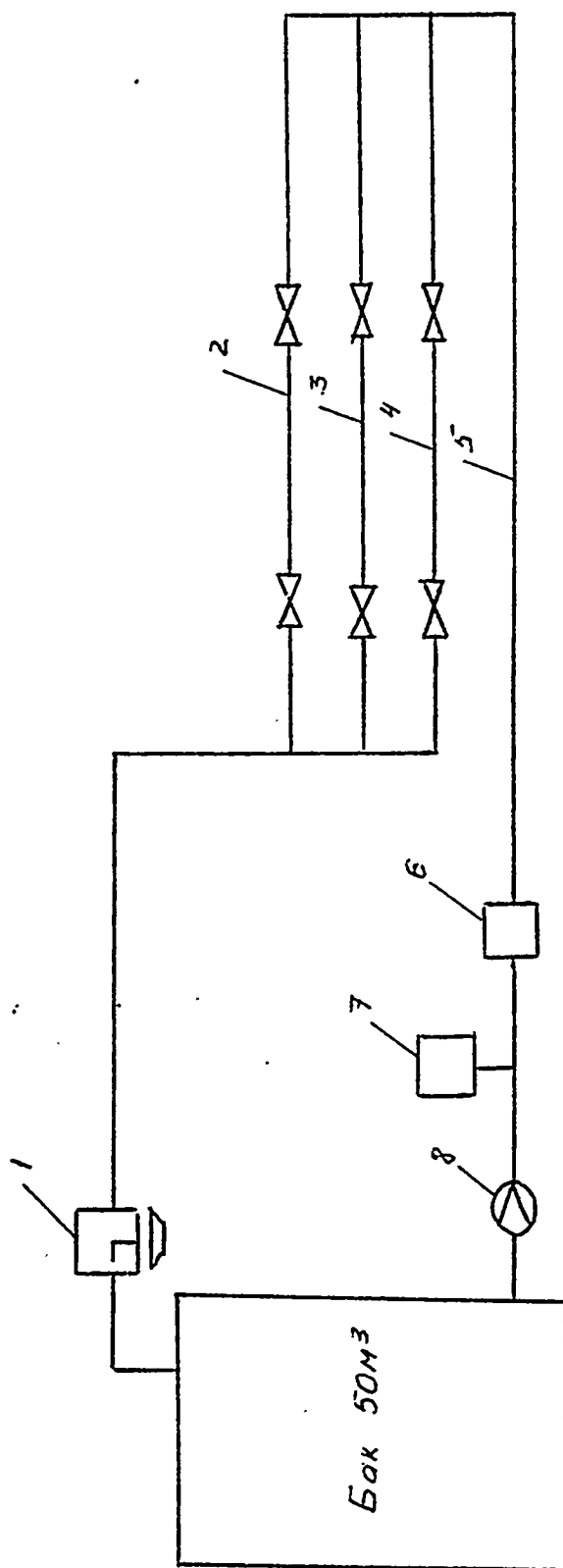


FIGURE 2 PRINCIPLE SCHEME OF TEST RING

1 - sampling apparatus; 2, 3, 4, 5 - pipes of 200, 150, 100, 400 mm in diameter accordingly; 6 - IR-61 flowmeter; 7 - pulsation damper; 8 - 6FSH pump.

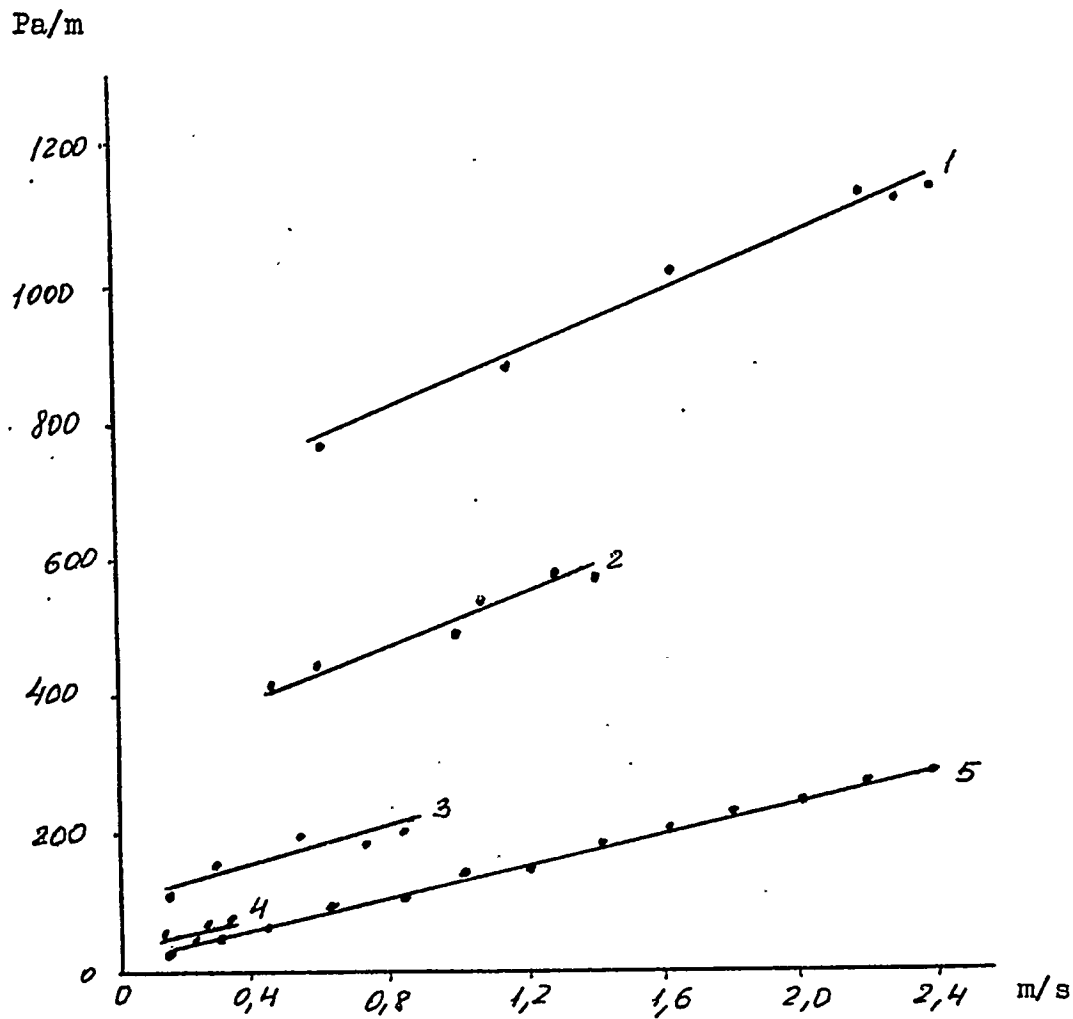


FIGURE 3 RELATIONSHIP BETWEEN PRESSURE LOSS AND MIXTURE FLOW SPEED IN PIPES OF DIFFERENT DIAMETERS
 1, 2, 3, 4, 5 - pipes of 100, 150, 200, 400 and 400 mm in diameter accordingly (theoretically)

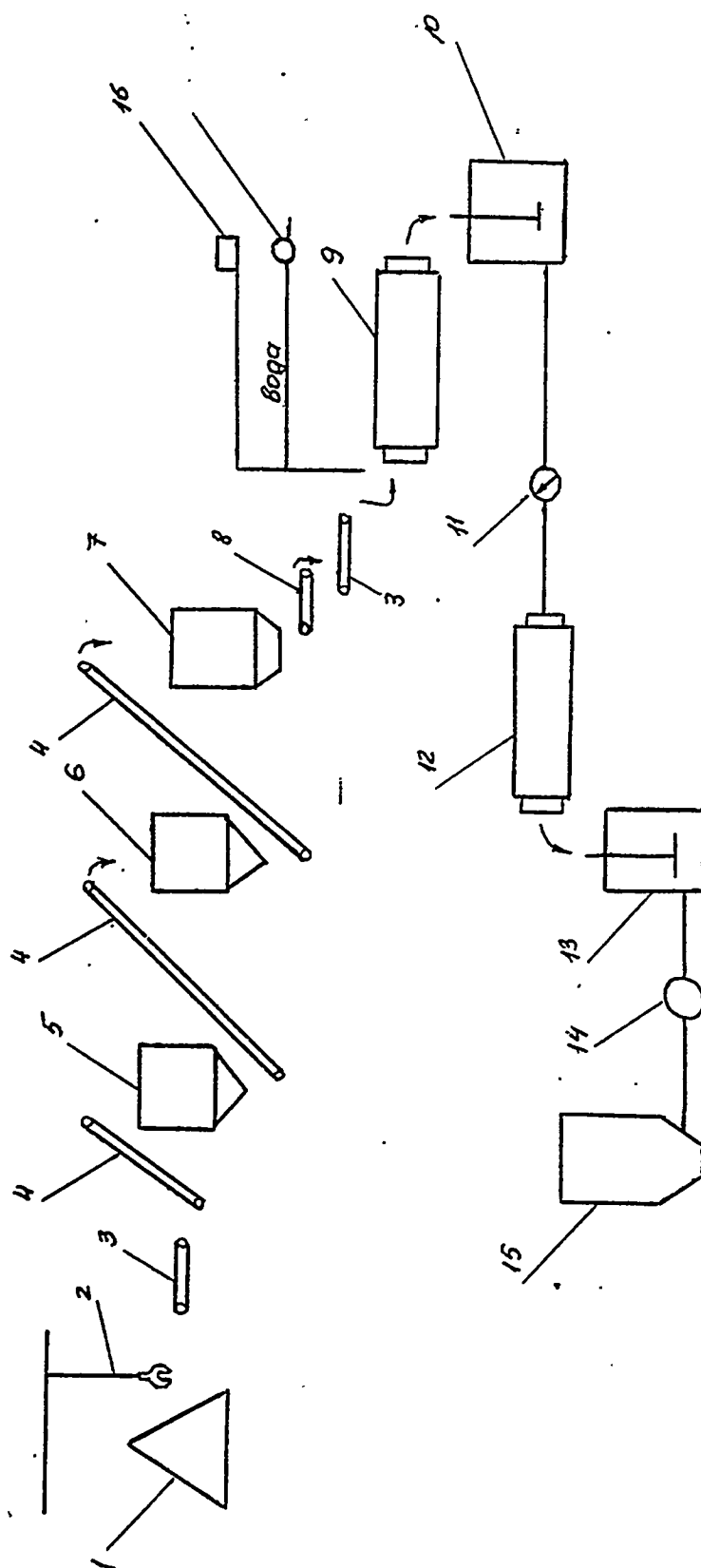


FIGURE 4

TECHNOLOGICAL SCHEME OF HLCWM PRODUCTION ON THE BASE OF BROWN COAL

1 - store-room; 2 - clamshell crane; 3 - reciprocating plate feeder; 4 - belt conveyor;
 5 - primary crushing crusher; 6 - fine crushing crusher; 7 - bunker; 8 - belt weigher;
 9 - ball mill; 10, 13 - tank with chain mixer; 11, 14 - pump; 12 - rod mill; 15 - vertical
 correction pool; 16 - measuring tank for admixtures.

TABLE 1

Physical-Chemical Properties of Coals

Sample Number	Content, %									Q_s^{daf} , MJ/kg
	W_t^z	A^d	V^{daf}	S_t^d	C^{daf}	H^{daf}	N^{daf}	O_t^{daf}	$(HA)^{daf}$	
1	28.1	27.6	53.4	0.9	72.0	5.0	1.0	21.1	47.8	---
2	31.3	26.9	53.6	1.1	73.5	5.1	0.8	17.6	37.2	---
3	32.4	17.6	51.2	0.8	70.5	4.8	0.8	23.1	54.2	---
4	25.4	10.6	50.9	0.5	71.3	5.1	0.8	22.3	55.8	---
5	27.9	9.1	45.0	0.6	72.8	4.8	0.9	20.9	37.2	---
6	27.3	6.5	49.5	0.3	68.8	3.8	1.2	25.9	28.3	27.1
7	28.3	6.2	52.5	0.2	69.1	4.3	0.8	25.7	29.9	27.6
8	33.0	13.1	43.5	0.9	72.6	4.8	1.3	20.4	33.4	28.7

TABLE 2
Ball Mill Operating Regimes and Based on Brown Coal HLCWM Properties
Under Pilot Conditions

Experiment Number	Coal Consumption, t/h	Water Consumption, m ³ /h	Coal ash content, %	Coal Classification Yield				HLCWM concentration, %
				+1 mm	1-0.2 mm	0.2-0.5 mm	-0.05mm	
1	4.0	2.0	27.6	---	---	---	---	---
2	4.0	2.5	26.9	0.7	21.4	35.0	42.9	42.0
3	5.0	4.0	27.6	3.5	24.6	34.7	37.2	41.6
4	5.0	2.5	9.1	1.6	21.7	27.0	49.7	40.0
5	5.6	3.5	27.6	4.4	26.8	29.7	39.1	43.6
6	6.0	3.0	9.1	2.1	27.6	28.8	41.5	44.1
7	6.0	3.5	27.6	4.5	25.3	30.5	39.7	---
8	6.0	4.0	26.9	2.5	26.8	30.0	40.7	43.2
9	6.5	4.6	6.2	---	---	---	---	---
10	7.0	5.0	26.9	5.4	30.9	26.9	36.8	40.4
11	8.0	4.0	26.9	6.1	26.4	34.6	32.9	46.7
12	8.0	4.7	26.9	5.0	32.4	33.9	33.7	42.2
13	11.7	6.0	26.9	13.1	38.1	28.8	20.0	47.0
14	12.0	9.0	6.5	---	---	---	---	---

TABLE 3

Technological Indexes of the Rod Mill's Work and HLCWM Properties on the Base of Brown Coal under Pilot Conditions

Operating Regime N	Mill Productivity, t/h	Coal Classification Yield, %				HLCWM concentration, %	$\mu\text{c, Pa.s}$	To, Pa
		+1 mm	1-0.2 mm	0.2-0.05 mm	-0.05mm			
1	2	3	4	5	6	7	8	9
1	6.0	0.1	2.9	15.1	81.9	42.0	0.1	7.0
1	6.0	0.1	3.0	17.3	79.9	42.4	0.5	11.0
1	6.0	0.4	3.9	14.8	80.9	44.0	0.8	30.0
2	6.5	0.1	3.3	13.8	82.8	41.2	0.24	13.5
2	6.5	0.1	2.9	16.0	81.0	39.2	0.1	6.5
2	6.5	0	1.0	17.9	81.1	38.7	0.2	12.0
3	9.0	0.3	3.1	22.0	74.6	43.6	0.9	20.0
4	7.5	0	1.6	20.5	77.9	39.5	0.2	9.0
5	9.1	0.2	3.6	25.3	70.9	44.2	0.75	9.5
6	9.0	0.1	3.5	26.0	70.4	43.6	---	---
6	9.0	0.1	3.1	27.0	69.9	43.5	---	---
7	9.5	0.4	3.3	26.1	70.5	44.3	0.8	10.0
8	10.0	0.3	2.2	22.0	75.5	40.0	0.16	10.0
8	10.0	0	3.4	25.5	71.1	44.2	1.0	10.0
9	10.0	0.2	1.5	27.0	71.3	38.7	0.3	16.0
9	11.1	0.1	1.0	20.8	78.1	35.0	0.1	4.5
9	11.1	0	2.6	28.1	63.3	39.8	0.8	14.0
10	12.0	1.8	6.0	24.5	67.7	40.8	0.2	9.0
11	12.0	2.6	5.8	36.7	57.4	45.1	1.1	24.0
12	12.7	0.1	2.0	37.7	60.2	42.8	0.45	12.0
13	17.7	1.3	14.5	38.2	46.0	46.1	1.05	22.0
14	21.0	2.4	9.4	39.9	48.3	38.7	1.1	8.0

TABLE 4

Physical-Chemical Properties of Coals

Rank of Coal	Content, %					Calorific Value, MJ/kg	
	W_t^z	A^d	V^{daf}	S_t^d	C^{daf}	Q_s^{daf}	Q_i^z
Brown B2	30.5	8.2	50.2	0.43	71.7	27.88	14.86
Bituminous D	15.2	21.6	48.0	0.30	76.6	29.77	18.67
Bituminous D	15.3	11.4	42.5	0.31	78.4	31.48	22.36

TABLE 5

HLCWM Properties Based on Two-Stage Grinding of Bituminous Coal

Mill productivity	HLCWM concentration	+ 1.0 mm	0.4-1.0 mm	0.2-0.4mm	0.1-0.2 mm	0.1-0.05 mm	-0.05-0mm	μ c, Pa.s	To, Pa
4.5	50.5	0.3	0.9	2.9	8.9	16.4	70.5	0.7	19.7
6	56	0.5	1.2	4.1	13.5	20.6	60.0	2.6	42.9
8	55.8	0.1	0.7	5.5	19.0	22.4	52.3	1.7	48.5
9	49.6	1.0	4.0	7.6	23.5	23.0	40.9	0.2	7.1
12	49.6	7.5	8.1	15.3	28.2	24.5	16.5	0.2	8.8

TABLE 6

HLCWM Properties Based on Two-Stage Grinding of Coals Mixture

Mill productivity of coal, t/h	HLCWM concentration, %	+ 1.0 mm	0.315-1.0 mm	0.2-0.315 mm	0.16-0.2 mm	01-16 mm	0.05-01 mm	-0.05 mm	Mc, Pa.s	To, Pa
4	53.8	0	0.3	0.5	---	18.2	16.7	64.2	0.6	14.2
5	48.8	0	0.1	0.2	0.41	3.3	19.3	76.8	0.5	5.6
6	49.6	0	0.3	0.5	---	13.7	19.9	65.7	0.3	3.8
7	50.25	0	0.3	0.6	1.1	7.2	23.4	67.5	0.4	4.2
8	51.0	0.2	3.6	6.5	---	27.7	14.5	47.5	0.3	5.6
9	52.4	1.6	5.9	6.8	6.1	13.3	15.6	50.7	0.4	6.1

TABLE 7
Technological Indexes of the Ball Mill's Work and HLCWM Properties on the Base of Brown Coal Under Industrial Conditions

Coal consumption, t/h	Water consumption, t/h	HLCWM yield from the mill, %	HLCWM concentration, %	Coal classification yield, %			μc , Pa.s	To, Pa
				0.2 mm	0.2-0.05 mm	-0.05 mm		
90	70	160	35.0-38.0	5-7	40-42	51-55	0.03-0.09	2-5
100	65	165	38.0-40.8	6-8	41-45	47-53	0.06-0.12	2-6
110	90	200	35.0-38.0	8-10	41-45	45-51	0.05-0.06	2-4
120	95	215	35.0-38.0	8-11	41-45	44-51	0.04-0.06	2-4
140	110	250	36.0-38.0	11-15	41-45	40-48	0.05-0.06	4
150	90	240	38.0-42.3	10-17	40-50	33-50	0.07-0.3	6-7
145	90	235	39.0-40.0	12-14	44-50	36-44	0.1-0.2	3-4
145	80	225	40.0-41.0	12-14	44-50	36-44	0.2-0.3	4-5

TABLE 8
Technological Indexes of the Rod Mill's Work and HLCWM Properties on the Base of Brown Coal Under Industrial Conditions

Mill productivity, t/h	HLCWM concentration, %	Coal classification yield, %				μ c, Pa.s	τ_0 , Pa
		+0.2 mm	0.2-0.1 mm	0.1-0.05 mm	-0.5 mm		
160	34.0-36.9	0.6-1.1	3.4-4.9	16.6-17.1	76.9-79.4	0.04-0.1	4-9
165	36.8-37.6	1.1-1.6	3.1-5.4	16.9-20.6	72.4-78.9	0.1-0.2	5-12
200	36.6-36.4	1.1-1.7	5.2-5.4	19.8-20.6	72.3-73.9	0.08-0.1	5
210	35.2-36.4	1.1-1.7	5.4-6.1	20.6-21.9	70.3-72.9	0.09-0.1	5-6
250	36.2-36.5	1.1-2.3	5.4-10.1	20.6-18.9	68.7-72.9	0.09-0.1	5-6
240	38.0-42.0	2.5-4.6	6.5-8.9	19.5-20.1	66.0-71.5	0.1-0.5	8-27
235	39.2-40.4	2.0-2.5	7.0-10.0	19.0-19.5	68.5-72.0	0.2-0.4	10-22
225	40.0-40.8	1.5-2.5	7.5-10.0	17.5-19.0	68.5-73.5	0.4-0.5	22-27

TABLE 9
The Results of HLCWM Properties Investigations During the Storage in the Correction Pond

Storage period 24 hours	HLCWM concentration, %	Rheological characteristics		Granulometer composition, %		
		μ c, Pa.s	To, Pa	+0.2 mm	0.05-0.2 mm	-0.05 mm
0	37.6	110	5	1.6	24.5	73.9
2	37.6	200	11	2.1	25.0	72.9
3	38.4	100	7	2.1	23.9	74.0
4	38.0	110	5	2.1	23.7	74.2
7	38.1	150	6	2.1	24.6	73.3
9	38.0	170	6	2.9	24.4	72.7
11	37.6	120	7	1.6	24.3	74.1
14	38.0	140	7	1.6	25.3	73.1
15	38.0	110	5	1.6	23.3	75.1

Environmental Science

Session C2

DETERMINATION OF HEAVY METALS IN SOLID EMISSION AND IMMISSION SAMPLES USING ATOMIC ABSORPTION SPECTROSCOPY

Milan Fara
František Novák

EGÚ Prague, PLC
Bichovice
Prague, Czech Republic

ABSTRACT

Both flame and electrothermal methods of atomic absorption spectroscopy (AAS) have been applied to the determination of Al, As, Be, Ca, Cd, Co, Cr, Cu, Fe, Mn, Ni, Pb, Tl, Se, V and Zn in emission and immission (deposition) samples decomposed in open PTFE test-tubes by individual fuming-off hydrofluoric, perchloric and nitric acid. An alternative hydride technique was also used for As and Se determination and Hg was determined using a self-contained AAS analyzer. A graphite platform proved good to overcome non-spectral interferences in AAS-ETA. Methods developed were verified by reference materials (inc. NBS 1633a).

OBJECTIVE

The analysis of emission and immission (deposition) samples to the trace metals content may be carried out by different analytical methods from which the neutron activation analysis (NAA), X-ray fluorescence (XRF) and atomic absorption spectroscopy (AAS) are mostly used. Although, considering the requirements of trace analysis, the use of several analytical methods based upon the different principals would be the most convenient approach to the problem of reliable results ("true value" phenomenon), the technical possibilities are destining to the application of one method only.

Unlike NAA and XRF, the AAS method requires the sample dissolved and therefore the sample pretreatment step is necessary. Nevertheless, the AAS with both flame and electrothermal techniques is more attainable method because of its versatility and moderate costs.

To decompose solid emission and deposition samples prior to AAS analysis, the methods of alkaline fusion and acid autoclave decomposition were developed earlier (1). While the acid autoclave decomposition has been found suitable for the metal determination by both flame and electrothermal AAS, the alkaline fusion with lithium metaborate brought matrix interferences mainly into the AAS-ETA procedure. An alternative method of sample decomposition, based upon the open-air digestion of the sample with mineral acids, is described in this paper.

APPARATUS

VARIAN SpectrAA 30P atomic absorption spectrometer with the deuterium background corrector and fitted with the GTA-96 graphite atomizer and VGA-76 vapor generation accessory was used.

A device for the sample decomposition consists of a home-made aluminium heating block electrically supplied via thyristor controller and provided with the holes for PTFE cylindrical test-tubes of 25 mm bore, 80 mm length and 2 mm wall thickness.

SAMPLES, SAMPLING TECHNIQUE AND REFERENCE MATERIALS USED

The ash samples examined originated from the combustion of high-ash brown coal and were collected in bulk from hoppers and from the stack breaching upstream and downstream the electrostatic precipitators or dry mechanical separators of power and/or heating plants.

The fly ash samples were collected isokinetically according to procedures outlined in CS Standard 12 4070 which is equal to USA EPA Methods 1 to 5. The isokinetic sampling procedure requires recording of a number of variables at the source while extracting a sample of known volume from the gas stream, incl. gas velocity, volumetric flow rate, moisture content of stack gas, temperature, etc. Isokinetic conditions were guaranteed by a control system using differential pressure signal which was produced by a specially corrected zero balanced nozzle. The samples were collected on cellulose fiber filters without separation respecting the particle size.

Ambient aerosols were sampled by filtration using NUCLEPORE or SYNPOR filters without fractionation or by means of sampling device VAPS from USA - EPA which separates particles into fine ($< 2.5 \mu\text{m}$) and coarse ($2.5 - 10 \mu\text{m}$) fractions on the NUCLEPORE filter. The density of particles on the surface of the filter was set by air volume flow through the filter (2).

To verify the method of determination, the following reference materials were used:

- Standard Reference material 1633a "Coal Fly Ash" (NBS, USA)
- Standard Reference Materials produced by Institute of Radioecology and Nuclear Techniques, Košice, Slovakia:

Fly Coal Ash from Coal Fired Power Plants ENO
 Fly Coal Ash from Coal Fired Power Plants EOP
 Fly Coal Ash from Coal Fired Power Plants ECH
 Fly Coal Ash ECO
 Steel Plant Flue Dust OK
 Copper Smelting Plant Flue Dust KHK.

SAMPLE TREATMENT

Prior to sample weighing, the pulverized samples were dried at 105°C for 4 hrs, the membrane NUCLEPORE and SYNPOR filters were dried at 85°C for 6 hrs and then stored in dessiccator over night.

For analysis, approx. 200 mg of the pulverized sample were weighed in the PTFE test-tube or the weighed and carefully folded membrane filter was inserted into the test-tube.

The samples were decomposed by fuming-off hydrofluoric, perchloric and nitric acids in following steps:

step	acid added	fuming temp., $^\circ\text{C}$
1	2 ml, nitric acid, 65%	140
2	1 ml, hydrofluoric acid, 39%	90 - 110
3	2 ml, perchloric acid, 70%	190 - 200
4	2 ml, nitric acid, 65%	140

All acids added were of *p.a.* grade.

Resulting solids were dissolved in 1 ml of 65% nitric acid and 5 ml of de-ionized water under heating to 65°C , the solution was cooled down, transferred into the 100 ml volumetric flask and diluted up to the mark with the de-ionized water. The solids resulting from the decomposition of immission samples trapped on membrane filters were dissolved similarly in 1 ml of 65% nitric acid with 5 ml water under

heating, and after cooling down diluted with water to 25 ml. The samples were stored in polyethylene bottles.

OPTIMUM INSTRUMENT PARAMETERS

The optimum instrument parameters for AAS flame technique were set up using the *Utilities SpectrAA-Plus, Vol. 1* software (VARIAN). The same programme has been used for the determination of detection limits. The parameters, calibration range and detection limits are given in Table 1.

Similary, the instrument parameters, calibration range and detection limits for AAS-ETA determination are given in Table 2. The drying step for all elements was set to 115 °C with the graphite tube and to 200 °C with the graphite platform, in both cases for 30 seconds. A matrix modifier 10 l of 14 ppm Ni solution was added to 10 l of the sample in case of As and Se determination. Argon was used as an inert gas with the flow rate 3 l/min and a gas-stop option was set during the atomization period.

To determine arsenic and selenium, a technique of hydride generation has been applied using VARIAN VGA-76 accessory. The calibration range were 0-40 and 0-80 ppb and the detection limits were 0.2 and 0.3 ppb, resp.

To determine mercury, a self-contained AAS analyzer TMA-254 or AMA-254 (Altec, Ltd., Prague) enabling the direct sample analysis was used. The instrument has two working ranges 0.05-40 ng Hg and 40-500 ng Hg and the detection limit 0.01 ng Hg. With the above instrument, there is no need of sample pretreatment. On the other hand, the instrument needs a new portion of the sample.

RESULTS

Analysis of reference materials verified the analytical process applied. All results of the reference materials analyzed were within the allowed interval.

Selected sample batches were analyzed by NAA parallel to AAS analysis. Results illustrating the comparison are given in Table 3.

The determination of As and Se by hydride technique is by one order more sensitive than with AAS-ETA. An addition of nickel modifier to the sample on the graphite platform reduces an effective sample volume to a half.

With AAS-ETA, the use of platform technique enable to overcome the matrix interferences. The platform extended the life time of the graphite tube and the recalibration interval. Thanks to the isothermal atomization, an improvement of the signal course was achieved by elements with the atomization temperature up to 2400 °C.

CONCLUSIONS

A method applied to the sample decomposition proved as an alternative to the acid autoclave method which is usually used. Control of the whole decomposition process and repeating of individual steps, if necessary, can be applied with advantage. In comparison to the autoclave method, the method is more versatile but it is time-consuming and requiers a clean fume chamber.

TABLE 1

Instrument parameters, calibration ranges and detection limits
for elements determined by AAS flame technique (VARIAN, SpectrAA 30P instrument)

parameter	Al	Ca	Cd	Co
lamp current, mA	10	10	4	7
slit width, nm	0.5	0.5	0.5	0.2
wavelength, nm	309.3	422.7	228.8	240.7
air flow, l/min	-	-	13.5	13.5
N ₂ O flow, l/min	11.0	11.0	-	-
C ₂ H ₄ flow, l/min	7.75	6.75	1.80	2.25
background corr.	no	no	no	no
caln. range, ppm	40.0	3.0	1.0	5.0
detection limit, ppm	0.13	0.007	0.001	0.007

parameter	Cr	Cu	Fe	Mn
lamp current, mA	7	4	5	5
slit width, nm	0.2	0.5	0.2	0.2
wavelength, nm	357.9	324.8	248.3	279.5
air flow, l/min	13.5	13.5	13.5	13.5
N ₂ O flow, l/min	-	-	-	-
C ₂ H ₄ flow, l/min	3.60	1.60	2.40	2.35
background corr.	no	no	yes	yes
caln. range, ppm	6.0	8.0	8.0	2.0
detection limit, ppm	0.039	0.002	0.018	0.003

parameter	Ni	Pb	V	Zn
lamp current, mA	4	5	20	5
slit width, nm	0.2	1.0	0.2	1.0
wavelength, nm	232.0	217.0	318.5	213.9
air flow, l/min	13.5	13.5	-	13.5
N ₂ O flow, l/min	-	-	11.0	-
C ₂ H ₄ flow, l/min	2.30	2.40	7.50	2.00
background corr.	yes	yes	no	yes
caln. range, ppm	12.0	5.0	40.0	1.5
detection limit, ppm	0.008	0.015	0.05	0.02

TABLE 2

Instrument parameters, calibration ranges and detection limits for elements determined by AAS-ETA
(VARIAN SpectrAA 30P with GTA-96 graphite atomizer)

parameter	Al	As	Be	Cd	Co
lamp current, mA	10	10	5	4	7
slit width, nm	0.5	0.5	1	0.5	0.2
wavelength, nm	309.3	193.7	234.9	228.8	240.7
platform	no	yes	yes	yes	yes
ash: temp., °C/ time, s	1400/10	800/20	500/10	500/15	1100/20
atomize:temp., °C/time,s	2500/2	2300/2	2000/2	2000/1.5	2500/3
background	no	yes	yes	yes	yes
sample volume, l	20	10	20	20	20
calibration range, ppb	50	50	50	50	50
detection limit, ppb	0.5	2	0.07	0.2	0.2

parameter	Cr	Cu	Fe	Mn	Ni
lamp current, mA	7	4	5	5	4
slit width, nm	0.2	0.5	0.2	0.2	0.2
wavelength, nm	357.9	324.8	248.3	279.5	232.0
platform	yes	yes	yes	no	yes
ash: temp., °C/ time, s	1300/20	850/10	1000/20	800/10	1100/10
atomize:temp., °C/time,s	2600/3	2300/2	2400/4	2400/2	2600/3
background	no	no	yes	yes	yes
sample volume, l	10	20	20	20	20
calibration range, ppb	20	20	20	10	100
detection limit, ppb	0.5	0.5	0.1	0.05	0.6

parameter	Pb	Se	Tl	V	Zn
lamp current, mA	5	10	10	20	5
slit width, nm	0.5	1	0.5	0.2	1
wavelength, nm	283.3	196.0	276.8	318.5	213.9
platform	yes	yes	yes	no	yes
ash: temp., °C/ time, s	500/15	700/20	500/10	1400/10	800/20
atomize:temp., °C/time,s	2000/1.5	2400/2	2000/2	2700/2	1700/2
background	yes	yes	yes	no	yes
sample volume, l	20	10	20	40	10
calibration range, ppb	50	50	50	200	2
detection limit, ppb	0.5	2	0.07	2	0.007

TABLE 3

Comparison of the determination of selected elements by AAS and NAA

sample No	Cd, g/g		Co, g/g		Cr, g/g	
	NAA	AAS	NAA	AAS	NAA	AAS
67	25.11	1.8	38.42	21.1	158.64	150
68	34.78	7.8	48.73	22.9	181.75	150
70	18.70	1.2	34.74	17.2	129.37	120
71	24.74	2.6	52.16	4.6	168.23	180
74	27.10	3.7	45.57	4.6	235.25	210
75	20.80	0.1	50.76	4.8	247.26	190
76	20.67	3.7	63.62	9.0	246.79	180
77	19.94	2.5	60.13	24.9	241.92	180
78	20.37	0.1	68.79	7.4	278.09	210

sample No	Cu, g/g		Fe, g/g		Ni, g/g	
	NAA	AAS	NAA	AAS	NAA	AAS
67	424.69	490	44066	47300	344.13	90
68	1160.40	1750	42469	48100	354.67	120
70	1460.10	1950	31799	30000	337.87	80
71	1950.90	2090	37033	37200	372.06	120
74	871.23	1070	41415	39000	400.51	80
75	247.23	350	34983	30700	364.51	80
76	327.55	460	33051	31300	391.25	110
77	322.90	430	343181	32300	385.07	110
78	336.84	440	37376	31200	343.39	120

sample No	Zn, g/g	
	NAA	AAS
67	597.83	550
68	2216.80	2380
70	953.68	1070
71	1712.30	1700
74	887.34	920
75	479.06	420
76	610.72	580
77	541.91	520
78	600.19	540

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BIOSURFACTANT—ENHANCED SOIL BIOREMEDIATION

Naim Kosaric
Gang Lu
J. Velikonja

Chemical & Biochemical Engineering Department
The University of Western Ontario
London, Ontario, Canada

ABSTRACT

Bioremediation of soil contaminated with organic chemicals is a viable alternative method for clean-up and remedy of hazardous waste sites. The final objective in this approach is to convert the parent toxicant into a readily biodegradable product which is harmless to human health and/or the environment.

Biodegradation of hydrocarbons in soil can also efficiently be enhanced by addition or in-situ production of biosurfactants. It was generally observed that the degradation time was shortened and particularly the adaptation time for the microbes. More data from our laboratories showed that chlorinated aromatic compounds, such as 2,4-dichlorophenol, a herbicide Metolachlor, as well as naphthalene are degraded faster and more completely when selected biosurfactants are added to the soil.

More recent data demonstrated an enhanced biodegradation of heavy hydrocarbons in petrochemical sludges, and in contaminated oil when biosurfactants were present or were added prior to the biodegradation process.

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Pollution Prevention/ Waste Management

Session C3

POLLUTION PREVENTION: THE ROLE OF A UNIVERSITY

Jack N. Barkenbus

Energy, Environment and Resources Center
University of Tennessee
Knoxville, Tennessee, USA

ABSTRACT

Pollution prevention is at the top of the waste management hierarchy in the United States. If you don't create pollution in the first place, concerns about transportation, treatment, storage, and disposal of waste are moot. While industry is on the front line in accomplishing significant pollution prevention, universities can play a meaningful role in its accomplishment as well. Universities can do this through three basic missions: education, research, and public service. Examples of how this is carried out at the University of Tennessee, Knoxville are provided. To be fully effective, universities need to organize in an interdisciplinary manner and adopt a public outreach agenda.

INTRODUCTION

In a general sense, pollution prevention is viewed as the most desirable element in a waste management strategy. The most commonly used definition of pollution prevention derives from the Pollution Prevention Act of 1990 passed by the U.S. Congress, and states that pollution prevention involves any practice which:

- reduces the amount of any hazardous substances, pollutant or contaminant entering any waste stream or otherwise released in the environment prior to recycling, treatment, or disposal;
- reduces the hazards to public health and the environment associated with the release of such substances, pollutants or contaminants.

Under the Pollution Act of 1990, therefore, pollution prevention is equated with "source reduction," although it may also be used to describe "in-process recycling."

Large scale efforts are underway in the United States, primarily on a voluntary basis, to implement pollution prevention. Significant progress has already been made, but if these efforts are to produce achievements on a sustainable basis, dedication to pollution prevention principles must become a routine and regularized process over time. Universities have a key role in ensuring that significant momentum for pollution prevention is sustained.

What follows is, first, a more explicit listing of what activities normally come under the rubric of pollution prevention, in addition to a description of the key factors that are driving the movement to source reduction. Next, the possible role of universities, and the University of Tennessee, Knoxville, in particular, will be highlighted. The contributions that universities make to pollution prevention can span time dimensions, from short to long. In any event, a real commitment to interdisciplinary involvement is a prerequisite for success.

WASTE HIERARCHY

Waste is an inevitable product of industrial civilization. But, there is no iron law of waste generation that requires x amount of waste to be generated per unit of output. What we have seen is that with some thinking and ingenuity, it is possible to significantly reduce levels of waste generation while maintaining high levels of productivity. When perceived costs, both in terms of public health and economics, of waste management and disposal were low, there was little incentive for pollution prevention. Those costs are no longer perceived to be low, and hence attention is increasingly being directed to examining the potential of pollution prevention in the United States.

From a national perspective, pollution prevention is clearly at the top of the waste options hierarchy, as seen in Figure 1. Quite simply, if you do not produce a waste, you do not have to pay for increasing waste management costs or the costs associated with waste remediation. Treatment and disposal costs for non-hazardous solid waste, hazardous waste, and radioactive waste have increased significantly over the past decade. Even if these costs are affordable today for firms there is no guarantee that costs will not continue to escalate. The inability to expeditiously site new treatment and disposal facilities will force costs to go even higher, and may even lead to the absence of disposal options (at the current time, low-level radioactive waste generators in several states lack a commercial site in which to dispose of their waste). The specter of unforeseen and unlimited liability associated with previously disposed of waste provides an especially chilling prospect for waste generators. For all of these reasons, pollution prevention, where feasible, makes good business sense.

Figure 1

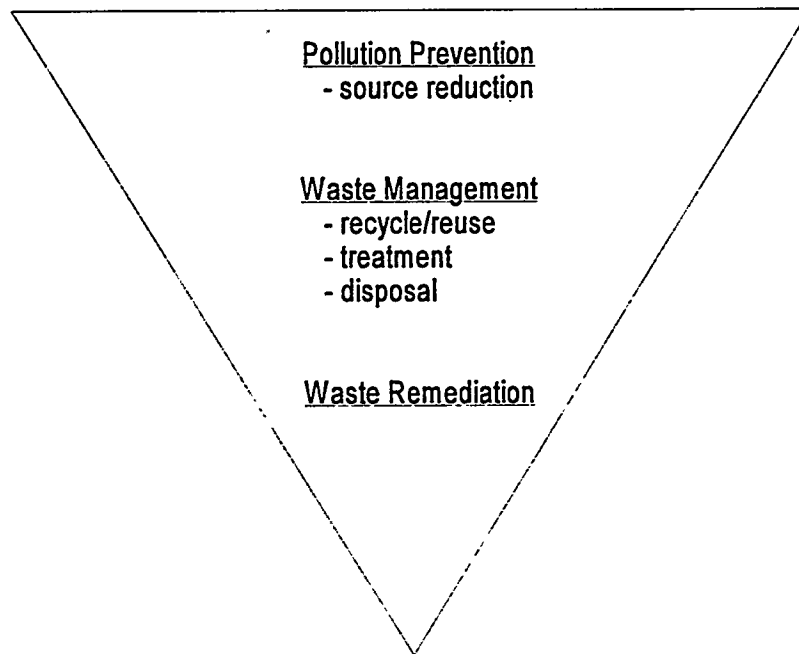


Figure 1. Hierarchy of Waste Options/Methods

DIMENSIONS OF POLLUTION PREVENTION

There are several dimensions to pollution prevention as seen in Figure 2.

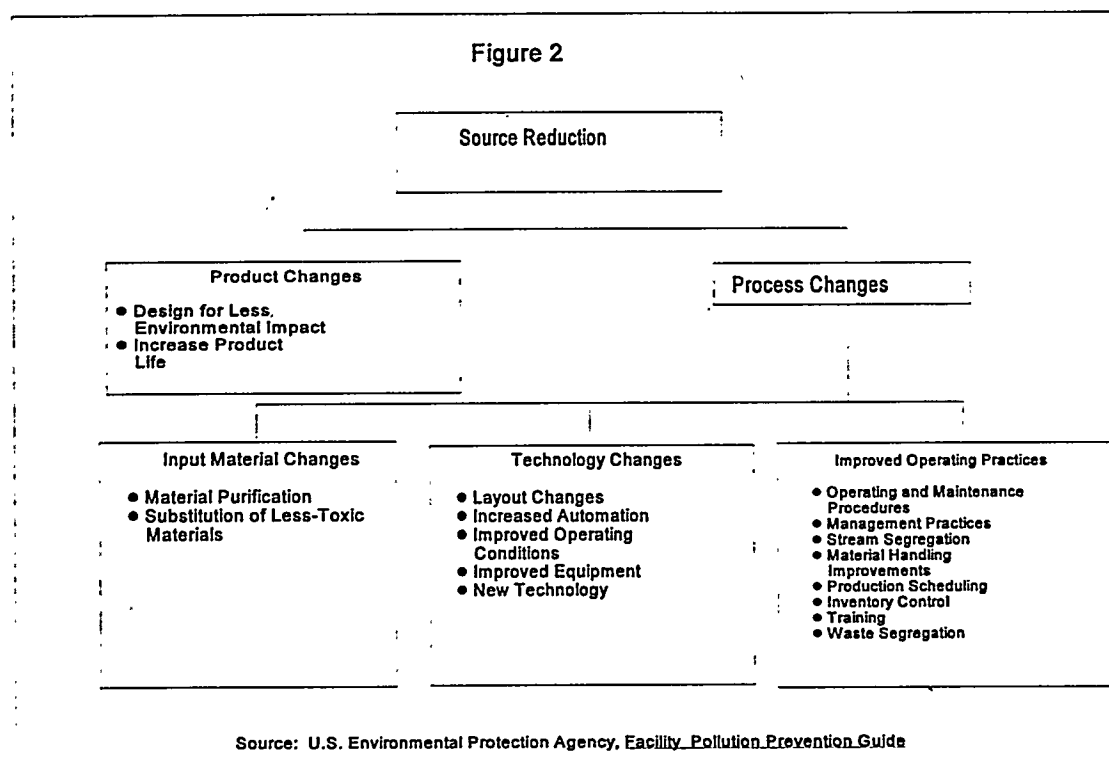


Figure 2. Source Reduction Methods

Firms are likely to approach the elements of pollution prevention in differing time frames as opposed to addressing them simultaneously. For example, most firms will first try to improve operating practices and only later begin looking at more far-reaching opportunities. This makes a good deal of sense. A firm that becomes serious about pollution prevention is likely, upon inspection, to find numerous operational improvements that can be made. Fundamental, of course, is first gaining a clear understanding of how and where waste is being generated, and, through plant-level audits establish a baseline. Employees also must be trained to segregate waste streams, improve maintenance, and optimize purchasing. All of this is commonly referred to as "good housekeeping" practices. Advantages of moving ahead on this front are that changes can be put in place fairly rapidly and there is little capital investment required. Quite often the benefit to cost ratio can be extremely high for these improvements.

"Good housekeeping", however, has its limits and more fundamental changes may be needed to fully address the pollution issue. A firm may then look to making changes in technology or in changing input materials. In some cases these changes are interchangeable. To avoid the use of solvents in cleaning, for example, some firms might install a mechanical paint stripping device. Another firm might substitute an aqueous based cleaner for the solvent. Solvent substitution is a high priority for several industries including chemical manufacturers, the printing industry, dry cleaning, and the automotive industry. In some cases, technological change may simply be the substitution of more efficient technologies for less efficient technologies or products (e.g. more efficient motors, and energy efficient lightbulbs).

Considerable progress has been made in developing substitutes for undesirable raw materials. Two obvious examples, are the phasing out of ozone-depleting chlorofluorocarbons, and the widescale removal of lead from batteries. Water- and soybean-based inks are also making heavy inroads in the printing industry. And considerable research and development is proceeding in the area of biodegradable plastics. Industries are likely to continue to search diligently for other "safe" substitutes.

The most fundamental and broad-ranging approach to pollution prevention is not through ad hoc process changes, but through a fully-integrated product redesign effort. It is ultimately desirable to identify the preferable characteristics of the end product and often work backwards into the manufacturing process to see how these characteristics can be implemented in the process. This "design for the environment" approach is gaining considerable momentum, and is perhaps best exemplified by wholesale efforts to re-invent the automobile.

GOVERNMENT ACTION

For the most part, pollution prevention is not being government-mandated—at least in the United States. Command-and control regulation is not appropriate when site-specific and industry-specific conditions loom so large in determining what makes good economic and environmental sense. For the most part, therefore, government is on the sidelines exhorting industry to take pollution prevention seriously, and then letting financial and public relations incentives drive firms toward implementation. The U.S. Environmental Protection Agency has established programs that seek to enlist voluntary commitments from firms to reduce their pollution. Typical are the "33/50 Program," the "Green Lights Program," "Energy Star Computers," and "Design for the Environment." Response to the EPA challenges has been encouraging. There continues to be a segment of industry, however, that refuses to respond to calls for voluntary pledges. For this reason some states—and the federal government—are contemplating regulations that would require pollution prevention planning. That is, firms would be required to demonstrate to regulators that they had, at least, reviewed all pollution prevention opportunities at their firm.

THE ROLES OF A UNIVERSITY

The primary role of a university, of course, is the transfer of knowledge, from professor to student and usually in the context of a classroom. But it is not the solitary role of a United States university. Faculty at universities are also deeply involved in research both applied and basic. In addition, many universities—particularly of the land-grant variety—take a public service mission very seriously. For these reasons, most universities see education, research, and public service as missions they must carry out equally to gain the respect of peer institutions and the public at large. Environmental issues, with pollution prevention being no exception, cut across disciplines and thereby the basic organizing structure of the university. This poses a significant challenge to university-based involvement. Universities either try to pigeonhole environmental issues into disciplinary constructs or they reorganize in some fashion to deal with them. Both approaches are fraught with pitfalls. Grafting environmental issues onto single disciplines is sure to eliminate the holistic approach to environmental solutions; creating new organizations and curricula on campus, on the other hand, runs the risk of establishing structures that are unsustainable in the "soil" of the university. Clearly, interdisciplinary approaches to pollution prevention are required. Chemical and environmental engineers are essential to any pollution prevention effort, but one cannot ignore the potential contributions that spring from economics, management science, biology, law, among other disciplines. Because of the difficulties in combining these perspectives, pollution prevention has not been at the center of university attention. But for those universities that have gained familiarity with multidisciplinary research, pollution prevention presents a topic around which much interesting and useful efforts can be marshalled. What follows is a description of the kinds of functions universities can participate in to further pollution prevention. Special attention will be given to showing how the University of Tennessee, at Knoxville (UTK) is carrying out many of these functions.

EDUCATION

Educating the next generation of engineers and managers in pollution prevention is an essential task that can easily be undertaken by universities. The issue is not one of simply transmitting technical information. To a significant degree education of the next generation also involves instilling another culture. For many engineers now working in the professional world, environmental concern was seen as designing optimum means for the treatment, storage, and disposal of wastes. It takes a different mind-set to address the issue of waste from the perspective of not creating it at all. New graduates entering the profession must bring the new mind-set or culture with them, or they will simply mimic existing approaches. One should not underestimate the importance of culture change. Pollution prevention opportunities will not arise unless one is looking for them. Figure 3 highlights the ways universities can structure their teaching mission to emphasize a pollution prevention ethic.

At present, a graduate level course in pollution prevention is being taught within the Chemical Engineering Department at UTK. A concentrated educational package—i.e. a curriculum module—is also being included in an undergraduate senior process design course within Chemical Engineering. Ideally, modules should be developed for numerous courses such that the pollution prevention theme is

Figure 3

EDUCATION

- Engineering Courses in Pollution Prevention
- Prepare Selected Modules for Insertion into Existing Courses
- Create Intern Opportunities

Figure 3. Education

integrated within a large part of the student's classwork. In this sense, pollution is presented as a cross-cutting ethic and not simply another discrete area of expertise. Certainly a wide range of engineering courses would be prime candidates for insertion of the module. Modules could also be appropriate for classes in business or management and economics, among others. Not all educational activities take place within a classroom. In fact, experience in the work world far outside the university campus has been shown to have major impacts upon student learning. The establishment of intern programs with industry, therefore, have extremely good educational value. UTK has established an intern program with Dow Chemical and DuPont focused on pollution prevention. Expansion of the program is being investigated. In short, there are several ways universities can approach the educational task. Payoffs to society from this role may not be great in the short term. Yet, the creation of a pollution prevention ethic through education will probably have the most significant long-term impact of any action the university might take.

RESEARCH

Research into pollution prevention can become an important activity at a university. Industry may be willing to support this research especially when it involves a specific, key technology that does not exist on-the-shelf, but which could, through research and development, be of use in the future. The College

of Engineering at UTK has, for example, developed a closed-loop plating system for the Ball Zinc Corporation and designed a reuse system for cooling water for the Saturn Corporation.

Even more noteworthy, UTK has established a multidisciplinary research center to examine issues going beyond single industries. The Center for Clean Products and Clean Technologies can perform a full range of research for cleaner products, including life cycle assessment studies, evaluation and comparisons of policy measures nationally and internationally, product development studies, new product demonstration programs, material use and substitution analysis, and toxic chemical impact

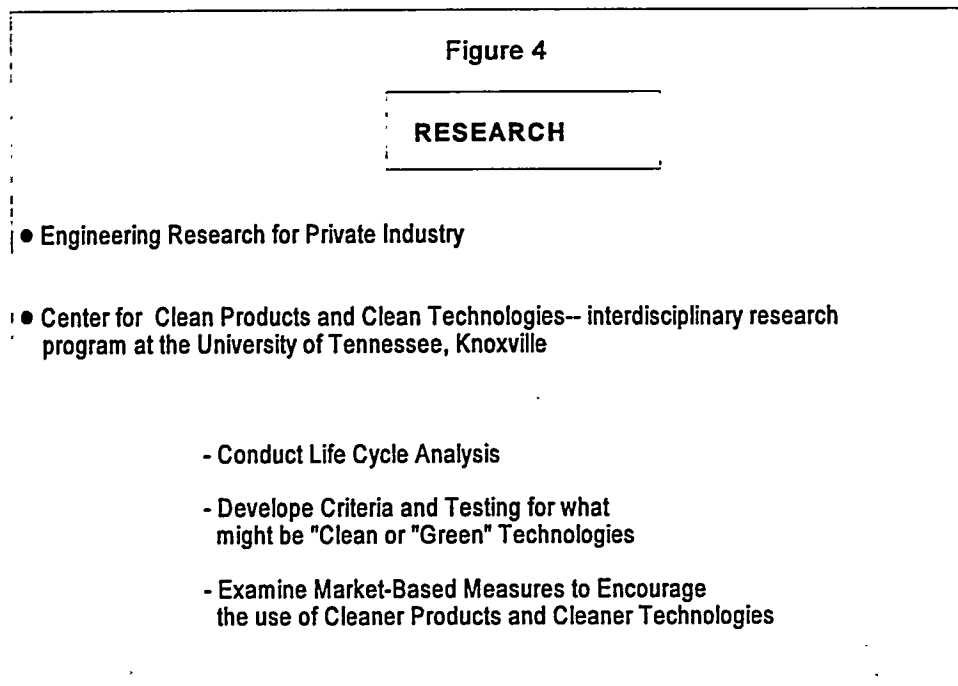


Figure 4. Research

assessment. Because of its dedication to impartial, scientific analysis, the Center has been able to attract funding from a multitude of government, private, and foundation sponsors. Once again, the Center is only successful because it takes a multidisciplinary approach to its research.

PUBLIC SERVICE

Universities in the United States take the obligation for public service seriously, if for no other reason than their ultimate health and even survival is contingent upon broad public support. The public as taxpayers expect a return on their money, and that return must be manifest in more than just education and research. Fortunately, there is a public service niche to be found for universities in the field of pollution prevention. This can be seen in Figure 5. Perhaps the most tangible public service contribution that can be made is through the conduct of waste reduction or pollution prevention audits at manufacturing firms in the vicinity of the university. Universities are repositories of technical expertise that can be tapped by local industries to assist in reducing the generation of waste. At UTK, two organizations have been formed to provide this service. The Center for Industrial Services (CIS) provides approximately 120 waste reduction assessments per year at small-to-medium size Tennessee manufacturing firms. The presumption is that larger firms have access to this expertise (from consulting firms) on a commercial basis; but that smaller firms lack the economies of scale to afford such services. The CIS audits result from specific state government funding to support this activity. The Tennessee Valley Authority (TVA) also funds CIS for the same purposes, but with a new dimension: TVA audits employ retired engineers

Figure 5

PUBLIC SERVICE

- Conducting Pollution Prevention Audits at Small to Medium to Size Firms
 - UTK Center for Industrial Services
 - UTK Waste Minimization Assessment Center
 - Information Dissemination
 - Response to Inquiries
 - Telecommunications
 - Workshops
-

Figure 5. Public Service

for the conduct of the audits. Retired engineers are an underutilized source in our society today, and this program has been successful in enlisting the time and expertise of the over-60 yrs. old community. In addition to on-site audits, CIS responds to general industry queries, with satellite teleconferences on waste reduction, and conducts workshops that average over 1,000 participants per year.

A second organization on the UTK campus—the Waste Minimization Assessment Center—also conducts audits at small-to-medium size firms. What distinguishes this program is the use of engineering graduate students. The Center receives funds from the U.S. Environmental Protection Agency for the program and carries out approximately 40 audits a year.

Both of the UTK programs are intended to assist firms in improving operating practices; that is, supporting "good housekeeping" practices. If firms seek to move more aggressively in the area of pollution prevention, toward input material or technology changes, they will contact private consulting firms or fund research. University technical assistance or public service is not intended to compete with private firms.

SUMMARY

Universities have the opportunity to be leaders, not followers, in promoting and furthering pollution prevention. While manufacturers are the key organizations that will carry out pollution prevention, universities can play a key role in producing a "climate" conducive to waste reduction. Much of what is needed to make significant gains is a cultural change in the business community. Universities can be at the forefront of cultural change from which specific and tangible efforts can be mounted by others. Universities are best positioned to play a significant role in early stages of the pollution prevention process. Product changes through source reduction require site- and product-specific knowledge that remains principally with the firm.

The University of Tennessee at Knoxville has made the commitment toward multipurpose involvement in pollution prevention, covering education, research, and public service. It is not the only university in the United States to do so, but this level of commitment and involvement is still rare. Universities structured solely on the basis of traditional departments and colleges are not positioned well to address most environmental issues, of which pollution prevention is just one. A university committed to multipurpose involvement in pollution prevention addresses the issue over all time dimensions. In the short term, public service, through waste audits, can provide tangible assistance to industry. Research results can span the time dimension, from short- to long-term. And education is best suited to long-term,

fundamental changes through the creation of a new technical and managerial elite. In short, involvement in pollution prevention can be a central university contribution to the goal of sustainable development.

UTILIZATION OF FLY ASH FOR STABILIZATION/SOLIDIFICATION OF HEAVY METAL CONTAMINATED SOILS

Dimitris Dermatas, Director
Xiaoguang Meng, Research Engineer

Keck Geoenvironmental Laboratory
Center for Environmental Engineering
Stevens Institute of Technology
Hoboken, New Jersey, USA

ABSTRACT

Pozzolanic-based stabilization/solidification (S/S) is an effective, yet economic technological alternative to immobilize heavy metals in contaminated soils and sludges. In the present study, fly ash waste materials were used along with quicklime (CaO) to immobilize lead, trivalent and hexavalent chromium present in contaminated clayey sand soils. The degree of heavy metal immobilization was evaluated using the Toxicity Characteristic Leaching Procedure (TCLP) as well as controlled extraction experiments. These leaching test results along with X-ray diffraction (XRD), scanning electron microscope and energy dispersive x-ray (SEM-EDX) analyses were also implemented to elucidate the mechanisms responsible for immobilization of the heavy metals under study. Finally, the reusability of the stabilized waste forms in construction applications was also investigated by performing unconfined compressive strength and swell tests. The experimental results suggest that the controlling mechanism for both lead and hexavalent chromium immobilization is surface adsorption, whereas for trivalent chromium it is hydroxide precipitation. Addition of fly ash to the contaminated soils effectively reduced heavy metal leachability well below the non-hazardous regulatory limits. However, quicklime addition was necessary in order to attain satisfactory immobilization levels. Overall, fly ash addition increases the immobilization pH region for all heavy metals tested, and significantly improves the stress-strain properties of the treated solids, thus allowing their reuse as readily available construction materials. The only potential problem associated with this quicklime/fly ash treatment is the excessive formation of the pozzolanic product ettringite in the presence of sulfates. Ettringite, when brought in contact with water, may cause significant swelling and subsequent deterioration of the stabilized matrix. Addition of minimum amounts of barium hydroxide was shown to effectively eliminate ettringite formation. Overall, due to the presence of very high levels of heavy metal contamination along with sulfates in the solid matrices under study, the results presented herein can be applied to the management of incinerator and coal fly ash, boiler slag and flue gas desulfurization wastes.

INTRODUCTION

Protecting the environment from hazardous pollutants associated with waste generation and disposal is a major concern in today's heavily industrialized world. Thus far, various technologies have been developed which transform hazardous wastes to non-toxic, or reduce the potential release of toxic species into the environment. One such promising technology is stabilization/solidification (S/S) of solid wastes by means of adding cementitious binders, like lime and cement [1,2]. During S/S applications, the toxic constituents present in the waste form are physically as well as chemically "fixed", that is their mobility is significantly reduced so as to minimize the threat to the environment and also ensure compliance with existing regulatory standards. Moreover, the stabilized wastes may attain adequate stress-strain properties to enable their utilization in construction applications, such as engineering fill, road or pavement subgrade, backfill, and base material.

Coarse-grained wastes, stabilized with quicklime or other chemical additives, will frequently attain poor geotechnical and environmental properties and may not meet the requirements for reuse in construction applications. That is mainly attributed to the coarse-grained waste's limited pozzolanic surface area that is available for cementing reactions. Fly ash can be added to such wastes (coarse-

grained) in order to increase the available pozzolanic surface area, and hence improve one or all of the following properties of the waste mixture:

- 1) Strength
- 2) Workability
- 3) Buffering capacity (capacity to resist pH changes)
- 4) Heavy metal leachability

Fly ash is defined as "the finely divided residue resulting from the combustion of ground or powdered coal which is transported from the firebox through the boiler by flue gases; known in UK as pulverized fuel ash (pfa)" [3]. Owing to its pozzolanic nature, fly ash can be used in a variety of construction applications. The majority of fly ash use is directed towards cement and concrete products, structural fills and embankments and road base and subbase applications. The use of fly ash in the United States has been primarily directed towards its incorporation in concrete products, which serves as an excellent example of cost effective waste product utilization. However, the amount of ash used in concrete is just a small portion of the volume of ash produced. In fact, if ash were used in all concrete produced in the United States, it would still be only a minor percentage of the volume available [4]. The latest published data [5] by the ACAA (American Coal Ash Association) indicate that overall there is only a 26% of the total quantity of fly ash produced annually in the United States is being used in construction applications, with the rest of it, about 40 million short tons, currently being disposed. This fly ash utilization rate compares with close to 100% fly ash use for countries like the Netherlands and Germany. Moreover, for all the fly ash that is not utilized the associated disposal cost is estimated at approximately \$1.2 billion per year (based on municipal waste disposal costs of \$30 per short ton). This disposal cost will only be increasing as solid waste disposal capacity is steadily decreasing. Consequently, there is an ever increasing necessity of encouraging large tonnage utilization of fly ash in the US.

Combustion of subbituminous coal produces a fly ash (fly ash class C) rich in calcium, with self-cementing characteristics, which has been successfully used in a wide range of construction applications [6]. Bituminous coals and many lignite coals when burned, produce a low calcium fly ash which is known as class F. Class F fly ash does not readily exhibit self-cementing characteristics but upon lime addition, similar to class C fly ash, pozzolanic reactions will be initiated, leading to calcium aluminum and calcium silicate hydrate (CAH and CSH) cementitious product formation. Since fly ash is by itself considered a waste, adding fly ash to treat contaminated media would be a cost effective method of disposing it. It would provide economic benefits by reducing disposal costs and mitigating possible negative environmental effects, originating in either the fly ash or the solid waste, through proper engineering control.

Laboratories throughout the world have already performed substantial research on solid waste stabilization/solidification, and many investigators have been experimenting with the possibility of using fly ash, in order to obtain a stabilized waste form that can be put to further beneficial use without posing a threat to the surrounding environment [3, 7, 8]. Fly ash possesses artificial pozzolans, which upon reaction with lime result in significant development of strength through cementation [9]. In addition, a number of other combustion products, such as incinerator ash, boiler slag, FGD wastes etc., are presently considered to belong in the broader fly ash category, mainly due to similarities in texture, physicochemical properties and overall behavior.

Here at Stevens Institute of Technology, at the Center for Environmental Engineering, an experimental study was initiated to test the use of fly ash in addition to quicklime and sulfate salts, in a stabilization/solidification (S/S) scheme, designed to remediate heavy metal contaminated coarse grained soils. This study was conducted using artificially contaminated soils, prepared in our laboratory, and the contaminants under study included lead (Pb^{2+}) and chromium (Cr^{+3} and Cr^{+6}). The addition of sulfates as well as high levels of heavy metal contaminant contents was pursued in order to be able to extend the present study results to other waste by-product reuse (incinerator ash, FGD wastes, etc.). Overall, the main study objectives can be summarized as follows:

1. Immobilize Pb, trivalent and hexavalent Cr within a solidified matrix. The main goal here is for regulatory compliance upon treatment application. That is, the treatment final product should satisfy the US Environmental Protection Agency (EPA) promulgation based on the Toxicity

Characteristics Leaching Procedure (TCLP) non-hazardous release criteria (5 ppm for all heavy metals studied).

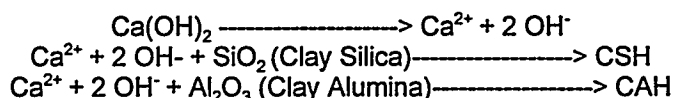
2. Investigate the potential for reuse of the treatment final product as readily available construction material. Strength and swell test results were the main tools used towards a preliminary evaluation of reuse potential.
3. Elucidate the mechanisms controlling heavy metal immobilization in the treated solids. To do so, heavy metal TCLP and controlled extraction test results, along with x-ray diffraction (XRD) and scanning electron microscope - energy dispersive x-ray (SEM - EDX) analyses were used.

In order to attain the study objectives, a laboratory evaluation of contaminated soil mixtures, stabilized with quicklime, sodium sulfate decahydrate and fly ash was performed. During laboratory experiments the strength, swell, TCLP (Toxicity Characteristic Leaching Procedure) concentrations, mineralogical, and micromorphological characteristics were monitored, for both treated and untreated specimens.

QUICKLIME S/S TREATMENT PRINCIPLES

When a significant quantity of lime is added to a soil-fly ash mixture, the pH of the soil-fly ash-lime mixture is elevated to approximately 12.8, the pH of saturated lime water. This is a very high pH compared to the pH of natural soil deposits, which are typically in the range of 5 to 8. The solubilities of silica, alumina, present in fly ash and clay minerals are greatly increased at this elevated pH levels, thus making them available for reaction with the calcium from lime and/or fly ash to form the cementitious hydrates, CAH and CSH. It is generally believed, that formation of these calcium aluminosilicate hydrates is mainly responsible for the high strength and low swell of the treated solids, as well as for heavy metal immobilization through surface sorption, inclusion and physical entrapment.

A simplified qualitative representation of some typical soil lime (pozzolanic) reactions is summarized below:



where: C=CaO, S=SiO₂, A=Al₂O₃, and H=H₂O. A wide variety of hydrate forms can be obtained, depending on reaction conditions, e.g., quantity and type of lime, soil characteristics, curing time and temperature.

When the soil and/or groundwater contain sulfates in solution, they may combine with the alumina liberated from the solids, to form a series of calcium-aluminate-sulfate hydrate compounds, leading ultimately to the formation of ettringite, [Ca₃Al(OH)₆]₂(SO₄)₃·26 H₂O. Ettringite, has a needle-like crystal structure based on columns of empirical composition [Ca₃Al(OH)₆ 12 H₂O]₃₊, which run parallel to the needle axis; between them lie channels composed of sulfate ions and remaining water molecules. Although not investigated systematically, previous research in Japan has established the effectiveness of lime stabilization on heavy metal wastes, as well as the potential for reuse of the treated waste as a construction material [10]. The Japanese seem to attribute the significant strength gains of the treated waste forms as well as the immobilization of the heavy metal species, to the formation of cement bacillus, commonly known as ettringite. Moreover, recently performed research [11] has established that hexavalent chromium immobilization may be achieved through isomorphous substitution of chromate for sulfate in the channels present in the ettringite crystal structure.

Ettringite however, is known to be quite expansive when brought in contact with water, and its swelling could lead to catastrophic failures [12, 13, 14, 15, 16], as well as possible releases of the previously immobilized toxic heavy metal components into adjacent water bodies. In the present study we took a closer look at ettringite formation and subsequent hydration under different conditions, and came up with an explanation as to whether ettringite formation is desirable or not, and under what conditions

of composition and confinement ettringite is not conducive to swelling. Furthermore, the contribution of ettringite and the other cementitious treatment products, to the resulting heavy metal immobilization and strength increases following treatment, was also investigated.

EXPERIMENTAL PROCEDURES

During treatment, clay-sand mixes, artificially contaminated using heavy metal salts or oxides, were dry mixed with quicklime (CaO) and sodium sulfate. For the artificial soil mixes, two different types of clay were used, kaolinite and montmorillonite. These types of clay were used because they represent the two extremes of layered aluminosilicate surface area attributes and overall behavior. This paper mainly focuses on results obtained for kaolinite-sand soil mixes but some results pertaining to montmorillonite-sand mixes are also presented. Fly ash, a non-layered iron aluminosilicate was added into the contaminated soils to improve their physico-chemical behavior. First, a number of batch-type tests were performed in order to optimize treatment design. The actual treatment entailed compaction of the dry-mixed soils at optimum water content, and curing of the compacted specimens. Following different curing periods, specimens were tested to determine their leaching potential and their stress-strain properties, under a variety of different testing conditions.

The mechanical and physico-chemical behavior of the compacted specimens, as determined during testing, formed the basis for evaluating both the degree of immobilization of the heavy metal contaminants and the reuse potential of the treated waste form. Specifically, the effectiveness of the quicklime treatment was evaluated based on the heavy metal leachability (in terms of the Toxicity Characteristic Leaching Procedure, TCLP), unconfined compressive strength and swell results. In addition to these basic tests, X-ray diffraction and scanning electron microscopy determinations, were used to elucidate the underlying mechanisms of heavy metal immobilization. A schematic representation of the experimental approach used during the present study is illustrated in Figure 1. Durability and column and monolithic leaching testing results are not presented in this paper.

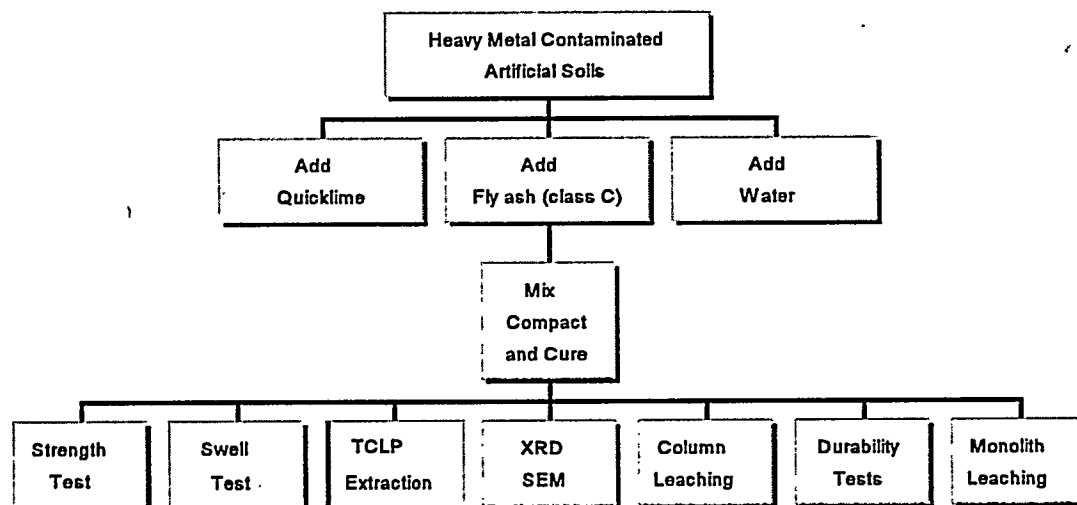


Figure 1: Outline of the experimental methodology.

Materials

Coal fly ash (Class C) was obtained from American Fly Ash Company (Naperville, Illinois) and used in the present study. Scanning electron microscopy (SEM) analyses showed that the fly ash basically consists of spherical glassy particles with particle size range between 1 to 6 μ m. Kaolinite and montmorillonite clay minerals with more than 99% of the particles passing through 325 mesh sieve were provided by Dry Branch Kaolin Company (Dry Branch, Georgia) and used as a source of surface area and

pozzolanic material in the base soil mixes. Chemical grade CaO (quicklime) powder which contains 95% of CaO was obtained from the Bellefonte Lime Company (Bellefonte, Pennsylvania). The chemical composition of the fly ash, kaolinite, montmorillonite and quicklime are listed in Table 1. Analytical grade potassium chromate (K_2CrO_4), chromium nitrate ($Cr(NO_3)_3$) and lead oxide (PbO) were used as the pollutant sources for Cr^{6+} , Cr^{3+} and Pb^{2+} , respectively.

Preparation of Artificially Contaminated Soil

Artificial soil specimens composed of kaolinite and fine quartz sand were prepared and used for the stabilization/solidification experiments. Mixtures of clay and sand were used, rather than pure clay, to obtain specimens with gradations more comparable to those of naturally occurring soils and to provide materials that could be compacted easier than pure clays. In order to avoid dilution effects caused by the addition of fly ash, all contaminants were simultaneously added on a total clay, sand and fly ash weight basis (Table 2). Quicklime (10% by total weight of the solids) and sodium sulfate decahydrate (5% by total weight of the solids) were then added, and following addition of water and mixing, samples were cured for 24 hours for Cr^{6+} reduction to take place. Specimens were then compacted at optimum water content according to ASTM D1557-91 standard (*Test Methods for Laboratory Compaction Characteristics of Soil Using Modified Effort*) [17], and cured at 20°C and 95% relative humidity (RH). Specimen dimensions varied depending on the type of test to be performed. For strength testing specimen dimensions were 3.6 cm in diameter and 7.1 cm in height. For swell tests specimens of 4 cm high and 4.7 cm in diameter were prepared. A 4 lb. (1.8 kg) compaction rammer with a 12 inch (30.5 cm) drop was fabricated in order to achieve the required compactive effort of 56,250 lb./ft² specified by ASTM D 1557-91 [17]. The compacted specimens were cured for 28 days before they were tested for their unconfined compressive strength and vertical swell.

Table 1

Characteristics of the materials used during the present study

COMPOSITION	% Content			
	Kaolinite	Montmorillonite	Quicklime	Fly ash
Silicon Dioxide	45.70	67.20	1.20	34.2
Aluminum Oxide	38.50	15.20	-	19.3
Iron Oxide	0.40	1.87	-	5.64
Calcium Oxide	0.20	1.92	95.40	25.8
Magnesium Oxide	0.10	3.20	0.85	5.07
Sulfur Trioxide	-	-	0.012 (as S)	2.2
Sodium Oxide	0.04	2.58	-	2.04
Potassium Oxide	0.10	0.96	-	0.52
Titanium Dioxide	1.40	0.16	-	-
R ₂ O ₃	-	-	0.75	-
Loss on Ignition	13.60	5.70	0.55	0.11
PROPERTIES	Values			
Surface Area (m ² /g)	66	760	40.0-41.5	31
Method used	EGME	EGME	BET N ₂ ads	EGME
pH	4.0-6.5 (20% solids)	7 (10% solids, dist. H ₂ O)	12.9 (50% solids, dist. H ₂ O)	12.3 (50% solids, dist. H ₂ O)
C.E.C (meq./100 g)	4.5-5.5	80	-	-

Table 2

Heavy metal contents in the artificial soils

Contaminant source	Heavy metal species soil concentrations (mg/kg soil)
$\text{Cr}(\text{NO}_3)_3$	4,000
K_2CrO_4	4,000
PbO	7,000

Strength and Swell Tests

Following specimen compaction and designated curing, specimens were taken out of storage and tested for strength and swell. Unconfined compressive strength testing was performed according to ASTM D2166-85 [17]. Swell tests were conducted in a water-saturated sand bath. The sand used for the sand bath, was a high permeability medium coarse clean quartz sand. The specimen was placed in a high density polyethylene cup that would not react under the treatment-induced high pH conditions, as would be the case for glass or metal containers. The specimen was placed in the middle of the cup, and confined laterally by the surrounding sand. The top of the specimen was at about the same level as the top of the plastic container. In such a way it was possible to measure the vertical swell by placing a dial gage on top of the specimen. The specimen and confining sand were soaked using distilled water. Immediately following initial saturation of the sand bath, a height reading was taken using a calibrated dial gage, and specimens were then placed in a 20°C and 95% RH soaking environment. Thereafter, dial readings were taken periodically until swelling reached equilibrium, in which case a final vertical swell value (percent of vertical swell) was recorded for each test specimen. All strength and swell tests were performed on specimen duplicates and average values were used.

Leaching Tests

Following strength testing, samples derived from failed specimens, were tested for their heavy metal leachability using the US Environmental Protection Agency (EPA) TCLP [18] test. During this leaching test, the solid was pulverized and mixed with an acetic acid solution (pH = 3 if solid pH is higher than 5 or pH = 5 if solid pH is lower than 5) at a solution to solid ratio of 20. The suspension was then tumbled for 18 hours and following this, separation of the extract solution from the solids was achieved by filtration. Lead and trivalent chromium concentrations in the solution were measured using an inductively coupled plasma atomic emission spectrometer. Hexavalent chromium concentrations in solution were evaluated using a UV-VIS spectrophotometer. All TCLP testing was performed on sample duplicates and average values were used. In addition, all analyses were performed by using two different quality control standards as well as the method of standard additions (spiking) to ensure proper quality control of the reported results.

Moreover, TCLP-based controlled extraction experiments were conducted by using the TCLP test procedure, as described above, while adjusting the pH of the suspension using concentrated nitric acid or sodium hydroxide. During controlled extraction experiments a total of 10-12 samples were prepared by mixing 3 grams of solid with 60 mL of pH=3 TCLP solution. Following pH adjustment from 3 to 13, samples were tumbled for 18 hours. Then the final pH was measured, samples were filtered and the aqueous extract was analyzed for heavy metal concentrations. Solubility experiments were also performed for both Pb and trivalent Cr, where 377 mg of litharge (PbO) or 754 mg of chromium sulfate along with 1 gram of quicklime (CaO) were dissolved in 1L TCLP solution (pH=3) and pH was adjusted by adding concentrated nitric acid or sodium hydroxide.

Specimen Designation

In order to effectively present the obtained results, a specimen designation scheme will be illustrated in the following examples. Letters in the specimen designation indicate mineralogy, i.e., K: kaolinite, M: montmorillonite, C: class C fly ash, and L: quicklime. Numbers following letters indicate the percent weight of the given attribute. Since the same type of fine quartz sand was added in all mixes,

complimentary to the clay and/or fly ash presence, sand is not included in the specimen designation. Sand content is always complimentary to the clay or fly ash content on a 100 percent basis. For example the specimen designation K30L10 stands for 30% kaolinite and 70% quartz fine sand at a treatment level of 10% quicklime by weight of the clay-sand soil. Conversely, K30L10S stands for 30% kaolinite and 70% sand at a quicklime treatment level of 10% and a sodium sulfate decahydrate addition of 5%, whereas K5C25L0 stands for 5% kaolinite, 25% fly ash class C and 70% sand at a treatment level of 0% quicklime (untreated).

RESULTS AND DISCUSSIONS

Strength and Swell

Compressive strength results are shown in Figure 2, as a function of the main solid mix design parameters (i.e., clay content, quicklime, sulfate and fly ash addition). The coarse-grained untreated (no quicklime-sulfate) soil (K5L0) possesses a minimum unconfined compressive strength of only 12.8 kPa. Upon quicklime treatment, a significant strength increase to 144.9 kPa without sulfate addition, and 257.5 kPa in the presence of sulfates was observed. Previous research [15, 16] has demonstrated this strength enhancement effect in clay-sand soils upon lime addition, especially in the presence of sulfates. When sulfates are present in clayey soils, the mineral ettringite is bound to form upon quicklime addition. Based on analyses of the lime treated soil crystallography, it was found that ettringite's needle-like structure leads to crystal interlocking, and therefore, a significant strength recovery. When the kaolinite clay content was increased to 30% (K30L10), an even higher level of strength enhancement is achieved, however, with no apparent effect due to sulfate presence. The increased strength is attributed to the increased amount of pozzolanic product formation due to the presence of increased amounts of clay alumina and silica. Sulfate addition does not affect strength levels probably due to the formation of a monosulfate hydrate instead of ettringite. Previous research [15, 16, 19] has established that when the molar ratio of alumina to sulfate in the solid is greater than one (1.0) monosulfate formation is favored, whereas if it is less than 1.0 ettringite formation is favored. In the present study as clay content was increased from 5 % to 30 %, the alumina to sulfate molar ratio shifted from a value of less than one to a value greater than one. Monosulfate is not as good of a strength agent as ettringite is, owing to its layer structure.

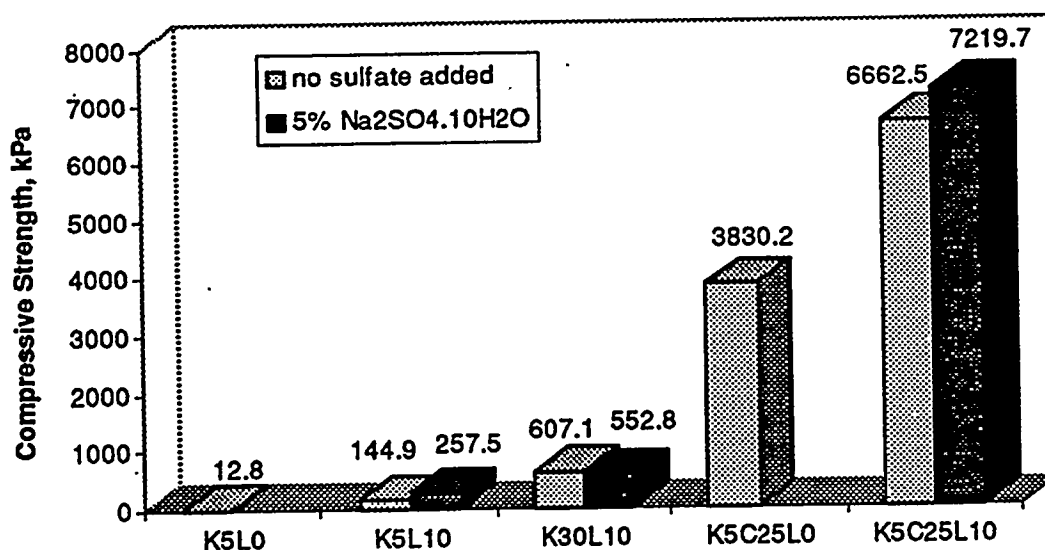


Figure 2: Specimen Unconfined Compressive Strength levels for different solid mixes with and without sulfate addition, following 28 days of specimen curing. (1 kPa = 6.9 psi)

Upon fly ash addition to the untreated low clay content, coarse-grained soil mix (K5C25L0), strength increases dramatically to 3830.2 kPa. Fly ash class C, upon exposure to the water of compaction and due to its high CaO content (~25%), hydrates forming cementitious pozzolanic products similar to those during the hydration of Portland cement or lime. Following quicklime treatment, where an additional 10% by weight of quicklime was incorporated into the kaolinite-fly ash-sand mix (K5C25L10), unconfined compressive strengths of 6,662.5 kPa without sulfates, and 7,219.7 kPa upon sulfate addition were evidenced. Clearly, fly ash in the presence of quicklime is a superior strength enhancement agent, especially for weak soils. Overall, the quicklime/fly ash treatment resulted in almost 1,000 times higher strength values than those measured for the untreated soil. The observed strength levels are comparable to those of concrete products.

X-ray diffraction analyses of a K30L10 sample indicated that pozzolanic product formation did take place within the 28-day curing period (Figure 3). Calcium silicate hydrate (CSH) and calcium silicate hydroxide (CSH*) were the main products identified. Some excess lime (Ca(OH)_2) was also identified, indicating that pozzolanic reactions were definitely not over by the end of the 28-day period. No calcium aluminum hydrate products (CAH or ettringite) were identified in the absence of sulfates. Conversely, in the presence of sulfates (K30L10S), the formation of calcium aluminum sulfate hydrate products was confirmed (Figure 4). Such products were tentatively identified as ettringite, even though they might as well be identified monosulfate hydrates, since both ettringite and monosulfate have identical X-ray diffraction identification patterns. It might as well be that both monosulfate and ettringite were present. In addition, CSH and some excess lime, in both its hydrated as well as quicklime form, were identified, indicating again on-going pozzolanic reactions. Finally, some minor peaks of Al_2O_3 were also picked up which seems to support the presence of monosulfate hydrates. If monosulfate forms instead of ettringite less alumina is used up, and therefore, excess alumina released from the clay and not used by the pozzolanic reactions may be present. X-ray diffraction analyses of the fly ash-clay-sand quicklime treated solid matrix (K5C25L10), shown in Figure 5, revealed the presence of both ettringite and calcium silicate hydroxide pozzolanic products, as well as some excess lime. Even though no sulfates were added, sulfate presence within the fly ash matrix (Table 1) was adequate for ettringite formation to be favored.

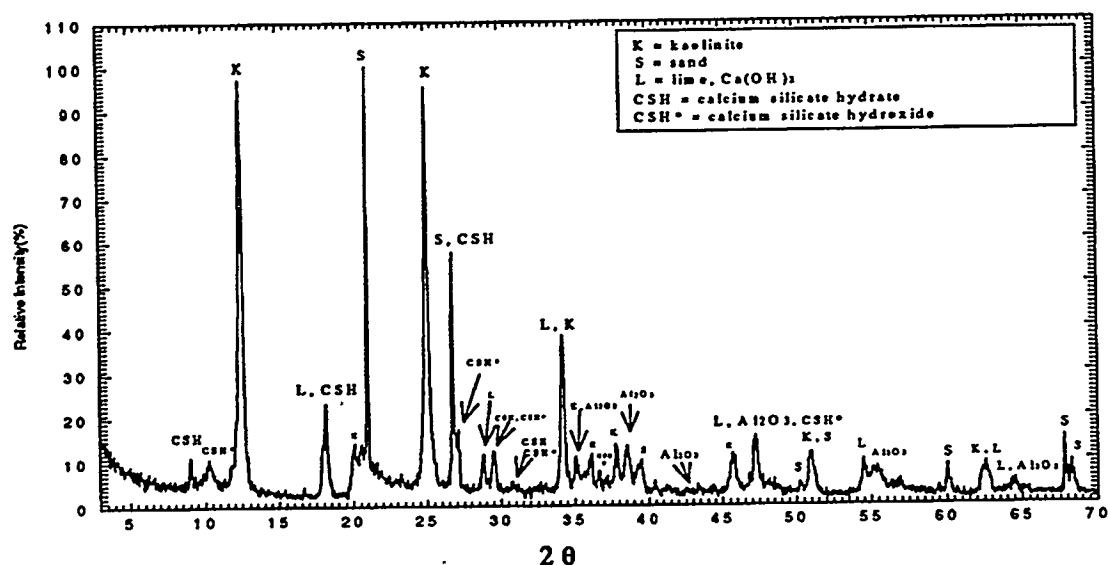


Figure 3. X - ray scan of 10% quicklime treated sample composed of 30% of kaolinite, 10% of lime and 70% of sand (K30L10), 28 days of curing.

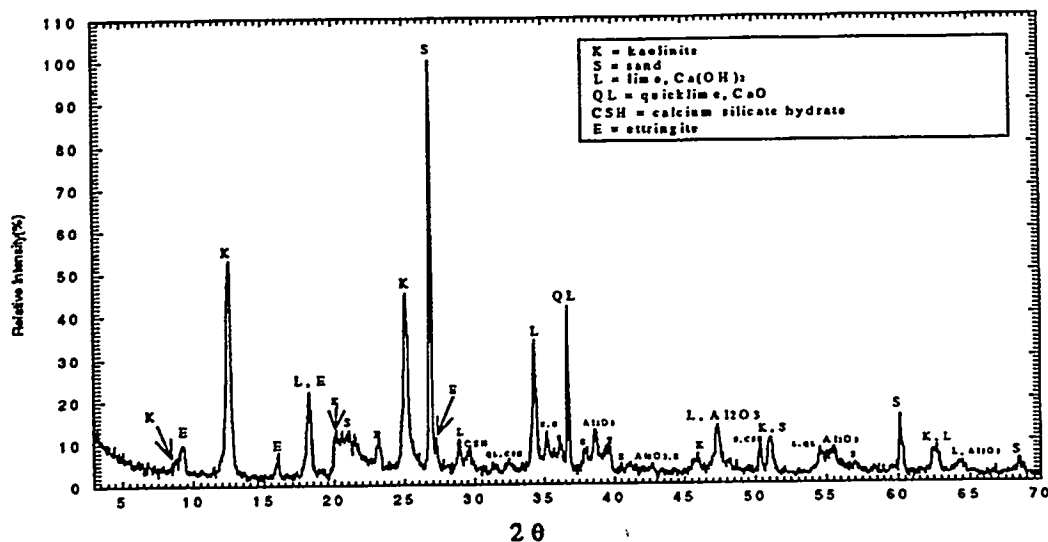


Figure 4. X - ray scan of 10% quicklime treated sample composed of 30% of kaolinite, 10% of lime, 5% of sodium sulfates and 70% of sand (K30L10S), 28 days of curing.

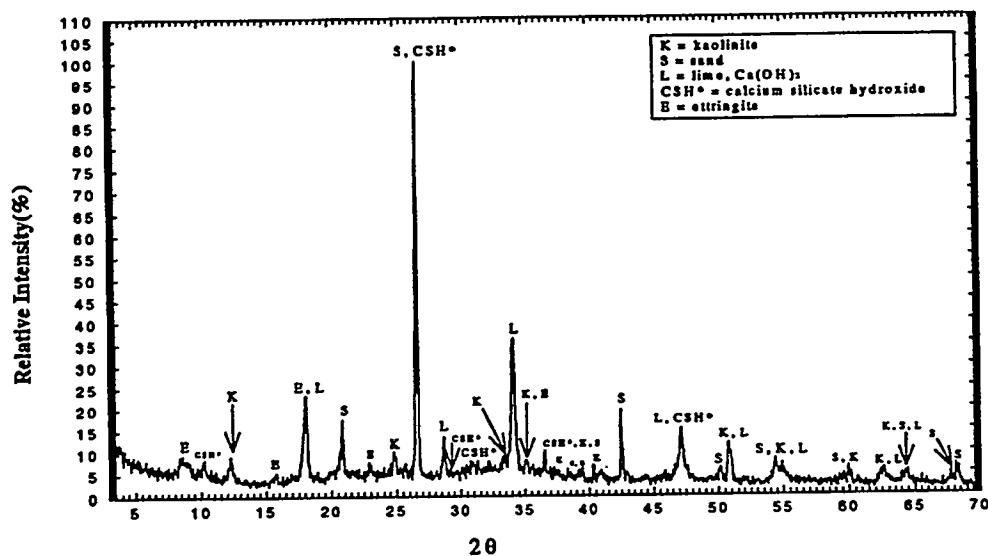


Figure 5. X - ray scan of 10% quicklime treated sample composed of 5% of kaolinite, 25% Class C fly ash and 70% of sand (K5C25L10), 28 days of curing.

Scanning electron microscope studies provided conclusive proof on the presence of ettringite in both kaolinite-sand mixes (K30L10S) as well as quicklime treated fly ash-clay-sand mixes (K5C25L10). As shown in Figures 6a and 6b, needle-like ettringite crystal formation covers most of the exposed surfaces. Ettringite crystals are more lath-like (wide tube-like) in the K30L10S (Figure 6a) sample and more needle-like in the K5C25L10 (Figure 6b) sample. This might partly explain the differences in strength gain for the two samples, as needle-like crystals have been shown to be better strength agents than lath-like crystals [15]. Absence of ettringite and the book-like fabric of kaolinite clays are the predominant feature on the SEM micrograph of the quicklime treated, no sulfate added, sample K30L10 (Figure 6c).

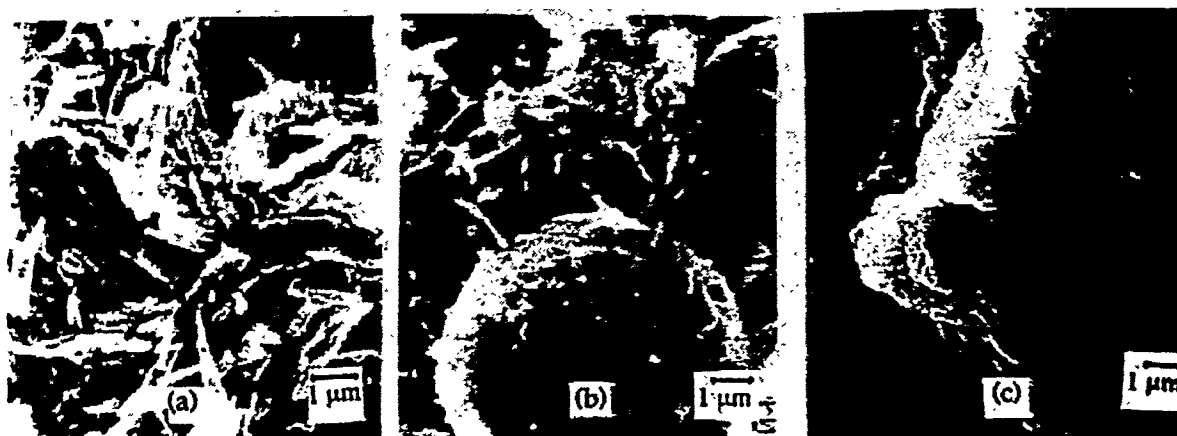


Figure 6. SEM micrographs, from left to right samples: (a) K30L10S (b) K5C25L10 (c) K30L10.

Within the general context that treated solids may be reused as engineering materials in construction applications, it should be noted that the presence of ettringite is not only accompanied by significant strength gains. Ettringite-induced expansion in the presence of water can have detrimental effects, possibly leading to failure of the construction application. In Figure 7, vertical swell is plotted as a function of solid mix design parameters. There, it is clearly shown that sulfate addition and the subsequent ettringite formation, may indeed create detrimental levels of vertical expansion (8.62%) in the kaolinite-sand quicklime treated specimens. However, no development of significant swell was observed for the ettringite-bearing fly ash-kaolinite-sand quicklime treated specimens, whether additional sulfate was added or not. As previous research has demonstrated [15], and Figure 7 results indicate, in the absence of a strong cementitious cohesive force, resembled by large strength gains (Figure 2), ettringite-induced expansion can lead to deleterious levels of vertical swell. Conversely, in the presence of fly ash, the pozzolanic cementing action is able to overcome the ettringite-induced swell pressures and specimens remain intact upon water exposure.

Additional experiments were conducted aiming to provide with a pretreatment solution for such cases where the cohesive or confining forces within the stabilized solid matrix were not able to overcome ettringite expansion tendencies upon water exposure. As previous research has demonstrated [15], a barium hydroxide pretreatment of sulfate-bearing soils was successful in eliminating ettringite formation and subsequent swell. During the present study, barium hydroxide was added to K30L10S mixes, at varying levels of addition, in order to control excessive swell development, while minimizing barium addition. Figure 8 illustrates the drastic decrease in vertical swell upon barium hydroxide addition, as a function of the barium hydroxide to sodium sulfate molar ratio. Addition of barium hydroxide at a molar ratio of at least 0.2 is sufficient to effectively control ettringite-induced swell development. The mechanism of ettringite-induced swell elimination is depicted in the SEM micrographs shown

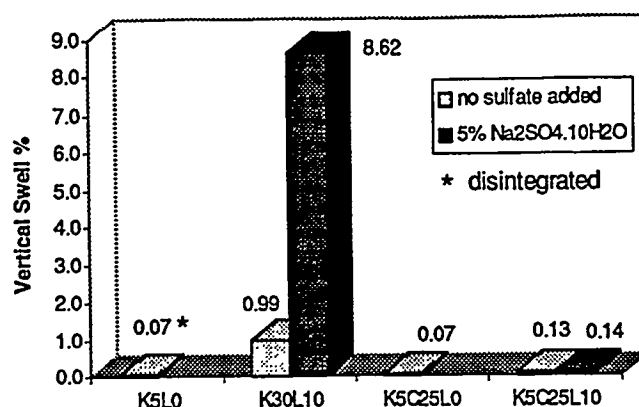


Figure 7. Specimen maximum vertical swell values for different solid mixes with and without sulfate addition, following 28 days of specimen curing.

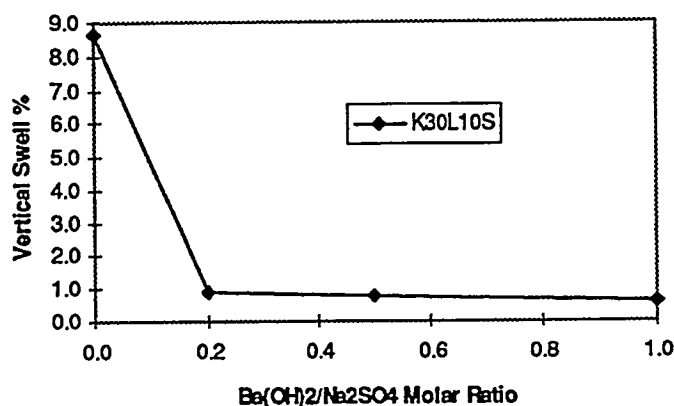


Figure 8. Specimen maximum vertical swell development as a function of the barium hydroxide to sodium sulfate molar ratio.

in Figure 9. Increased addition of barium hydroxide has an adverse effect on ettringite formation, since it shifts the thermodynamic balance to barium sulfate (barite) formation, thus making the sulfate ions inaccessible towards ettringite formation.

Overall, after establishing the mechanical properties of the treated solids, it was shown that high strength, low swell solids can be produced upon appropriate treatment design, even in the presence of ample amounts of sulfate. Therefore, treatment will result in a solid that attains adequate levels of strength and swell properties as to enable reuse of the treated solid as readily available construction material. The present study serves as a first step, as additional experimental research is needed to establish the full spectrum of stress-strain behavior as a result of treatment, so that the treated solids can be reliably used in a wide variety of construction applications.

Leaching Tests

Lead

Treated solids were tested for their regulatory levels of heavy metal leaching by means of conducting TCLP batch experiments. Following 28 days of specimen curing, levels of TCLP Pb release were below the regulatory benchmark of 5 ppm only when quicklime and fly ash were added to the

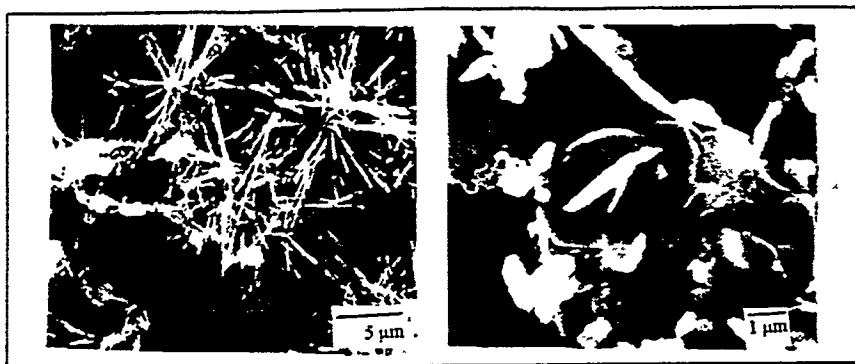


Figure 9. SEM micrographs illustrating sample fabric changes caused by the addition of barium. *left*: ettringite formation in the absence of barium; *right*: barite formation following barium addition

contaminated soil (Figure 10). In order to further understand the conditions and mechanisms that lead to Pb immobilization, TCLP-based extraction experiments, using different clay-sand lime treated mixes, were conducted. Based on these experiments, it was shown that lead immobilization was ensured if the treatment TCLP pH was kept between 8 and 11 (Figure 11). Moreover, after conducting lead solubility experiments under identical solution conditions, it was concluded that Pb immobilization could not be controlled by Pb solubility in the presence of quicklime treatment, at high pH. When pH is greater than 9, it appears that a Pb adsorption mechanism is predominant, as Pb release is significantly lower than Pb solubility. Conversely, when the pH is lower than 9, Pb release, even though somewhat influenced by surface adsorption, is mainly solubility-controlled. The addition of fly ash in low clay content quicklime treated solids has an obvious positive effect on Pb immobilization, as indicated by the K5C25L10 release curve shown in Figure 11. More specifically, fly ash addition results in further widening the pH range of Pb immobilization from 5 to 13.

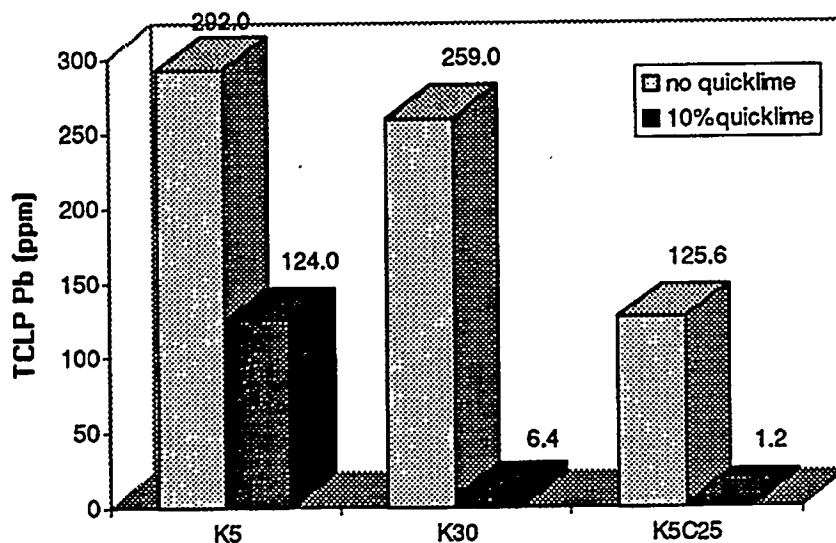


Figure 10. Levels of TCLP Pb release with or without quicklime treatment for different solid mixes, following 28 days of specimen curing.

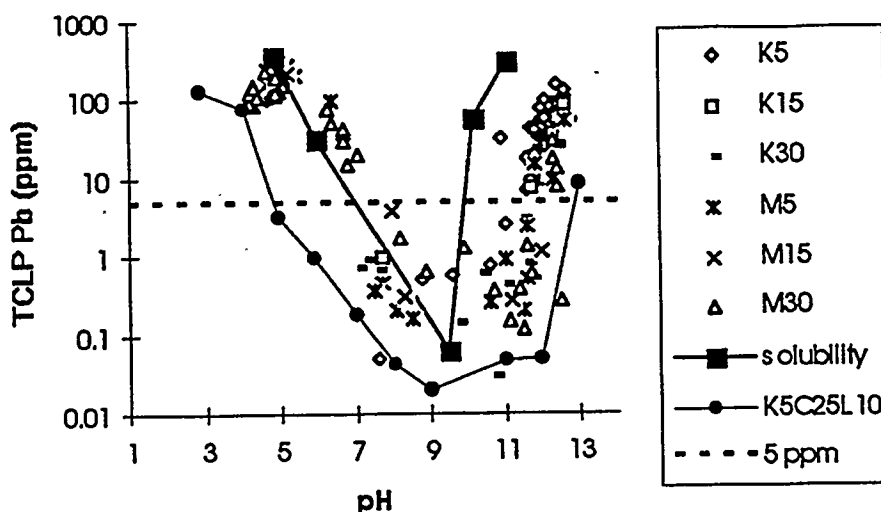


Figure 11. Summary of TCLP-based, controlled extraction and solubility Pb release results as a function of extract pH for different solid mixes.

Chromium

As shown in Figure 12, trivalent chromium TCLP release was high in untreated kaolinite-sand mixes, with an increased release as clay content decreases from 30% to 5%. This is attributed to the increased surface area available for Cr adsorption, as clay content is increased. Upon quicklime treatment, the levels of TCLP Cr release were reduced to values well below the non-hazardous regulatory benchmark of 5 ppm, irrespective of the clay content. The fact that Cr release is not affected by varying the amount of clay presence, indicates that immobilization is controlled by the solubility of Cr hydroxides rather than surface adsorption. Chromium hydroxides are generally insoluble at the high pH levels generated by quicklime addition. The addition of fly ash to the untreated samples reduced Cr leachability by as much as 90%, probably due to the inherent alkalinity of the fly ash (fly ash contains 25% by weight CaO). However, no dramatic reduction in Cr leachability was achieved when fly ash was added to quicklime treated samples, as Cr release was already very low in the quicklime (10%) treated samples.

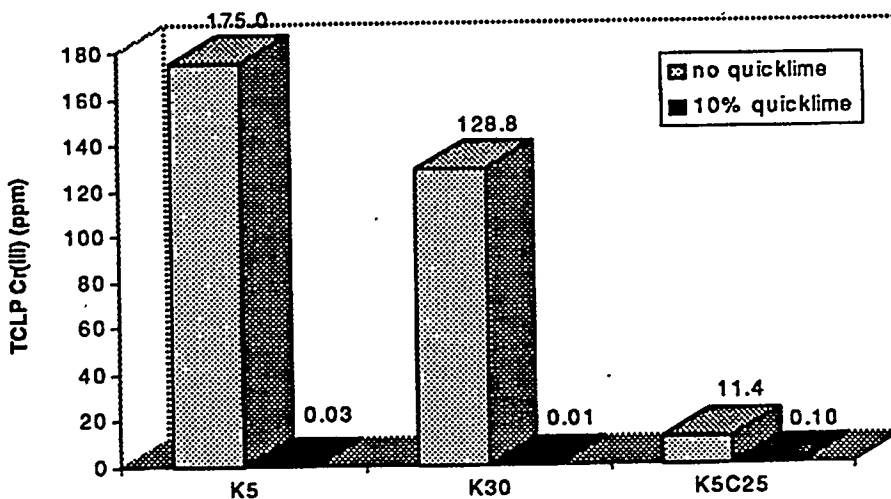


Figure 12. Levels of TCLP Cr (III) release with or without quicklime treatment for different solid mixes, following 28 days of specimen curing.

In an attempt to further elucidate the mechanisms responsible for trivalent Cr immobilization, controlled extraction as well as solubility experiments were undertaken. The results of these experiments are shown in Figure 13, where Cr release is plotted as a function of the release pH. Chromium release appears to be solubility-controlled when extract pH is greater than about 6. Generally, quicklime addition will always result in extract pHs greater than 6, mainly due to its strong alkaline nature. Therefore, the controlling mechanism of Cr immobilization upon quicklime treatment application is precipitation of insoluble hydroxides. This explains why the addition of fly ash can only enhance Cr immobilization at the lower pH range, where surface adsorption seems to be the controlling immobilization mechanism.

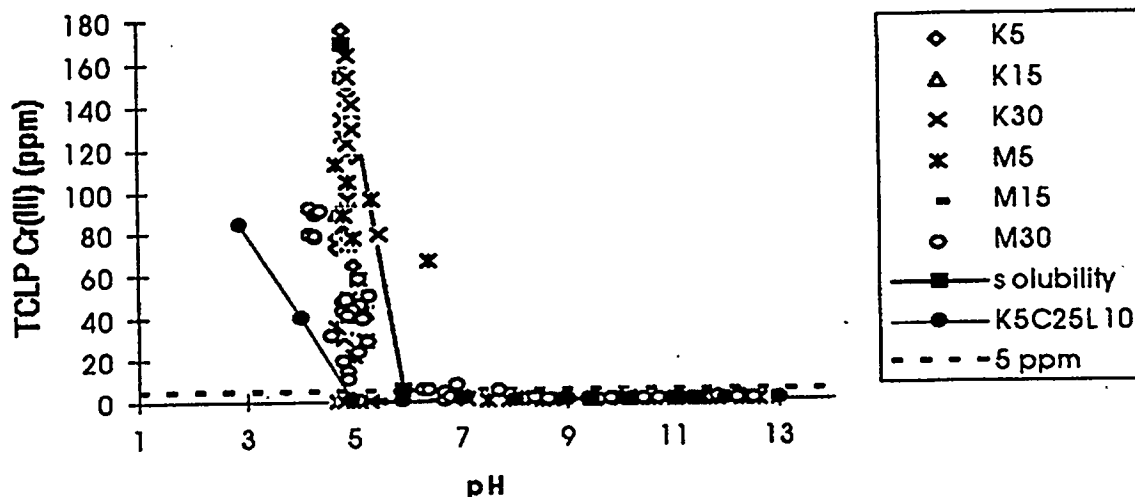


Figure 13. Summary of TCLP-based, controlled extraction and solubility Cr (III) release results as a function of extract pH for different solid mixes.

The situation is quite different for hexavalent Cr release. During preliminary experiments, it was concluded that Cr (VI) release levels could not be reduced by simply adding quicklime to the contaminated soils. However, in the presence of increasing amounts of fly ash there was a clear trend of increased reduction in Cr(VI) TCLP release, as shown in Figure 14. Fly ash addition alone could not effectively reduce Cr(VI) concentrations in the TCLP extract below the 5 ppm benchmark. Simultaneous addition of quicklime and fly ash was successful in effectively immobilizing Cr (VI). However, the mechanisms of immobilization could not be identified based on these results.

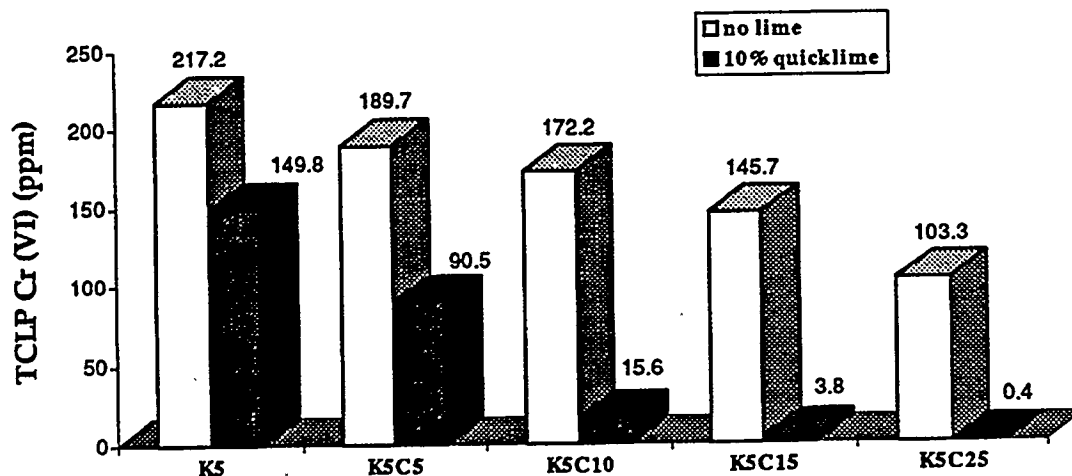


Figure 14. Levels of TCLP Cr (VI) release with or without quicklime treatment for different solid mixes, following 1 day of specimen curing.

Overall, there seems to be three types of mechanisms that may be responsible for Cr(VI) immobilization by the quicklime-fly ash treatment:

1. It may be that fly ash is acting as a reducing agent, effectively reducing Cr^{6+} to Cr^{3+} . Then Cr^{3+} is effectively immobilized at the quicklime-induced high pH, due to the precipitation of insoluble chromium hydroxides.
2. It may also be that Cr^{6+} is effectively immobilized due to its adsorption on fly ash at high pHs.
3. Finally, it could be that during ettringite formation there is isomorphous substitution of the sulfate ion by the chromate ion, thus Cr^{6+} is immobilized by ettringite crystal inclusion.

Previous research has demonstrated that in the presence of ferrous ions such a reduction would take place [20]. It follows, that ferrous ions present in the fly ash may have effectively reduced the hexavalent chromium to its trivalent form. In addition, it may also be that ferric ion surfaces present in the fly ash. In order to investigate such a possibility, controlled extraction experiments were conducted, where both total chromium as well as Cr^{6+} levels of release were measured. During these experiments sample mixes were prepared by adding ferrous sulfate, ferric chloride or fly ash to coarse-grained soil mixes (5% kaolinite and 95% sand), with and without quicklime treatment. Both ferrous sulfate and ferric chloride were added based on an iron to chromium molar ratio of 3.0. The results shown in Figure 15, demonstrate that even though addition of ferrous sulfate would result in substantial amounts of Cr^{6+} being reduced to Cr^{3+} , resulting in Cr^{3+} immobilization upon quicklime addition, no Cr reduction was evidenced in the presence of ferric ions or fly ash. Moreover, in the presence of ferric chloride, quicklime treatment resulted in increased release levels of Cr^{6+} . However, in the presence of fly ash, Cr^{6+} was effectively immobilized by quicklime. Overall, the results shown in Figure 15 demonstrate that the mechanism of Cr^{6+} immobilization is neither hexavalent reduction to its trivalent state nor Cr^{6+} surface adsorption on ferric ion surfaces that may be present in fly ash.

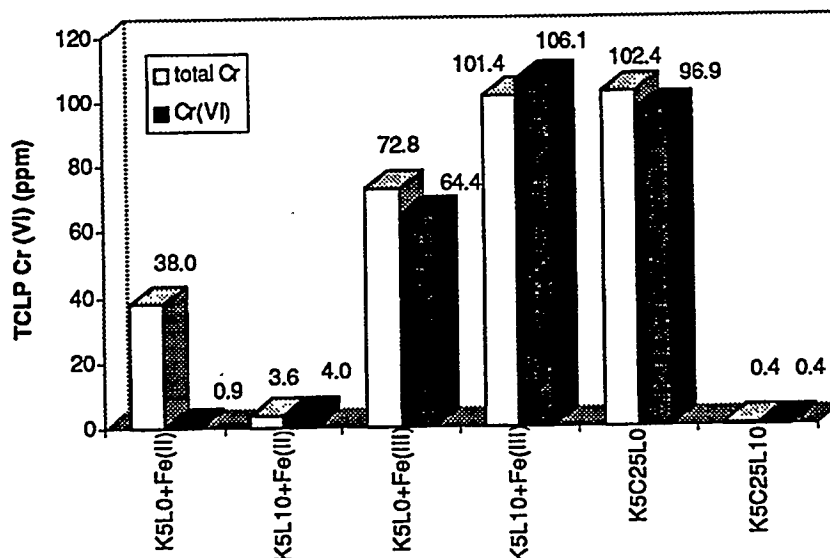


Figure 15. Reduction of hexavalent chromium assessment by comparing levels of TCLP total Cr versus Cr^{6+} release for different solid mixes.

Previous research [11] has shown that in the presence of chromate ions and during ettringite formation, chromate will substitute sulfate in the ettringite crystal structure to form what is known as Cr-substituted ettringite. It is only possible to distinguish Cr-substituted ettringite from regular ettringite by means of SEM-EDX analyses, since ettringite and Cr-substituted ettringite have identical x-ray diffraction identification patterns. In the present study, scanning electron microscope (SEM) analyses did reveal the presence of ettringite-like crystals for both untreated and quicklime treated fly ash-kaolinite-sand samples (Figure 16). However, when the elemental composition of these ettringite-like crystal surfaces was

studied by using energy dispersive x-ray (EDX) scans, only minor amounts of chromium substituted ettringite could be identified, whereas most of the Cr seemed to be attached to the rest of the area shown in Figure 16, and not to the needle-like crystals. As expected, x-ray diffraction results did not enable chromium substituted ettringite identification either. Therefore, even though Cr^{6+} immobilization by ettringite crystal inclusion was not ruled out, it seems that even to the degree that it indeed occurred, it cannot be the controlling immobilization mechanism for Cr^{6+} .

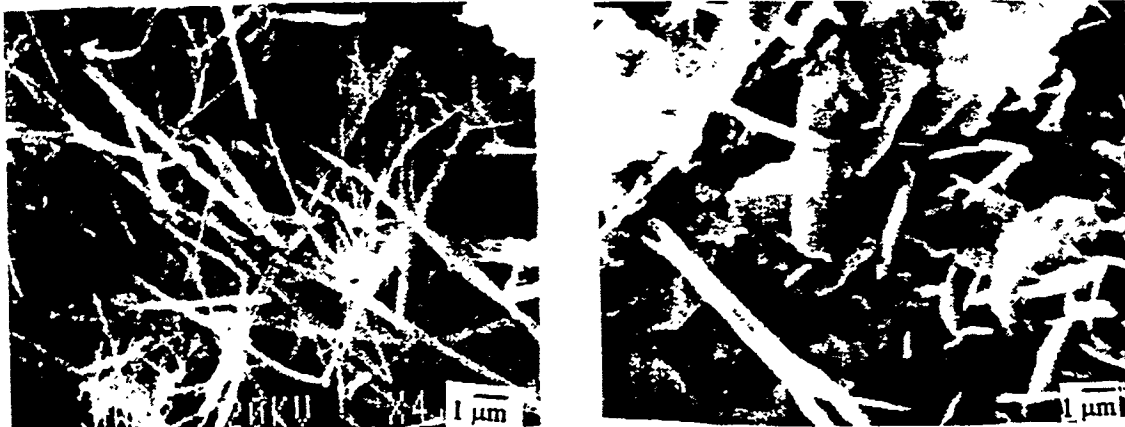


Figure 16. SEM micrographs depicting needle-like crystal formation. *Left:* sample K5C25L0; *Right:* sample K5C25L10

In a final attempt to elucidate the mechanism responsible for the immobilization of Cr^{6+} by the quicklime/fly ash treatment, controlled extraction experiments over a wide range of extraction pH values were carried out on different sample mixes. As shown in Figure 17, Cr^{6+} release is always high in the absence of fly ash, irrespective of the extract pH. It decreases upon quicklime addition (K5L0 to K5L10) and as the amount of clay increases from 5% to 30% (K5L10 to K30L10). Once fly ash is added to the solids, and in the presence of quicklime treatment, Cr release is further decreased but it is only at high pH values that Cr^{6+} seems to be effectively immobilized. It seems that in the presence of lime and fly ash,

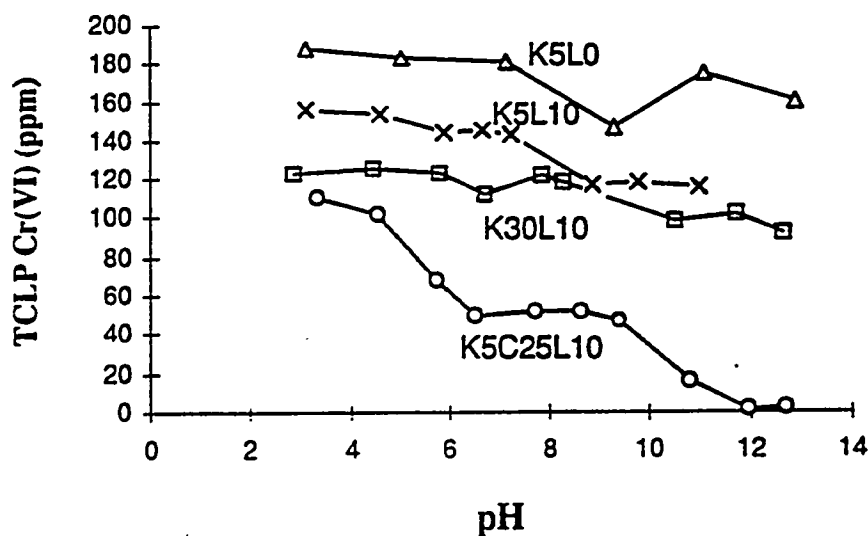


Figure 17. Solid sample Cr^{6+} TCLP levels of release as a result of varying the TCLP extract pH.

Cr release is strongly dependent on the pH of extraction. Increasing the pH results in Cr release decreases, with a minimum Cr release at a pH of about 12. The only possible explanation for this extraction release results, is that surface interactions in the treated solids are mainly responsible for the apparent reduction in Cr^{6+} release. Fly ash is a superior Cr^{6+} immobilization agent, as compared to the kaolinite clay, increasingly so with increasing pH. Research is currently underway in an attempt to further elucidate the hexavalent chromium immobilization mechanism.

CONCLUSIONS AND RECOMMENDATIONS

Presently in the US and other industrialized countries there is a need to increase the use of fly ash and other industrial by-products in order to avoid increasing disposal costs. Due to their pozzolanic nature, fly ash and other waste products, can be effectively used in a variety of construction applications. However, there is a legitimate concern with respect to the potential release of toxic contaminants associated with the use of such wastes. In the present study, the utilization of fly ash during quicklime-sulfate S/S treatment of Pb^{2+} , Cr^{3+} and Cr^{6+} contaminated soils, was evaluated. This evaluation was performed with respect to both the strength and swell properties of the treated solids as well as their respective regulatory levels of release.

The addition of fly ash during the quicklime-sulfate S/S treatment resulted in a high strength, swell-resistant monolithic solid, attaining levels of strength similar to those of concrete products. The only potential problem associated with treatment application is the formation of the mineral ettringite. Ettringite, when exposed to water, will swell, possibly leading to strength loss and accelerated physical deterioration of the treated solids. Minimum amounts of barium hydroxide addition were shown to be effective in eliminating ettringite formation and subsequent swell of the treated solids. Moreover, in the presence of fly ash, cohesive force development in the treated solids was adequate in overcoming ettringite-induced swelling pressures and specimen swell was avoided altogether. Overall, the present study demonstrated the potential for reuse of the treated solids, but additional research is warranted in order to establish the full spectrum of pertinent stress-strain properties of the treated solids.

With respect to heavy metal release, the addition of fly ash was directly responsible for the effective immobilization of both lead and hexavalent chromium, whereas it further enhanced trivalent chromium immobilization. Based on our results it was concluded that both Pb and Cr^{6+} immobilization were controlled by surface interactions and solution pH. More specifically, Pb is effectively immobilized by the quicklime-sulfate treatment as long as the TCLP extraction pH is maintained at values higher than 8 and lower than 11. However, upon treatment application the TCLP extract pH would always be higher than 8, in most cases higher than 11, thus causing Pb TCLP release levels to be higher than regulatory allowable levels. It is only in the presence of fly ash that treatment becomes effective, as fly ash addition increases the immobilization pH region. In fact upon fly ash addition Pb is immobilized as long as the pH is lower than 13, which is higher than 12.4, the maximum pH to be attained following treatment application.

For Cr^{6+} , fly ash addition was absolutely necessary for effective immobilization to take place. It was found that Cr^{6+} immobilization by fly ash was not achieved through the fly ash-induced reduction of Cr^{6+} to its trivalent form. Moreover, even though isomorphous substitution of Cr^{6+} in the crystal structure of ettringite was not ruled out, it was concluded that it could not have been the controlling mechanism, responsible for Cr^{6+} immobilization. Hexavalent chromium immobilization was attributed to physico-chemical interactions with fly ash surfaces, which are favored by increasing the matrix pH. The optimum pH for Cr^{6+} immobilization in the presence of fly ash, was found to be approximately 12, which makes quicklime addition also necessary. Trivalent chromium was also effectively immobilized by the quicklime-fly ash treatment. The controlling mechanism for Cr^{3+} immobilization was found to be precipitation of insoluble hydroxides at high pH, and therefore, fly ash addition was of increased benefit only at the lower pH range.

In summary, the addition of fly ash during the quicklime-sulfate S/S treatment of heavy metal contaminated soils is mainly responsible for their effective immobilization. This is achieved through an increase of the adsorption-controlled immobilization capacity of the treated solids as fly ash addition increases the Pb, Cr^{3+} and Cr^{6+} immobilization pH region. Fly ash addition also results in significant

improvement of the stress-strain properties of the treated solids, therefore enabling their reuse in construction applications. The high levels of heavy metal contaminant contents used, the presence of sulfates in our solid mixes and the gradation and pozzolanic content of the solids studied, enable the application of the results presented herein, to a wide variety of waste utilization scenarios. Moreover, the heavy metals studied happen to be the ones of highest concern from a risk assessment perspective. That is, with the exception of mercury and radionuclides, which however are not expected to be present in the vast majority of such wastes. Overall, with the exception of incinerator ash, for which the immobilization of cadmium would also have to be studied, the results presented in this paper can be safely applied to the management of most kinds of coal burning by-products including fly ashes, FGD wastes, boiler slags, etc. Additional research is currently underway in our laboratory to obtain actual levels of heavy metal release under both flow-through and diffusion-controlled infiltration conditions. These results that may be then used for contaminant fate and transport modeling purposes. Research is also conducted using field contaminated samples, in order to establish the applicability of the proposed treatment to actual field contamination scenarios.

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UTILIZATION OPTIONS FOR FLY ASH, BOTTOM ASH, AND SLAG IN EASTERN EUROPE

Oscar E. Manz, Consultant

Alvarado, Minnesota, USA

ABSTRACT

Since 1967, at least six ash utilization symposiums have been held in the United States, with papers presented by several European authors on the utilization of coal by-products in Eastern Europe. There is currently over 80,000 megawatts of installed coal-fired capacity available in that region. Unfortunately, of the 117,778,000 tonnes of fly ash, bottom ash, and slag produced in Eastern Europe in 1989, only 13% was utilized. This paper outlines the research and levels and kinds of coal by-product utilization taking place in Eastern Europe since the late 1960s.

OBJECTIVE

This is a summary of the research and utilization involving coal ash in Eastern Europe, beginning in the 1960s. The Eastern European countries include Albania, Bulgaria, the former Czechoslovakia, the former German Democratic Republic, Hungary, Poland, Romania, and the former Yugoslavia. Coal provides the fuel for power generation in Eastern Europe, with about 80,000 megawatts of installed coal-fired capacity.

METHODS/DATA/ANALYSIS

In 1958, within the framework of the Coal Committee of the United Nations Economic Commission for Europe, a Group of Rapporteurs started work on problems related to the utilization of ash, and in September, 1966, the group name was changed to "Group of Experts." The rapporteurs met twelve times up to 1966. In 1967, the first meeting of the Group of Experts was held in Pittsburgh, Pennsylvania, USA, at the First International Fly Ash Utilization Symposium.

Since 1970, there have been two United Nations Economic Commission for Europe symposiums in Europe dealing with ash from coal-fired thermal power stations. Since 1967, there have been at least six International Ash Utilization Symposiums in the United States, with several presenters from Eastern Europe.

There are several other sources of papers presented dealing either with research or utilization of Eastern European coal ash. A bibliography of papers presented by authors from Eastern Europe is included as Appendix A.

The author has conducted several international coal ash surveys since 1970, and results from the 1989 survey are presented here.

ASH PRODUCTION AND UTILIZATION BY COUNTRY (see also Tables 1-3)

Bulgaria

The fly ash produced in Bulgaria is almost totally from lignite (1).

The Former Czechoslovakia

Over 18 million tonnes of coal ash was produced in 1989, with 312,000 tonnes utilized in aerated blocks and 934,000 tonnes for landfill (2).

The Former East Germany

East Germany had the largest production of both lignite coal and coal ash in the world in 1989. There is no bituminous coal in East Germany. Over 705,000 tonnes were used in cement and concrete, 4,258,000 tonnes for soil conditioning, 1,045,000 tonnes for road stabilization, and 700,000 tonnes for mine fill (3).

Hungary

Hungary produced mainly lignite coal ash, with about 145,000 tonnes used in blended cement and 239,000 in aerated blocks (4).

Poland

In Poland, even though they produced 6.5 million tonnes of lignite coal ash and 23 million tonnes of bituminous ash, only the bituminous ash was utilized. Over 338,000 tonnes were used in cement and concrete, as well as about 920,000 tonnes in aerated blocks, and 1,570,000 tonnes for mine fill (5).

Romania

Production was reported only for lignite coal ash, consisting of 7 million tonnes of fly ash and 20 million tonnes of bottom ash. About 200,000 tonnes were used in cement and concrete, 120,000 tonnes in aerated blocks, and 600,000 tonnes for landfill (6).

The Former Yugoslavia

No data was available for 1989, but in 1987 there was about 6 million tonnes of bituminous coal ash and 7.2 million tonnes of lignite ash produced. Only 7.4% of the annual production was utilized, with 520,000 tonnes used in blended cement and as cement raw material (7).

CONCLUSIONS

Only 13.1 percent of the 117,788,000 tonnes of coal ash (fly ash, bottom ash and slag) produced in Eastern Europe in 1989 was utilized. Considering the extensive coal ash research that has been conducted in Eastern Europe since the 1960s, it is unfortunate that there has not been more coal ash utilized.

TABLE 1

Coal Ash Production and Utilization in Eastern Europe, 1989 and 1987*

Country	Production (thousands of tonnes)		Utilization (thousands of tonnes)
	Fly Ash	Bottom Ash and Boiler Slag	
Albania	NA	NA	NA
Bulgaria	5,300	1,060	115
Former Czechoslovakia	13,783	4,334	1,445
Former GDR	12,479	6,578	7,156
Hungary	3,880	937	597
Poland	26,300	3,200	4,455
Romania	7,000	20,000	745
Former Yugoslavia*	12,147	1,190	985
Total	80,889	37,299	15,498

NA = not applicable.

TABLE 2

Major Uses of Coal Ash in 1989 in Eastern Europe
(thousands of tonnes)

Structural, Land, or Embankment Fill	5,970
Mine or Quarry Fill	2,343
Aerated Blocks	1,618
Pavement Subgrade or Base Course	1,527
Cement Replacement	468
Bricks or Ceramics	444

TABLE 3
Coal Ash Production and Utilization in Eastern Europe, 1989 and 1987*

	Bulgaria	Former Czechoslovakia	Former East Germany	Hungary	Poland	Romania	Former Yugoslavia*	Total
Production (thousands of tonnes)								
Fly Ash	5,300	13,783	12,479	3,880	26,300	7,000	12,147	80,889
Bottom Ash and Boiler Slag	1,060	4,334	6,578	937	3,200	20,000	1,190	37,299
Utilization (thousands of tonnes)								
Cement Raw Material		8			78		50	136
Blended Cement			550	145		10	470	1,175
Cement Replacement	20	23	155		260	10		468
Grout				3			15	18
Non-aerated Blocks	50	9					30	89
Aerated Blocks		312		239	920	120	27	1,618
Lightweight Aggregate	30	91						121
Bricks or Ceramics		29			345	5	65	444
Asphalt Filler				1	12			13
Structural, Land or Embankment Fill	10	934	4,258	168		600		5,970
Pavement Base Course or Subgrade			1,045	12	270		200	1,527
Filler for Mines, Quarries, or Pits		39	700	29	1,570		5	2,343
Other	5		448		1,000		123	1,576
Total	115	1,445	7,156	597	4,455	745	985	15,498
% of Production	1.8	8	37.6	12.3	15.1	2.8	7.4	13.1

* Figures for 1987 taken from Manz, O.E., Faber, J.H., and Takagi, H. "Worldwide production of fly ash and utilization in concrete," American Concrete Association Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans in Concrete, Trondheim, Norway, 1989, Supplementary Paper, 15 pp.

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POWER PLANT WASTE DISPOSALS IN OPEN-CAST MINES

Jiří Herštus
Jaromír Št'astný

AGE s.r.o. - Aplikovaná geotechnika a ekologie
Thámová, Czech Republic

ABSTRACT

High population density in Czech Republic has led, as well as in other countries, to strong NIMBY syndrome influencing the waste disposal location. The largest thermal power plants are situated in neighborhood of extensive open-cast brown coal mines with huge area covered by tipped clayey spoil. Such spoil areas, technically almost useless, are potential space for power giant waste disposal position.

There are several limitations, based on specific structural features of tipped clayey spoil, influencing decision to use such area as site for waste disposal. Low shear strength and extremely high compressibility belong to the geotechnical limitations. High permeability of upper ten or more meters of tipped spoil and its changes with applied stress level belongs to transitional features between geotechnical and environmental limitations. The problems of ash and FGD products stabilized interaction with such subgrade represent environmental limitation.

The paper reports about the testing procedure developed for thickness and permeability estimation of upper soil layer and gives brief review of laboratory and site investigation results on potential sites from point of view of above mentioned limitations. Also gives an outline how to eliminate the influence of unfavorable conditions.

INTRODUCTION

Brown coal burning power plants in northwestern part of Czech Republic are situated in neighborhood of extensive open-cast brown coal mines. Claystone overlaying coal seams is excavated and disposed as tipped spoil fill. The areal extend of tipped spoil exceeds 100 km². The area of tipped fill before its reclamation seems to be suitable for power plant waste disposal settling especially due to negligible NIMBY syndrome.

The tipped clayey spoil fill as waste disposal subgrade has unfortunately certain disadvantages due to its specific structural features. Fill area utilization for waste disposal foundation thus requires the study of fill subgrade behavior under disposed waste load and study of waste - spoil interaction. As a result of such study constructional measures should be established.

CLAYEY TIPPED FILL CHARACTERIZATION AS POWER PLANT WASTE DISPOSAL SUBGRADE

Observed tipped spoil fill behavior

The thickness of tipped fill usually reaches 50 m, exceptionally as much as 150 m. General slope inclination seldom exceeds 1:8 to 1:10. Nevertheless landslides of fill shapes are relatively frequent especially when the fill is disposed on water saturated alluvial subgrade. The largest landslide involved almost 140 million cu meters of ground in motion (Fig. 1).

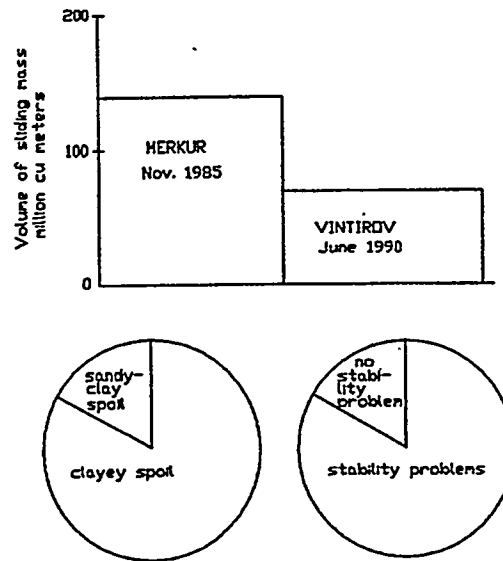


Fig.1. Landslides on tipped spoil fill.

Very large settlement of fill surface has been observed. Fig. 2 shows values of settlement vs. tipped fill height. Non-linear relationship indicates structural changes in tipped spoil due to the changes of stress level (1).

Random experiences with light building flat foundations on a tipped fill subgrade have shown that large and nonuniform compression under the applied load is common feature of upper 10 or 20 meters thick fill zone. Almost immediate infiltration of rainfall indicates also high permeability of the upper zone. On the other hand the stability problems mentioned above testify the existence of large pore pressure in the deeper fill strata, hence about very low fill permeability. It is in good accordance with supposed structural changes of the fill. The observations also have revealed landslide frequency increase with increasing fill age.

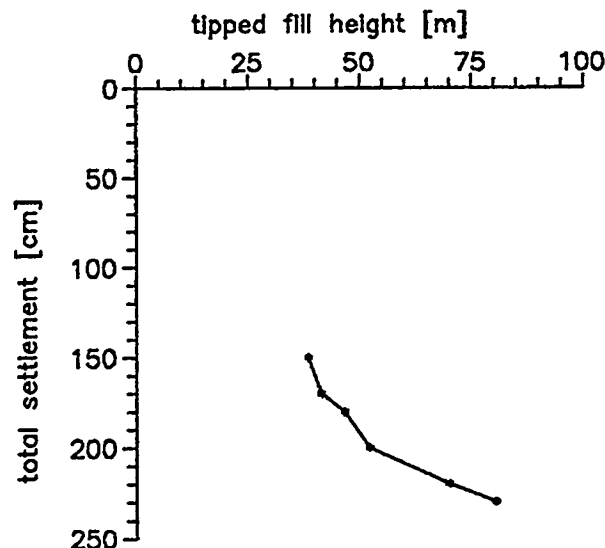


Fig. 2. Settlement curve of tipped claystone spoil fill.

Structural changes of clayey tipped spoil

Fresh tipped spoil consists of highly over consolidated, slightly lithified claystone fragments. A typical grain-size curve of such spoil is shown in Fig. 3. The influence of weathering being characterized as increase of finer particle amount is limited on several tens centimeters below the fill surface.

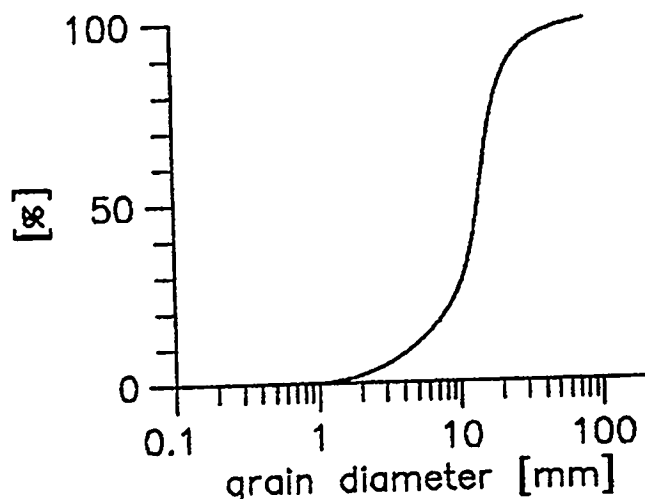


Fig.3. Tipped spoil granulometry

Infiltration of atmospheric water (or water from alluvial subsoil) through the spoil while it shows continuous gaps, results in considerable changes in the character and behavior of the spoil. Due to the over consolidation, the claystone fragments strongly absorb water. The surface of claystone fragments softens in relatively short period of time. When sufficient stress level is applied at such moment the spoil is altered fast into a stiff to soft clay in which "swimm" hard remnants of original fragments. These changes are accompanied by layer compression (interfragment gaps elimination) and by substantial fill shear strength decrease. The final soil is less compressible, has very low permeability and low shear strength (2).

On the other hand the upper layer being subjected to low stress level, maintains interfragment gaps and consequently high permeability and high compressibility while shear strength shows certain decrease.

Tipped spoil testing for the aim of waste disposal construction

Lower fill layers having structure of soft to stiff clay with "swimming" remnants of claystone fragments can be tested using conventional static cone penetration device. As a result of such testing the data about shear strength and modulus of deform ability are obtained. These data may be verified by laboratory tests of undisturbed samples taken from boreholes. Supplement of pore pressure tip in penetration device will make possible to estimate the pore pressure distribution in soil layer. Real values of pore pressure should be verified by pore pressure monitoring with measuring tips installed in proper depths. Such values will serve as input data for stability analyses of fill body loaded by power plant waste disposal.

Testing of the upper fill layer is rather complex. As first step in site investigation an attempt to ascertain its thickness should be made. Such layer is characterized by rockfill-like structure with continuous gaps. Consequently the testing procedure has been found on this knowledge. A needle with porous filter in bottom part is penetrated into the fill and in various depth interval about 2 m) the velocity

of dissipation of air pressure applied on the filter part is measured. It has been revealed that the smallest depth in with substantial dissipation needs time over 5 minutes may be taken into account as a base of compressible and permeable upper layer. An example of the results of such test is shown in Fig. 4.

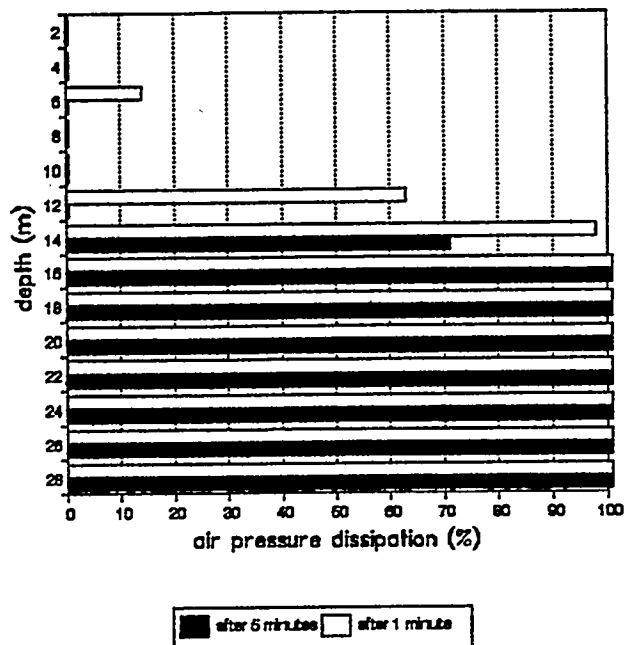


Fig. 4. Result of air permeability test

In the case when static cone penetration test had revealed the local ground water level (Fig. 5) in the upper layer the in situ permeability test has been used. The penetrated test device consists of the same needle as described above for air permeability test. After the penetration to the appropriate depth a constant or falling head test has been realized. Fig. 6. shows an example of test result.

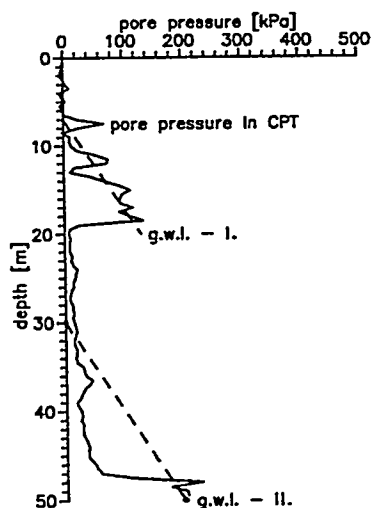


Fig. 5. Pore pressure changes with depth below tipped fill surface.

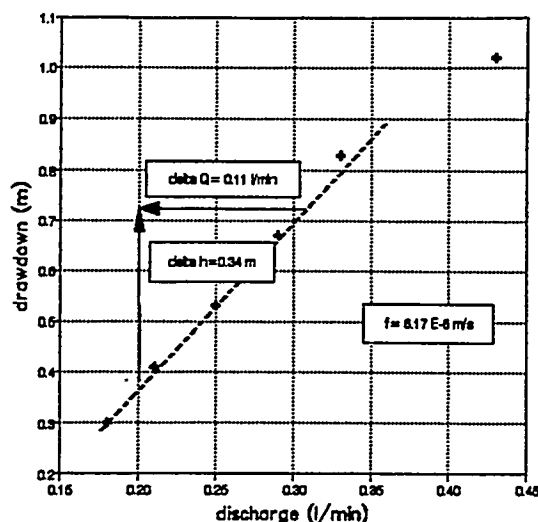


Fig.6. Result of in situ permeability test.

Very important role from point of view of waste disposal construction plays compressibility of the upper zone. Regarding to the common granulometry this layer laboratory testing seems to be unsuitable but field loading test is too expensive for common use. To simplify layer compressibility evaluation an attempt to establish relationship between cone resistance in static cone penetration test and modulus of deformation measured by means of in situ loading test has been made. The results of this research are shown in Fig. 7. It is also evident from this figure that freshly disposed fill has larger compressibility than the elder one.

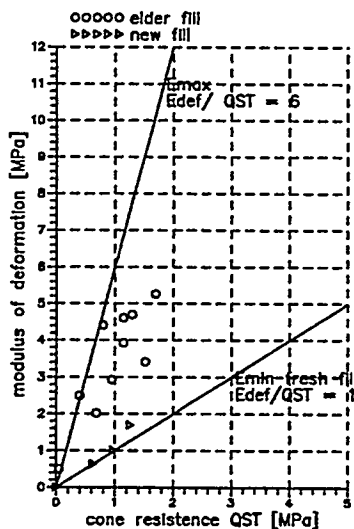


Fig.7. Relationship between initial modulus of deformation and cone penetration resistance.

Large and sometime nonhomogeneous compressibility of the tipped fill could influence the continuity of mineral sealing of the proposed disposal. Hence possible changes of the upper layer permeability due to the disposed waste load could play positive role. Experiments have revealed that the influence of the waste layer having thickness about 10 to 15 m should be sufficient for permeability decrease of upper fill layer from the initial value of about 10^{-5} m/s to lower than 10^{-10} m/s.

POWER PLANT WASTE CHARACTERIZATION

Sorts of waste to be disposed in mine tipped spoil area

Disposal on tipped fill are prepared only for power plants where disposed waste are ash and energogypsum (part of the total amount produced will be washed and used as commercial grade gypsum). Stabilization of ash and FGD product mixture has been rejected for the cost reasons.

Moreover a decision has been made to transport ash alone from several power plants situated in greater distance from mine area and to dispose it to the mine tipped fill. Railroad transport of ash and handling of large volume of ash during disposing has led to the need of antidusty arrangement of the proper ash using wetting by means of high speed agitation.

Properties of wetted ash

Aggregates of ash grains joined together mainly by capillary forces are formed during high speed agitation. The aggregates are formed only in very strictly defined range of water content. Degree of saturation (percent of water saturated pores) after agitation is about 20%, i.e. very low. The existence of aggregates has positive influence on the possibility of dust air pollution (aggregates will persist certain time after getting almost dry). On the other hand high speed agitation has almost no influence on mechanical properties of ash and on the leachate composition. According to Czech Waste Policy Act #513/1992Sb a mineral sealing layer of the disposal of such waste is necessary.

Properties of energogypsum

Disposed energogypsum (no washed at the end of technological process) contains about 15% of saline water. Degree of saturation usually does not exceed 25%. Common bulk density in loose state is about 1000 kg/m³. Cohesion and angle of internal friction may be expect on the level of 5 kPa and 36° respectively. The eluate contains chloride and sulphate ions in great concentration. According to above mentioned Policy Act the disposal of such waste should be sealed by mineral impermeable layer.

Properties of ash energogypsum mixtures

Moist mixture of ash and energogypsum does not get hard without lime additive and maintain soil like character even after long time. Permeability of such waste is about 10⁻⁶ to 10⁻⁷ m/s. Bulk density in loose state is about 900 kg/m³ with slight increments under the weight of overlying layers. Leachate from such waste is influenced by ash and energogypsum components. Consequently disposals of such waste need to be sealed by mineral impermeable layer according Czech P.A. #513/92Sb.

TECHNICAL MEASURE RECOMMENDATIONS

Stability of disposal site

Place for disposal site on the mine tipped spoil area should be elected taking into account slope stability requirements. Mine Policy Act #26/1989Sb states minimal factor of safety 1.5 for general slope. Recent experience shows the common thickness of accumulated waste can be about 15 to 25 meters to fulfil safety requirement. Maximum thickness of waste can be in unique cases as high as 45 meters.

Disposal settlement under the waste load

Extremely high compressibility of tipped clayey subsoil leads to several meters large settlement of disposal bottom (Fig. 8). Improvement of foundation conditions by excavation of upper very compressible layer seems to be impossible due to the costs reason (extremely large area for power plant disposal).

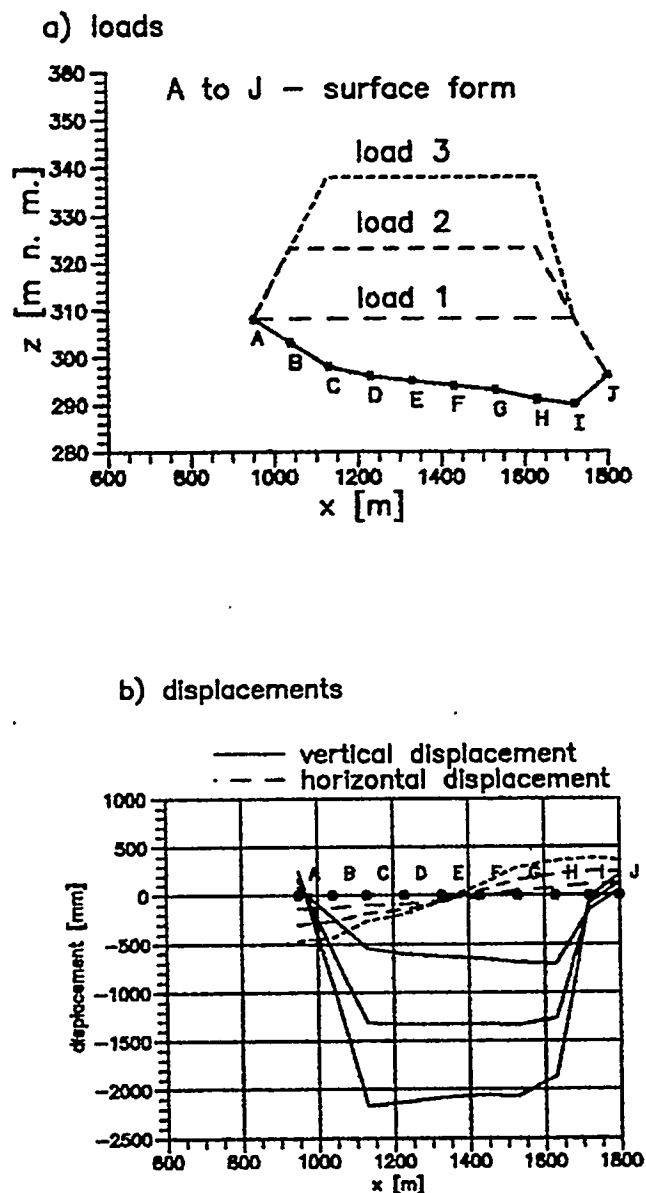


Fig. 8. Displacements due to the load of disposed waste.

As the settlement value depends mainly on the tipped spoil thickness it is good rule of practice to orientate disposal drains in the direction of its increments. It seems to be almost impossible to maintain sufficient infiltration of the drains and its continuity due to the differential settlement (see Fig. 8) near the disposal boundaries. Consequently it is recommendable to collect leachate in concrete shaft founded on tipped spoil subsoil situated near the disposal boundary but well inside the disposal area. One could

object that such arrangement will evoke the necessity of permanent pumping of leachate. Calculation has shown, however, that low degree of saturation of disposed waste should be sufficient to prevent steady flow of rain water in the waste for very long time. Then it is very probable that no or very little amount of leachate will formate by filtration of rain water through the waste during the whole disposal life. After the final level of waste will be reached the upper sealing layer should be construct. Hence no additional development of leachate will be probable.

Large settlement and unnegligable horizontal displacements (see Fig.3) could cause failure of continuity of base sealing layer and fissure formation. Consequently an afford has been made to clarify the possible selfsealing capacity of tipped clayey subsoil loaded by disposed waste. The research has shown that the pressure of 15 to 20 m of accumulated waste will be sufficient for practical impermeability coefficient of filtration of order 10^{-10} m/s or lower) achievment of originally granular subsoil.

Monitoring

Hydrogeological monitoring is obligatory according to Czech Policy Act #513/1992Sb. Because of impermeability of deeper layers of tipped clayey subsoil it seems to be sufficient restrict this monitoring to more permeable upper layer having average thickness of about 15 m.

Monitoring of slope deformation due to the waste accumulation in the disposal using inclinometric measurement should be a matter of course as control of general slope stability of underlying tipped fill. State mine authority should require it (internal prescription) in every case where landslide could cause larger damage. Measurement of horizontal displacement by means inclinometers should be realized on total fill thickness, i.e. between the fill surface and original ground level at least.

It is recommendable to realize settlement monitoring in the case of several first cases at least to confirm the theoretical consideration and to make the following disposals construction in such complex environment more safe and with the lowest cost consume possible. Certain monitoring activity should be also made to confirm or correct optimistic estimation about the leachate formation. Lyzimeters installed in the waste bode probably would be a good solution.

CONCLUSION

The area of mine tipped spoil seems to be good space for power plant waste disposal especially due to the lack of NIMBY syndrome, due to large capacity of proposed disposals and short transport distances for the largest power plants in Czech Republic. Such advantage is accompanied by some technical complications. The paper has shown how to overcome them. Minimal requirements on the monitoring extend are presented and obligatory and advisable parts are distinguished.

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FLY ASH LEACHATE GENERATION AND QUALITATIVE TRENDS AT OHIO TEST SITES

Jaroslav Šolc, Principal Hydrogeologist
H. John Foster, Geologist
Ray D. Butler, Senior Research Manager

Energy & Environmental Research Center
Grand Forks, North Dakota, USA

ABSTRACT

Under the sponsorship of the U.S. Department of Energy, the environmental impact and potential contamination from landfilled fly ash (coal conversion solid residues – CCSRs) have been studied at field sites in Ohio. The progressive increase of moisture content within pilot cells over depth and time facilitated intensive chemical processes and generation of highly alkaline (pH of 10 to 12) leachate. Chemistry of pore water from lysimeters and ASTM leachate from fly ash and soil cores indicate the leachate potential to migrate out of deposit and impact the pore water quality of surrounding soils. Na, SO₄ and, particularly, K, Cl, pH, and EC appeared to be valuable indicator parameters for tracking potential leachate transport both within the cells and below the ash/soil interface.

INTRODUCTION

Coal conversion solid residues (CCSRs) currently pose a serious environmental problem because of the increasingly large volumes to be disposed of and the complexity of their chemical and physical behavior. In 1989, two 2.4-m-thick test cells containing approximately 700–1000 tons each of residues were constructed in Ohio. Advanced process residues from combined lime injection multiphase burner (LIMB) retrofit were studied to assess (1) the long-term impact of natural leaching processes on the surrounding environment, (2) chemical and mineralogical transformations of buried advanced process residues, and (3) engineering behavior.

SITES CHARACTERISTICS

Residues at the Ohio North cell (613 m³) and South cell (490 m³) were moisturized to 25% (North) and 35% (South) during construction, with a resultant variability in compaction and moisture build-up. The cells were left uncovered for the first year to facilitate environmental interaction of disposed residues and simulate typical industrial deposition. After this initial period, cells were covered by 60 cm of compacted soil. Relatively high precipitation, the porous nature of the residues, and low permeability of surrounding soils (Table 1) facilitated early saturation and intensive leaching processes within the cells.

FIELD MONITORING PROGRAM AND ANALYTICAL WORK

Both cells were instrumented with pressure vacuum soil lysimeters (North 12, South 10), 4 neutron access tubes, and runoff collectors. Nests of upgradient and downgradient monitoring wells were installed (8 wells). The sampling schedules and measurements were conducted on a quarterly basis during the first year, followed by annual sampling of fly ash and soil cores and measurements of volumetric moisture content (neutron probe) and field saturated hydraulic conductivity (Guelph permeameter). Water samples from monitoring wells and lysimeters were collected on a quarterly basis. ASTM (American Society for Testing and Materials) standard leaching tests, x-ray fluorescence bulk analyses (XRF), x-ray diffraction

mineralogical analyses (XRD), and some key engineering tests (moisture, permeability, unconfined compressive strength, etc.) were performed on selected ash and soil cores.

TABLE 1

Physical Parameters									
Year	Precipitation (mm)	Permeability-lab. ash (cm s ⁻¹)	soil ¹ (cm s ⁻¹)	Ash-Guelph permeameter (cm s ⁻¹)	ash (%)	Moisture soil (%)	ash ² (%)	Volumetric moisture ³ (%)	Compressive strength (MPa)
Ohio-North									
1989		2.5E-6			30	9			4.9
1990	1367	1.1E-5		1.4E-4	60	10	60	67	3.9
1991	830	7.9E-4		1.0E-4	73	12	51	59	5.2
1992	1232	3.2E-5	2.1E-6	1.1E-4	89	11	73	57	2.4
Ohio-South									
1989		1.9E-6			33	9			7.7
1990	1367	1.5E-6		8.0E-4	42	7	46	62	6.2
1991	830	5.5E-6		8.5E-4	52	14	40	65	5.6
1992	1232	1.5E-4	2.1E-6	3.1E-4	84	10	60	62	2.1

¹ average values from 1989-1992

² lab averages to depth of 1.8 m

³ volumetric moisture - neutron probe measurements to depth of 1.8 m

The extensive project data processing and interpretation was based on a common-sense model, which tracks changes in chemistry of waters percolating through the cells in time and assesses the quality and extent of the resulting impact of highly alkaline leachates on the environment. Figure 1 shows the typical chemistry of the waters in Ohio selected to represent mean values, illustrating the movement and evolution of water from the surface of cells downward to lysimeters and finally to monitoring wells.

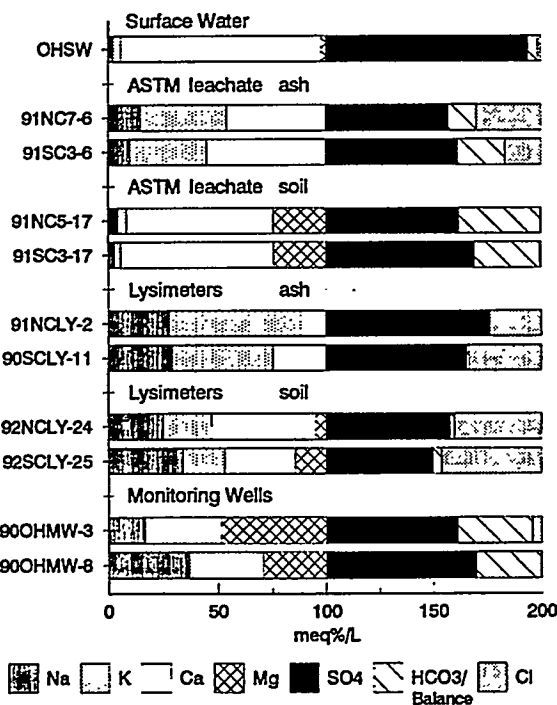


Figure 1. Typical chemistry of sampled water.

RESULTS

Chemistry of fly ash and physical properties

Coal used at the Ohio Edgewater power plant (LIMB) at the time of cell construction had an ash content of slightly over 10% and a sulphur content of about 2.5%.⁽¹⁾ The bulk composition of ash averaged about 40% CaO, 23% SiO₂, 13% SO₃, and 9% of both Al₂O₃ and Fe₂O₃. There were no significant time- or depth-related qualitative trends observed (except at the ash/soil interface) in bulk chemistry of residues during 1989-1992.

Physical parameters measured in the laboratory and in the field (Table 1) greatly influence the potential for, and intensity of, leachate generation. Laboratory permeabilities and field Guelph permeameter values differ by approximately one to two orders of magnitude and, in general, indicate a higher permeability in compacted residues than surrounding soils. This is attributed to formation of microfractures as a consequence of mineralization, dissolution and precipitation reactions, and freeze-thaw processes. Progressive increases in moisture content with depth and time, with maximum values near the ash/soil interface, indicated moisture build-up toward the bottom of cells⁽²⁾. Physical processes and intensive leaching resulted in a general decrease of compressive strength of bulk ash with time (Table 1).

Leachate quality characteristics and trends

Although initially low permeabilities slowed the downward migration of strongly alkaline pore waters (pH 10 to 12), saturation increased over time, and samples were collected in the vacuum pressure lysimeters. A time-dependent decrease of Na, K, SO₄, and Cl concentration (Fig. 2), with an attendant decline in pH and pore water electrical conductivity (EC) in the upper part of the cell, contrasts with increasing concentrations in samples from the lower part of the cell and below the ash/soil interface.

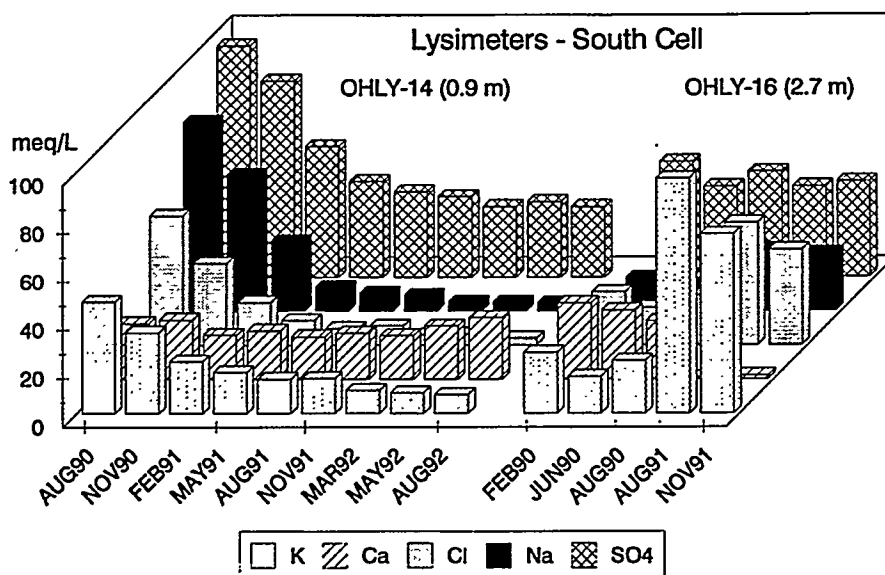


Figure 2. Pore water chemistry trends.⁽²⁾

While sulphate and sodium showed trends similar to those of potassium and chloride, calcium concentration remained more stable both in depth and time. The concentrations of these ions were highly variable spatially, depending on lysimeter environment and depth. However, obvious trends in the chemistry of samples from each lysimeter have been observed.

Potassium, chloride, pH, and EC analyzed in ASTM leachate from annually sampled fly ash and soil cores appeared to be the most indicative of leachate transport both within the cells and under the ash/soil interface. Increased potassium concentrations and increased pH and EC in ASTM soil leachate analyses have been observed approximately 40–60 cm below the bottom of cells, which might support an estimation of the rate of vertical contaminant transport (Fig. 3).

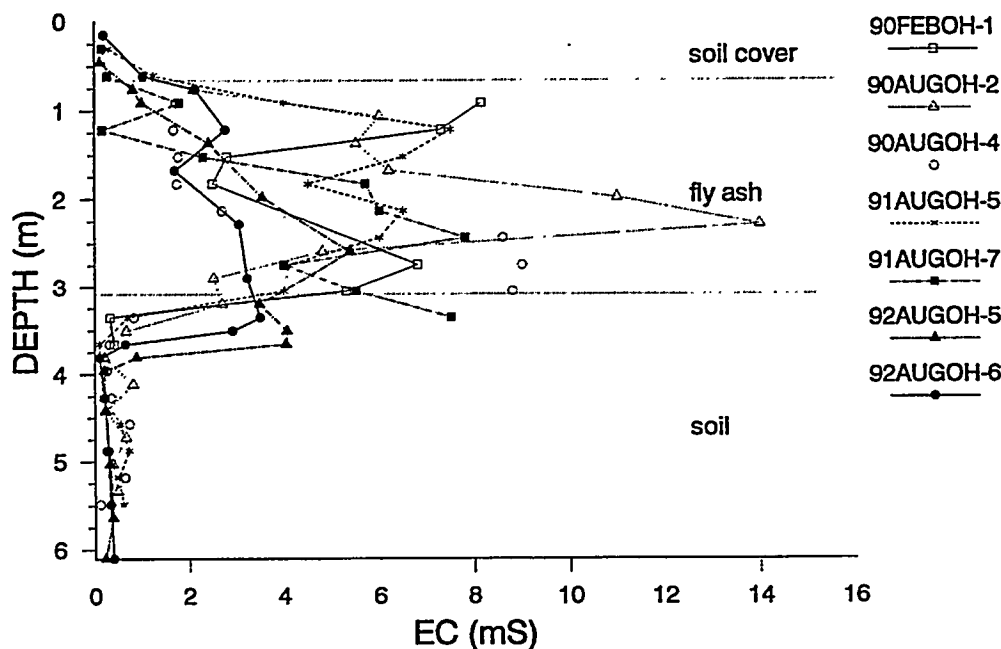


Figure 3. North cell - ASTM leachate EC trends.

The Ohio monitoring nests, consisting of vertically staggered wells, are located about 10 m upgradient and downgradient from the cells. Groundwater levels at the Ohio site are about 2–3 m below the bottom of the cells and have fluctuated about 1–1.6 m during monitoring since 1989. Na, Ca, Mg, SO_4 , and Cl ions dominate groundwater chemistry. The presence of chloride indicates possible contamination of downgradient wells. However, only the shallowest well (OHMW-6, 5 m) shows a steady increase in chloride concentration. Similar trends have not been shown by other ions, pH, or EC.

CONCLUSIONS

Intensive monitoring and analyses at Ohio test sites indicate that even "dry deposition" of coal combustion residues can have a potential to impact the soil pore-water and groundwater quality. With

time, increasing moisture content within the landfills allowed for the generation of a highly alkaline leachate (pH of 10 to 12), which migrated from the landfills to surrounding soils. Na, K, SO₄, and Cl ions, together with pH and EC, were the most indicative parameters for monitoring leachate behavior and migration. The rate of leachate transport, its chemistry and limits of potential environmental impact depend on the initial quality of combustion residues and, particularly, methods of deposit, containment, and site specific hydrogeological and climatic conditions.

ACKNOWLEDGEMENTS

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*Computer Applications/
Modeling/Power Systems*

Session C4

A COMPUTERIZED COAL-WATER SLURRY TRANSPORTATION MODEL

Blažo R. Ljubičić, Research Engineer

Energy & Environmental Research Center
University of North Dakota
Grand Forks, North Dakota, USA

Brad Trostad

Department of Electrical Engineering
School of Engineering & Mines
University of North Dakota

Grand Forks, North Dakota, USA

Zarko Bukurov
Petar Cvijanovic

Faculty of Technical Sciences
University of Novi Sad
Novi Sad, Yugoslavia

ABSTRACT

Coal-water fuel (CWF) technology has been developed to the point where full-scale commercialization is just a matter of gaining sufficient market confidence in the price stability of alternate fossil fuels. In order to generalize alternative fuel cost estimates for the desired combinations of processing and/or transportation, a great deal of flexibility is required owing to the understood lack of precision in many of the newly emerging coal technologies. Previously, decisions regarding the sequential and spatial arrangement of the various process steps were made strictly on the basis of experience, simplified analysis, and intuition. Over the last decade, computer modeling has progressed from empirically based correlation to that of intricate mechanistic analysis. Nomograms, charts, tables, and many simple rules of thumb have been made obsolete by the availability of complex computer models. Given the ability to view results graphically in real or near real time, the engineer can immediately verify, from a practical standpoint, whether the initial assumptions and inputs were indeed valid. If the feasibility of a project is being determined in the context of a lack of specific data, the ability to provide a dynamic software-based solution is crucial. Furthermore, the resulting model can be used to establish preliminary operating procedures, test control logic, and train plant/process operators. Presented in this paper is a computerized model capable of estimating the delivered cost of CWF. The model uses coal-specific values, process and transport requirements, terrain factors, and input costs to determine the final operating configuration, bill of materials, and, ultimately, the capital, operating, and unit costs.

INTRODUCTION

Analysis of the transportation and behavior of solid-liquid mixtures, including coal-water fuels (CWF) has progressed over the last decade from empirically based correlations to intricate mechanism analysis. "Analysis," however, requires a specialist, a powerful computer, and time. To understand the significance of this statement, we have to go back in time to B.C. (before computers). Design was done with a few simple diagrams and the "build-test, build-test,..." mentality. Though it "worked," this approach usually resulted in a grossly overdesigned and costly product. When computers first became common engineering tools, many design engineers were trained, but soon they realized they had a

documentation tool, not a design tool. Often the design was in production before an analysis could be completed, and the analysis step was frequently by-passed altogether. Unfortunately, analysis became a tool used in the attempt to fix the design. One frequent abuse of computer-aided design (CAD) is if you don't see what you expect, change parameters and try again.

Today, software allows designers to combine state-of-the-art graphics, up-to-date databases, and artificial intelligence. Complex processes can appear in full color, be marked, rescaled, and examined from any point of view. Designers can add or change equipment components (e.g., valves, flanges, fittings) while tablet-driven applications track every element from gaskets to bolts. Accurate bills of material and price lists are available at any time during design. From a code and standards point of view, only approved components are allowed to be used. Equipment alignment is accurate, and connections are precise. Software also helps guide and check each design action from initial concepts to subsequent modifications. All errors involving component interference, compatibility, size, rating, facing, and alignment are avoided or reported before final design validation. From a construction viewpoint, software can travel with the project into the field by modem and/or portable computer. Equally important is that the software can be used while drafting proposals, conducting preliminary analysis, and improving basic plant design.

Whether the intention is to analyze an old or existing system or design a new one, today's designer will probably turn to one of the currently available software packages. Many of these packages can operate on a personal computer (PC) with the added flexibility of tying into a host computer. These products offer excellent record-keeping and design capabilities. They eliminate design errors that create havoc during field construction and retrofit by minimizing the problems latent in the thousands of available components, and widely varied construction materials, safety and pressure requirements, codes, and company policies. New CAD techniques streamline the design and construction process, facilitate modular construction, simplify retrofit, and revamp projects in all fields of engineering.

STATUS OF CWF TECHNOLOGY

Coal-water fuels seem likely to emerge as a clean, efficient, and cost-competitive source of fossil fuel-based electric power and thermal energy. Environmental and market forces are combining to demand such systems, and a variety of companies are committed to meeting this challenge with large-scale commercial applications. This new fuel can supply power plants varying from small units to those needed for utility baseload generation.

CWF production is based on two different technologies. The first technology prepares the fuel through the use of additives, while the second method involves hydrothermal coal processing. Each of these technologies has a unique set of advantages, disadvantages, costs, and risks, which determine in which segment of the market it will succeed and in what time frame. Within each technology and market segment, developers are evolving various product designs and manufacturing approaches. Ultimately, market forces will select the winners for each market segment. Sponsors of CWF technologies need to determine the validity and the attractiveness of the technology to the market in terms of meeting requirements and providing a profit that exceeds the total cost of ownership. The current status of CWF Technology is shown in Table 1.

Of all the classes of coal found around the world, low-rank coals (subbituminous and lignite) have only recently stimulated interest among process developers as feedstock for producing CWF. This interest can be explained by a combination of the intrinsic advantages of the many low-rank coals (LRCs). Low mining costs and low sulfur content are the two outstanding advantages of LRCs. Offsetting these advantages are a number of characteristics that have impeded their wide-scale use. Low heating value, remoteness from high concentrations of industry and deep water ports, and rail transportation costs that are higher relative to mining costs have been major obstacles. Poor transportation and storage characteristics (excessive dusting, tendency towards spontaneous combustion) have contributed to the "dirty" image of LRCs.

TABLE 1

Current Status of CWF Technology

Commercially Available for High-Rank Bituminous Coal

- Russia
 - 1.2 MM tpy Belovo-Novosibirsk Pipeline – Snamporgetti
- Japan
 - 0.6 MM tpy, 1991, to 9.3 MM tpy by 1995
 - 0.3 MM tpy Japan COM (Onahama)
 - 0.25–1.0 MM tpy–JGC Corp. (Yanzhou, China)
 - 0.25–3.0 MM tpy–Nissho Iwai, Mitsui, and JGC Corp.
 - 0.50–5.0 MM tpy–Idemitsu Kosan and Marubeni

Pilot-Scale Only for Low-Rank Coal

- USA
 - 7.5 tpd EERC¹ (North Dakota)

¹ Energy & Environmental Research Center, University of North Dakota.

Improved coal properties achievable via CWF production include the following:

- Higher energy density
- Lower sulfur content
- Convenience of a liquid fuel
- Reduced ash content
- Increased stability during shipment and storage

These coal-based fuels are not only taking a new form, they provide the means to use multiple modes of transport and increase the number of alternative routes to given destinations.

NEED FOR COMPUTERIZED CWF TRANSPORTATION MODEL

The intention in developing a computerized transportation model is to assess the costs associated with various mine-to-market scenarios involving various coal preparation and processing steps that will provide a higher-valued CWF product. Although technology is developed to the point where full-scale commercialization is feasible, the lack of any substantial large-scale CWF commercialization has led to the deficiency of reliable and well documented production costs. CWF developers reluctantly make some generalized costs available, even though these costs have not yet been established under actual operating conditions. Most of the data are in the form of simple tables or diagrams similar to the one shown in Figure 1 and could be used only as preliminary guidelines.

The range of uncertainty associated with such estimates is understandable; however, this only increases the need for computerized models and simulations. In view of the obvious lack of precision in many of the cost factors associated with emerging CWF technologies, it is essential to extend the need

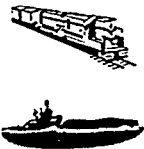
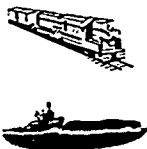
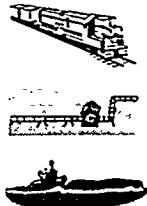
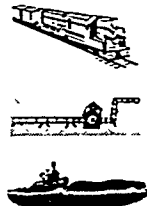
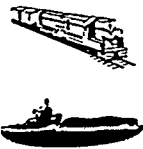
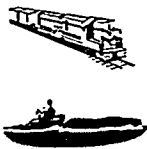
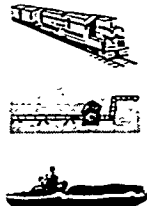
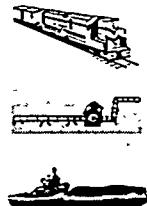
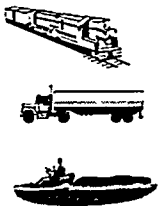
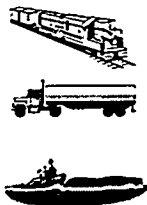
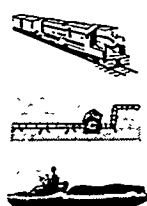
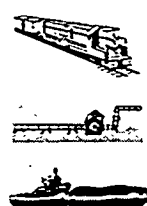
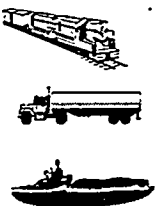
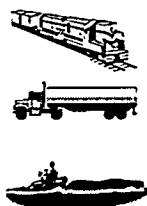
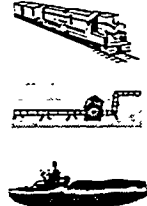
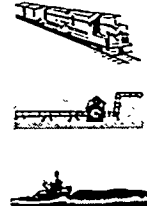
	Very Low, 0.5 Mt/Y	Low, 1.0 Mt/Y	Medium, 5.0 Mt/Y	High, 10 Mt/Y
Long, 600 Miles				
Medium, 300 Miles				
Short, 100 Miles				
Very Short, <35 Miles				

Figure 1. Preliminary CWF transportation mode selection guidelines.

for flexibility to the sequential and spatial arrangement of the various processing steps. All these factors lead to the conclusion that a computerized mine-to-market coal transportation model should be developed.

The development of computer technology over the past decade has led to dramatic changes in the way design and analysis of power production and transportation is performed. Use of dynamic computer models, particularly during the early stages of design has many advantages:

- Reduced engineering design labor costs
- More cost-effective design
- A better designer-operator understanding of system operations
- Designs that are rigorously proven to be within safety codes

Computer modeling methodology is useful in many ways. The model can test numerous scenarios ensuring a design's integrity while at the same time optimizing materials and equipment use. The model can be used to develop operating procedures, test control logic, and train operators. Indirect benefits

such as reducing operational errors can be expected because the computerized model will provide operators with practice in handling many system upsets that cannot be experienced before actual operations.

Databases containing environmental laws, regulations, codes, and limits could also be included within the model. These are mandatory when dealing with constantly changing statutes, since they can be updated frequently or even instantaneously if needed. The user can be assured that, as opposed to printed material, the outline file will have the most current information available. A new and growing format, the CD-ROM, offers unimagined possibilities. This format can allow over 600 MB of information (the equivalent of over 250,000 pages of text) to be stored on one disk. CD-ROMs can store entire databases, pieces of larger databases, or even customized databases.

DESCRIPTION OF CWF TRANSPORT MODELING SOFTWARE

By far, the most powerful feature of a computerized CWF transportation model is its ability to store and use all the necessary parameters for estimating feasibility and economics. These parameters range from the slurry fuel preparation stage to final delivery and storage requirements. In order to accomplish this task, several modules are required to deal with the different stages of CWF production and transportation.

The first module, called the "CWF Editor" is the backbone of the model. In this module, the various CWFs and their properties will be stored in a database for easy retrieval. Properties such as cost, solids loading, particle-size distribution, yield stress, flow factor, consistency, heating value, ash content, etc., will be entered and stored here. Entering a matrix of known parameters for each possible fuel allows combinations of parameters to be easily extrapolated where actual lab data are not available. This feature is essential in modeling CWF transportation because it provides the capability to use iterative techniques to find optimum solutions and breakpoints. Of course, as new slurry fuel data becomes available, it can be added to the database and used to quickly regenerate existing models.

The next module required for modeling CWF transport is called the "Pressure Drop Module." Because of the complex flow behaviour of slurries, special algorithms must be employed to estimate the pressure drop throughout the pipeline system. The importance of this module is twofold: First, the pressure drop must be known in advance to allow design and layout of the pipeline network to continue. Second, it is imperative that the pressure drop can be estimated accurately without having to build an expensive test pipe loop for each feasibility study. Obviously, as test pipe loop data becomes available, they can be compared to the estimated pressure drop and used to update the current model.

The "Pipeline Design Module" is the third module used in modeling CWF transport. Several features are required within this module. Essential to the pipeline design is the overland routing of the pipeline. Within this module, will be a library of 3-D ground profiles for various existing and proposed pipelines. Each ground profile entry can have various degrees of resolution; thus, simple profiles from existing data (contour maps, etc.) can be used for initial estimates, while high-resolution profiles unique to the project can be used during advanced stages of the model. Given the operating conditions, pressure drop parameters, and the pipeline route terrain, the selection and placement of pumping stations and pipe can be made. For each pumping station, selection of the pumps and various hardware is allowed from a user-modifiable library of components. Finally, within this module, the designer can select which storage components are required at the output of the pipeline.

The last module required is the "Economics Module." After the fuel is selected, the pressure drop is estimated, and the pipeline has been laid out, the economics for the pipeline can be determined. By using a library of various costs for raw coal, land, equipment, labor, utilities, etc., the final delivered cost of the slurry fuel and other costs can be determined. Because the various modules work together, many scenarios can be evaluated quickly to find an optimum cost solution. Equally important, as the model

inputs become more accurate, the economics can be updated. Put simply, this means that an initial feasibility estimate can be done very quickly and updated automatically as more data become available.

CWF PIPELINE SYSTEMS

A slurry pipeline system in general consists of the following four components:

- Slurry preparation plant
- Pumping stations
- Pipeline
- Storage and holding facilities

The design of such a system with a given set of demand points and a source requires determination of the following parameters:

- Rheology of the slurry fuel to be pumped
- Number, location, and capacity of pumps to be used
- Nodes (i.e., source and demand points) to link directly with the pipeline
- Exact path for laying the pipeline between two nodes
- Pipe diameter
- Slurry solids loading
- Number and capacity of storage tanks at the source and at each demand node

The safety record for slurry pipelines is a good one, but with a computerized approach, this record can be improved even more. A coordinated effort by regulatory agencies to develop a common safety database is needed. The focus should be on collecting, archiving, analyzing, and reporting safety data with the intent of improving design and operating regulations. Specifically, regulatory agencies should agree on a constant risk management strategy that sets priorities for human safety criteria and use of cost-benefit analysis, thus reducing property and environmental damages.

Pipeline operators could benefit from these computerized models as well. Using a combination of leak detection methods, computers could perform an otherwise time consuming detection of a broad range of leaks. The set point-limit control system, where practical, could be used to provide quick detection of relatively large leaks. Line balance calculations should be conducted daily to monitor for small- to medium-sized leaks. Periodic visual inspection should still be used to detect tiny leaks and those leaks which are not detected by computerized monitoring methods.

ECONOMICS OF CWF TRANSPORTATION

The energy market is dynamic, and the expansion of CWF technology allows competition with the increasing near- and mid-term availability of other clean coal technologies. This is all set in a context increasing environmental concern with rapidly changing political and economic environments. There are a variety of risks involved in deciding to switch between various fuels. Transportation costs top that list. Certainly, coal routes around the world will face increased obligations as environmental concerns grow. This is no small issue.

Development of known coal resources depends not only on the economics of coal mining, but also on having transportation networks that can bring the product to the consumer. All three components—mining, transportation, and combustion—must achieve an adequate rate of return for the companies making the initial investment. An important part of the commercialization of new coal-based fuel forms concerns transportation from the processing plant to the facilities where it will be consumed. Given the remoteness of many coal deposits, transportation costs are an important determinant of overall economics.

CWF development sponsors addressed this issue by requiring developers to prepare projections of the future cost of their CWF, given commercial quantities. Many attempts have been made over the years to audit these cost projections, but the real needs go well beyond a simple review of numbers. Today, CWF sponsors are trying to probe the underlying technical and financial assumptions, sources of data on material and equipment costs, and issues such as the realistic manufacturing yields that can be expected from various processes. These case studies bring up an interesting point: They suggest that potential suppliers of materials and equipment critical to the production of CWF have not been not learning about and acting upon the opportunities early enough to participate in the industrial development while ensuring a good starting position.

Major factors that influence the economics of CWF are the handling quantities and the distance from the mine to the end user. The rheological properties of CWF greatly rationalize the forms of handling, such as pumping, pipelining, transport by barge or tanker, and storage compared to pulverized coal. The greater the capacity and the longer the distance, the lower the transportation cost. The influence of transportation distance comparing pulverized and slurried coal delivered at the boiler is shown in the Figure 2.

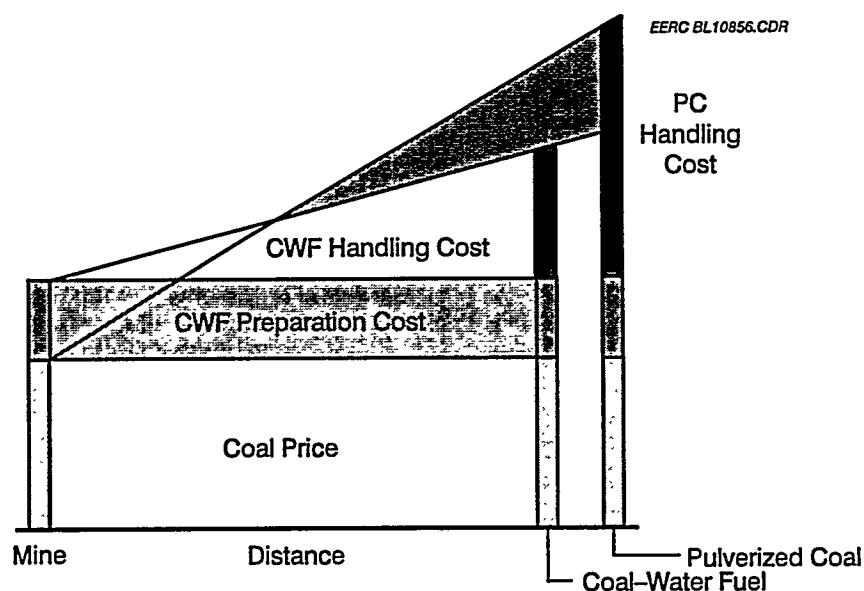


Figure 2. Comparison of effect of transportation distance on costs of pulverized and slurried coals.

The relative cost structures for pulverized and slurried coal are shown in Figure 3. A comparison is made for a typical case where 5 MMt/year of pulverized and slurried coal are delivered, including the cost of ocean transport.

Given only one coal slurry pipeline in operation (Black Mesa, USA, 273 miles), the novel nature of CWF, the large volume of product, and a transport mode not previously used, technical problems are likely to arise. When they do, they will impose additional transportation costs. In the absence of data that define the precise nature and behavior of CWF, it is difficult to estimate these costs.

Coal-handling systems are another unknown that adds to the total cost. When a coal is upgraded by as much as 50 cents/MBtu, the developer often does not include this in the final cost because utilities must add the expense of installing new silos or covered conveyors to prevent loss from fire. Although not major increments, they do add to the overall cost when comparing options of minemouth to power plant scenarios and they can flip the balance for or against. Here a computerized model could determine the point where upgrading is no longer feasible.

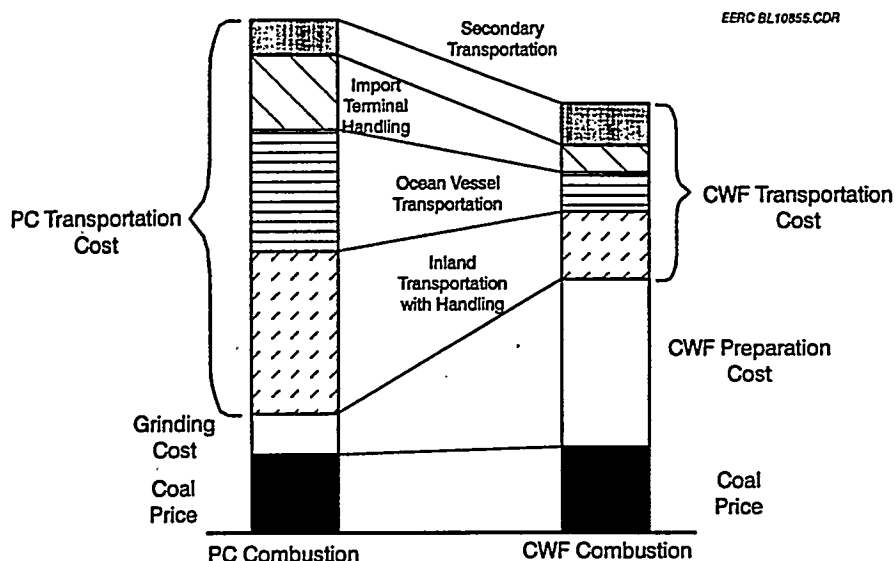


Figure 3. Relative cost structures of pulverized and slurried coals.

CONCLUSIONS

In summary, it is clear that a CWF design and cost estimate tool, which includes the capability to assess industrial infrastructure to support the venture, would be important for developers and their sponsors. Such information is useful early in the new product development cycle in selecting which technical options to pursue. It becomes even more vital as commercial introduction nears and large investments are considered.

The Energy & Environmental Research Center (EERC) is constantly conducting a preliminary evaluation of the commercial viability of advanced coal-related technologies. Technology evaluation, process design specifications, and specific cost information items are identified and evaluated using existing cost models, vendor quotations, and coal conversion specialist information. From the compiled material, a computer program will be written to encompass various scenarios with the flexibility to be expanded to future domestic and international coal-processing strategies. In addition, the model will be designed to be flexible enough to accommodate changes in plant capacity, specific location, and process options. Unit operations to be reviewed will be coal receiving and storage, coal preparation, coal slurry handling and transport, thermal treatment processing, and CWF handling and transport mechanisms.

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UNDERSTANDING COAL QUALITY AND ITS RELATIONSHIP TO POWER PLANT PERFORMANCE AND COSTS

Kevin D. Jennison, Leader of Performance Analysis Section
G. Scott Stallard, Project Manager

Black & Veatch International
Overland Park, Kansas, USA

ABSTRACT

The availability of reliable, reasonably priced energy is a necessary cornerstone for established and emerging economies. In addition to addressing coal quality issues strictly at a plant level, it is now prudent to consider long-term performance and economics of particular fuel sources to be selected in the light of system economics and reliability.

In order to evaluate coal quality issues in a more comprehensive manner, it is important to develop both an approach and a set of tools which can support the various phases of the planning/analysis processes. The processes must consider the following:

- Cost/availability of other potential coal supplies, including "raw" domestic sources, "cleaned" domestic sources, and other internationally marketed coals.
- Power plant performance issues as function of plant design and fuel properties.
- System expansion plans, candidate technologies, and associated capital and operating costs.
- Projected load demand, for system and for individual units within the system.
- Legislative issues such as environmental pressures, power purchase agreements, etc. which could alter the solution.
- Economics of potential plans/strategies based on overall cost-effectiveness of the utility system, not just individual units.
- Anticipated unit configuration, including addition of environmental control equipment or other repowering options.

The Coal Quality Impact Model (CQIM™) is a PC-based computer program capable of predicting coal-related cost and performance impacts at electric power generating sites. The CQIM was developed for EPRI by Black & Veatch and represents over a decade of effort geared toward developing an extensible state-of-the-art coal quality assessment tool. This paper will introduce CQIM, its capabilities, and its application to Eastern European coal quality assessment needs.

Paper unavailable at time of publication.

MODERN FLUIDIZED BED COMBUSTION IN OSTRAVA-KARVINÁ COGENERATION PLANTS

Vladislav Mazáč
Energoprojekt Praha, a.s.
Ostrava, Czech Republic

Alexej Nováček
Moravskoslezské teplárny a.s.
Ostrava, Czech Republic

Josef Volný
Teplárny Karviná a.s.
Karviná, Czech Republic

ABSTRACT

The contemporary situation of our environment claims the sensitive approach to solving effective conversion of energy. Limited supplies of noble fuels and their prices evoke the need to use new combustion technologies of accessible fuels in given region without negative ecological influences. Energoprojekt participates in the preparation of the two projects in Ostrava-Karviná black coal field in Czech Republic.

The most effective usage of fuel energy is the combined of electricity and heat. If this physical principle is supported by a pressurized fluidized bed combustion (PFBC) one obtains a high electricity/heat ratio integrated steam-gas cycle on the basis of solid fuel. Cogeneration plant Tøebovice is the dominant source (600 MW_{th}) of Ostrava district heating system (1100 MW_{th}). The high utilization of the installed output and utilization of the clean, compact and efficient of the PFBC technology is the principal but not the single reason for the selection of the Tøebovice power plant as the first cogeneration plant for installation of the PFBC in Czech Republic. The boiler will burn black coal from the neighboring coal basin.

The intensive mining hard coal led recently to great production of waste coal slurries. Dumps of slurries are concentrated in the Karviná Region. As this region is interesting for further cogeneration production (425 MW_{th}) the location of new power source was predetermined. The new unit will fluidized bed boiler (CFB 315 or 126 MW_{th}) which will mainly combust slurry. The production of energy from waste without negative influence on environment is the common goal.

Both projects are prepared to be put into operation in 1997-1998 how the new laws for environmental protection determine. Large retrofitting energetical sources is possible only with a support of domestic and foreign suppliers. Partner co-operation motivates both industry and human capacities of countries resulting in the integration not only within the energy field.

PFBC OSTRAVA - TŘEBOVICE

In September 1992 the contract was subscribed between ABB Carbon (Finspong, Sweden)/ PBS (Brno, CR) and Moravskoslezské teplárny a.s. (MST Ostrava, CR) for delivery of steam-gas block with pressurized fluidized bed combustion (PFBC 200) on the basis of solid fuel.

The best economic result and best efficiency of the PFBC technology will be if it is applied at the relatively large district heating system. These requirements are fulfilled by the Ostrava district heating

system. Due to interconnection of the hot water and steam systems it is the largest district heating net in Czech Republic (1100MW). The dominant production unit of this district heating system is the cogeneration plant of Třebovice (ETB).

MST District Heating System

The high utilization of the installed output and utilization of the clean, compact and efficient of the PFBC technology is the principal but not the single reason for the selection of the ETB power plant as the first cogeneration plant for installation of the PFBC in Czech Republic. The problems of renewal and elevation of capacity of the cogeneration plant at ETB have been dealt with for more than two decades. This problem is associated with the fact that apartments and industrial buildings are located on distances for rational district heating supplied from the ETB cogeneration plant. The large number of operational hours per year for a new PFBC 200 base load unit, makes this site economically very suitable for the location of the first PFBC unit.

The implementation in the center of the heating system should meet the demands on the city skyline and environmental requirements in the region, the country and other countries affected by the acid emissions from ETB. These demands can be met thanks to the compact solution of the PFBC units and to low emissions of SO_2 , NO_x etc. The PFBC ash product has thanks to its content of calcium components excellent binding properties and can be utilized as raw material for local building industry.

It can be assumed that usage of fuels based on hard coal available from the local coal mines close to Ostrava will enable to make use of the experiences from the existing PFBC cogeneration plant at Värtan (Stockholm) where fuels of similar properties is fired. Another important factor is the availability for heavy steel structures which exist in the nearby located steelworks.

All the aspects mentioned above support the conclusion that the PFBC under the ETB conditions would provide the best conditions for a commercially successful introduction.

The power and heating plant of Třebovice is one of the fundamental sources for centralized heat supply at Ostrava. It provides supply of heat of 433 MW in form of hot water of 160/60 °C and steam of 167 MW with 1,0 and 1,7 MPa.

The operational lifetime of a part of the ETB sources (the boilers K 13 and K 14) is approaching the end and complex investments will have to be realized in 1997. Construction of the PFBC blocks is an alternative route instead of a general reconstruction of the boilers K 13 and K 14 including renewal of the electric-energy generation. The first stage of the PFBC route is installation of one PFBC P 200 block with some necessary general investment costs for a second PFBC block. The fact that the PFBC block is running with an efficiency much higher than today's ETB blocks, supports the maximum utilization of the PFBC as the unit for base load operation.

The total production of electricity and district heating from the new PFBC unit during one year is estimated to:

Electricity (gross)	479 000 MWh
Electricity (net)	445 000 MWh
District heating	787 000 Mwh _{th}

The concept of the PFBC P 200 block is providing supply of heat of 99 MW in form of hot water of 160/60°C and steam of 10 MW with 1,5 - 1,7 MPa in cooperation with the existing ETB units. The generation of electric energy from the steam turbine varies with heat delivery. In this way of combined generation of and electric energy, the maximum generation of electric energy will reach 60 MW generated with a total efficiency of 81,8 %. At condensing operation of the steam turbine with minimum delivery of heat, the maximum generation of electric energy attains 76 MW (with heat delivery of 50 MW from the basic heater) with a total efficiency of 60 %.

The electric power from the PFBC, i. e., from the steam turbine and the gas turbine will be led into the existing switch yard of 110 kV. A proper connection will be provided by a branch line from the turbine generators.

Lay-out

The generating block is designed as a separate unit with possible completion of a second PFBC block. The building part is considered with general investments that would enable an easy and relatively cheap installation of two blocks (chimney, silos for limestone, pumping station for cooling water etc.)

The supporting steel structure is due to the stability demanded by the technology and the effect of undermining. Each dilatation piece will have separate of foundation plate. The basement and the floor parts will be monolithic of reinforcing concrete. The mantling of house will be made by suspended insulating panels. The chimney will be of reinforcing concrete, 100 m high, based on a circular reinforcing-concrete plate.

The general parts of the outside fuel and limestone storage will be made of steel provided with lining, while the underground parts will be monolithic reinforcing concrete protected against the effect of ground water. The steel structures will be modified for possible rectification.

Fuel and Environmental Aspects

The PFBC block of the ETB power plant is fired by hard coal. The guarantee testing is considered to be carried out with fuel having following features:

Heating value H_u	23.7 MJ . kg ⁻¹
Water W_t	6.9 %
Ash A^d	22.4 %
Sulphur S^d	0.9 %

The produced ash with PFBC will be separated in cyclones inside the pressure vessel and then supplied to the ash silos. The combustion gases will be finally cleaned behind the gas turbine in filters to get an outlet concentration of less than 50 mg/m³.

Estimated sulphur removal in the PFBC proposal is approximately 90% which gives an emission level less than 400 mg/Nm³.

Estimated NO_x levels (measured as NO₂) in the PFBC proposal is less than 300 mg/Nm³ on all monthly average NO_x emission levels above the minimum load (50%) for the PFBC plan in Třebovice (at 6% excess O₂).

The high efficiency for the combined cycle PFBC plant gives 25% lower CO₂ emissions in cogeneration mode for the same total MW-output.

Principle

The Pressurized Fluidized Bed Combustion principle is based on fluidized bed combustion of coal under pressure in a combined cycle with a gas turbine for pressurizing the fluidized bed and utilizing the combustor gases for driving the gas turbine and with a steam turbine for utilizing the steam produced in a steam generator in the combustor. By adding sorbent (limestone) to the bed the sulphur emission can be reduced during combustion. The combustion temperature is relatively low (860°C) which results in low NO_x emission also.

The gas turbine provides the combustor with pressurized cooling, fluidizing and combustion air. In return it receives the hot and cleaned combustion gas. The energy in this gas is utilized for driving the compressors and alternator and for preheating the condensate and feedwater in economizers.

The gas turbine is connected to the combustor by a coaxial pipe. The inner pipe leads the hot gases to the gas turbine and the outer concentric pipe leads the compressed air to the combustor. An intercept valve assembly at the gas turbine isolates the gas turbine from the combustor and by-passes the combustor at some parts of the start, stop or trip sequences.

The air intake is provided with a silencer and a filter. The flue gases after the gas turbine are cooled by feedwater in the economizer to an outlet temperature of about 140°C. A bag filter cleans the gases from most of the remaining fly-ash before leaving through the chimney.

Fuel storage for the PFBC unit will use today's coal stockpile of ETB. A slot bunker will be installed at the existing coal yard where coal will be swept by a bulldozer. The limestone will be transported to the ETB power plant in covered railway wagons in sufficient quantity and in required quality.

The fuel preparation systems prepare coal and sorbent, from raw material silos, into a paste like fuel. Coal are first crushed grain size, then mixed with sorbent and water (to about 25% total water content) and finally pumped with parallel pumps via inlet pipes to distributors in the combustor bed. The required ratio calcium to sulphur content, Ca/S is controlled by the level of SO_x emissions. The combustor is a pressurized combustion/steam generating unit enclosed in a pressure vessel of about 11.5 m diameter and 31 m height. Operating pressure at full load is about 1.2 MPa and the vessel is cooled by incoming air of about 300°C. Combustion takes place in the bed vessel about 860 °C. Bed material is ash and sorbent. Bed height is 3.5 m at full load and fluidising velocity less than 1 m/s. Bed height is kept constant at full load by releasing bed ash in the bottom of the bed which is cooled by incoming feedwater. The combustion efficiency is higher than 99%.

The steam is generated mainly in tube bundles in the bed. At full load all tube bundles are in the fluidized bed. By decreasing bed height, by releasing bed ash to the bed ash containers inside the pressure vessel, and thereby making part of the tube bundle free from the bed, the steam generation decreases due to lower heat transfer in the gas compared to that when the tube bundles are surrounded by bed materials. The combustion gases after the bed will now be cooled by the tube bundles above the bed and the temperature of the gas to the gas turbine decreases, which automatically decreases the speed of the LP compressor and the airflow to the combustor. The load is governed by varying the bed height i. e., by filling up the bed with bed ash from the containers and vice versa and vary the air flow by controlling the speed of the LP turbine and compressor.

The steam generator is once-through boiler with one evaporating section, one steam/water separator and two superheated sections with water injection before the second superheated for steam temperature control and two reheat sections with water injection in between.

The hot gas is cleaned from fly ash in up to 10 parallel two stage cyclones, depending on coal, to an acceptable dust content for the gas turbine. The fly ash from the cyclones, after having been pre-cooled by combustion air, is depressurized and cooled by condensate coolers, outside the pressure vessel, to about 120 °C and pneumatically transported to an ash silo on site.

Operational Data

Under cogeneration conditions the PFBC P 200 unit will have the following performance at 100% load, compared with combustion of existing boiler:

	PFBC	Existing K 14 Boiler + ST
Firing rate, MW_{th}	207.2	185.6
Steam turbine output, MW_e	44.7	16.0
Gas turbine output, MW_e	15.3	0
Total gross output, MW_e	60.0	16.0
Auxiliary power	4.2	14.8
District heating, MW_{th}	109.3	109.3
Gross efficiency, $MW_{th} + MW_e$, %	81.8	67.5
Net efficiency, $MW_{th} + MW_e$, %	79.6	59.5
Fly ash emissions, $kg \cdot h^{-1}$	12.7	2 758
SO ₂ emissions, $kg \cdot h^{-1}$	61.2	530
No _x emissions, $kg \cdot h^{-1}$	115.0	497
CO ₂ emissions, %	75.0	100

A PFBC P 200 unit in Třebovice will highly improve the environmental situation in comparison with the impact from the existing boiler.

The project economy gives a positive total cash-flow and a positive hard currency flow, where the minimum export price/kWh has been simulated. The result shows rapid return of invested capital. A PFBC realization in Třebovice will generate economic activity to further industrial CR/Nordic cooperation for a top modern and commercially demonstrated clean coal technology that will put MST, a. s., Ostrava on the international energy map.

CFB KARVINÁ - DOLY

The intensive mining of hard coal and preparation technologies led recently to great production of waste coal slurries. The methods of mechanical, chemical and also energetic exploitation of slurries were proved. The combustion was performed mainly in home fireplaces, which caused great devastation of environment. Slurries were added to standard fuel of great power plants only rarely. Mining company has been solving these environmental and economic problems for many years.

Good experiences of power utilization applied in conditions of Lorrain Coal Region HBL-E.Huchet Power Plant, which are similar to those of ours led to the cooperation of French and Czech experts. The feasibility study, in which the technical solution of slurry utilization, as well as its environmental reasonability and economic usefulness, was projected.

Dumps of slurries are concentrated in Karviná area of Region. As this region is interesting of heat-power plant utilization, the location of new power source was predetermined. To find an optimal place respecting transport distances both of fuel and heat, sufficient amount of areas suitable for construction and attachment to the existing power systems was necessary. This activity was complicated by considerable effects of undermining of the area.

In a proposal stage of feasibility study construction of a new condensing power plant was considered. Area-technical conditions and operating conditions given by regulations led up to high construction costs and economic disadvantage of the designed work. Therefore a new solution was looked for consist in the incorporation of a new cogeneration capacity into the existing cogeneration power plant.

TEK District Heating System

In the watched area there are three power plants supplying heat for the towns of Havířov and Karviná and for the adjacent mines.

This large district heating system is operated by Teplárny Karviná a.s. (TEK). ČS Armády cogeneration Plant (TČA) has 323 MW_t total output in six steam boilers and two turbines with total output of 24 MW_e. It supplies heat for the town of Karviná (160/60°C hot water) in quantity of 165 MW_t. At the same time it supplies steam 27 MW_t for a mine and coking plant and thus they form an industrial unit together.

Suchá cogeneration Plant (TSU) is located at Dukla Mine. This plant, consisting of four steam and two hot water boilers with the total output of 264 MW_t and 12 MW_e turbine, supplies heat for the town of Havířov 190 MW_t (160/60°C hot water) and steam 21 MW_t for the mine.

Karviná cogeneration Plant (TKV) is situated in the area linking to Barbora Mine. There are installed four boilers with the total output of 248 MW_t and two turbines with the total output of 33 MW_e. It secures heat supply for the mine 22 MW_e (120/80°C hot water and 1 MPa steam). At the same time it can cover from the exchanger 33 MW_t a peak heat demand of Havířov.

Location of TKV and area-technical conditions were the main reasons for design of construction of the new cogeneration power plant linked up with this locality.

Proposal of TEK Power and Heating System

The new source called Karviná-Doly cogeneration Plant (TKD) has to assure the basic heating capacity for the integrated complex Karviná-Havířov and three mines (ČSA, Barbora, Dukla). The whole complex heating need is 425 MW_t, the heating capacity of TKD is 176 MW_t. This rate enables all-year operation and high effective utilization of the new power plant, in this way positive economical and ecological utilization of slurries.

In order to verify output parameters of a new TKD power and heating source and to determine its operating dependencies, it is necessary to evaluate the complete TEK system. On the basis of a character of this source, the below mentioned alternatives of existing TKD power and heating capacities have been taken into consideration.

Alternative I

A new TKD large-scale heating unit for the combustion of coal slurries situated in the construction site outside the existing TKV production unit is suggested. The construction planned for 1996 - 98 includes also the construction of new exchanger and circulation stations and adaptations of facilities of el. distribution systems. The construction of heat pipelines enables an integration of TEK systems and choosing the suitable period for the construction of new ash deposit sites. A new heating plant TKD will play a role of a main source in the TEK system. The modernized TKV and TČA plants will provide peak and backup outputs.

Main equipment:

- Fluidized-bed boiler K11 with parameters of 13 MPa, 540 °C, 400 t/h, 315 MW with intermediate re-heating up to temperature of 540 °C for combustion of hard coal or slurries
- PT 135 MW condensing extraction turbine with two controlled take-offs for 176 MW heat supply and uncontrolled take-offs, with absorption capacity of 400 t/h

Alternative II

A new heating unit (50 MW_e) for the combustion of coal slurries situated in the existing TKV production buildings in which by means of the back-pressure turbine (40 MW_e) the power generation will be rationalized. The construction works planned for 1996-98 include new heat exchanger and circulation

stations, heat pipeline to Havířov, TKV-TČA pipelines and modifications of facilities of el. distribution systems.

A new TKD unit will be a main source in the TEK system. The existing and modernized sources of TKV and TČA will be peak and backup sources.

Main equipment:

- Fluidized-bed boiler K7 with parameters of 9.6 MPa, 540 °C, 170 t/h, 126 MW for combustion of hard coal or slurries
- PT 50 MW condensing extraction turbine with two controlled take-offs for heat supply and uncontrolled take-offs for regeneration with absorption capacity of 170 t/h
- PR 40 MW back-pressure extraction turbine with one controlled take-off for heat supply and uncontrolled take-offs for regeneration with absorption capacity of 170 t/h

Alternative III

A new heating unit for the combustion of coal slurries with a postponed construction of fluidized-bed boiler in 1999-2000 and situated in the existing TKV production buildings in which from 1999 turbines (50 + 40 MW_e) rationalizing power generation will be installed. The construction of new heat exchanger and circulation stations, heat pipelines to Havířov and adaptations of facilities of el. distribution systems is also planned.

In the following stage a fluidized-bed boiler and other necessary equipment will be installed. After the completion of the construction of TKV-TČA pipelines the integrated TEK system will be created. When capacities of existing ash deposit sites are exhausted, new localities will be built.

Main equipment:

- the same as alt.II.

Retrofit of existing TEK sources

Providing peak and backup outputs to the TEK system is considered from TKV and TČA plants. For this reason these heating plants will be retrofitted and adapted in order to meet environmental requirements and maintain operational reliability. The installation of new dust collectors and the stabilization by TČA natural gas is still continuing.

Economic Analyses

All alternatives are evaluated in a condensing operation. Under this term we understand a heat generation and 20% of condensing generation of electricity.

During works it has been decided to abandon alternative II due to its economic disadvantage. This disadvantage is apparent in attached graph at the end of the paper. The main reason for this abandonment is the fact that on the basis of potential prices for electricity, the resulting price for heat would be substantially higher in comparison with other alternatives and this difference is significant.

Operational Data

TKD output per year:

	Alt I	Alt III
El. energy (gross), Gwh _e	670	259

El. energy (net), Gw _n	615	235
Heat, TJ	3400	1638
Total gross efficiency (el.energy + heat), %	72.5	73.1
Total net efficiency (el.energy + heat), %	70.0	70.6

TKD fuel consumption per year:

Slurries from slurry ponds, kt	450	160
Coal shed, kt	39	45.5

After the recoverable reserves of slurry ponds estimated up to 8100 kt are exhausted, the basic fuel will be coal shed.

Fuels characteristics:	Slurries	Coal shed	Coal
Heating value H _u , MJ.kg ⁻¹	13-19	13-18	20-22
Water W ^r , %	20-33	8-12	8-10
Ash A ^d , %	35-45	35-45	20-25
Sulphur S ^d , %	0.6	1.1	0.9

For the utilization of fuels with above mentioned characteristics a circulating fluidized bed boiler was forged as it completely fulfills requirements for combustion technology as concerns environment. In this type of boiler a large amount of inert material is maintained circulating and is not sensitive to sudden fuel characteristics changes. This fact makes possible slurry injection directly into the furnace without previous drying. As well there is not necessity to treat coal shed by a grinding process, crushing at 0-10 mm size is sufficient.

Environmental Aspects

The following tables illustrate a comparison of fly ashes from TEK in 1990 and from TKD, TKV and TČA.

Annual fly ashes from TEK in 1990

	TSU	TKV	TČA	TEK
	t / year			
ash	1399.9	1950.1	1430.4	780.4
SO ₂	2046	1276.1	1434.5	4756.6
No _x	1613	866.3	1235.3	3714.6
CO	66	49.3	75.8	191.1

Annual fly ashes in 1998 from TKD, TKV and TČA

Alternative I

	TKD	TKV	TČA	TEK	index TEK 1990
	t / year				-
ash	107.6	18.30	16.60	142.50	0.03
SO ₂	860.6	523.6	474.6	1858.8	0.391
No _x	430.3	336.6	305.1	1072.0	0.289
CO	537.9	19.8	18.0	575.7	3.013

Alternative III

	TKD	TKV	TCA	TEK	index TEK 1990
	t/year				-
ash	45.7	84.1	12.50	142.30	0.030
SO ₂	365.6	2402.0	358.4	3126.0	0.657
NO _x	182.8	1544.0	230.5	1957.3	0.527
CO	228.5	91.0	14.0	333.5	1.745

Note: The TKD emissions are based on a boiler guaranteed values which are as follows: for ash 50 mg/Nm³, for SO₂ -400 mg/Nm³, NO_x - 200 mg/Nm³, CO - 250 mg/Nm³ and it complies with legal requirements. In the case of TKV and TCA the values have been derived from existing actual values.

According to measurements carried out in 1993 in the fluidized-bed boiler for slurries in France (E.Huchet Power Plant), the average annual emissions (at 6% of O₂) as follows for ash 24 mg/Nm³, for SO₂ 324 mg/Nm³, NO_x 79 mg/Nm³, CO 176 mg/Nm³. The similar decreasing tendency can be expected in the case of TKD.

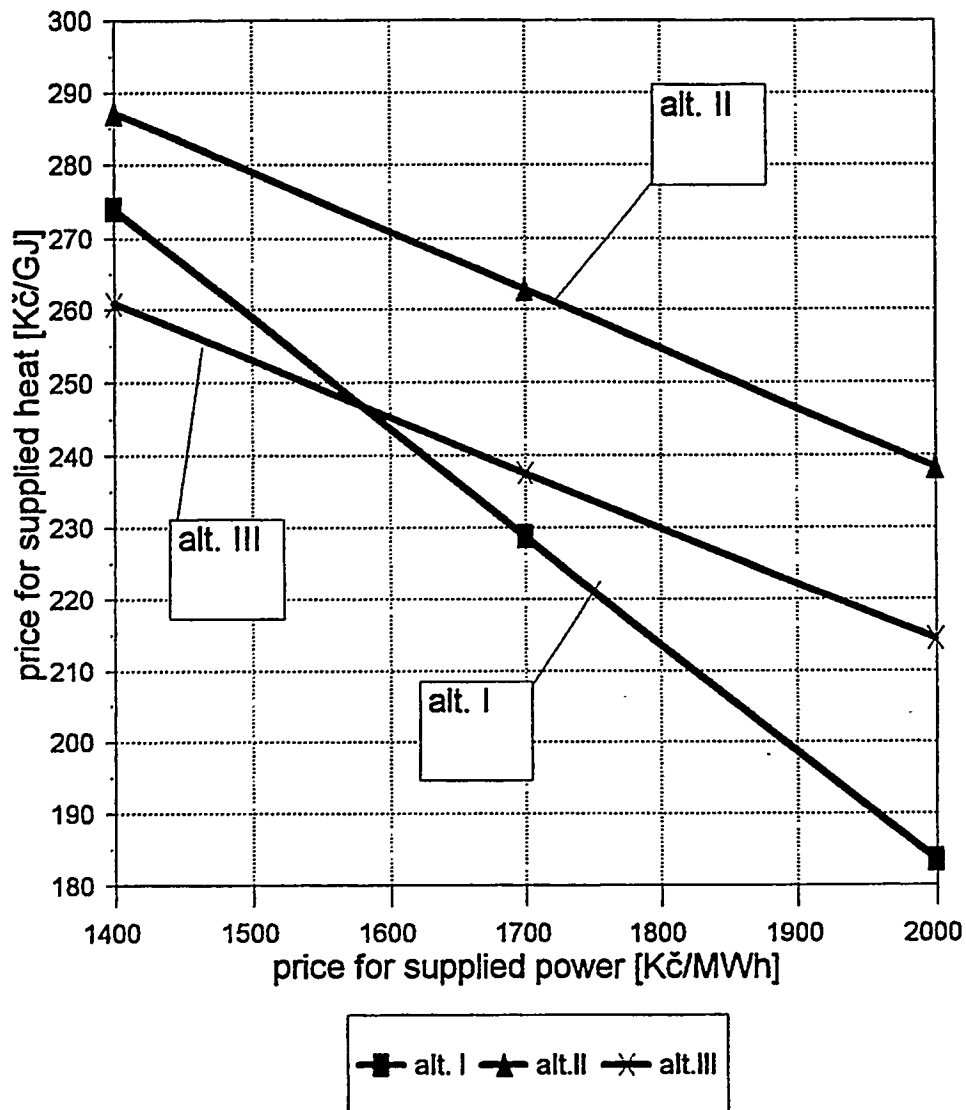
The following methods of disposal of ash are considered: surface deposit, underground deposit, ash utilization in land reclamation.

Final Recommendation

The comparison made between alternatives is in favor of the alternative I. The technical and economic conception of this alternative is focused on maximizing the electric power generation from cheap fuel on the well tested facility in order to cover higher costs associated with construction. Such extensive investment works require a good organization and cooperation with partners on the contractual basis. There are some risks in connection with the construction of such a big unit and demands for electricity generation from condensing unit.

Due to these reasons alternative III is recommended, since the risks are not so high. As a result of economic calculations and sensitivity analyses which are based on the above-mentioned assumptions, the estimation is more favorable for alternative I, which preparation is very time-consuming, it was agreed that both alternatives will be prepared for the area proceedings. This offers a certain, although somehow limited space for the final solution of the commercial and organizational relationships, thus avoiding the undesired obstacles in the preparatory process of the TKD construction.

TKD - Dependence $C_q = f(C_{el})$
condensing alternative(1400,1700,2000)



BOXBERG III – 2 × 500 MW UNITS: REFURBISHING AND ENVIRONMENTAL PROTECTION MEASURES ON THE 815 T/H STEAM GENERATOR OF WORKS II IN BOXBERG POWER STATION

R. Cossman
M. Fritz
R. Bauchmüller

L&C Steinmüller GmbH
Gummersbach, Germany

ABSTRACT

BOXBERG III – 2× 500 MW UNITS

The object of the upgrading measures on the steam generators is:

- To comply with the requirements of the German antipollution law, which imposes a permissible NO_x content in the flue gas of less than 200 mg/m^3 STP and a CO content of less than 250 mg/m^3 STP.
- To increase the boiler efficiency and availability and the efficiency of the water/steam cycle.

Design Data

4 × once-through boilers with superimposed circulation, each 815 t/h / 226 kg/s.

HP part 188 bar/535°C, LP part 46 bar/560°C.

Fuel: brown coal 8200 kJ/kg.

First commissioned 1980.

First unit taken out of service in May 1993, recommissioned in January 1994.

Second unit will be taken out of service in May 1994.

BOXBERG IV – 800 MW UNIT

One of the largest brown coal fired boilers in the world, designed for Eastern German brown coal as once-through steam generator with supercritical steam parameters, equipped with most modern firing system technology for primary No_x reduction.

Design Data

Steam Flow (SH)	636 kg/s (2286 t/h)
Temperature (SH/RH)	545/563°C
Max. allow. working pressure (SH)	285 bar g
Pulverized brown coal firing (NCV)	8.6 MJ/kg
Unit dimensions:	
Height	160m
Width	33m
Depth	33m
Furnace height	99m

Furnace outlet temperature	950°C
Exit gas temperature	170°C
Boiler efficiency	89.56%

Paper unavailable at time of publication.

WASTE-HEAT BOILER APPLICATION FOR THE VŘESOVÁ COMBINED CYCLE PLANT

Zdeněk Vlček, Ing.

Energoprojekt Praha
Prague, Czech Republic

ABSTRACT

A project proposal and implementation of two combined-cycle units of the Vřesová Fuel Complex (PKV) with 2 x 200 MWe and heat supply. Participation of ENERGOPROJEKT Praha a.s., in this project.

INTRODUCTION

In the introduction we would like to inform you about the works of Energoprojekt Praha (EGP) concerning just an employment of new possibilities of fossil fuel combustion for electric power generation and heat supplies. Energoprojekt Praha has developed and at present it has under development a great deal of projects dealing with economic and technical evaluation of heat power plant upgrade and reconstruction.

In most cases, the investor today requires the development of a variant innovation and upgrade study for his plant. For most works it means to examine the possibility of switch to gas fuels (SGF). This transfer to gas fuels is required either with using purely gas boilers or with the possibility of using the combined cycle (CC). The use of a combined cycle, either with reheating or without it, is influenced to a certain extent by process requirements of heat and electricity demands or by the possibility of electricity or heat sales in the given region. Another, most attractive variant solution is the transfer from brown-coal burning to low-sulphur bituminous coal combustion in a modern combustion plant.

After economic evaluation and recommendation of the best variant it is much easier for the investor to make decisions regarding his existing plant.

Most of these works are even today rather of study or bid natures. This fact is in most cases caused on the one hand by a heavy financial situation of the concerned companies and by high investment demands of those projects. On the other hand, companies are facing a crucial decision how to go ahead with power policy, both to cope with the pressure of the Act No. 309/91 (emission limits) and to master new economic conditions.

As an example, I would like to name here some of the projects being developed, both in the form of bids and works performed for the investor. Those are heat and power plants of Uherské Hradiště and Děčín, Transgas KS 04, Liberec, Plzeň etc.

All the mentioned works have been or are for the time being in the stage of preliminary project or bid documentation. One of the large projects, being now in the stage of advanced implementation and being unique in the Czech Republic as for its scope, is the project of two combined-cycle units, the investor and the future operator of which will be Sokolovská uhelná, a.s., before known as Palivový kombinát Vřesová (PKV)(Vřesová Fuel Complex). Supposed investment costs amount to 5,5 mld. CZK and ENERGOPROJEKT Praha a.s., has been taking part in this project as the General Designer since the beginning of study works.

NOW TO THE HISTORY OF THE PROJECT OF THE VŘESOVÁ COMBINED-CYCLE PLANT

The Fuel Complex of Vřesová (PKV) is the biggest producer of gas in the Czech republic. For gas production it employs the Hradec Králové's gasification gas generators with sliding beds and subsequent raw-gas cleaning in two Lurgi rectisol banks. Developments in gas industry in the Czech Republic results in a step-by-step reduction of town gas supplies and to its gradual conversion by natural gas. Therefore, the Vřesová Fuel Complex (PKV) has faced a great task of ensuring further development of this enterprise.

Based on the experience, several possible variants of further operation of the existing plant have been chosen by PKV's experts, such as methanol production from town gas, gas-plant shutdown and operation of the existing heat and power plant only and heat supplies to the neighbouring agglomerations, construction of a new conventional 300 MW power plant burning brown coal, and construction of a combined-cycle plant with using the existing gas plant.

First study works on the 330 MW combined-cycle plant firing energy gas started in EGP in 1991. A part of these works was also an economic comparison with the above variants. Gained results showed the combined-cycle plant construction and implementation as the most favourable variant.

Based on the study, well-known producers of combustion turbines such as Siemens, ABB, Westinghouse and Alsthom, were called for bid submission. One of the principal requirements for combustion turbines was a parallel combustion of energy gas and natural gas in any ratio for combustion-turbine (CT) loads ranging from 0 - 100% Nj, then plant connection to the EU grid (meeting the UCPTe requirements) and, of course, another significant criterion was to meet emission limits as prescribed by the Act No. 309/91, which are 300 mg/Nm³ of flue gases for this case. After bid evaluation, two companies were selected. Alsthom with the turbine 9171 E having the capacity of 125 MW and Westinghouse with the 50 MW turbine 251 B 11.

EGP prepared a task specification for these two variants of combustion turbines. In case of Alsthom bid it covered 2 combustion turbines 125 MW and 1 steam turbine 125 MW with a subvariant including 2 units with 1 combustion turbine 125 MW and 1 steam turbine 60 MW. In case of Westinghouse, solution included 2 units equipped with 2x50 MW CTs + 1 ST 50 MW.

Based on the prepared task specifications, Czech companies were invited to develop their bids for possible general supply of this work with selected combustion turbines. After bid evaluation a couple of Alsthom and PBC was chosen.

In 1992 the project works started in EGP to obtain a necessary building permit. The document was submitted in 12/93. After the submission of design documents, one of the most difficult stages began for the investor, i.e. negotiations with authorities and securing the building permit. In order to obtain the building permit, it was necessary to develop as well the documentation on the environmental project impact as prescribed by the Act No. 244/92. This documentation was prepared by EGP in cooperation with the organizations dealing with partial specifications. The negotiations too nearly 7 months. Upon negotiating the documents, several comments arose which had a back impact to the project solution, and which had to be considered in the project. Most comments were related with the operation of the existing heat and power and gas plants.

Another very lengthy procedure needed for project implementation was the preparation and the signature of the contract both between PKV and PBS and between PBS and Alsthom. I am not going to speak here about problems of financing and needed credits as those would require the specific paper of its own.

When negotiating the contract, the greatest problem was to secure guarantees and to get term confirmation that the plant is able to burn both the gas in any ratio and with any output.

Now let us approach an actual design of the plant.

The plant is designed with two main units:

- 2 combustion turbines Alsthom 9171 E with nominal output of 125 MW - see Annex no. 1
- 2 steam turbines with two controlled extractions
PP 57 - 6,6/3,5 - 0,55
- 2 steam double-pressure waste-heat boilers with circulating water heating

Lay-out is given - see Annex no. 2, 2a

SCHEME DESCRIPTION (ANNEX NO. 1)

The Vřesová Combined-Cycle Plant (PKV) is a steam-gas condensing unit with a possible heat power supply in the steam MPa/350°C and 0,55 MPa/220°C.

Gas section of the cycle is designed so that the combustion turbine enables the combustion of syngas and natural gas and any of their mixtures. Syngas is lead to the combustion chamber via a control valve. This enables a constant pressure to be kept in the syngas network. For the purpose of output and frequency controls, natural gas is introduced into the combustion chamber. For the needs of combined-cycle, natural gas is supplied from the outside distribution system via an appropriate stepdown station providing the required parametres, i.e. 25 bars/15°C.

In order to meet the NO_x emission limits prescribed by the law, injections of steam 22bars/340°C are introduced into combustion chamber from steam section of the cycle.

Combustion air for 14 combustion chambers is supplied by an axial compressor driven by the gas turbine which is directly connected to this compressor. Air is fed into the compressor through suction ducts equipped with a mechanical filter and a silencer.

From combustion chambers, flue gases flow to the gas turbine. This combustion turbine drives both the axial compressor and the alternator T 900 (139 MW).

Cooling of the combustion turbine generator is performed with air being cooled via an air-water exchanger by tower circuit water. Cooling of oil system of the combustion turbine is carried out by means of an insert cooling circuit which is cooled again via the water-water cooler by cooling tower water.

Flue gases at the combustion turbine outlet are lead to the steam section of the cycle - to a waste-heat boiler.

Main components of the steam section of this combined cycle are a double-pressure waste-heat boiler and a turboset.

The waste-heat boiler is a double-pressure one with high-pressure (HP) and low-pressure (LP) steam generations (7,0 MPa-510°C and 0,6 MPa-220°C).

A heating medium of the boiler is exhaust flue gas from combustion turbines. In the boiler there are placed the other heat-absorbing surfaces for increased use of waste heat from combustion turbines as well. In the position of the last heat-absorbing surface, a heater of prior-gasification condensate is located and in front of it there is a heating-water heater (70/90° C). Further the heat-absorbing surfaces are aligned in the following order: HP-EKO I, LP-EKO, LP-evaporator, LP-reheater, HP-EKO II, HP-evaporator, HP-reheater.

The turboset 57 - 6,3 / 3,5 / 0,55 consists of a two-cylinder condensing turbine with two controlled steam bleeders (3,5 and 0,55 MPa) and an alternator PH 63 0832/2.

High-pressure turbine section is supplied with HP boiler steam flowing through the HP steam piping DN 250 PN 160 into a distributor from which two steam pipings DN 200 PN 150 are lead to RZ valves of the turbogenerator.

The high-pressure piping has two branch pipes directed to by-pass 0,55 MPa station and 3,5 MPa collectors.

The controlled extraction steam 3,5 MPa flows into the collectors 3,5 MPa via a steam cooler through the piping DN 250 and via the distributor for both the collectors.

Steam leaving the high-pressure turbogenerator section is lead through two pipings into the distributor DN 800. From the distributor, steam flows through LP extraction retain flap valves into the LP section of the turbine. Low-pressure extraction steam is then taken off by two pipings DN 400 from the distributor via special two-way swing-check valves into the collector of 0,65 steam. LP steam of the boiler is lead to these pipings in such a way that steam admission is possible both into the turbogenerator and into the network, which is ensured by special two-way flap valves.

Steam output from LP section of the steam turbine is introduced into a condenser. The condenser is a two-pass type, transversally fitted, equipped with a continual heat-absorbing surface cleaning system from the cooling water side.

In case of a TG outage, HP steam is lead to by-pass stations of HP steam, i.e. to the by-pass station for the 0,55 steam collectors and to the by-pass 3,5 steam station via respective coolers. Condensate for coolers is brought from the interbleeding point of HP feeding pumps into an injection-water distributor from where each cooler is independently connected via an appropriate RV. The by-pass station for the Δ 0,55 MPa collector is designed and dimensioned to enable - by means of the set-up trend - the pressure in HP pipings to be increased when HP piping pressure being 4 MPa and choking flow 45 tons/h. The by-pass stations of the 3,5 MPa collectors work only upon increasing the pressure in HP steam piping by Δ P 0,5 Mpa. Behind both the by-pass stations there are impulse safety valves.

LP steam is - in case of the TG outage - lead to LP by-pass stations from which it is brought to the 0,55 MPa collector.

LP steam piping is connected with a stepdown station for heating the gasifier and for expanding the feeding-tank (FT).

From the piping supplying LP steam 0,55 MPa from the boiler, there is a branch pipe directed to a seal-steam step-down station supplying steam for seal choking-up.

Bleeder steam is drawn off from the seals through a bleeder-steam condenser by a steam jet air pump into which seal steam is introduced.

The condenser condensate is carried by means of condensate pumps (2+1) through seal- and bleeder-steam condensers to a special valve maintaining the level in the condenser, and through a surface-blowdown cooler paralelly incorporated into a condensate heater, to the boiler. Exchanger-station condensate is also introduced into the condensing pump delivery.

Make-up condensate from the chemical water treatment plant is introduced together from the condenser via feeding heads of the feeding tank (FT) level into a condenser heater. Due to the protection of the boiler heat-absorbing surfaces, input condensate temperature at the inlet of the condenser heater is maintained at the minimum temperature of 70°C using mixing pumps and mixing control valves.

Mixing pumps draw in the condensate heated behind the condensate heater and deliver it via RV to the inlet of the condensate heater. In order to keep condensate temperature at the deaerator inlet at the maximum value of 90°C which is necessary due to the deaeration temperature of 105°C, there is a branch pipe of the condensate heater by-pass, leading from the condensate piping behind the bleeder-steam condenser. This branch pipe is equipped with RV maintaining the maximum temperature of the condensate prior its deaeration.

Deaerated condensate is delivered by LP feeding pumps (1+1) via the feeding head of LP drum and LP-EKO into a LP drum. The LP-drum feeding head is designed with one main RV (pressure reduction valve) 100% QN and with one start-up RV 30% QN.

Deaerated condenser is delivered by means of feeding pumps via the HP-drum feeding head to the HP drum.

The HP feeding pumps (1+1) are designed with electronic speed control and by means of speed, the pressure level is maintained in the HP drum. The HP feeding head is operating only under failure conditions (electronic control outage) or upon start-up or shutdown.

From HP and LP boiler drums, the surface blowdown is taken to a surface-blowdown expander. This expander is two-chamber one and steam from the expander is introduced into feeding tanks. Vacuum in the TG condenser is kept by means of water jet pumps (1+1). Cooling water as a work medium is delivered by vacuum air pumps from the vacuum air-pump reservoir. A portion of this water is taken back to the tower circuit to avoid its overheating.

Cooled make-up water from cooling tower circuit is introduced into the vacuum air pump reservoir via a pressure reduction valve (RV) maintaining a constant level in the air pump reservoir.

For cooling small consumers in the machine and boiler houses, demineralized water conditioned with phosphate is used. This closed pressurized circuit with circulating pumps and a vertical nitrogen-cushion expansion tank distributes pressurized cooling water to individual consumers. When having been heated, this water is transferred by a pressurized waste water collector to the cooler of small-consumers cooling circuit.

Circulating cooling tower water is delivered to turboset oil coolers, steam turbogenerator air coolers and to small-cooling circuit coolers by means of boost pumps. Boost pumps incorporation has been necessary due to the potential operation of circulating tower cooling circuit with a variable circulating water volume. Boost pumps then maintain the required pressure conditions in particular coolers.

Turboset oil distribution system consists of lubricating and control-circuit oil systems with a lubricating-oil reservoir, lubricating-oil coolers, lubricating and control-circuit oil pumps and the piping, leading through oil ducts along the turbine.

For case of electric supply outage of lubricating-oil pumps, an emergency lubricating-oil pump is used with a DC engine.

OVERVIEW OF MAIN CALCULATION DATA FOR THE UNIT

Operation mode	Ambient temperature, °C	Fuel heat, MW	Heat output of el. unit, MW	Power output of the unit, MW	Efficiency of the unit, %
Condensing, 100%	+ 8	374.2	0	177	47.3
Condensing, 80%	+ 8	327.6	0	146.6	44.7
Condensing, 60%	+ 8	247.3	0	109.3	44.2
Condensing, 100%	- 15	418.4	0	195.2	46.6
Cogeneration, 100%	+ 8	374.2	102.5	147.4	66.8

In the electrical part, also the method (see Annex no. 6) for taking-off the power from the combined-cycle unit is solved in most interesting way. The generator 11,5 kV outputs from ST (steam turbine) and CT (combustion turbine) are interconnected and together lead into 242/11,5kV/235 MVA and from here power is conducted along a 220kV link to the Vítkov substation. This solution has saved nearly 180 mil. CZK otherwise needed for switchgear encapsulation.

TECHNICAL DESCRIPTION OF THE WASTE-HEAT BOILER

The steam boiler consists of low-pressure and high-pressure steam circuits and condensate and circulating water heaters. Owing to the fact that the plant is located in the area of the Vřesová Fuel Complex (PKV) which is much space-confined, the tower type boiler had to be used.

The boiler has flue-gas duct 7,6 x 13,2 ms and heating surfaces arrangement downstream flue gases:

- high-pressure superheater
- high-pressure evaporator
- high-pressure water heater - stage II
- low-pressure superheater
- low-pressure evaporator
- low- and high-pressure heaters - stage I
- circulating water heater
- condensate heater

Heat-absorbing tubes

- tubes $\varnothing 38 \times \varnothing 32$ with outer ribbing
- spiral integral-weld ribbing
- rib height 10, 13, 15 mms
- rib number per 1 m of the piping-200 ribs/1 bm
for LP superheater-80 ribs/1 bm
- piping material-ČSN 12 022
HP superheater-ČSN 15 128
- tube manufacturer: Železářny Podbrezová
KPS Brno
Mannesmann

Tubes shall be installed independently on the building site.

Stack

- double-inlay type with thermal insulation
 - inner $\varnothing$ 5500 mms
 - outer $\varnothing$ 6900 mms

Technical data of the boiler

High-pressure section

Rated output of the boiler	51.8 kg/s (186.5 t/h)
Rated pressure	7.0 MPa
Rated temperature	500.8°C
Feeding water temperature	105°C

Low-pressure section

Superheated steam output	14.0 kg/s (50.4 t/h)
Superheated steam pressure	0.6 MPa
Superheated steam temperature	225°C

Flue gases

Flue-gas temperature	528.0°C
Flue-gas flow rate	446.7 kg/s
Composition: O ₂	13.03% vol.
N ₂	72.40% vol.
CO ₂	3.23% vol.
H ₂ O	10.47% vol.
Ar	0.87% vol.

Boiler layout is shown in Annexes no. 3, 4, 5.

TECHNICAL DESCRIPTION OF THE TURBINE PP 57 - 6,6/3,5/0,55

The condensing turbine 57 MW of PBS system; two-cylinder mixed-pressure steam turbine having two controlled extractions of steam for driving the alternator. The turbine allows the use of excess LP boiler steam 0.55 MPa.

The turbine design enables the operation with sliding parameters of admission steam.

Technical parameters of the turbine PP 57 - 6.3/25/0.55

maximum output	57 MW
rated speed	3000 l/min
admission steam pressure range	
if operated with sliding parameters	
- with pressure control of bl. I	5 - 6.8 MPa
- without pressure control of bleeder I	3.5 - 6.8 MPa

Additional steam parameters (at the inlet of the turbine LP section)

rated pressure	0.55 MPa
rated temperature	223.9°C
additional steam pressure range	0.45 - 0.7 MPa

Controlled extractions

extraction (bleeder)	I II
rated pressure	3.5 0.55 MPa
lower and upper pressure limits	3.3 - 3.8 0.45 - 0.4 MPa
maximum steam flow-rate	116 97 t.h ⁻¹

Cooling water parameters (at the inlet of the condenser)

rated temperature	21°C
maximum temperature	33°C
minimum temperature	15°C

Steam flow rates

admission steam entering HP section with rated parameters	185 t.h ⁻¹
max. permissible flow-rate with increased admission-steam pressure	195 t.h ⁻¹
steam entering MP section with 3,5 MPa pressure of controlled bleeder I	185 t.h ⁻¹
steam entering MP section with a maximum pressure of controlled bleed.I	190 t.h ⁻¹
admission steam in front of LP section with 0,55 MPa pressure and at the temperature 223,9°C	49.97 t.h ⁻¹
of which taken-off for the deaerator	6.2 t.h ⁻¹
mximum permissible flow-rate	50 t.h ⁻¹
maximum steam flow-rate entering LP section	
with the controlled bleeder II pressure of 0,55 MPa	222 t.h ⁻¹
maximum permissible flow-rate	225 t.h ⁻¹

ENVIRONMENTAL IMPACT ANALYSIS OF THE PROJECT

The developed NO_x dispersion study has shown that by using the present solution when combustion turbine emissions are 92,3 mg/Nm³ in dry combustion products at the temperature of 0°C and with the pressure of 101,32 kPa, and 15% O₂ in flue gases, which is (more than) three times less than admitted by the Act no. 309/91, subs. 1.1.1.6.3, where this limit is prescribed as 300 mgs/Nm³; the short-term imission limit will be exceeded several times in neighbouring municipalities, particularly under deteriorated dispersion conditions. This limit is 200 µgs/Nm³.

Low emission values of the combustion turbine are reached by means of the primary provision taken inside the combustion chamber where steam of 2,2 MPa at the temperature of 340°C is introduced for cooling the flame.

Due to these unfavourable results, we have developed two variants for technical solution of the plant in order not to exceed the combined-cycle NO_x emission limits and the surrounding imission ones. In the first case, the stack crown height was increased with keeping the combustion turbine emissions on the level of 92,3 mgs/Nm³ guaranteed by the combustion turbine manufacturer. In the second case, the combustion turbine emissions were reduced with maintaining the stack crown height of the waste-heat boilers on the level of 60 ms.

In the first case, the stack height was 128 m; in the second case, combustion turbine NO_x emissions should be reduced to $12,7 \text{ mgs/Nm}^3$. Both the solutions were technically unrealistic, therefore, we have come to the following solution compromise: the stack crown has been increased from 60 to 80 m and, at the same time, the possibility of short-term reduction of the combustion turbine emissions with steam injection increased to 45 mg/Nm^3 , has been examined with the combustion turbine manufacturer.

Owing to this solution, the requirement of immission limit minimization ($200 \text{ } \mu\text{gs/Nm}^3$) under deteriorated dispersion conditions has been met.

CONCLUSION

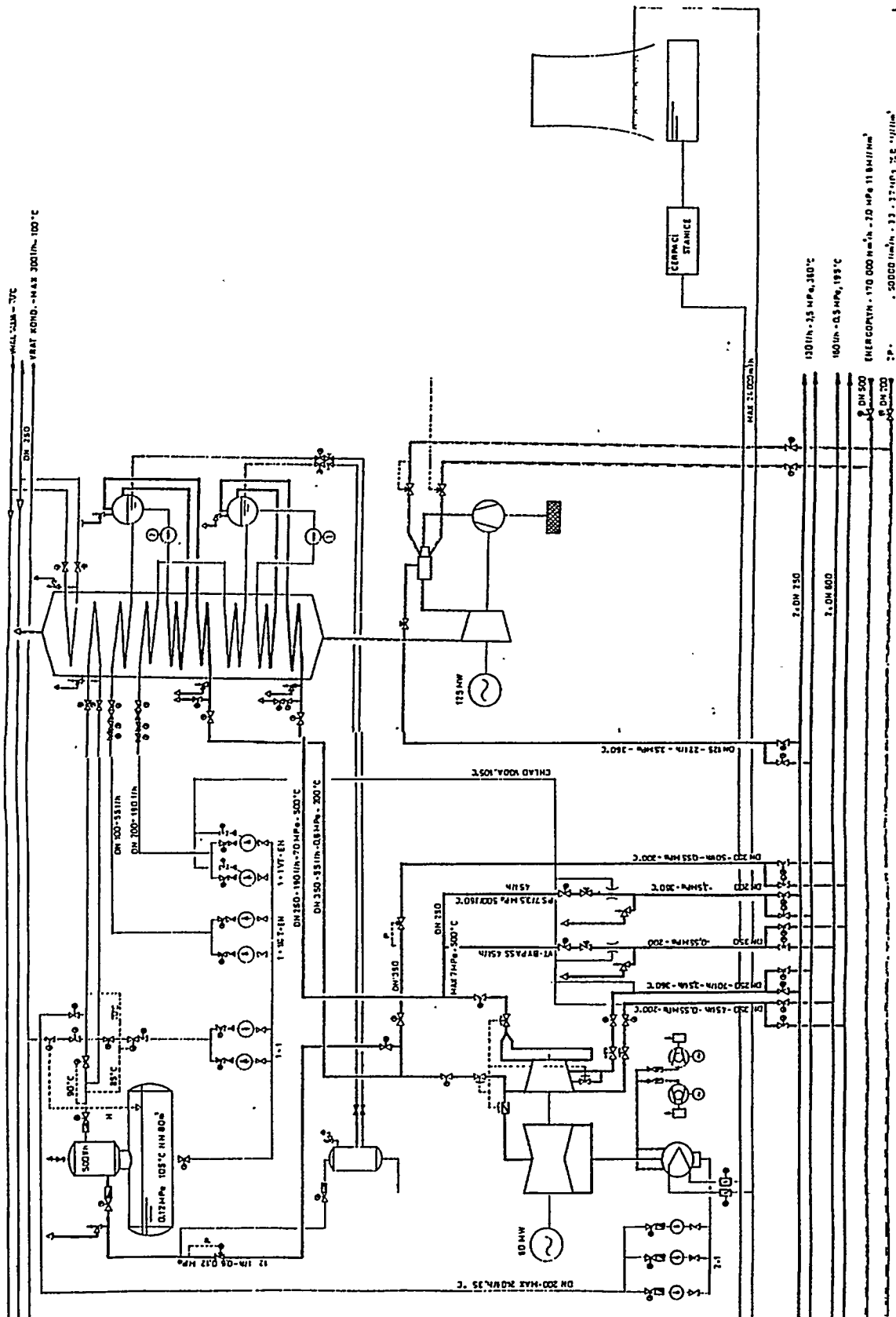
If we come back to the time schedule of the project; i.e. design work beginning in 6/92 and start-up of the first unit in 6/95 and of the second unit in 6/96; this fact is unique as well within the framework of the construction of such a power source in the Czech Republic. The employees of Energoprojekt Praha a.s., have no small merits in fulfilling these deadlines.

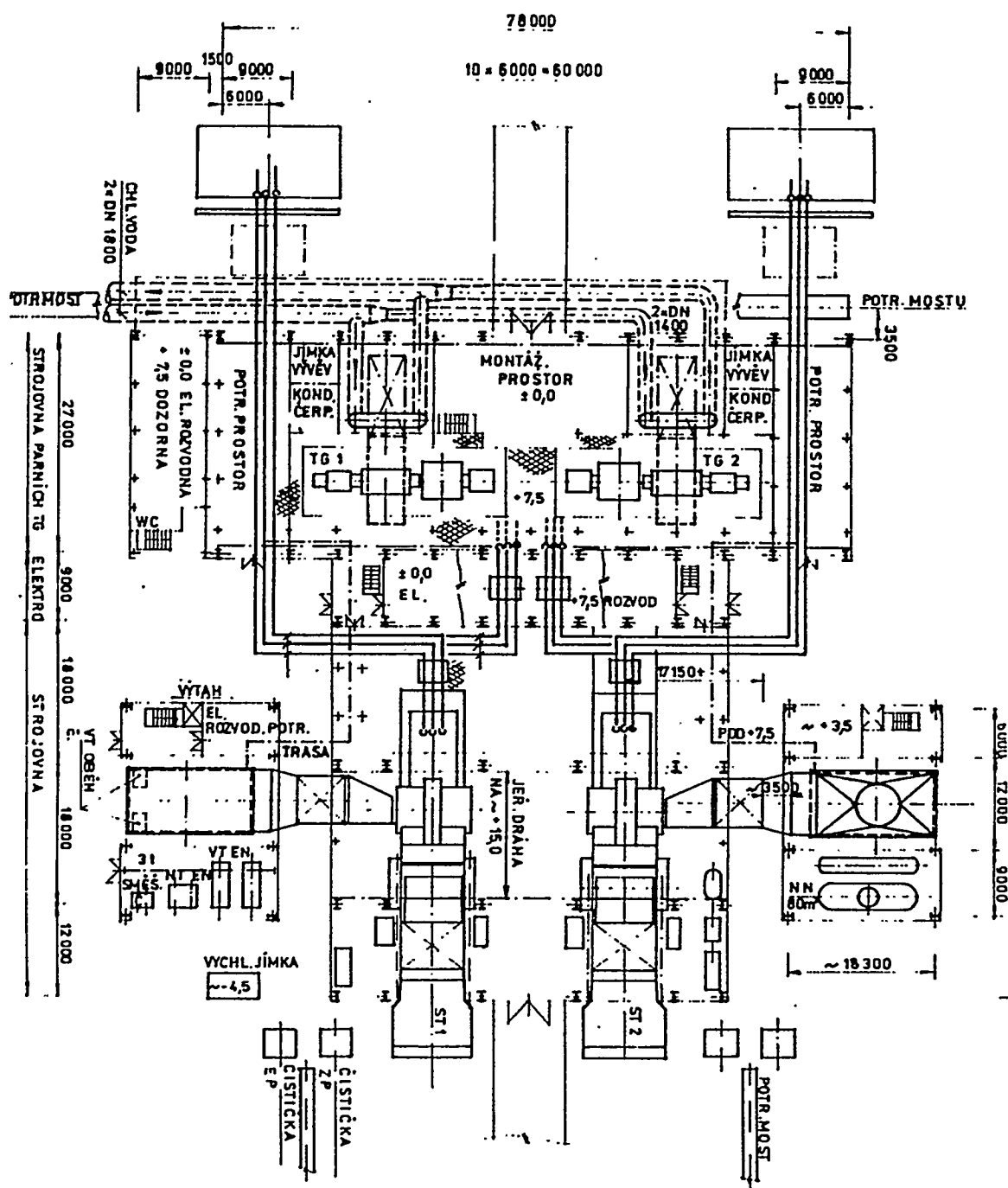
At present, a similar combined-cycle project has been developed in EGP for the Úžín heat and power plant, for the time being in the form of task specification. For the implementation of this project, the Siemens V 94.1 150 MW combustion turbine, the Škoda Plzeň 70 MW steam turbine and the Deutsche Babcock design boiler have been used. As yet, this project has met with unsettled financing questions and with the problem of obtaining a favourable credit. However, decision has been already made on its implementation.

In conclusion, we can say so much: although the Vřesová Combined-Cycle Project has up-to-now advanced the most of all the orders being implemented in Energoprojekt, the other orders being yet in the stage of preliminary project preparation are also expected to boom. That is why Energoprojekt Praha a.s., is in an intensive preparation for increased demand for those works. We believe there are only a few companies possessing such complex professional outfits for the implementation of those projects in the Czech Republic, behind which the particular results of their work can be seen. Undoubtedly, Energoprojekt Praha a.s., belongs to those companies. I believe that they are just the companies having experience in capital construction and its preparation in the field of power engineering, rich references, a sufficient number of required top-skilled specialists of all professions; realistic price requirements and developed quality control system, which shall be predominantly developing such projects.

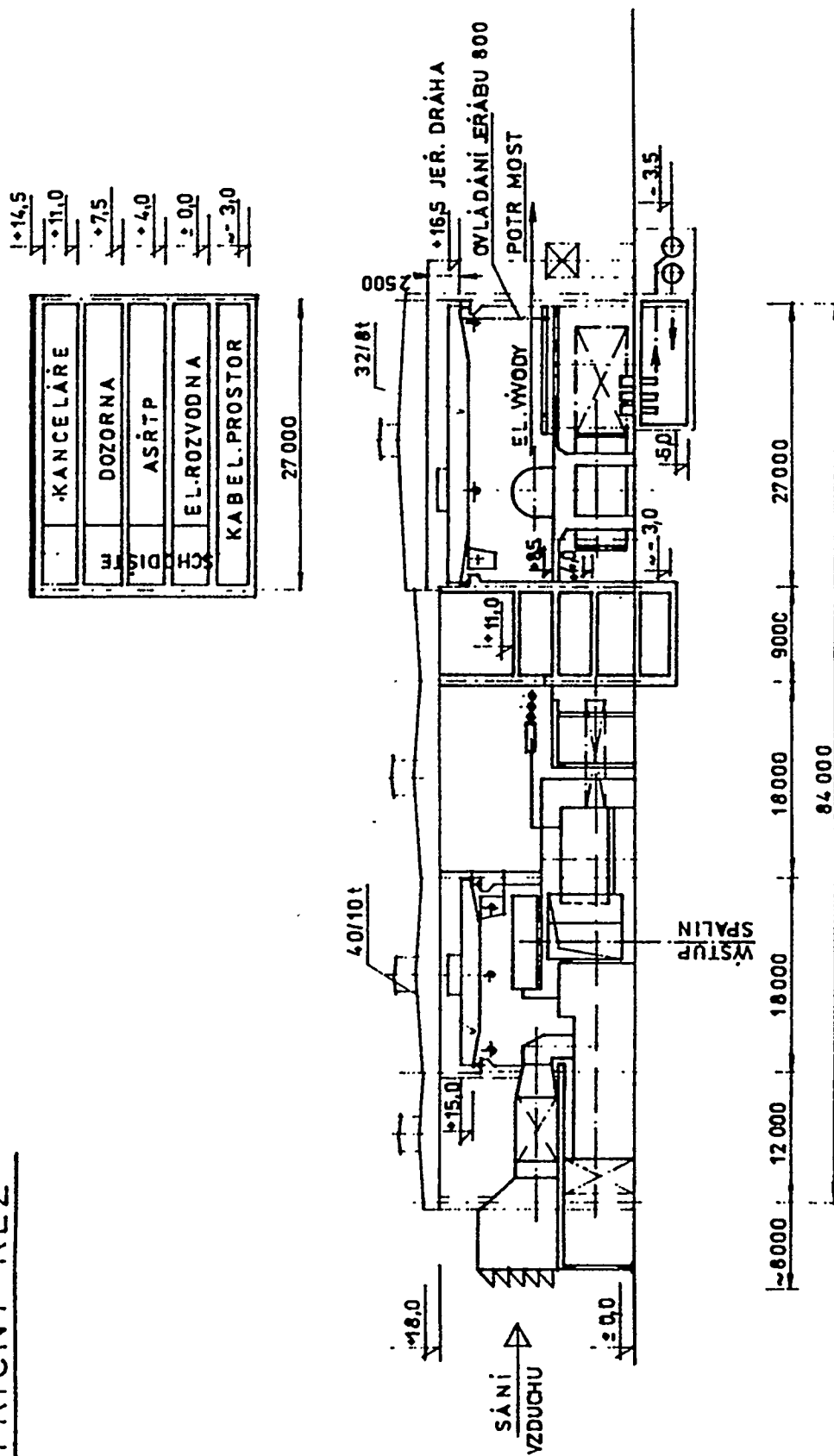
ABBREVIATION LIST

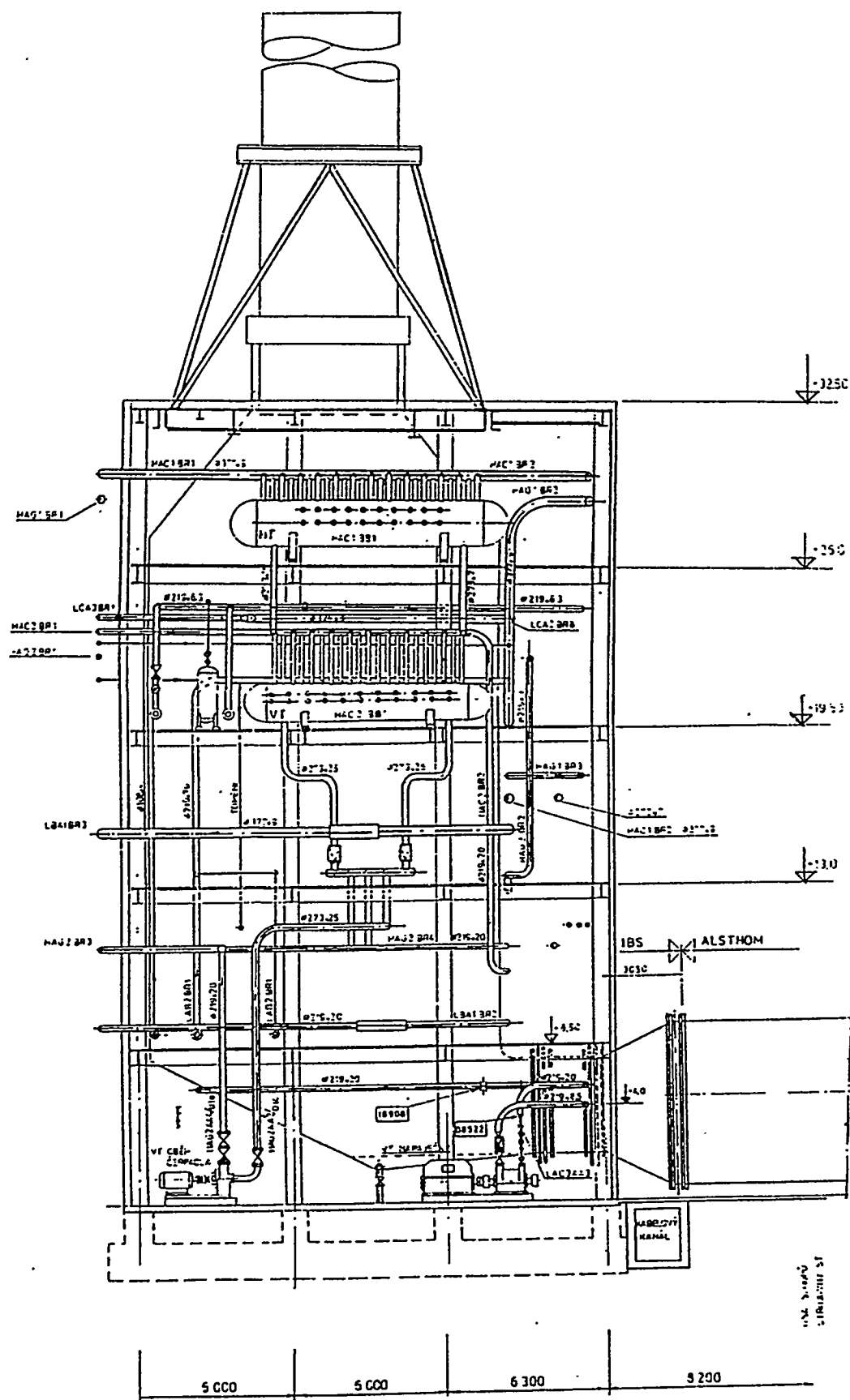
CC	Combined cycle
EGP	Energoprojekt Praha, a.s.
PKV	Fuel Complex of Vřesová
KPS	Královopolské strojírny Brno
PBS	První brněnská strojírna
SGF	Switch to gas fuel
TG	Turbogenerator
ST	Steam turbine
CT	Combustion (gas) turbine
LP	Low pressure
MP	Medium pressure
HP	High pressure
FT	Feeding tank
CWTP	Chemical water treatment plant (demineralization plant)
RV	Pressure reduction valve
EKO	Economiser
ČSN	Czechoslovak standard

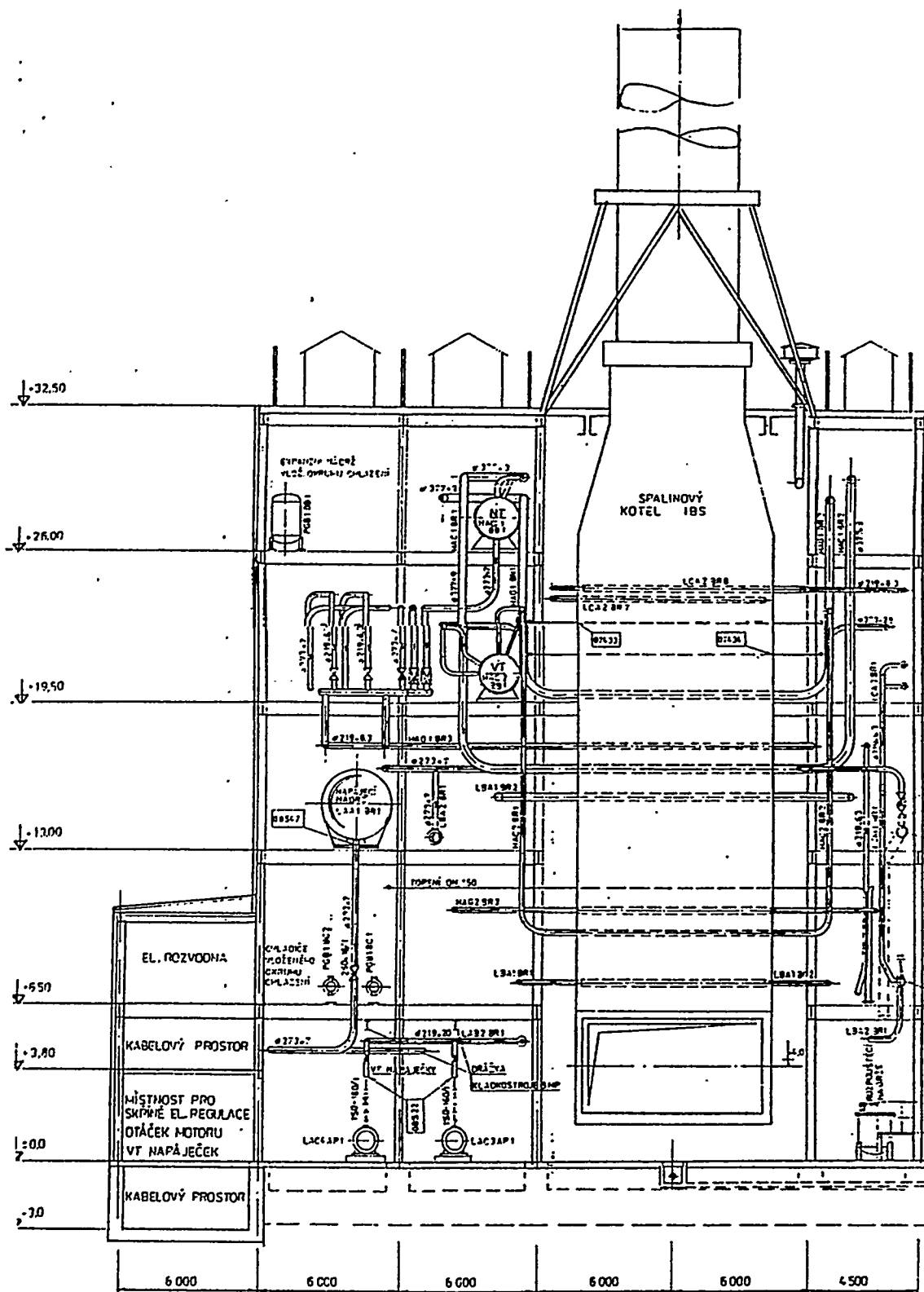


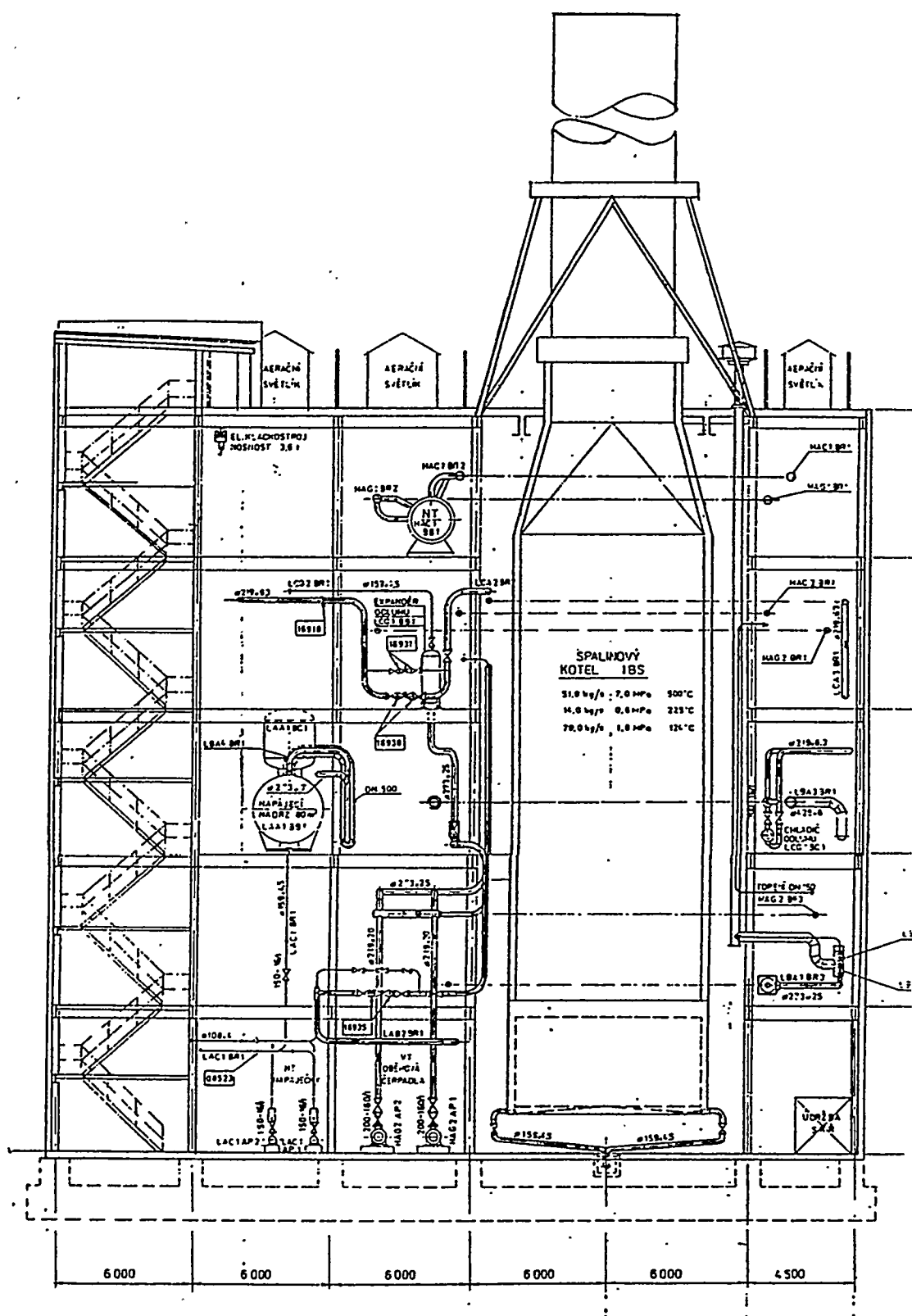


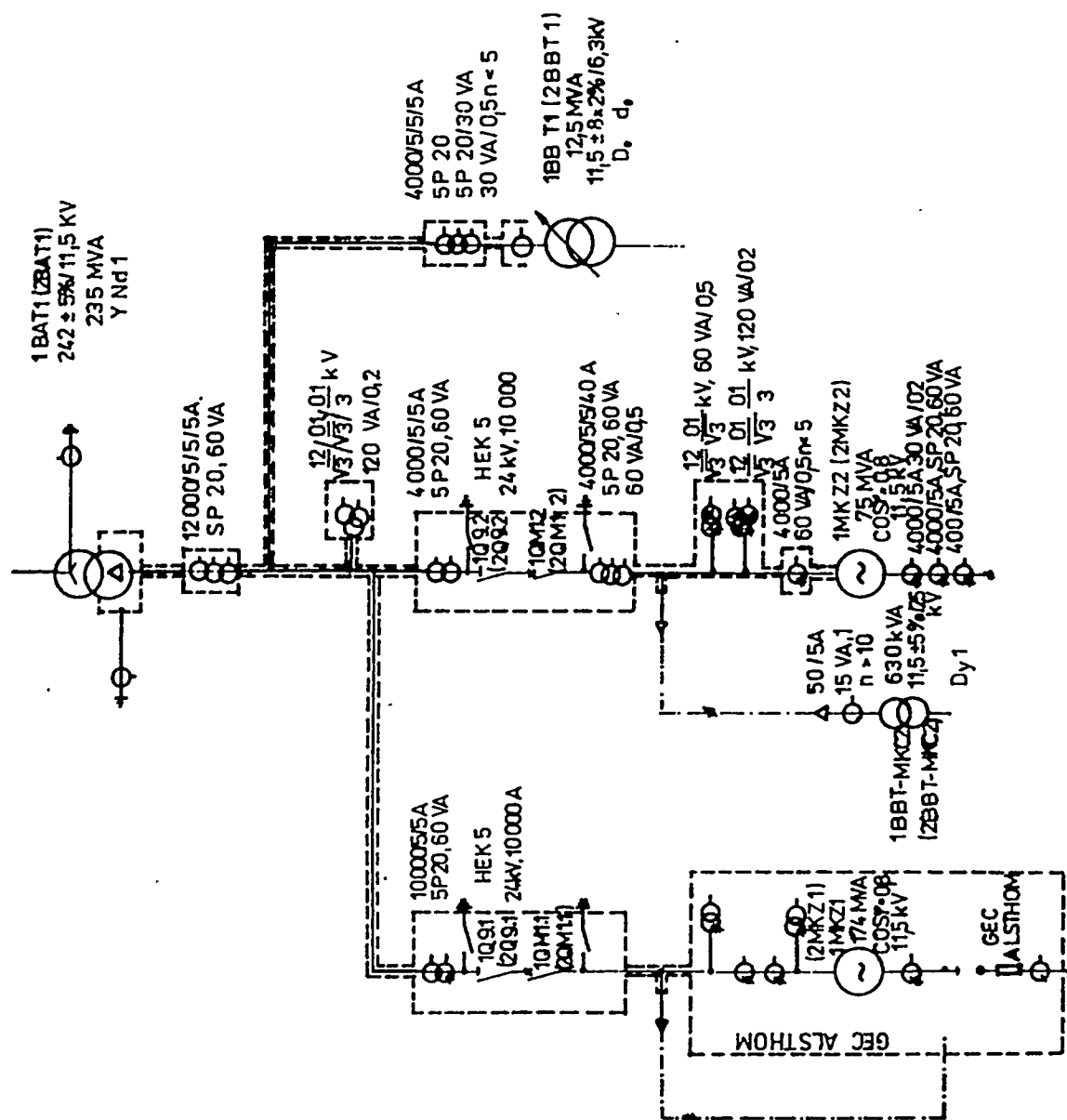
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FLUE GAS CLEANUP

Session C5

HIGH SO₂ REMOVAL DUCT INJECTION: A LOW-COST FGD ALTERNATIVE

Sidney G. Nelson

Sorbent Technologies Corporation
Twinsburg, Ohio, USA

ABSTRACT

Sorbent Technologies Corporation, of the United States, is currently developing and demonstrating a new waste free, retrofitable, high-SO₂ removal duct-injection process. Up to 85 percent SO₂ removal is achieved by simply injecting a new dry lime-based sorbent into the flue-gas duct, collecting the sorbent downstream in a particulate collector, and then recycling the sorbent. By avoiding large, expensive components, the process can have low capital costs, making it especially appropriate for smaller, older, less-utilized plants.

The key to the new technology is the use of sorbent supports. Supported sorbents are produced by coating hydrated lime onto inexpensive mineral supports, such as exfoliated vermiculite or perlite. Consequently, there are no liquid, sludge, or solid wastes with the new technology. Once saturated with SO₂, the spent sorbent can be easily pelletized into a valuable soil-conditioning agricultural by-product, for the sustainable development that the future requires.

This paper describes Sorbent Technologies' pilot demonstration of supported sorbent injection at the Ohio Edison Company's R.E. Burger station. The Burger effort is also the first demonstration of the Electric Power Research Institute's new "COHPAC" baghouse technology in a sorbent-injection desulfurization application.

BACKGROUND

During the past few years, various sorbent injection processes have received wide attention as possible dry, retrofitable substitutes for wet scrubbers by boiler-operators grappling with acid-rain compliance regulations. The initial promise of sorbent duct-injection technologies was that they could be easy and inexpensive to retrofit onto existing boilers and would be particularly appropriate for the many older, smaller, and non-base-loaded plants.

In practice, however, weak sorbent performance has plagued these injection schemes. Typically, unassisted SO₂ removal of 40% to 60% and low sorbent utilizations of from 20% to 40% were seen. Moreover, particulate-control problems have occurred in these trials. By adding, literally, many tons of ultra-fine sorbent particles to the flue gas stream, a typical plant's particulate removal requirements were significantly increased. A particulate compliance problem simply replaced the acid-gas problem. Low sorbent utilizations means that huge amounts of very fine, unused reactants, mixed-in with electrostatic precipitator (ESP) flyash, required disposal as wastes.

To help solve these problems, Sorbent Technologies Corporation has formulated an acid-rain-control sorbent material specifically designed for integrated retrofit duct-injection application. The new supported-sorbent emissions control technology simultaneously achieves:

- 1) High duct-injection SO₂-removal levels;
- 2) Improved PM-10 and toxins control; and
- 3) High-volume, high-value by-products; instead of wastes.

Fundamental to the technology are new "supported" sorbents. These granular sorbents contain a hydrated lime coated onto the large internal surface areas of inexpensive mineral supports, such as exfoliated vermiculite or prelite. Because of the supports' unique sponge-like characteristics, the sorbents can carry with them the high amount of moisture needed for optimum acid-gas removal. Early test results indicate potential for 85 + % SO₂ removal and 55 + % net lime utilizations in a retrofitable duct-injection system.

When used in a duct-injection mode, the supported-sorbents are called "Fluesorbents", (See Figure 1). The Fluesorbents are monster-sized particles compared to typical lime injectants. Consequently, they

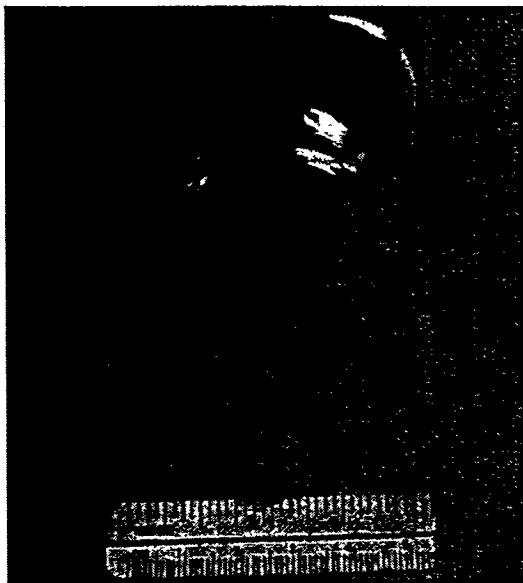


Figure 1. Moist and free-flowing, the new sorbents are fine enough to be easily entrained, yet coarse enough to be easily removed.

are easy to remove from the gas stream and particulate problems do not result, even when recycling sorbent back into the gas stream. To ensure that particulate emissions are reduced, rather than increased, Fluesorbent injection is typically envisioned with a microbaghouse included. This allows for increased toxins removal as well.

Unlike other advanced coal technology wastes, saturated Fluesorbents contain a large amount of a premium horticultural growth medium, exfoliated vermiculite or perlite, the sponge-like mineral support. By increasing the lime utilization and decreasing capital equipment requirements, these expanded mineral supports pay for themselves.

But more importantly, because of the vermiculite or perlite supports, saturated Fluesorbents are not wastes, but rather feedstocks for high-volume, high-value, slow-release soil-amendment by-products. Once saturated with SO₂, it appears that they can be advantageously applied to agricultural or turf lands either by themselves or, preferably, pelletized with urea or other fertilizer chemicals and pesticides. Initial plant tests have been very promising. The vermiculite/calcium-sulfite/unutilized-lime substrate of the saturated sorbents is similar to some compositions being commercially marketed today. Because these are essentially waste materials, however, it may be possible to create slow-release products from them at only a fraction of the cost of virgin materials, thus opening up new markets. Examples are shown in Figure 2.



Figure 2. Trial pellets were made from dry FGD waste and fine vermiculite. The left sample was extruded; the right sample was agglomerated. The plant was grown in a potting soil containing supported-sorbent.

SUPPORTED-SORBENTS

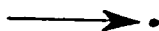
The new supported-sorbents are easily produced. An extremely-fine vermiculite ore is used, usually #5 waste grade. The ore is thermally expanded in the traditional, automated manner, where it increases in volume by a factor of about ten. Vermiculite, a clay mineral, expands upon heating like an accordion, exposing hundreds of thin, mica-like plates. The result is a material extremely light and porous. Perlite, an alternate mineral support, pops like an exploding onion, similarly exposing a high internal macro-surface area. These expansions allow for a very high loading of reactive species, in this case hydrated-lime, with a resulting sorbent composition of about 60% $\text{Ca}(\text{OH})_2$ by weight. The material is then moistened before use.

The key to Fluesorbent FGD performance is the sorbents' moisture-carrying-capacity. It has been well established that the higher the relative amount of water in the flue gas, that is, the lower its approach to adiabatic saturation, the better the lime sorbent utilization and SO_2 removal. Because their mineral supports are like sponges, the sorbents can be heavily loaded with water, up to 40% of their final weight, yet remain free-flowing and dry to the touch. When exposed to the gas stream, they carry their water tightly with them, right along with the widely-exposed lime. The optimum quantity of water is exactly where it is needed. As the water evaporates from the sponge-like supports, the sorbents are cooled, dropping the wet-bulb temperature in their micro-vicinity and accelerating SO_2 sorption through the thin film of water on the sorbent surfaces.

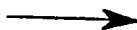
The key to Fluesorbents' application is their size. The sorbents are about 0.2-mm on a side: small and light enough so that they can be entrained in the gas stream, yet large enough that are easily removed from the gas once saturated. Traditional lime or lime-slurry injectants and flyash are thousands of times smaller in mass than the sorbents. It is much easier and cheaper to separate a single, saturated 200-micron diameter supported-sorbent from the gas stream than 10,000 equivalent, but tiny, 5-micron lime particles.

Commercial Lime Hydrate		Fluesorbent
5μ	Approx. Mass Mean Particle Diameter	200μ
$200\mu^3$	Volume (Diameter ³ ($\propto$ to mass))	$8,000,000\mu^3$
1	Relative Size	40,000
1	Relative Lime Mass	10,000

If this is
a hydrate particle



then this is the size
of a Fluesorbent



SUPPORTED-SORBENT INJECTION

Supported sorbents can be injected either before or after the plant's existing electrostatic precipitator (ESP) or fabric filter. If injected before the ESP or baghouse, capital costs are very low, because little construction is necessary. Existing ductwork and particulate collection is used. In this case, the sorbents become intermixed with flyash, but with their dramatic size and density differences, they can be easily and substantially separated for use in the agricultural by-products.

The Fluesorbents can also be injected after the ESP (See Figure 3) and collected in an added particulate device, as in the Electric Power Research Institute's (EPRI) HYPAS concept. This scheme

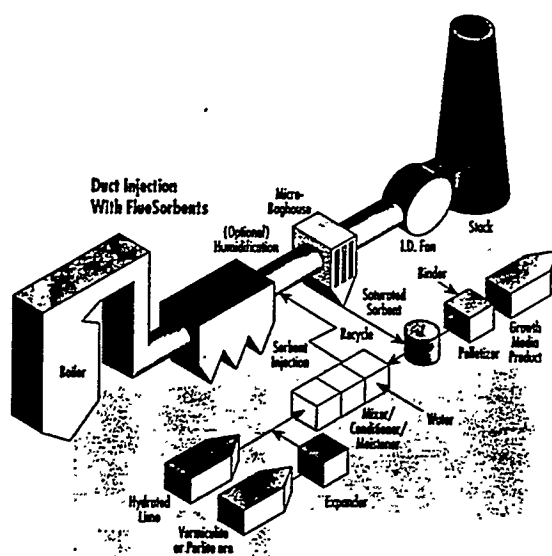


Figure 3. Supported-sorbent injection flowsheet, without a scalping device.

has higher capital costs, but allows the sorbents to be internally recycled, resulting in higher overall SO₂ performance. Fortunately, because the new sorbents are so relatively large, it is possible to use fabric filters that are less than one-fourth the size and cost of those required to filter out the usual 5-micron particles. EPRI recently developed an extremely-high-ratio pulse-jet baghouse ("COHPAC") for retrofit back-ups to aging, marginal ESPs for PM-10 particulate and toxins removal. Over a Gigawatt of COHPAC baghouses are now being constructed at Texas Utilities Big Brown station. These units can operate with acceptable pressure drops at air-to-cloth ratios of 12 to 16 acfm/ft², if the particulate loading is low or if the particles are large and porous, as with Fluesorbents, Special sorbents or activated carbons can also be injected into the COHPAC for mercury removal, if needed.

For high-sulfur coals, most particulate matter in the flue gas can be scalped out with a mechanical device, such as a cyclone or a simple entry device on the microbaghouse. The sorbents are internally recycled by simply remoistening them and reinjecting them into the gas stream. Because sorbent injection is after the ESP, fine flyash is not recycled along with the sorbents. This also means that any existing flyash sales would be unaffected, which is not the case with most other retrofit FGD technologies. EPRI recently licensed the COHPAC microbaghouse technology to Sorbent Technologies.

Because of their abilities to be injected moist and to be internally recycled back into the gas stream, allowing a higher apparent lime stoichiometry in the duct, supported-sorbents have been found to result in very high SO₂ removal rates. Lime utilization is also very high.

When fully saturated, Fluesorbents appear to be excellent substrates for agricultural and turfgrass products. The new dry sorbent materials differ from others in three important ways:

- 1) They contain large amounts of vermiculite or perlite, which are premium soil amendment materials:
- 2) They contain little or no deleterious flyash, with its associated heavy metals; and
- 3) They are already substantially granular and easy to pelletize.

They also contain a significant amount of unutilized lime, which can help neutralize acidic soils.

By themselves, the saturated vermiculite sorbent pellets have been found to possess water-retention, soil-aeration, and cation exchange properties that benefit plant life. However, further, they also form an excellent solid substrate for other potential additives. Two specific commercial products are currently being targeted: an agricultural product and a turfgrass product.

The Ohio Agricultural Research and Development Center (OARDC) of the Ohio State University has begun working with Sorbtech in analyzing supported-sorbent-by-products. Raw saturated sorbents and trial pellets, without additives, from power plant slipstream trials have been analyzed by OARDC for leachates. Typical results are given in Table 1.

The data in this table show that neither the raw sorbents nor the pelletized sorbents came close to qualifying as solid wastes. Within the limits of the measurement methods, the TCLP leachates even met the drinking water standards for regulated heavy metals. Leachate measurements were also made of 20 other metals, from Al to Zn, and none showed any problems. Importantly, pelletizing the saturated vermiculite sorbents significantly decreased the release rate of their alkalinity. Thus, they should be capable of neutralizing acidic soils without overwhelming them, unlike most FGD wastes containing unutilized lime.

Table 1

Toxic Characteristic Leaching Procedure Extract Concentrations of Utility-Saturated Sorbents (in mg/liter)
(20:1 solution to solid ratio, 18 hr extraction, acetic acid extract pH 2.9)

	Raw Saturated Sorbent	Pelletized Sorbent	Drinking Water Standard (& Solid Waste Standard)	
pH	12.4	6.1		
As	<0.08	<0.08	0.05	(1.50)
Ba	0.322	0.106	1.0	(30)
Cd	<0.003	0.005	0.010	(0.30)
Cr	0.013	0.006	0.050	(1.50)
Hg	<0.04	<0.04	0.002	(0.06)
Pb	<0.04	<0.04	0.05	(1.5)
Se	<0.27	<0.27	0.04	(0.30)

EXPERIMENTAL RESULTS

After successful initial Fluesorbent SO₂ removal experiments at its own laboratory and successful trial baghouse injection runs at a commercial gardening-soil producer in Pennsylvania, Sorbent Technologies had outside in-duct testing performed at an independent facility. These trials were carried out at the U.S. EPA's 40-acfm duct injection test facility in Research Triangle Park, N.C. by Acurex Corporation, the site-contractor. With an inlet SO₂ concentration of 1500-ppm and a 20°F approach to adiabatic saturation, 88-percent SO₂ removal was observed by Acurex with a fresh-lime-consumption stoichiometry of only 1.5:1 and a simulated recycle rate of 4:1.

Based on the EPA results, EPRI later sponsored tests employing the new sorbent in their experimental 5000-acfm COHPAC baghouse at Public Service of Colorado's Comanche station. The purpose of this testing was to see how the sorbents would act in an actual microbaghouse. Even without any added scalping device, the sorbents demonstrated acceptable baghouse pressure drops, operating at an air-to-cloth ratio of 16-fpm, four times faster than usual. No SO₂ removal was expected in this testing, because there was no humidification of the flue gas at the site. However, despite the highly non-optimal 100°F approach temperature, the sorbents averaged about 40% SO₂ removal in simulated steady-state operation, with a stoichiometric injection ratio of 1.7:1 and recycle ratio of 3:1.

To optimize the process, a larger 100 acfm duct-injection test unit, modeled on the EPA unit but specially designed for Fluesorbents, was built and installed at Sorbent Technologies' facilities. In an extensive experimental program on this apparatus for the National Science Foundation (NSF), SO₂ removal performance in the recycle mode was observed to be significantly better than that seen in the various first-generation sorbent-injection efforts of others. This can be seen in graphs below (Figure 4). The bottom curves were taken directly from pages 1-12 of the new U.S. Department of Energy DUCT INJECTION DESIGN HANDBOOK, and the top curves were drawn from NSF test results.

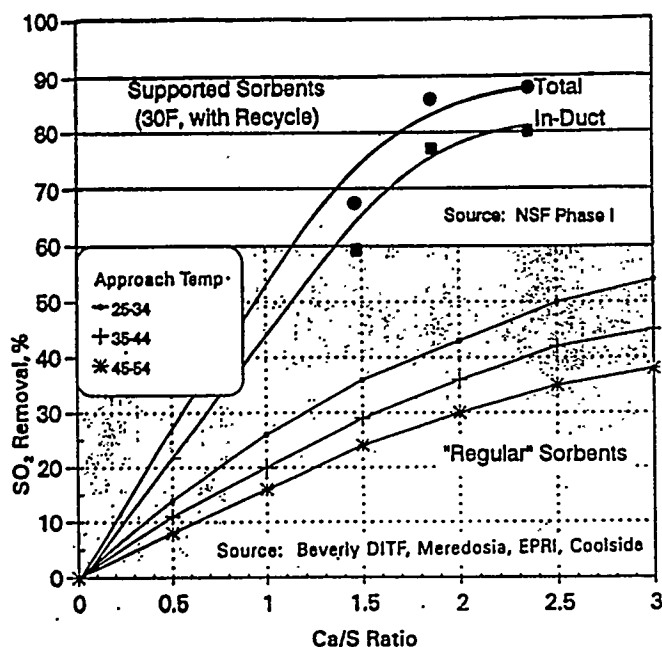


Figure 4. SO₂-removal as a function of Ca/S ratio for supported sorbents in comparison with conventional or regular lime sorbents.

PILOT TESTING AT OHIO EDISON'S BURGER STATION

Based on the test results to date, Sorbent Technologies has designed and is constructing a large, dedicated pilot facility to demonstrate the new technology. This facility will allow the testing of a variety of integrated supported-sorbent process schemes. The project is being co-sponsored by the Ohio Edison Company and the Ohio Coal Development Office. The Electric Power Research Institute is contributing an experimental COHPAC microbaghouse to the project.

The facility is being installed at Ohio Edison's base-loaded R.E. Burger station near Wheeling, West Virginia. It consists of a 6500-acfm, 2-MWe duct-injection pilot plant designed specifically for use with supported-sorbents. The facility, taking a slipstream of flue gas after the plant ESP, includes optional flyash reinjection, sorbent production and injection, flue-gas humidification, a long run of insulated fiberglass-reinforced plastic (FRP) ductwork, a cyclone, the EPRI microbaghouse, a measurement venturi, an I.D. fan with associated controls, heat-traced sample-gas lines, various gas-analysis instrumentation, and a computerized data-acquisition system. The layout of the facility is shown in Figure 5, and a photograph is provided on the next page.

The plant flue gas at the burger power plant typically contains about 2000 ppm SO₂. The Sorbent Technologies facility can take 6500-acfm of flue gas from either of two boilers trains, in case one unit is down. The project includes the testing of the various facility subsystems and a parametric test program examining different process options and many process variables.

The project will generate a significant amount of spent Fluesorbent for processing into trial agricultural and turfgrass products. A greenhouse study and a multi-year field-testing program have been planned for performance at the Ohio Agricultural Research and Development Center.

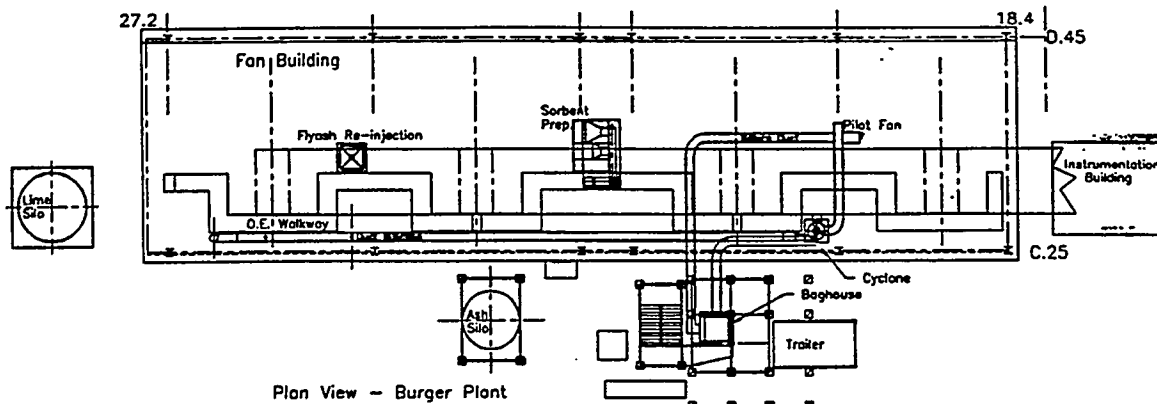


Figure 5. Layout of pilot test facility.

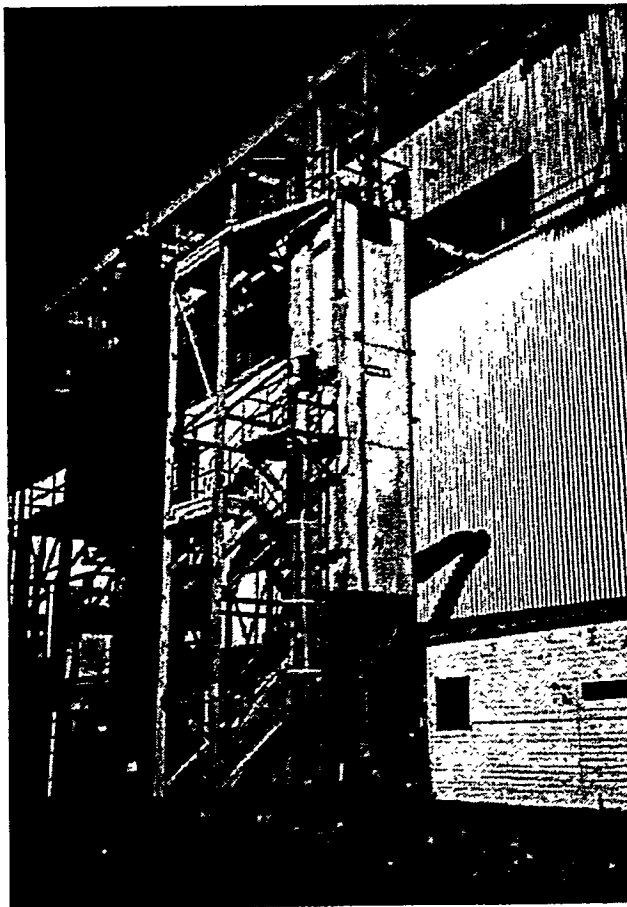


Figure 6. The pilot test facility at Ohio Edison's R.E. Burger Power Plant.

If the pilot project goals are accomplished, a full-scale demonstration of the new technology would follow in the near future.

APPLICATION TO EASTERN EUROPE

Most analyses in the past have indicated that for older plants, smaller plants, or plants with low operating factors, duct injection options offer significant economic benefits over conventional wet scrubbers and spray dryers. In particular, duct-injection processes are easily retrofitable and are much less capital-intensive than controls which require a great deal of construction. This can be a significant advantage where capital is scarce or expensive. With the exception of the baghouse, which may be needed for particulate control anyway, Fluesorbent capital equipment requirements are very low.

Because of the vermiculite or perlite supports, Fluesorbent material costs will be higher than simple lime or limestone, but for many plant situations, this cost is not a pivotal item. The mineral-supports decrease the amount of lime consumed and if local supplies can be used, their true cost is very low. Moreover, the agricultural by-products can provide a significant income stream, while other technologies impose land disposal and water pollution control costs.

The Fluesorbent technology should be of interest to Eastern European firms employing coal or fuel-oil fired plants, particularly smaller and older facilities where large capital expenditures make no sense. It is an ecologically and economically sustainable technology appropriate for many plant situations.

PROGRAM TO DEMONSTRATE ADVOCATE TECHNOLOGY IN POLAND

Wojciech Jozewicz
Carl Singer

Acurex Environmental Corporation
Research Triangle Park, North Carolina, USA

Charles B. Sedman

Air and Energy Engineering Research Laboratory
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina, USA

Tom Lillestolen

ABB Environmental Systems
Knoxville, Tennessee, USA

ABSTRACT

The objective of this program is to demonstrate and introduce the ADVOCATE process commercially for the control of SO₂ emissions from utility and industrial boilers. The program will facilitate the transfer of technology developed by the U.S. Government, and its introduction in Poland for air pollution control technology users. The ADVanced siliCATE (ADVOCATE) process has been jointly developed by the U.S. Environmental Protection Agency (EPA), Acurex Environmental Corporation, and the University of Texas. This low-cost process for dry flue gas desulfurization (FGD) is currently licensed worldwide by ABB Environmental Systems (ABBES). EPA has sponsored testing of Polish fly ashes from several power plants in the Upper Silesia region. The testing was aimed at evaluating the applicability of Polish fly ashes for the ADVOCATE process.

Five fly ashes were characterized extensively before and after grinding in a vertical ball mill. Following the characterization, ADVOCATE sorbents reactive to SO₂ were prepared from the ground and unground Upper Silesia fly ashes slurried with Ca(OH)₂. Sorbent reactivity increased with increasing slurry time from 3 to 6 h, and with increasing ground fly ash fraction from 0.2 to 0.8.

During Phase I of the program, the design, construction, and operation of a 5-MW_e pilot-plant ADVOCATE installation will occur at the Łaziska Power Plant in the Upper Silesia region of Poland. The sorbent will be prepared on-site by slurrying at high temperature for a prolonged period of time. Fly ash will be ground prior to high-temperature slurrying with lime. Cured slurry will be mixed with dry recycle from the particulate matter control device in a paddle mixer. From there, the solids will be introduced into the duct. During Phase II of the program, it is anticipated that a full-scale ADVOCATE installation will be built.

BACKGROUND

The ADVOCATE process has been developed in anticipation of a need for low-cost SO₂ control in the United States. Countries of Central Europe are currently in the process of undertaking efforts to improve their air quality, which has been compromised by decades of an intense development of heavy industry and a considerable amount of environmental neglect. The magnitude of air quality problems in

Central Europe is amplified by the economic challenges in the region. Although there is a strong dependence on coal as a source of energy, funds to install costly, high-efficiency control technologies for flue gas desulfurization (FGD) are often limited.

ADVOCATE has previously been presented as a low-cost alternative for SO_2 control throughout the region.¹ The program described in this paper will facilitate the transfer of technology developed by the U.S. Government and licensed by private industry and its introduction in Poland for air pollution control technology users. During Phase I of the program, preliminary testing on the 5-MW_e pilot-scale will take place at Łaziska Power Plant in Łaziska Górne, Poland. Following successful pilot-plant testing, it is anticipated that a full-scale ADVOCATE installation will be built at Łaziska, which is located in the Upper Silesia region of Poland. The selection of this location follows EPA's multimedia Silesia study² and a long-term commitment of the power plant management to solve their environmental problems³.

This paper discusses the preliminary work that was performed to investigate properties of Polish fly ashes, and specifically, fly ash from the Łaziska Power Plant. Additionally, it presents the process concept intended for use during the pilot-plant testing.

PROCESS DEVELOPMENT

The reaction of fly ash with calcium hydroxide [$\text{Ca}(\text{OH})_2$] for the production of reactive sorbents for use in FGD processes has been studied under EPA sponsorship since 1984⁴. This work demonstrated that solids produced by slurring fly ash and $\text{Ca}(\text{OH})_2$ were significantly more reactive than $\text{Ca}(\text{OH})_2$ alone, and that silica was the most reactive compound of fly ash. It also postulated that the rate limiting step of the reaction of fly ash with $\text{Ca}(\text{OH})_2$ was the dissolution rate of silica from fly ash. Three different approaches were tested that could increase the dissolution rate of silica: additives (sodium hydroxide, ammonium phosphate, phosphoric acid), more reactive forms of silica (diatomaceous earth, bentonitic clay), and an increased slurring temperature (pressure hydration).^{5,6} The use of additives or more reactive forms of silica significantly increased the cost of sorbent preparation. High capital cost of pressure hydration and decreased conversion of $\text{Ca}(\text{OH})_2$ above 150 °C, likely due to the formation of crystalline calcium silicates, indicated that the commercial competitiveness of calcium silicate sorbent could be increased by the elimination/modification of this hydration step. Another means to increase the rate of formation of calcium silicates is to increase the availability of silica by fly ash grinding. This approach has the demonstrated capability to decrease the slurring time and, at the same time, avoid the formation of crystalline solids.⁷

Following the signing of the Cooperative Research Agreement between the U.S. Environmental Protection Agency (EPA) and ABB Environmental Systems (ABBES) in November 1988 and through EPA's research agreements with the University of Texas and Acurex Environmental, the ADVOCATE process has evolved into a simple add-on technology easily retrofitted on the existing utility boilers with minimal disruption. The process couples the advantages of a highly reactive $\text{Ca}(\text{OH})_2$ /fly ash sorbent with the dry injection technology called Moist Dust Injection (MDI) that uses moistened recycle product and fresh $\text{Ca}(\text{OH})_2$.

ADVOCATE/MDI system was tested on a 10-MW_e scale at the Tennessee Valley Authority's (TVA's) Shawnee Station in Paducah, Kentucky, USA. The ADVOCATE process SO_2 removal performance achieved 89 percent at a stoichiometric ratio of 1.47. All tests were conducted with an inlet flue gas temperature of 160°C, approach to adiabatic saturation temperature of 11 °C and duct residence time of approximately 2 s.⁸

STUDIES WITH POLISH FLY ASHES

Solids Characterization

Six siliceous samples from Poland were obtained for the testing of their suitability for ADVOCATE sorbent production. Five of the samples were fly ash from the combustion of coal in Upper Silesia, and the sixth was silica fume waste from a local iron smelter. The samples were analyzed by X-ray fluorescence for elemental composition. Results of these analyses are presented in Table 1. All six samples conformed chemically to ASTM-618 Class F pozzolans specifications.

Brunauer, Emmett, and Teller specific surface area (S_A) was measured by nitrogen adsorption/desorption. A portion of each fly ash sample was ground in a vertical ball mill prior to preparation of some sorbents. Ground fly ash S_A measurements are also presented in Table 1.

Screening Tests

ADVOCATE sorbents were prepared from the six siliceous materials described above. These siliceous materials were slurried with reagent grade $\text{Ca}(\text{OH})_2$ at 15 parts water to one part solids at 90 °C for varying lengths of time. Solids were then filtered from the slurry and dried in a vacuum oven at 110 °C. The filtrate was discarded. Sorbents were analyzed for acid soluble silica and bench-scale reactivity to SO_2 . The bench-scale test stand, discussed in detail in previous papers,^{4,5} was operated at the following test conditions: 64 °C reactor temperature, 60 percent relative humidity, and 1000 ppmv SO_2 .

TABLE 1

Upper Silesia Ash Analysis.

	HALEMBA	OPOLE	ŁAGISZA	ŁAZISKA (120 MW)	ŁAZISKA (200 MW)	SILICA FUME (ŁAZISKA SMELTER)
Silicon	23.	20.	23.	22.	21.	51.
Aluminum	6.8	6.8	13.6	11.	8.5	0.19
Titanium	0.62	0.55	0.65	0.63	0.60	0.0
Iron	6.0	4.7	3.9	5.1	4.3	0.29
Calcium	2.7	2.7	1.7	2.0	2.0	0.076
Magnesium	1.7	1.4	1.2	1.3	1.27	0.55
Sodium	0.93	0.67	0.82	0.83	0.91	0.22
Potassium	2.3	2.0	2.5	2.3	2.4	0.55
Sulfur	0.54	0.41	0.28	0.34	0.29	0.06
$\text{SiO}_2/\text{Al}_2\text{O}_3$	3.8	3.3	1.9	2.3	2.8	3.0E2
Base/Acid	0.30	0.28	0.18	0.23	0.24	0.21
T_{250} (°C)	1400	1420	1520	1460	1450	1090
Fly Ash Surface Area (m^2/g)	1.10	9.05	4.74	2.83	2.53	19.5
Ground Fly Ash Surface Area (m^2/g)	2.63	9.71	7.19	4.44	3.68	N.A.

Suitability of siliceous materials for the ADVOCATE sorbent formation was first screened by preparing ADVOCATE sorbents at 3 and 6 h, slurrying 3 parts siliceous material to 1 part reagent grade $\text{Ca}(\text{OH})_2$ (by weight). Sorbents were then exposed to SO_2 in the bench-scale reactor at conditions described above. As shown in Figure 1, bench-scale reactivity indicates that ADVOCATE sorbents highly reactive toward SO_2 may be produced from all six materials. Reagent grade $\text{Ca}(\text{OH})_2$ yielded approximately 20 percent utilization in this test stand. All siliceous material/ $\text{Ca}(\text{OH})_2$ sorbents prepared at the 3:1 weight ratio and slurried for 3 h yielded more than 25 percent utilization. Grinding the fly ashes before slurrying with $\text{Ca}(\text{OH})_2$ improved bench-scale reactivity. Bench-scale reactivities of 3:1 silica fume/ $\text{Ca}(\text{OH})_2$ sorbents were greater than 90 percent utilization, indicating its great potential as an additive to improve total system performance.

Parametric Tests

Halemba and Łagisza fly ashes were slurried over a wide range of fly ash to $\text{Ca}(\text{OH})_2$ ratios to simulate commercial operation. ADVOCATE sorbent composition in a commercial operation will be determined by a variety of factors including: stoichiometry, recycle ratio, feed-solids moisture content, coal ash content, and coal sulfur content. The recycle ratio, a major factor in determining ash content in the slurry, will be limited by the slurry solids content and the water needed for humidification. Bench-scale reactivities of these sorbents prepared by slurrying fly ash and $\text{Ca}(\text{OH})_2$ at varying weight ratio are shown in Figure 2.

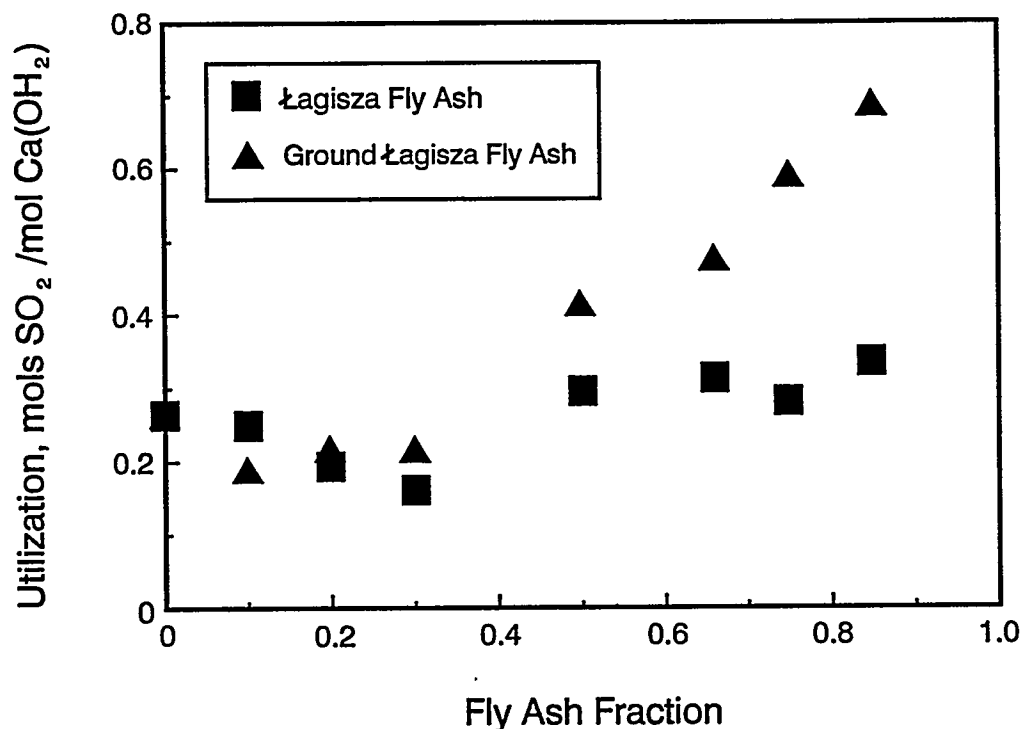


Figure 1. Results of screening studies of Upper Siliceous materials.

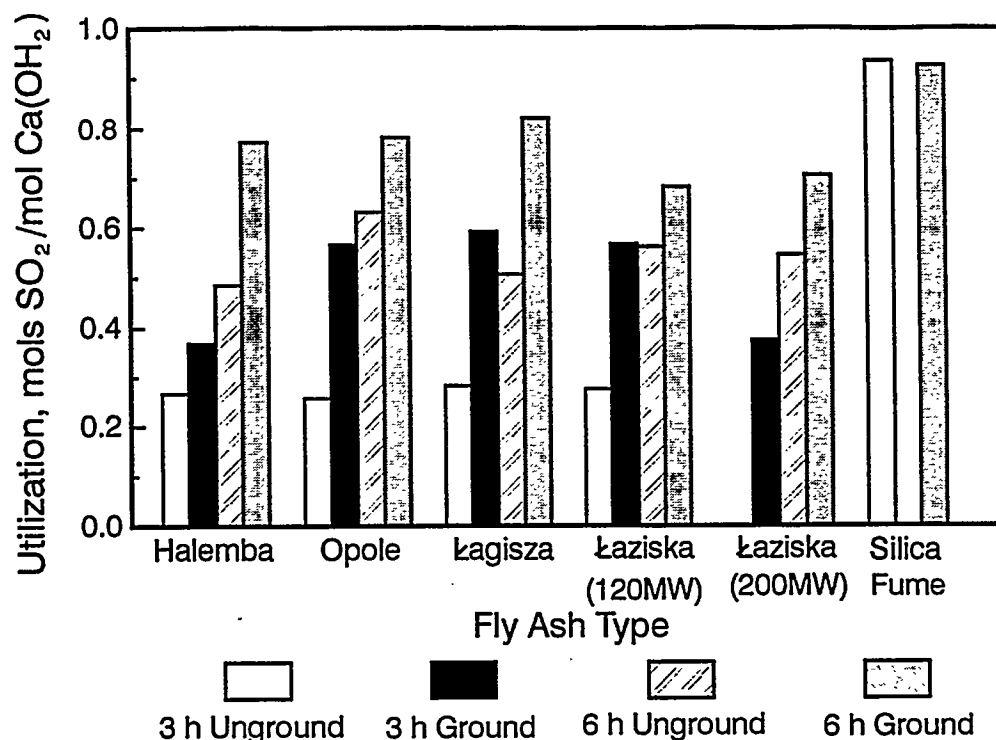


Figure 2. The effect of fly ash-to- $\text{Ca}(\text{OH})_2$ weight ratio on reactivity of ADVOCATE sorbent.

Within the experimental range tested, increasing fly ash content had little effect on the reactivity of sorbents made with unground Łagisza fly ash slurried for 3 h. Sorbents made with ground Łagisza fly ash exhibited increased reactivity with increased fly ash content. Increased reactivity with increasing siliceous material-to- $\text{Ca}(\text{OH})_2$ weight ratio has been reported with several siliceous materials.^{4,5,6} It is therefore advantageous to maximize the fly ash in the system.

Fly Ash Dissolution Modeling

The rate of fly ash dissolution is an important factor controlling the rate of ADVOCATE sorbent formation. A simple model was constructed to understand fly ash dissolution better. For fly ash dissolution modeling purposes, the extent of reaction (X) was defined as:

$$X = \frac{\text{acid soluble silica}}{\text{total silica fly ash}}$$

X represents the fraction of the fly ash that has been dissolved from the glass. The total silica in the fly ash (based on X-ray fluorescence) was used to define X . However, some of the silica in the fly ash is in crystalline phases, such as quartz, and is virtually unavailable for ADVOCATE sorbent development. In a batch system, the derivative of X is expected to be dependent on the surface area of the unreacted core of pozzolan (S_{A_i}) and hydroxide concentration ($[\text{OH}^-]$) as follows:

$$\frac{dX}{dt} = K \times S_{A_i} \times [\text{OH}^-]^a$$

Peterson⁹ indicates coefficient a to be approximately 1 for Class F fly ashes. Expressing the surface area of the ash at time t as a function of X and integrating yields:

$$(1 - X)^{1/3} = K_2 - \frac{1}{3} \times K_1 \times S_A \times [OH^-]^a \times t$$

Figure 3 shows the effect of varying sorbent composition on X , the fraction of fly ash dissolved, for sorbents slurried for 3 h at 90 °C. The model indicates the X for a particular fly ash at any fixed slurry time and fly ash surface area is dependent on $[OH^-]$. X was much higher in sorbents made with an abundance of $Ca(OH)_2$ than in $Ca(OH)_2$ -poor sorbents. This effect is the result of the $Ca(OH)_2$ dissolution rate limiting the system pH. The $Ca(OH)_2$ dissolution rate in a full-scale system will be affected by many factors (not discussed in detail here) including the following: increased slurry solids concentration, increased shear of mixing, $Ca(OH)_2$ particle size distribution, $Ca(OH)_2$ S_A , and the presence of recycle materials.

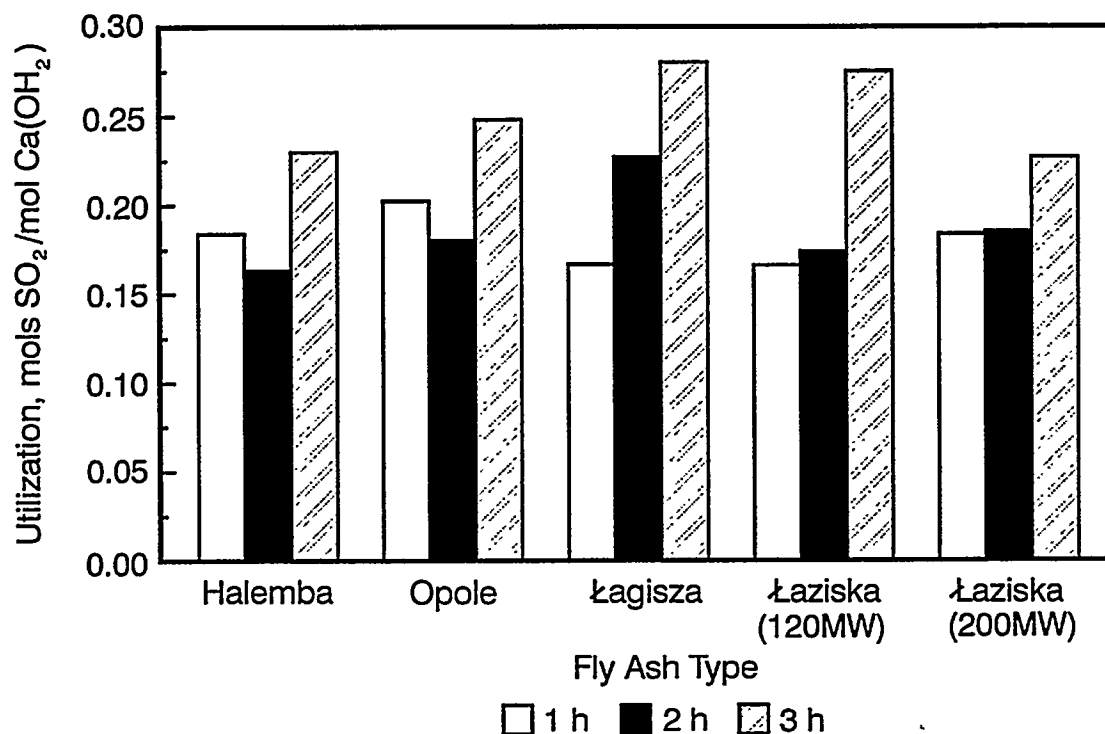


Figure 3. The effect of ADVOCATE sorbent composition on the amount of dissolved silica.

The ground fly ashes were slurried at 90 °C at 0.3 parts fly ash to 0.7 parts (by weight) $Ca(OH)_2$ from 1 to 6 h. This ratio is expected to approximate the total ash-to- $Ca(OH)_2$ weight ratio expected at a typical power plant burning coal from Upper Silesia. Bench-scale reactivities of these sorbents are shown in Figure 4.

The reactivity of sorbents slurried for 3 h was substantially higher than that for respective sorbents slurried for 1 to 2 h. Sorbent prepared from Łagisza fly ash slurried for 6 h yielded 40 percent utilization. In addition to the factors affecting $Ca(OH)_2$ dissolution mentioned above, a commercial system may

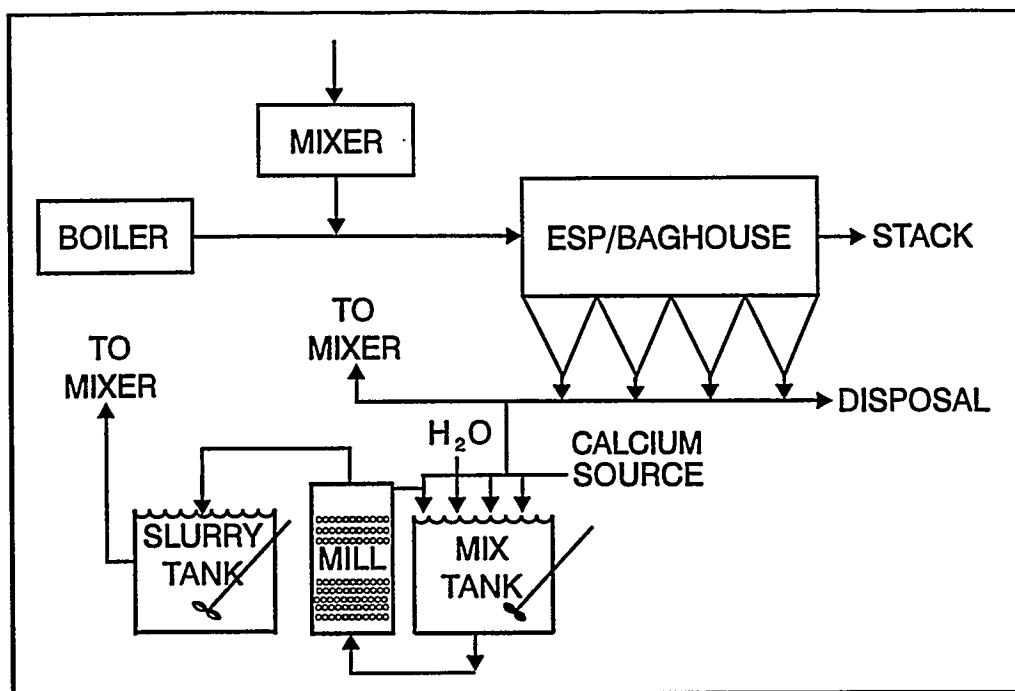


Figure 4. Effect of slurring time on reactivity of ADVACATE sorbent.

benefit from the following: reactivation of spent ADVOCATE, continuous slurry conditions, staged slurring, and process modifications in development that will increase the fly ash concentration.

Acid-soluble silica was evaluated in the above samples to confirm model predictions. The model predicts a linear relationship between $(1-X)^{1/3}$ and time for fixed slurring conditions. As shown in Figure 5, the results appear to be linear for slurry times up to 6 h.

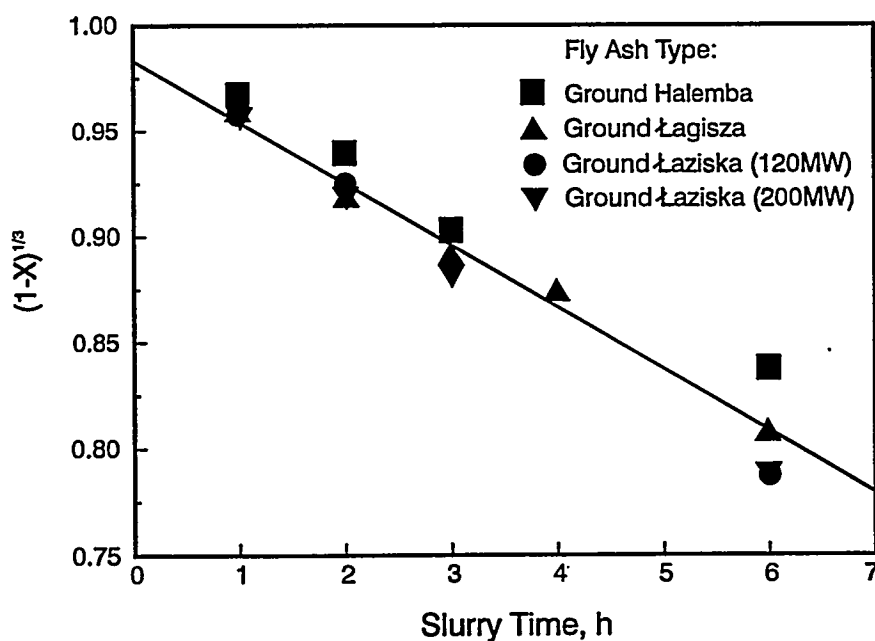


Figure 5. Modeling results of silica dissolution.

PROCESS SCHEME FOR ŁAZISKA DEMONSTRATION

Figure 6 presents the concept of the pilot-plant installation considered for the Łaziska Power Plant. Key process features include: in-duct sorbent drying and SO_2 absorption; one-step sorbent mixing/injection; and sorbent preparation with two slurry tanks and one tower mill (attritor). Spent sorbent and boiler fly ash are collected in the particulate control device (electrostatic precipitator or baghouse), which have been modified mechanically for higher loadings. A portion of the waste material is fed to a mix tank along with fresh calcium source. A larger portion is diverted directly to the mixer and the remainder is discarded as waste. From the mix tank, calcium/fly ash slurry is pumped to a tower mill; from there, it is fed into a slurry tank.

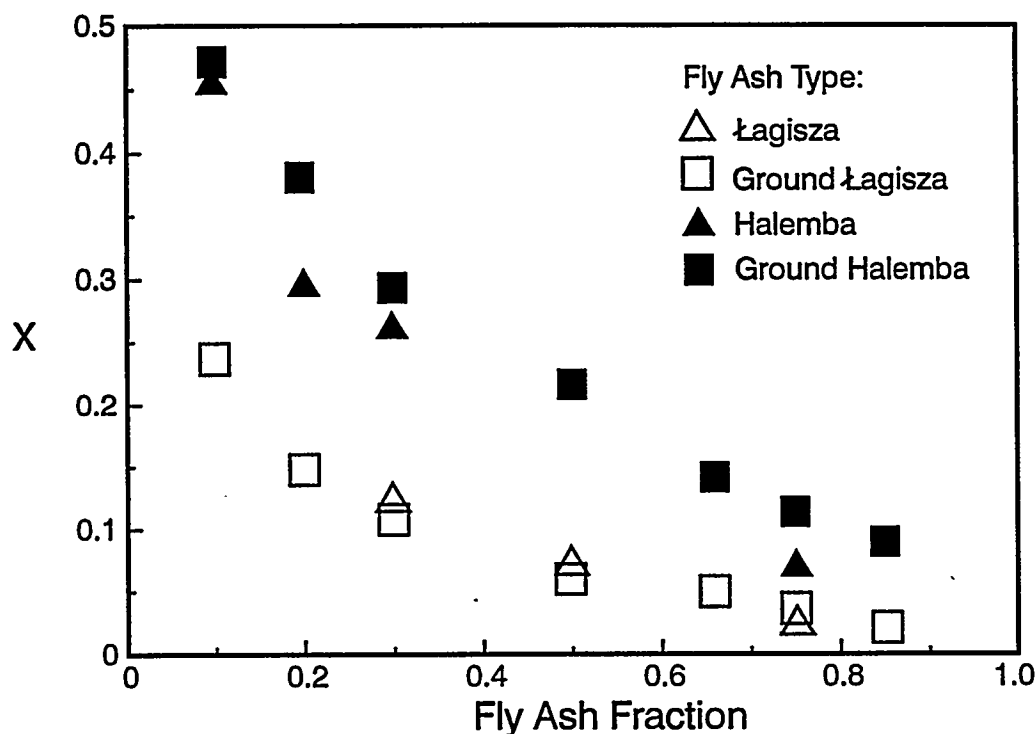


Figure 6. Schematic of ADVACATE process considered for Łaziska Power Plant.

The product of a slurry tank (silicate slurry) is next routed to the mixer and blended with dry recycle solids to form a damp, free-flowing powder that is then injected into the duct at approximately 1 s upstream of the dust collector.

The test objectives for the Łaziska pilot-plant demonstration are: SO_2 removal of 80-90 percent at stoichiometry of 1.2 at 17 °C approach to adiabatic saturation. The sorbent's moisture content will be 20-30 percent by weight. Additional parameters that will be investigated during the Łaziska test program is the effect of chlorides and the extent of corrosion (typical Łaziska coal contains 0.8 percent sulfur and 0.2 percent chlorine).

CONCLUSIONS

The following conclusions can be made based on the results of the work presented here:

- ADVOCATE sorbents reactive to SO_2 were prepared from the Upper Silesia fly ashes.

- For the ADVOCATE prepared from the Upper Silesia fly ash, sorbent reactivity increased with increasing ground fly ash content.
- ADVOCATE sorbent reactivity increased with increasing slurry time from 3 to 6 h.
- The dissolution rate of ground fly ash from Upper Silesia increased with decreasing ground fly ash content.
- The dissolution rate of ground fly ashes correlates well to a shrinking core model.

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OTHER

Session C6

DRYING GRAIN USING A HYDROTHERMALLY TREATED LIQUID LIGNITE FUEL

Zarko Bukurov
Petar Cvijanovic
Masa Bukurov

University of Novi Sad
Faculty of Technical Sciences
Novi Sad, Yugoslavia

Blažo R. Ljubičić, Research Engineer

Energy & Environmental Research Center
University of North Dakota
Grand Forks, North Dakota, USA

ABSTRACT

A shortage of domestic oil and natural gas resources in Yugoslavia, particularly for agricultural and industrial purposes, has motivated the authors to explore the possibility of using liquid lignite as an alternate fuel for drying grain. This paper presents a technical and economic assessment of the possibility of retrofitting grain-drying plants currently fueled by oil or natural gas to liquid lignite fuel. All estimates are based on lignite taken from the Kovin deposit. Proposed technology includes underwater mining techniques, aqueous ash removal, hydrothermal processing, solids concentration, pipeline transport up to 120 km, and liquid lignite direct combustion. For the characterization of Kovin lignite, standard ASTM procedures were used: proximate, ultimate, ash, heating value, and rheological analyses were performed. Results from an extensive economic analysis indicate a delivered cost of US\$20/ton for the liquid lignite. For the 70 of the grain-drying plants in the province of Vojvodina, this would mean a total yearly saving of about US\$2,500,000. The advantages of this concept are obvious: easy to transport and store, nonflammable, nonexplosive, nontoxic, 30%–40% cheaper than imported oil and gas, domestic fuel is at hand. The authors believe that liquid lignite, rather than an alternative, is becoming more and more an imperative.

INTRODUCTION

Much has been written during the past years regarding the impending problem of feeding the expected increase in world population, although this is hard to visualize with the so-called surplus of agriculture products on hand. Various methods of preserving or increasing the usable economic life of grain are used. For a long time drying has not been considered as an emergency measure, but rather part of a normal farm production. Even though there may be a surplus of some farm crops in Yugoslavia, government programs have encouraged drying and storing. Throughout the agriculture and processing industries, there are many and varied requirements for thermal drying, and it is very important to optimize energy consumption related to harvesting, transporting, and processing of grain. To assist manufacturers in arriving at a reasonably accurate assessment of drying economics, this paper describes the most promising oil-alternative type of fuel and gives an indication of total potential savings for the province of Vojvodina. The cost of drying systems varies with the type of drying equipment, energy, and other prices, so actual values will not be included here. Generally, the less supplementary heat required, the less expensive the system will be; however, drying will be slower. Several items must be considered in calculating the cost of drying. This would include ownership costs such as interests, depreciation, and insurance and operating expenses such as fuel and electricity. The labor required and the amount of

grain to be dried are also important factors to be considered. In this study only cost of fuel will be discussed.

CURRENT STATUS

It generally is necessary to employ thermal methods of drying in order to reach what is termed "commercial dry grain" condition. As a result, drying is an important part of most food-processing industries and accounts for a significant proportion of total fuel consumption in Yugoslavia. The uncertainty of fuel costs, future availability, and possible supply limitations highlight the continued need to actively engage in the development of new fuel forms.

In Yugoslavia, insufficient quantities of domestic oil and gas and a permanent lack of hard currency for import, especially for agricultural purposes, offer an opportunity for the application of hydrothermal liquid lignite fuel. Liquid lignite has one-third the heating value of natural gas or heavy oil. However, it can be considered a liquid fuel with the same usage and handling characteristics as heavy oil and gas, requiring minimal changes to existing furnaces. During the combustion of liquid lignite, a lower temperature (1100°–1200°C) is reached in the combustion chamber; however, the lower temperature does not have a significantly adverse effect for applications in drying facilities, greenhouses, dehydrating plants, heat plants, and a great number of industrial furnaces.

PROJECT KOVIN

To meet growing energy demands in the province of Vojvodina, Yugoslavia, plans were prepared to mine the lignitic coal deposit along the Danube River. As a consequence, Project Kovin was implemented to produce 5.5 million tons/year of raw coal with a stripping ratio of 4.2 cubic meters per ton of coal. Because of the proximity of the river, open strip mining techniques or conventional mining would have to operate under complex geological and hydrological conditions, making the mining difficult and economically questionable. Therefore, plans were implemented to use underwater mining that uses dredgers and hydraulic transport of the coal and overburden. The underwater mining takes advantage of the natural conditions surrounding the deposit. Core samples were collected from a nearby trial dredging area and used to establish computer maps of the coal region for the full-scale dredging operation. The coal deposit is a lignite with a heating value of approximately 6000 Btu/lb. The main coal seam is about 8 meters thick with about 20 meters of overburden, and the second seam is between 30 and 40 meters below the surface, with the maximum mining depth estimated to be 65 meters.

The dredging method produces a coal slurry containing 85% to 90% water. Plans included draining the water from the coal, drying, and then burning it in the conventional coal plant. In looking for alternative ways to utilize the "wet coal" in a more efficient and economical way, a consortium of Yugoslavian companies entered into a technological agreement with the Energy & Environmental Research Center (EERC) to facilitate the conversion of the dredged lignite into a lignite-water fuel (LWF) using hot-water-drying (HWD) technology. HWD is a high-temperature, nonevaporative drying technique carried out at high pressure in water to permanently alter the structure of low-rank coals. Changes effected by the drying process include the irreversible removal of moisture, micropore sealing by tar, and enhancement of heating value by the removal of oxygen, enhancing the coal's ability to make a water slurry.

HOT-WATER DRYING

The specific objective of this agreement was to evaluate the application of physical cleaning and HWD on dredged Yugoslavian lignite. Two samples were received from the Danube dredging test area for bench-scale testing using EERC equipment. Physical cleaning results on one sample indicated a 51 wt% reduction in ash content with a 76 wt% yield and enhanced flow behavior. Combustion studies were then performed on the raw and physically cleaned samples. The results indicated that both samples

were very reactive, making them excellent candidates for HWD. Bench-scale HWD results indicated that energy densities increased by over 60%, when raw lignite slurries were compared to LWF. Figure 1 summarizes the results from the testing by reporting apparent viscosity versus solids content for the raw slurry and LWF and energy densities at 500 cP.

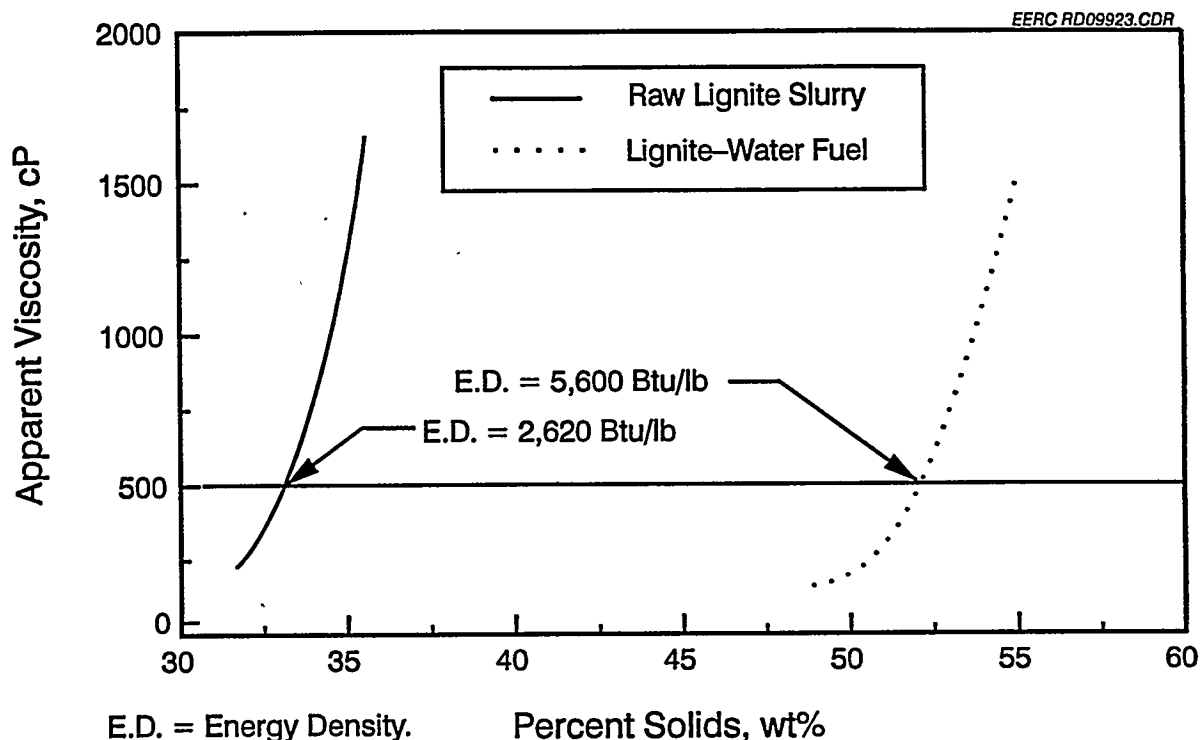


Figure 1. Rheological results for raw lignite slurry and HWD lignite-water fuel.

RHEOLOGICAL CHARACTERISTICS OF LIQUID LIGNITE

Liquid lignite is non-Newtonian, pseudoplastic, and thixotropic, with a lower heating value of 12 MJ/kg. The equation describing LWF rheological behavior may be written as

$$\tau_{(dv/dy,c)} = \tau_{o(c)} + K_{(c)} \left(\frac{dv}{dy} \right)^{n(c)} \quad [\text{Eq. 1}]$$

Figure 2 gives a three-dimensional rheological diagram of Kovin liquid lignite for various concentrations (c%). It indicates the possibility of pipeline transport with relatively small pressure drops in laminar fluid flow. This expressed by an energy equation in the form

$$2 \frac{v}{d} = \frac{\left(\frac{1}{k} \right)^{\frac{1}{n}}}{\left(D \frac{\Delta p}{4L} \right)^3} \left(D \frac{\Delta p}{4L} - \tau_0 \right)^{\frac{1+n}{n}} \left[\frac{\left(D \frac{\Delta p}{4L} - \tau_0 \right)^2}{\frac{1+3n}{n}} + \frac{2\tau_0 \left(D \frac{\Delta p}{4L} - \tau_0 \right)^2}{\frac{1+2n}{n}} + \frac{\tau_0^2}{\frac{1+n}{n}} \right] \quad [\text{Eq. 2}]$$

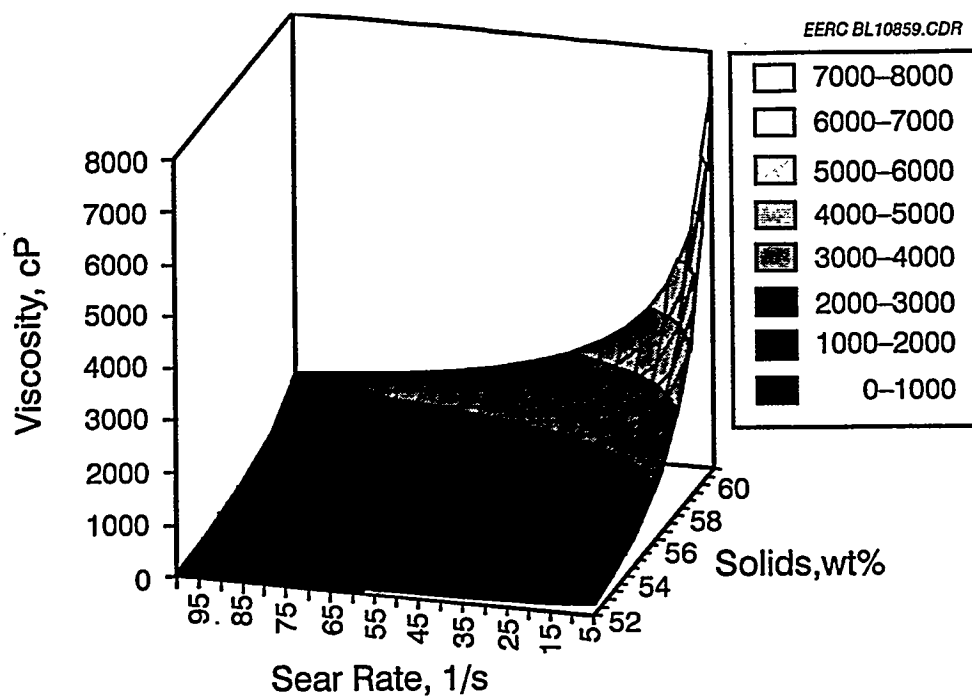


Figure 2. HWD Kovin, enhanced, shear rate-shear stress vs. solids loading.

The value for D_p/L is obtained from the computer program "Slurry Pipeline Designer" (Ljubičić, Trostad, 1992) that can be used for other non-Newtonian fluids given by the Yield Power Law. A three dimensional diagram in Figure 3 shows pressure drop as a function of slurry concentration and pipeline diameter for Kovin liquid lignite.

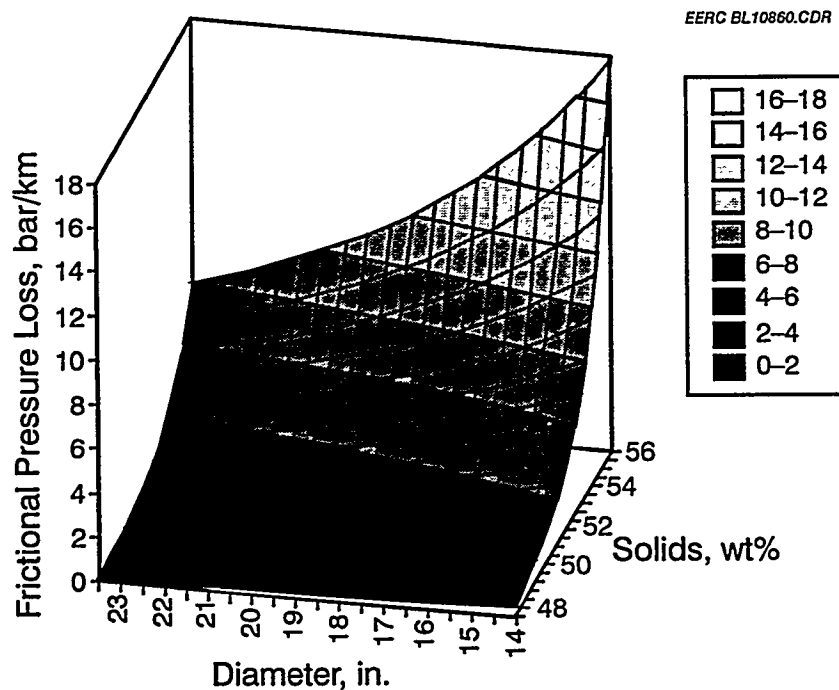


Figure 3. HWD sheared Kovin frictional pressure loss range.

LIQUID LIGNITE APPLICATION POSSIBILITIES IN DRYING CHAMBERS

Development of a new energy supply system using low-rank coals has progressed to the point of indicating that production of a new fuel in form of liquid lignite is technically feasible. The process is particularly close to economic viability in situations such as in Yugoslavia, where government programs are directed toward reducing the country's dependence on imported oil or gas. The nearness of LWF technology to economic feasibility emphasizes the need to consider carefully all the risks and benefits, refining the concept appropriately. As LWF systems become more fully developed and integrated, it is likely that they will become competitive with conventional oil or gas systems.

There are about 120 grain-drying facilities in Vojvodina. Almost 42% use direct and about 52% use indirect or combined methods to heat air for drying. Because of unavoidable sulfur separation during liquid lignite combustion, use of this fuel is recommended only for indirect or combined heating. This means that about 70 drying chambers in Vojvodina could use liquid lignite as a fuel.

It is estimated that these 70 drying facilities could dry about 700,000 t of corn per year, from 32% relative moisture to equilibrium moisture of 14%. The same capacity would be available for other cereals (wheat, sunflower, soy beans) that have an average relative moisture of 16% and equilibrium moisture of 13%. For these reductions in relative moisture, it is necessary to evaporate about 150,000 t of water. A great number of drying facilities (90%) use one pass of drying air. Their expected service life is over 10 years. The combustion temperature of liquid lignite is lower (1100°–200°C) than the temperature for natural gas or heavy oil (1900°C). Taking all of this into account, it can be estimated that the average consumed specific heat is 8.5 MJ/kg of evaporated water. According to these values, the necessary quantity of thermal energy is about 1275 TJ. With a liquid lignite heating value of 12 MJ/kg, the 70 drying facilities in Vojvodina would require about 100,000 t of CWF for one drying season. It is necessary to emphasize that minimal adjustment to combustion chambers and burners is required. Liquid lignite particles are small (80 μ m) and are covered with bituminous film, which enables quick and total combustion (combustion rate is 99 %). Unlike other liquid fuels, LWF has considerably higher noncombustible content, (coal inorganic matter and water), and lower per pound heating value than does oil or gas. Thus, using LWF in dryers designed for premium fuel will require some degree of derating in order to avoid serious reduction in combustion efficiency. Derating may be caused by several factors. Three major factors for derating are:

- Residence time for carbon burnout when using LWF could be too short, therefore decreasing firing capacity.
- More time may be needed for combustion products (ash particles) to cool prior to entering the dryer heat-exchange section in order to reduce fouling.
- At rated capacity using LWF, the flue gas velocity in the heat-exchange section may be so high as to cause erosion or inefficient transfer of air and therefore decreased firing rate.

The LWF demonstration projects operated at various loads showed derating anywhere from 50% (Swedish commercial projects) to almost 0% (no derating, as in Charlottetown, Canada, and coal-fired Japanese Nakaso No. 8 units). All aspects related to coal rank, composition, and properties must be evaluated prior to actual implementation of the conversion of the unit to fire LWF. These include LWF properties and composition, dryer type, size, and design specification and operating conditions.

COST ESTIMATE FOR LIQUID LIGNITE

There is an economy of scale in the production of liquid fuel from low-rank coals. The availability of large quantities of lignite in Yugoslavia is not an issue, but quality of feedstock can affect the economics of the conversion process. Further pilot-scale testing is needed to predict adequately the economics of HWD using Kovin reserves. Environmental constraints are not thought to be significant, though more data

are needed on emission control. The only significant constraint to the large-scale commercialization of liquid lignite is the extensive new infrastructure required to store and distribute LWF. A combination of research and development and policy change is needed to assure that liquid fuel from lignite becomes a viable technology.

The average price of liquid lignite includes the following:

- Price of raw lignite from underwater mine, about 5.3 DEM/t
- Price of liquid lignite production, based on an output of 3Mt/yr, about 18 DEM/t
- Price of pipeline transportation (without storage and manipulation costs) for up to 2 Mt/year and 100 km of pipeline, about 6.8 DEM/t

According to general feasibility studies and calculations, the total yearly cost of liquid lignite (including transport up to 100 km) for up to 2 Mt/yr is 30.1 DEM/t, which means 3,000,000 DEM for 70 grain-drying facilities in Vojvodina. Today it costs 7,000,000 DEM to dry the same amount of grain with natural gas or heavy oil. In summary, the economics involved in converting of grain dryers to use LWF are related to the cost of the fuel in current use, LWF cost, the extent of modification required for conversion, and the operating and maintenance associated with LWF firing.

CONCLUSIONS

Many characteristics of liquid lignite give it great promise as a new energy source. They include the advantages of underwater mining, with the possibility of liquid lignite production in a continuous process near the mine site, and easy, inexpensive transportation over fairly long distances (up to 600 km). With small amounts of ash and sufficient heating value and combustion chamber temperatures, liquid lignite can successfully meet the needs of indirect grain-drying facilities. From the environmental aspect, liquid lignite does not represent a pollution factor either in transport or in combustion. For the liquid lignite combustion process, it is possible to chemically clean raw lignite according to consumer requirements.

This preliminary study indicates that, given the per pound heating value of liquid lignite, it is possible to replace about one-third of the natural gas used in grain drying at about a 30%–40% lower cost. Because liquid lignite can be used in various agricultural applications (heating, greenhouses, etc.), an industrial-commercial liquid lignite production program is expected to receive strong professional and political support in Yugoslavia.

A number of factors must be considered to achieve a successful conversion to LWF of grain dryers design and for premium fuel. These factors include the coal type and composition, the need for beneficiation to minimize coal-ash content, and the need for fine-size coal particles combined with efficient atomizers to produce small LWF droplets. Most of the plants will require one or more of the following modifications to use LWF:

- Replacement of burner/atomizer
- Installation of ash removal equipment in the unit
- Installation of particulate removal system to clean the flue gases after combustion

The conversion to LWF will probably force derating of the premium fuel-fired grain dryers from existing design specifications. Also inclusion of some emission controls equipment is to be expected. The practicality of conversion, therefore, will be determined by load demand, tolerance of the unit to the mineral matter, and environmental control, all of which are associated with the utilization of coal-based fuels.

LIST OF SYMBOLS

$t(\text{Pa})$ - Shear stress of liquid lignite

$t_0(\text{Pa})$ - Initial shear stress

$dv/dy \text{ (s}^{-1}\text{)}$ - Velocity gradient

K - Consistency coefficient

n - Exponent

c - Mass concentration (ms /mv)

$k(m)$ - Maximal pipe roughness

$D_p(\text{Pa})$ - Laminar friction pressure drop

$L(m)$ - Pipe length

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ROLE OF FUEL UPGRADING FOR INDUSTRY AND RESIDENTIAL HEATING

Norman W. Merriam

Western Research Institute
Laramie, Wyoming, USA

Robert H. Gentile

KFx Atlantic Partners
Arlington, Virginia, USA

ABSTRACT

The Koppelman Series C Process is presently being used in pilot plant tests with Wyoming coal to upgrade the Powder River Basin coal containing 30 wt% moisture and having a heating value of 8100 Btu/lb to a product containing less than 1 wt% moisture and having a heating value of 12,200 Btu/lb.

In the Series C Process coal is charged into the heated processor tubes at ambient pressure, the reactor valves are closed, and the reactor is then pressured to about 120 psig using nitrogen. The tubes, which are designed to optimize heat transfer, are heated by a flow of hot heat transfer fluid. As the coal in the tubes is heated, moisture is driven from the coal and the pressure increases. Condensate and gas are vented from the bottom of the processor at a rate determined to control the pressure in the processor. When the preselected time, pressure, and temperature are reached within the processor the rate of venting is increased to depressure the tubes. After the pressure has decreased to less than 5 psig the bottom valves are opened and the product is discharged from the processor into a holding bin for cooling.

The analyses of the products from tests using heat transfer fluid at temperatures from 500 to 740°F show increasing heating value from 11,868 Btu/lb at 500°F to over 12,600 Btu/lb at 740°F. The oxygen content of the product decreases from 13.3 wt% oxygen at 500°F to 8.3 wt% at 740°F. This temperature range brackets the target values of 12,100 to 12,200 Btu/lb and 7 to 10 wt% oxygen set for the product before the tests were conducted.

Our preliminary evaluation of the temperature data from tests CSER-7 and CSER-14 indicates several temperature patterns within the processor during these tests. The first part of the tests is characterized by high temperature differentials between the heat transfer fluid and the coal and high heat transfer rates. The second portion of the tests is characterized by rapidly rising pressure in the processor and convergence of temperatures to the saturation temperature of steam at the pressure in the processor. The final portion of the tests is characterized by temperatures rising above the saturation temperature beginning with temperatures in the upper portion of the processor and heating sequentially until the temperatures in the lower portion of the processor increase to approach the temperature of the heat transfer fluid.

CLEAN COAL TECHNOLOGY VERSUS NATURAL GAS

Many cities and villages of central and eastern Europe are plagued by pollution from coal-burning stoves, furnaces, and small boilers. The challenge for these cities and villages is to find cost-effective means of providing heat and energy to their residents, businesses, and institutions while bringing under control the rampant pollution that has burdened these areas for decades and even centuries.

The U.S. Department of Energy recently completed a three-year, comprehensive study of the trade-offs of costs and emissions for the city of Krakow Poland. Krakow is one of those many cities troubled by coal-fired, low-level emissions. As a result of the study, Krakow found they could control 90% of their particulate emissions for a mere 11% increase in annual heating costs by deploying a variety of low-cost, coal-based technologies. Although converting to natural gas could result in a more significant 99% reduction in emissions, the cost of that conversion would be a 106% increase in annual costs.

All decision-makers in the region are facing tough environmental problems with limited financial resources. This is the dilemma of "sustainable development"; ameliorating and protecting the environment while assuring growth and sustainability of the economy. The work in Krakow has shown us that the analysis for the decision-making process must include the annualized long-term, life-cycle costs of indigenous versus imported fuels in addition to short-term, capital (equipment) costs. The costs of these decisions will greatly impact the local economy. Only if both the environment and the economy are protected will sustainable development occur.

KFx Atlantic Partners is one of those companies that offers a low-cost, coal-based solution to the environmental problems of the region.

KFx Inc. is a technology company that has developed and controls worldwide patents to the K-Fuel technologies which are expected to play a vital role in facilitating the compliance in the United States with the Clean Air Act of 1990. The technologies are also expected to play very significant roles in other countries with indigenous low-rank coal resources, such as the Czech Republic, where the challenge is to use those resources in an economic and environmentally acceptable manner. KFx operates internationally under the names KFx International and KFx Atlantic Partners.

Approximately \$50 million and ten years have been spent developing these patented processes. The technologies transform high-moisture, low-heat value coal and other carbonaceous feedstocks into a lower-moisture, higher-heat value solid fuel, which can be custom designed to meet the end user requirements.

There are currently two principal series of the technology which can produce equivalent products. The first is the steam-based Series B technology which will be used at the large commercial facility to be constructed by Heartland Fuels Corporation, a holding of the American utility, Wisconsin Power and Light. This technology will be deployed in conjunction with the Thermochem Gasifier under the auspices of the U.S. Department of Energy's Clean Coal Program. The second technology is the Series C technology which we will discuss here in greater detail.

In the United States, the Clean Air Act of 1990 provides the impetus for large-scale fuel switching by utilities. Initially, the K-Fuel will be used in cyclone and stoker furnaces which were designed to use high-sulfur, low-ash fusion temperature bituminous coal. The modification costs that a utility will need to expend to accommodate the switch to K-Fuel are minimal, whereas modification costs to scrub emissions or to retrofit the plants for the burning of oil and gas are substantial. In the United States, K-Fuel will be a competitive option because it will produce an efficient fuel product geared specifically to meet SO₂ and NO_x compliance standards at a relatively low cost.

Much like in the United States, the Czech Clean Air Act and the environmental laws of other countries in the region will have dramatic impact on the deployment of clean fuel, combustion and emission control technologies.

PROCESSING LOW-RANK COALS

The seeds for development of the K-Fuel technology were planted in the United States in the late 1970s and the early 1980s after the energy shortages of the early 1970s led American energy producers

to develop the huge deposits of low-sulfur coal in the Powder River Basin (PRB) in the Western United States.

PRB coal is a subbituminous C coal containing about 30 wt % moisture and having heating values of about 18.6 MJ/kg (8150 Btu/lb). PRB coal contains from 0.3 to 0.5 wt % sulfur, which is nearly all combined with the organic matrix in the coal, and is in much demand for boiler fuel because of the low-sulfur content and the low price. However, the low-heating value of PRB coal limits the markets for the coal to boilers specially designed for burning the high-moisture coal. Thus, the advantages of the low-sulfur content are not fully available to many potential customers having boilers which were designed for bituminous coal.

Each year about 200 million tons of coal is shipped from the Powder River Basin of Wyoming. The high-moisture content and, consequently, the low-heating value of this coal causes the transportation and combustion of the coal to be inefficient. When this coal is processed to remove the moisture and increase the heating value the same bundle of energy can be shipped by using one-third less train loads. Also, the dried product can be burned much more efficiently in large and small boiler systems. This increase in efficiency reduces the carbon dioxide emissions from combustion of the coal.

Also, the processing used to remove water and restructure the coal removes sulfur, nitrogen, mercury, and chlorides from the coal. This precombustion cleaning is much less costly than postcombustion stack scrubbing.

PRB coal, and other low-rank coals, tend to be highly reactive when freshly mined. These reactive coals must be mixed regularly (every week or two) when fresh, but become somewhat more stable after they have aged for several weeks. PRB coal is relatively dusty and subject to self-ignition compared to bituminous coals. PRB coal dried using conventional technology is even more dusty and more susceptible to spontaneous combustion than the raw coal. Also, PRB coal if dried at low temperature typically re-adsorbs about two-thirds of the moisture removed by drying. This re-adsorption of moisture releases the heat of adsorption of the water which is a major cause of self-heating of low-rank coals at low temperature.

Ingram and Rimstidt¹ attribute increased moisture in naturally oxidized coals to the effects of weathering and an increase in organic acids, which are known to attract water to coal particles. Thus, an effective drying process must destroy or remove carboxylic acids and phenolic-like compounds to prevent re-adsorption of moisture.

The University of North Dakota Energy Research Center has explored the use of various techniques to upgrade low-rank coals². They found that coals processed at low temperature re-adsorb moisture after cooling and return to essentially the original equilibrium moisture level. In contrast, they found that the processes using temperatures high enough to alter the structure of the coal particles resulted in reduced re-adsorption of moisture. They also concluded that the lowered equilibrium moisture levels resulted from the rejection of carbon dioxide by the decarboxylation reactions which occur during high-temperature processing.

The re-adsorption of moisture by coals dried at temperatures much lower than about 260°C (500°F) is consistent with Western Research Institute experience³.

DEVELOPMENT OF K-FUEL TECHNOLOGY

Mr. Edward Koppelman has developed technologies for over 50 years. All U.S. aircraft used during World War II used deicing and defogging equipment developed and produced by his organization. He has developed three-dimensional weaving techniques for fiber glass used to reinforce complex-shaped military components; antenna systems used on aircraft; the technology used to produce perlite insulation;

and has patented processes used to dry wood under vacuum using radio frequency heating. Mr. Koppelman has also developed processes to recover furfural, carbon black, activated carbon, and sodium silicate from rice hulls and his activities have included exploration and production of oil and gas, and mining uranium.

Mr. Koppelman has worked to develop processes which produce clean-burning, high-value fuel from low-rank coals, wood waste materials, and biomass products for over 20 years. Early development work was conducted at the Stanford Research Institute (SRI) in Palo Alto, California. His work at SRI led to the development of numerous processes and many patents were awarded for these processes. The predecessor company of KFx Inc. was started in 1984 to further the development of the Series A Process developed by Mr. Koppelman at SRI.

In 1986 the Series A process pilot plant was relocated to the present site located near Gillette, Wyoming to develop the huge resource of low-rank PRB coal. Since that time KFx Inc. has developed and tested processes to upgrade PRB coal at the site. In the early 1990s Koppelman's Series B Process was tested at the same site. After successful testing, the technology for the Series B Process, in which coal is heated by direct contact with steam at high pressure, was licensed to Heartland Fuels Corporation.

This development work, combined with Koppelman's long experience, has resulted in the Series C Process which is based upon the following principles:

- Nearly all of the moisture is removed in an efficient manner
- Decarboxylation is caused to remove much of the oxygen
- Particles are restructured and shrink during processing
- Sulfur content of sulfur-bearing coals is reduced

The above process concepts require that coal be heated to the range of 325 to 475°C (600 to 900°F) under pressure to confine condensable volatiles within the particles, and that gases and condensate be removed during the processing. The use of pressure combined with careful control of temperature causes nearly all of the energy content of the feed coal to be retained in the process while creating a high-calorific value product.

Economic constraints make the process low-cost and efficient. The Series C Process avoids moving coal into or from high pressure. Condensing steam, formed from moisture in the coal, causes efficient heat transfer and uniform heating of particles.

Koppelman has conducted bench-scale tests using the Series C Process to show that subbituminous Powder River Basin (PRB) coal can be converted to a higher-value product having the characteristics of a low-sulfur bituminous coal. In the process, PRB coal (Table 1) having a heating value of 19.5 MJ/kg (8367 Btu/lb) is upgraded to a higher-rank fuel having a heating value of about 28.8 MJ/kg (12,400 Btu/lb) by removing all of the moisture and by reducing the oxygen content of the coal from about 29 wt % (dry basis) to about 7 wt %. The sulfur content of the low-sulfur PRB coal is further reduced in the process resulting in a product containing about 0.56 lb of SO₂/million Btu (Table 2).

The successful conclusion of the bench-scale tests resulted in the need to construct and operate larger-scale test facilities.

TABLE 1

Analyses of Coal Used for the Bench-Scale Tests, wt%

Proximate Analysis			Ultimate Analysis		
	As Received	Dry		As Received	Dry
Moisture	28.91	—	Moisture	28.91	—
Ash	4.81	6.76	Carbon	42.26	59.45
Volatile	32.17	45.25	Hydrogen	1.98	2.79
Fixed C	34.11	47.99	Nitrogen	1.12	1.57
Total	100.0	100.0	Sulfur	0.26	0.37
			Ash	4.81	6.76
			Oxygen	20.66	29.06
Heating Value, MJ/kg	19.5	27.4	Total	100.00	100.00
Sulfur	0.26	0.37			
MAF Calorific Value, MJ/kg		29.4	Moisture is not included in the hydrogen and oxygen values		
lb SO ₂ per million Btu = 0.63					

TABLE 2

Properties of Product Made from Bench-Scale Tests Using the Series C Process, wt %

Sample	Proximate Analyses			
	4FT87	4FT89	4FT91	4FT92
Moisture	0.00	0.00	0.00	0.00
Ash	7.41	7.56	7.40	7.75
Volatiles	39.67	36.58	38.68	37.90
Fixed C	52.92	55.86	53.92	54.35
Total	100.00	100.00	100.00	100.00
Heating Value, MJ/kg	28.70	29.33	28.96	28.89
Sulfur	0.35	0.34	0.35	0.35
MAF Calorific Value, MJ/kg	30.99	31.73	31.27	31.32
lb SO ₂ per million Btu	0.57	0.54	0.56	0.56
	Ultimate Analyses			
	4FT87	4FT89	4FT91	4FT92
Moisture	0.00	0.00	0.00	0.00
Carbon	79.39	79.77	79.08	80.07
Hydrogen	3.46	3.41	3.47	3.60
Nitrogen	1.63	1.79	1.75	1.73
Sulfur	0.35	0.34	0.35	0.35
Ash	7.41	7.56	7.40	7.75
Oxygen	7.76	7.13	7.93	6.50
Total	100.00	100.00	100.00	100.00
Moisture is not included in the hydrogen and oxygen				

OBJECTIVE OF DEMONSTRATION PLANT TESTS

The objective of the tests described in this report is to demonstrate the Koppelman Series C Process in a 450 kg (1000 lb) capacity per batch demonstration plant by upgrading PRB coal to a high-Btu, low-sulfur, fuel. Our early efforts focused upon determining the time-temperature-pressure cycle required to alter the structure of the product to produce a stable, high-heating value, clean fuel from the pilot plant. We later conducted tests to evaluate the effects of varying particle size and have recently conducted tests to gather in-depth information for use in designing effluent water and gas treatment systems for a commercial-scale plant.

DESCRIPTION OF SERIES C DEMONSTRATION PLANT TESTS

The demonstration plant consists of coal feed and product discharge systems, a batch processor, a hot oil heating system, and effluent measurement and control systems (Figure 1). In the demonstration plant, crushed and sized coal from an enclosed bin is weighed and flows through a feed screw into a bucket elevator, where it is lifted into a feed bin located above the 13-meter (40-feet) high reactor system. The coal drains by gravity through an open valve into the top of the preheated reactor and fills the conical cavity below the reactor and the tubes within the reactor. The seats in the valve at the top of the reactor are cleaned by a blast of nitrogen gas, and the valve is then closed by a pneumatic operator. Air is swept from the processor by displacement using nitrogen gas and the pressure is then increased to about 8 atmospheres (atm) using nitrogen. The processor is heated by a flow of 25 liters per second (400 gpm) of heat transfer fluid, which is continuously circulated through a 1050 MJ (2 million Btu) per hour (net heat transferred) heater fired with propane. As the coal is heated by transfer of heat through the tubes, the

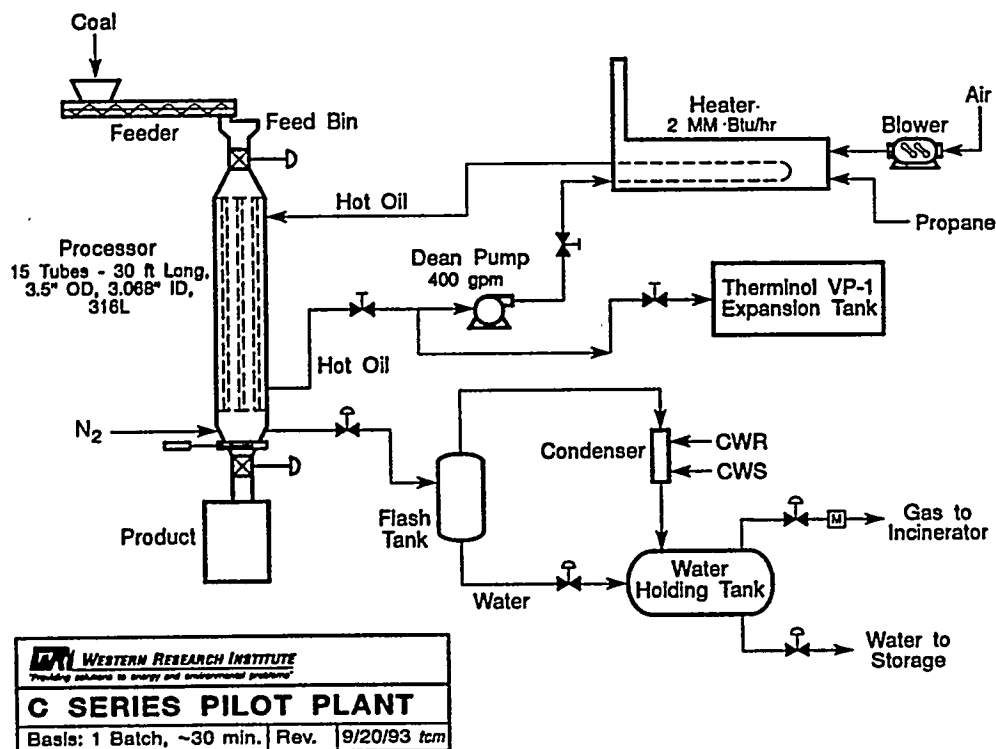


Figure 1. Simplified flow diagram of the Series C pilot plant.

water on the coal is evaporated to form steam which again condenses and heats more coal. The condensate from the moisture in the coal, after evaporating and condensing several times, is drained from the bottom of the processor. When the coal has been heated sufficiently to alter the structure and increase the heating value of the product, the reactor is depressured. When the pressure is less than 0.3 atm (5 psig) the valve at the bottom of the processor is opened. The product falls from the reactor into a nitrogen-blanketed product collection bin. The product is then transferred by a screw conveyor to a storage bin where it is held in a nitrogen atmosphere until it is cool enough to be exposed to air (about 120°C or 250°F). The product is then weighed, sampled, and held for evaluation.

Condensate drained from the processor is cooled by contact with cold water in a flash tank, filtered to remove coal dust and any coal tars released during processing, and transferred to a storage tank. The gas is vented from a gas-water separator, through a gas meter, and into the stack of the hot oil heater for incineration.

Temperatures within the processor are measured by four groups containing 24 thermocouples which are strategically placed within the coal bed. The temperatures of the feed coal, the product, the heat transfer fluid flowing into and out of the heater and into and out of the processor, as well as temperatures in the effluent gas and water lines are recorded. Pressures are recorded using pressure transducers located at the top and the bottom of the processor and in the flash tank. Pressures are also measured in the heat transfer fluid at the circulating pump suction and discharge, on both sides of the filter in the pump suction line, as well as in the cooling water system, the nitrogen system, and the propane supply system. Temperatures and pressures are recorded at preselected intervals using a computer-based data acquisition system. The timer, which controls the programmable logic controller, is used to establish a time-based series of data. The temperature and pressure readings are continuously visible upon a terminal located near the processor.

The rate of water and gas production are measured by instruments selected for those purposes. Samples of coal and product are analyzed following American Society for Testing and Materials procedures. Water samples are collected and analyzed following protocols established by the U.S. Environmental Protection Agency. Gas samples are analyzed using a gas chromatograph.

Characteristics of the Fort Union Coal Used for the Tests

The PRB feed coal used for the tests described in this report was taken from the Fort Union Mine which is located adjacent to the pilot plant northeast of Gillette, Wyoming. The coal was crushed and screened at the mine and was held in 2 ton capacity enclosed bins until used for testing. Typical size distributions of coal used for tests is shown in Table 3.

Typical composition of Western U.S. PRB coal from the Fort Union mine is shown in Table 4. The high-moisture content prevents the coal from being used in boilers designed for bituminous coal.

Design Conditions in the Processor

We selected the following product quality characteristics to produce a marketable product:

- Heating Value - 28.14-28.38 MJ/kg(12,100-12,200 Btu/lb)
- Yield - Approximately 64%
- Oxygen Content - 7 to 10 wt % (dry basis)

TABLE 3

Size Distribution of Fort Union Coal Used for
Demonstration Plant Tests, wt% retained

Test Number		CSER-4	CSER-5	CSER-27	CSER-28
Nominal Size Range, cm.		$\frac{1}{4}$ by $\frac{1}{2}$		$\frac{1}{4}$ by $\frac{3}{4}$	
Screen	Opening				
1.90 cm sq.	1.90 cm	0.0	0.0	0.0	0.0
1.27 cm sq.	1.27	0.1	0.0	0.3	0.6
0.94 cm sq.	0.94	9.6	12.6	9.0	9.4
0.64 cm sq.	0.64	55.9	57.8	47.9	48.2
No. 6 sq.	0.34	28.4	24.5	29.0	30.7
No. 8 sq.	0.24	2.5	1.9	4.5	4.3
No. 16 sq.	0.12	1.3	1.2	4.0	3.0
No. 50 sq.	0.03	0.96	0.9	2.7	1.8
Pan		1.2	1.1	2.7	2.1

TABLE 4

Composition of Wyoming PRB Coal Used for Tests, wt%

Test	Proximate Analyses			
	CSER-24	CSER-25	CSER-27	CSER-28
Moisture	30.4	30.7	32.2	32.0
Ash	5.9	5.8	5.3	5.5
Volatiles	33.8	35.2	32.6	32.8
Fixed C	29.8	28.3	29.9	29.7
Total	100.00	100.00	100.00	100.00
Heating Value, MJ/kg	18.95	18.93	18.55	18.53
Sulfur	0.36	0.35	0.31	0.31
MAF Calorific Value, Mj/kg	29.75	29.80	29.70	29.66
kg SO ₂ per gigajoule	0.39	0.38	0.30	0.34
lb SO ₂ per million Btu	0.90	0.88	0.78	0.79
	Ultimate Analyses			
	CSER-24	CSER-25	CSER-27	CSER-28
Moisture	30.4	30.7	32.2	32.0
Carbon	45.1	45.3	44.3	44.9
Hydrogen	2.4	2.5	2.5	2.5
Nitrogen	0.74	0.85	0.70	0.69
Sulfur	0.36	0.35	0.31	0.31
Ash	5.9	5.80	5.3	5.48
Oxygen	15.1	14.6	14.6	14.1
Total	100.00	100.00	100.00	100.00
Moisture is not included in the hydrogen and oxygen				

The bench-scale tests indicated that the product quality characteristics were most likely to be attained by using the following conditions in the processor:

- Initial Nitrogen Pressure - 8 atm (120 psig)
- Maximum Processing Pressure - less than 55 atm (800 psig)
- Heat Time (not including filling or discharge) - 25 minutes
- Initial Reactor Temperature (when loading) - less than 395°C (740°F)

Production Simulation Tests

At first, the coal would not flow into the top of the processor rapidly because gas being displaced from the processor was escaping through the same opening. A vent tube was installed into the bottom of the feed hopper, which permitted air to escape while rapidly loading the coal. No plugging of the processor occurred during this work. After test 11, a screen was added into the condensate vent opening which permitted faster draining of the condensate. The temperature of the heat transfer fluid entering the processor is the primary control variable (Table 5). We also controlled the heating time carefully. Our initial effort with the demonstration plant was to make the processor function mechanically and to determine the inlet temperature of the heat transfer fluid needed to control the product heating value in the range of 28.14 to 28.61 MJ/kg (12,100 to 12,300 Btu/lb). Later tests emphasized variations in pressure, feed coal particle size and heating time. An inspection of the processor after test 29 showed that the center tube was free of any accumulation of particles and the tube walls were shiny clean.

RESULTS OF TEST USING PRB COAL

Evaluation of Pressure and Temperatures in the Processor During a Typical Test (CSER-14)

Figure 2 shows the pressure in the processor, the temperature of saturated steam equivalent to the pressure (taken from steam tables), and the temperatures of coal in the tubes and in the chamber below the tubes. During the test the pressure rises quickly to about 8 atm(120 psig) as nitrogen is added. Pressure increases geometrically as the water and gas are driven from the coal and is then controlled at about 48 atm (700 psig) by venting gas and condensate from the processor.

The temperature of the coal corresponds to saturated steam temperature as the pressure rises to about 48 atm (700 psig). The presence of condensate during this period causes uniform heating throughout the processor. When the temperature exceeds about 260°C (500°F) the condensate becomes a heat sink and retards further temperature increase. Thus, control of the removal of condensate is important both for product quality and process thermal efficiency.

Figure 3 shows the large differential temperatures between the temperature of the hot oil and the coal early in the test. The differential temperature decreases as the coal is heated rapidly. Temperatures of the coal in the upper part of the processor increase first, followed by the temperatures in the middle, and finally the temperatures in the lower processor increase.

The product characteristics (Table 6) are controlled by the temperature of the heat transfer fluid entering the processor and the heating time (Figure 4). Also, the oxygen content of the product decreases as the processor is operated at higher temperatures. The PRB coal used for the tests described in this paper is a low-sulfur coal in which most of the sulfur exists in the form of organic compounds. The PRB coal contains very little pyrite. The removal of sulfur is increased by using more

TABLE 5

Conditions Used for Series C Pilot Plant Tests

Test	Coal Source	Size, inches	Hot Oil In, Temp., °F	Pressure, psig	Load Cycle-Press	Times, Heat	Minutes, Vent-Disch	Notes
CSER-1	Ft. Union	¼ by ½	500					No coal
CSER-2	Ft. Union	¼ by ½	500					Vent plugged
CSER-3	Ft. Union	¼ by ½	500	700				Feed hopper plugged
CSER-4	Ft. Union	¼ by ½	500	700	7	52	57	
CSER-5	Ft. Union	¼ by ½	550	700	6	41	24	
CSER-6	Ft. Union	¼ by ½	600	700	7	41	26	
CSER-7	Ft. Union	¼ by ½	600	700	6	41	29	
CSER-8	Ft. Union	¼ by ½	650	700	6	45	26	
CSER-9	Ft. Union	¼ by ½	650	700	6	40	36	
CSER-10	Ft. Union	¼ by ½	650	700	6	41	32	
CSER-11	Ft. Union	¼ by ½	650	700	6	31	21	Johnson screen in vent
CSER-12	Ft. Union	¼ by ½	700	700	6	28	10	Rupture disc failed
CSER-13	Ft. Union	¼ by ½	700	700	6	41	18	
CSER-14	Ft. Union	¼ by ½	740	700	6	41	15	
CSER-15	Ft. Union	¼ by ½	740	700	8	31	17	
CSER-16	Ft. Union	¼ by ½	740	700	8	24	15	
CSER-17	Ft. Union	¼ by ½	700	700	7	31	18	
CSER-18	Ft. Union	¼ by ½	700	700	6	25	17	
CSER-19	Ft. Union	¼ by ½	700	750	6	25	14	
CSER-20	Ft. Union	¼ by ½	700	800	6	22	4	Rupture disc failed
CSER-21	Ft. Union	¼ by ½	700	700	6	25	20	
CSER-22	Ft. Union	¼ by ½	700	700	6	25	23	
CSER-23	Ft. Union	¼ by ½	700	120	6	61	14	
CSER-24	Ft. Union	¼ by ½	740	50	7	60	8	Water with product
CSER-25	Ft. Union	¼ by ½	740	300	6	64	8	
CSER-26	Ft. Union	¼ by ¾	740	700	6	13	11	Rupture disc failed
CSER-27	Ft. Union	¼ by ¾	740	650	6	25	16	
CSER-28	Ft. Union	¼ by ¾	740	650	6	25	20	
CSER-29	Ft. Union	¼ by ¾	740	650	5	31	21	

severe processing conditions (Figure 5). The removal of sulfur in proportion to the weight of the gas and liquid byproducts is typical of organic sulfur compounds found in PRB coal⁴.

Table 6 is a summary of the analyses of the products from the Series C plant demonstration tests described in the previous section of this report.

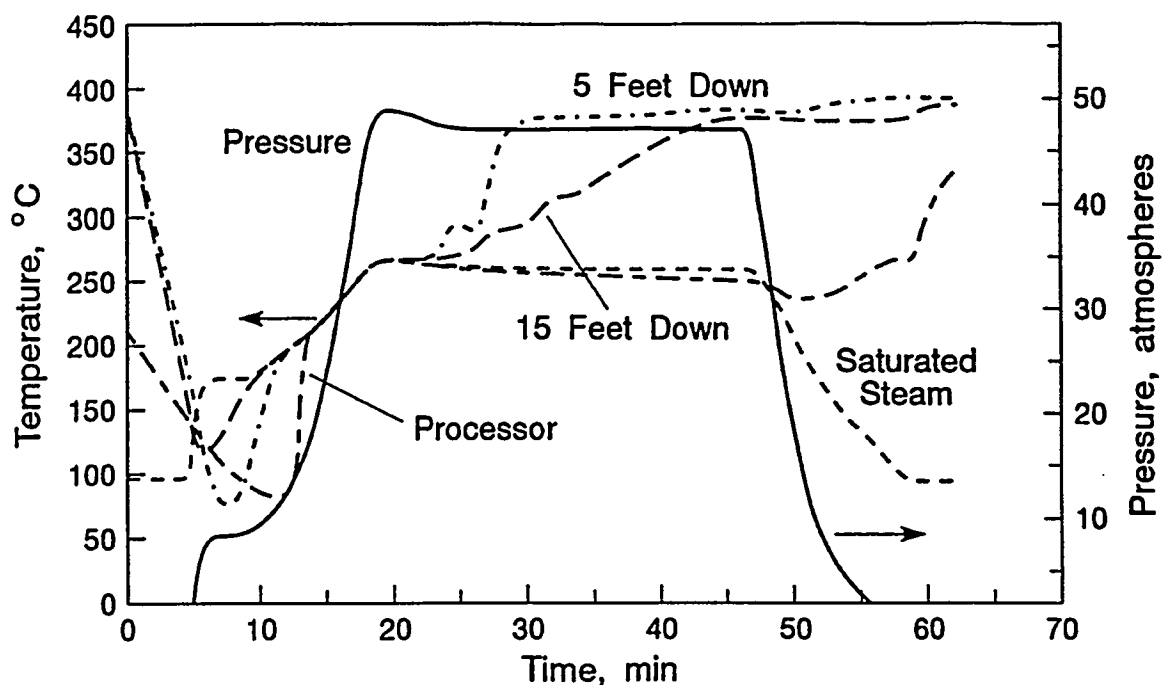


Figure 2. Pressure, saturated steam temperature, and temperature of coal at three locations in the processor during Test CSER-14.

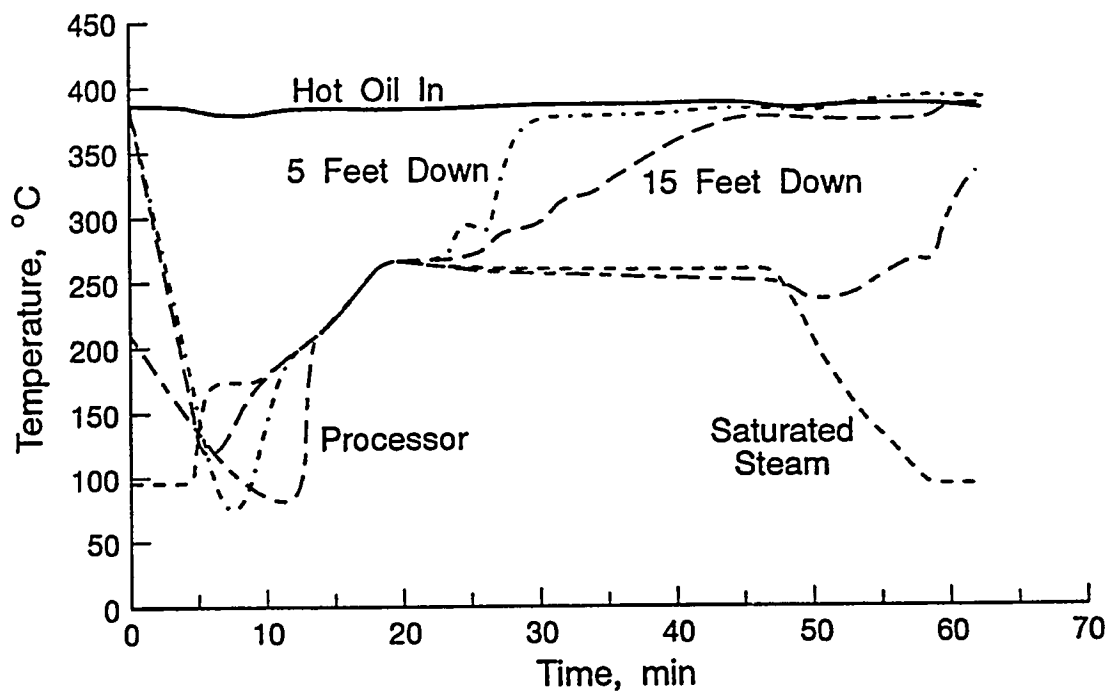


Figure 3. Temperatures of hot oil, saturated steam, and coal at three locations in the processor during Test CSER-14.

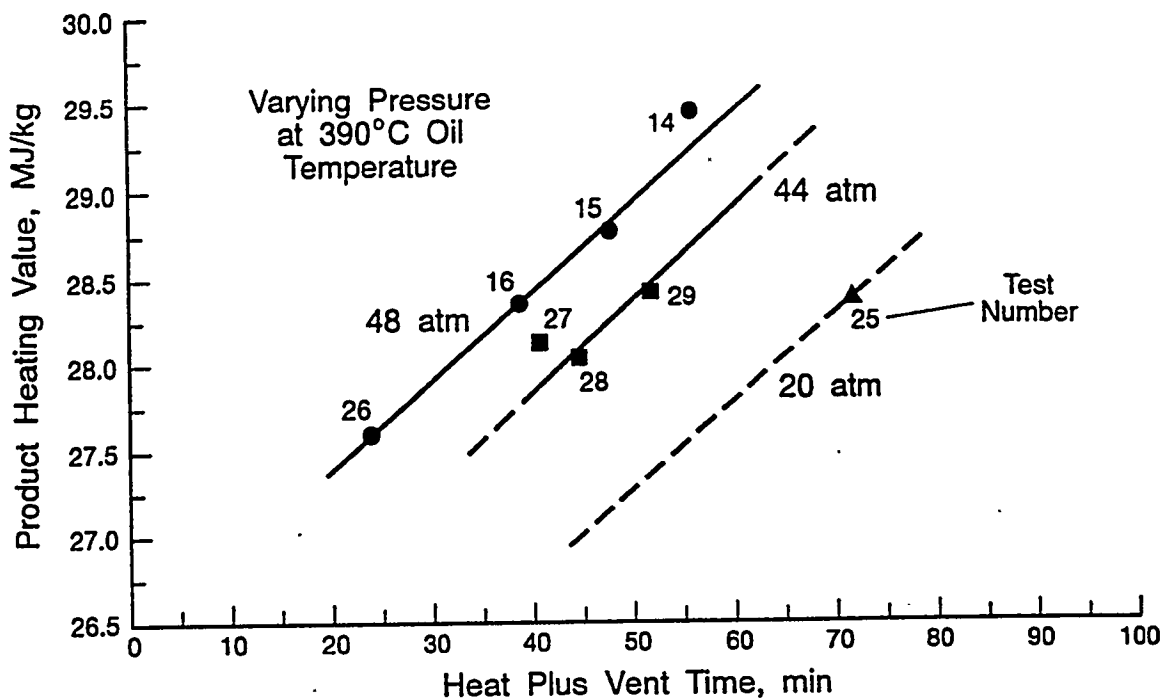


Figure 4. Use of time and temperature to control heating value.

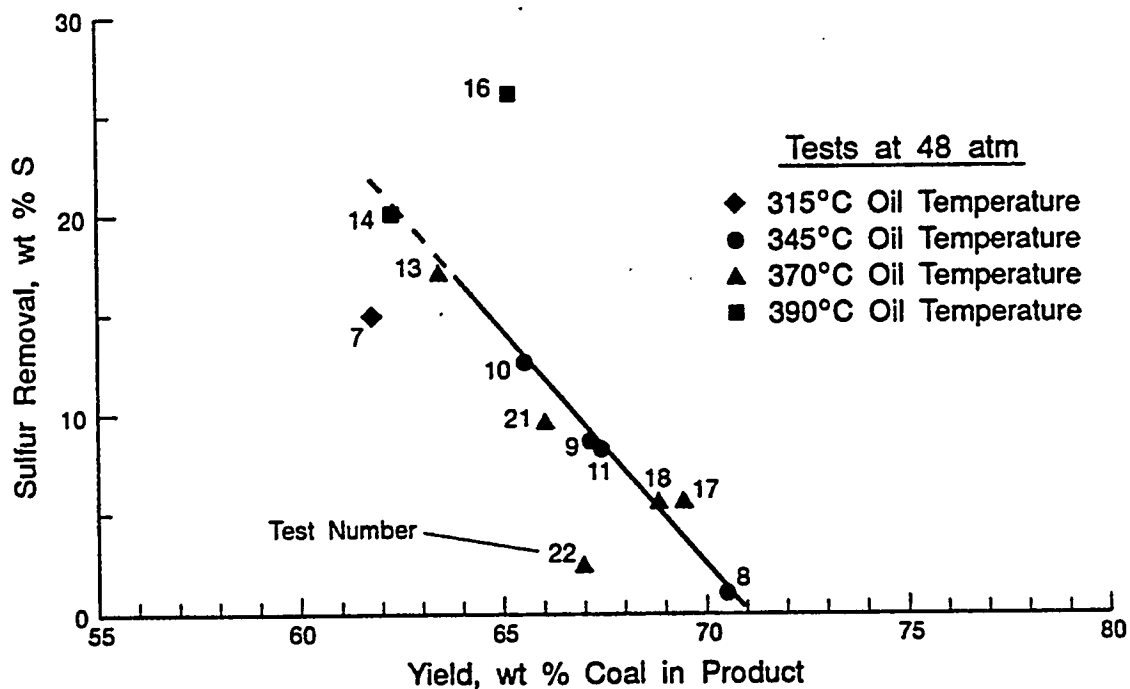


Figure 5. Sulfur removal from low-sulfur Powder River Basin coal.

TABLE 6

Composition of Products from Typical Demonstration Plant Tests, wt%

Test	Proximate Analyses			
	CSER-24	CSER-25	CSER-27	CSER-28
Moisture	1.4	0.310	0.40	1.5
Ash	7.8	8.9	8.9	8.0
Volatiles	44.5	42.3	43.6	44.6
Fixed C	46.4	48.6	47.2	45.9
Total	100.00	100.00	100.00	100.00
Heating Value, MJ/kg	27.97	28.39	28.13	28.04
Sulfur	0.48	0.46	0.47	0.45
MAF Calorific Value, MJ/kg	30.78	31.25	31.00	30.99
kg SO ₂ per gigajoule	0.34	0.33	0.33	0.30
lb SO ₂ per million Btu	0.80	0.76	0.77	0.75
	Ultimate Analyses			
Moisture	1.4	0.31	0.40	1.5
Carbon	70.1	72.0	70.6	69.4
Hydrogen	4.7	4.8	4.7	4.6
Nitrogen	1.1	1.1	1.1	1.0
Sulfur	0.48	0.46	0.47	0.45
Ash	7.8	8.9	8.9	8.0
Oxygen	14.5	12.5	14.0	15.1
Total	100.00	100.00	100.00	100.00
Moisture is not included in the hydrogen and oxygen				

CONCLUSIONS

An extensive series of tests has been conducted using the Koppelman Series C process in a demonstration plant located near Gillette, Wyoming, USA. The demonstration plant has been operated successfully, with no plugging experienced within the processor. We have used the temperature of the heat transfer fluid entering the processor and the heating time to control the heating value of the product within our target range of 28.14 to 28.61 MJ/kg (12,100 to 12,300 Btu/lb). The oxygen content of the product decreases as the heating value increases, resulting in a product containing from 13 to 8 wt % oxygen. We have removed up to 25 wt % of the sulfur from the low-sulfur PRB coal using conditions which were not selected to maximize sulfur removal.

Typical product yields can be varied from about 63 to 70 wt % of the feed coal depending upon the severity of the conditions used. The energy content of the product varies from about 96% of the heating value of the feed coal with a yield of 64 wt % to nearly 100% energy recovery with a yield of 67 wt %.

We are continuing to conduct tests to acquire design data for a commercial plant using the Koppelman Series C Process.

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REACTIVITY OF NORTH BOHEMIAN COALS IN COPROCESSING OF COAL/OIL MIXTURES

Gustav Šebor
Jaroslav Černý
Daniel Maxa
Josef Blažek

Department of Petroleum Technology and Petrochemistry
Institute of Chemical Technology
Prague, Czech Republic

Ivana Sýkorová

Institute of Rock Structure and Mechanics
Czech Academy of Sciences
Prague, Czech Republic

ABSTRACT

Autoclave experiments with North Bohemian coal were done in order to evaluate their reactivity in coprocessing with petroleum vacuum residue. Selected coals were comprehensively characterized by using a number of analytical methods. While the coals were of similar geological origin, some of their characteristics differed largely from one coal to another. Despite the differences in physical and chemical structure, the coals provided very similar yields of desired reaction products. The yields of a heavy non-distillable fraction and/or an insoluble solid residue were, under experimental conditions, largely affected by retrogressive reactions (coking). The insoluble solid fractions were examined microscopically under polarized light.

INTRODUCTION

For the coprocessing of coal/oil mixtures to produce liquid fuels, either bituminous or subbituminous coals and lignites can be used as a feedstock [1,2]. The choice of a suitable coal is usually limited by the regional circumstances and the coal availability. Attention has also been paid to the reactivity testing of the coals under consideration. Generally, the lower rank coals provide reaction products with a higher amount of light distillates [3]. Also the total coal conversion to liquid fuels is higher for lower rank coals. However, the hydrogen consumption is usually higher than for the coprocessing of bituminous coals due to the production of a higher amount of reaction water. Despite the general tendency, relatively large differences in conversion can usually be found among coals of similar rank. However, the differences in coal reactivity can be largely suppressed by using either a hydrogenation catalyst or more severe processing conditions.

In the Czech Republic, vacuum residue from West Siberian crude oil is at this time the only available petroleum feed for the coal/oil coprocessing. Among the Czech coals, subbituminous coals from the North Bohemian mines should be preferred.

This work is a part of the project, which is aimed at testing the Czech coals in the coal/oil coprocessing. Coal conversion and product yields were selected as a criterion for the coal reactivity assessment. Another goal of the project consists in the comparison of coal conversions and fundamental structural characteristics of the coals. Characterization and processing of a set of 11 North Bohemian

coals are considered to fulfil the project demands. For the research reasons, the coal set also includes some coals with a high ash content. Results of the characterization and coal/oil coprocessing experiments are presented in this paper for 5 coals.

EXPERIMENTAL

The coal/oil coprocessing experiments were performed in a 500-ml rotary autoclave at 440 °C under hydrogen atmosphere. Reaction pressure was 20 MPa and reaction time 1 h. The constant mass ratio of coal and residue of 26:74, daf basis, was maintained in the feed mixture. Under these reaction conditions, the highest yield of distillable products was obtained in preliminary experiments with the ČSA 92 coal [4]. Therefore, these reaction conditions were also used for coprocessing experiments with the other coals. A reference experiment was also performed with the petroleum residue alone.

Coals were milled before processing to less than 0.2 mm and dried under vacuum. Reaction products were distilled into three fractions, i.e., up to 185 °C (gasoline), 185-360 °C (light gas oil, LGO), and 360-500 °C (heavy gas oil, HGO). The distillation residue was fractionated into the fraction soluble in benzene and/or insoluble organic matter (IOM). The gas yield was obtained by difference.

Coals were characterized with proximate and ultimate analysis, microscopic examination, ¹³C CP MAS NMR and FTIR spectroscopy. Pore texture of coals was determined by using mercury porosimetry and CO₂ sorption isotherm. Coal extract ability was examined by using Soxhlet extractions with chloroform, tetrahydrofuran, and pyridine, respectively.

RESULTS AND DISCUSSION

Coal Characteristics

Coals used for experiments originated from North Bohemian mines, namely from the ČSA (samples ČSA 92 and ČSA 93), Nástup (samples Nástup and Libouš), and Šverma mines. Their proximate and ultimate analysis is given in Table 1.

TABLE 1

Ultimate and Proximate Analysis of Coals and Petroleum Residue (wt % daf)

Feedstock	C	H	S _o	N	O*	(H/C) _{at}	Ash (wt %)	Calorific value (MJ.kg ⁻¹)	Volatile matter
ČSA 92	71.1	5.3	2	0.9	20.7	0.89	21.8	29.4	48.8
ČSA 93	74.6	6.2	0.9	1	17.3	1.00	4.7	32.1	55.9
Nástup	70.2	4.9	1.2	1.8	21.9	0.84	8.6	28.0	50.5
Libouš	68	5.4	1.6	1.4	23.6	0.95	32.9	27.5	51.0
Šverma	71.5	5.9	0.9	1	20.7	0.99	15.7	30.0	46.8
Petroleum residue	84.5	10.4	3.7	0.5	0.9	1.48	0.06	-	-

* by difference

Table 2 presents pore texture characterization of the coals. Some remarkable differences can be found in the pore texture of coals. The ČSA 93 coal had an increased volume and surface of meso- and macropores, which in coal processing can serve as transport pores. The Nástup and Libouš coals had somewhat increased values of microporosity, and, in turn, the Nástup coal had a small volume of meso- and macropores.

TABLE 2

Pore texture characterization of coals (daf)						
Coal	V_{mm} (cm ³ .g ⁻¹)	V_{micro} (cm ³ .g ⁻¹)	S_{mm} (m ² .g ⁻¹)	S_{micro} (m ² .g ⁻¹)	Pr_{mm} (%)	Pr_{micro} (%)
ČSA 92	0.170	0.065	10.7	230	18.7	7.1
ČSA 93	0.222	0.051	21.6	180	25.3	5.9
Nástup	0.092	0.076	3.6	277	11.5	9.5
Libouš	0.166	0.072	9.6	260	20.7	9.1
Šverma	0.122	0.063	10.8	224	14.4	7.5

V_{mm} meso- and macropore volume
 V_{micro} micropore volume
 S_{mm} meso- and macropore surface
 S_{micro} micropore surface
 Pr_{mm} porosity based on meso- a macropores
 Pr_{micro} porosity based on micropores

The characterization parameters obtained from the microscopic and spectroscopic analysis are given in Table 3. The mean reflectance of huminite and aromaticity of coals did not show any remarkable variances in their values. Also the main maceral group content was very similar for each coal (not presented in Table 3). In turn, remarkable differences in aliphatic hydrogen content were assessed using FTIR spectroscopy. Whereas the aromatic hydrogen content remained almost constant for each coal (about 0.8-0.9 wt % daf), the amount of aliphatic hydrogen ranged from 2.4 to 5.6 wt % daf. However, the cumulative amount of aromatic and aliphatic hydrogen is, especially for the ČSA coals, very close to

TABLE 3

Microscopic and Spectroscopic Characterization of Coals					
Coal	R_o (%)	f_a	H_{al} (wt % daf)	H_{ar} (wt % daf)	H_{al}/H_{ar}
ČSA 92	0.38	0.53	4.3	0.9	4.7
ČSA 93	0.37	0.51	5.6	0.9	6.4
Nástup	0.33	0.57	2.4	0.8	2.9
Libouš	0.35	0.53	3.4	0.8	4.0
Šverma	0.36	0.50	4.3	0.8	5.3

R_o mean reflectance of huminite
 f_a aromaticity
 H_{al} amount of aliphatic hydrogen
 H_{ar} amount of aromatic hydrogen

the total hydrogen content, which also includes the hydroxyl hydrogen. This is due to the use of the average aliphatic absorptivity in the evaluation of the FTIR spectra [5]. A high amount of waxes and resins in some coals can cause an overestimation of the aliphatic hydrogen content, because the long methylene chains are known to have a strong signal in FTIR spectra. Despite this ambiguity in FTIR spectra evaluation, the differences in aliphatic hydrogen content are likely.

Table 4 presents the yields of solvent extracts for the coals. There are large differences in extract abilities of the coals with the respective solvents. A high extract ability of the ČSA 93 coal can be due to both a high porosity of the coal and an increased hydrogen content, which is a consequence of a high amount of easily extractable waxes and resins. An increased hydrogen content of the Šverma coal can also be associated with somewhat higher amount of extractable matter, especially for chloroform and tetrahydrofuran, than expected from the pore texture characteristics. On the other hand, the Nástup and Libouš coals provided small yields of the extract for each solvent.

TABLE 4

Extract Ability of Coal in Solvents (wt % daf)			
Coal	Chloroform	Tetrahydrofuran	Pyridine
ČSA 92	5.2	10.70	16.90
ČSA 93	8.6	13.10	25.00
Nástup	1.2	4.00	8.00
Libouš	1.9	5.00	9.70
Šverma	4.5	10.40	13.30

Coprocessing Experiments

Table 5 presents the coal content in the feed mixture and moisture in coals used for coprocessing. In Table 6, there are given the yields of individual fractions of the reaction products. It is evident that the coals yielded very similar amount of the respective product fractions. The highest yield of the gasoline fraction was found for the Šverma coal, and the smallest for the Libouš and Nástup coals. The latter coals provided, in turn, somewhat higher amount of LGO. The yields of gases were largely affected by the experimental errors as they were obtained by difference.

TABLE 5

Concentration of Coal in Coal/oil Mixtures and Moisture in Coals Used for Coprocessing

Coal	Coal concentration (wt %)	Coal concentration (wt % daf)	Moisture (wt %)
ČSA 92	31.6	26.1	2.1
ČSA 93	27.1	26.1	0.4
Nástup	28.3	26.1	2.1
Libouš	34.8	26.1	1.4
Šverma	29.7	26.1	0.8

TABLE 6

Yields of fractions from coprocessing products (wt % daf)						
Coal	Gases*	Gasoline	LGO	HGO	Vacuum residue	
					Benzene solubles	IOM
ČSA 92	17.7	16.2	16.6	12.7	5	29.4
ČSA 93	16.4	16.2	16.7	12.1	5.4	30.9
Nástup	19	15.8	19.2	11.1	5.9	26.2
Libouš	18.4	15.4	19	13.2	3.9	29.1
Šverma	15.3	17.6	17.5	11.2	5.4	30.5
Petroleum residue	13.2	16.9	20.6	17.2	19	12.9

* by difference

Coal conversions were determined on the basis of the yields of the individual fractions as a difference between the coprocessing experiment and the reference experiment with the petroleum residue alone, i.e., under the assumption of additive contributions of both feed mixture components to the product yield. The conversion to distillable products (up to 500 °C) and to oils were obtained, both including gases, and they are presented in Table 7.

TABLE 7

Coal Conversions		
Coal	Coal conversion (wt % daf)	
	Distillates	Benzene solubles
ČSA 92	50.4	17.4
ČSA 93	43.0	10.0
Nástup	57.0	26.0
Libouš	60.9	21.9
Šverma	43.5	10.3

It is evident that the conversions to benzene solubles are not reasonable, as they are lower than the conversions to distillable products. Similar results were also obtained in some recent papers [6-8], which present even negative coal conversions in coprocessing experiments at the corresponding yields of the respective fractions were in coprocessing experiments largely reduced to 11,1-13,2 wt %, daf, and 3,9-5,9 wt %, daf (Table 6). On the other hand, the yield of the IOM fraction was drastically increased from 12.9 wt %, daf, for the reference, to about 30 wt %, daf, for the coprocessing experiments. The experimental data clearly show that the yields of the coprocessing products were at 440 °C largely affected by interactions of the petroleum residue with coal, which led to an extensive coking of the coal/oil mixture.

Different nature of the IOM fractions originated from the reference and coprocessing experiments is well documented in Figs. 1 and 2 by microscopic examination under polarized light. Processing of the petroleum residue alone provided the IOM fraction with a well-developed mesophase mainly with a flow-



Figure 1. Mesophase texture of IOM from a reference experiment.

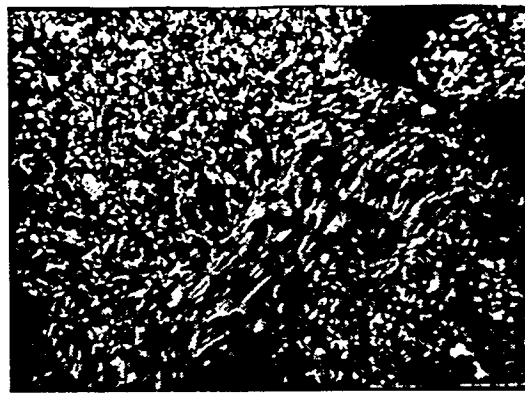


Figure 2. Mesophase texture of IOM from coprocessing of ČSA 92 coal.

domain anisotropy (Fig. 1). Typical character of the IOM fraction from coprocessing experiments is shown in Figure 2, which clearly shows the fine and medium grained mosaic texture of the mesophase. The much smaller mesophase grains of the IOM from coprocessing experiments are likely due to the presence of a higher amount of reactive centers and much faster growth of the mesophase. The increased amount of IOM after coprocessing of coal/oil mixtures due to the presence of coal particles was also observed by Schobert and Tomic, who found the reactive centers for mesophase formation at the coal surface [8,9].

CONCLUSION

The presence of coal in coal/oil mixtures leads to an extensive coking of the feed mixture at elevated temperatures, such as 440 °C. A large extent of retrogressive reactions also caused nearly uniform yields of coprocessing products and coal conversions, despite the coal examined showed relatively large variances in basic coal characteristics and properties.

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POSSIBILITIES OF PRODUCTION OF SMOKELESS FUEL VIA CARBONIZATION OF CZECH COALS

Jaroslav Buchtele
Pavel Straka

Institute of Rock Structure and Mechanics,
Academy of Sciences of the Czech Republic
Prague, Czech Republic

ABSTRACT

It was consumed 48 - 51 % of hard coal (total output 28 - 30 Mt/year) in a long period for the production of coke. It appears to be anomaly in comparison with other coke producers in Europe and in the world, it was predetermined by "steel conception" of state's economics. The production of coke reached 10–11 Mt/year in former Czechoslovakia in the period 1970–1990. A considerable quantity 1.2 - 1.7 Mt/year of produced coke was utilized for heating. In comparison, 7–5.4 Mt coke/year was it in Poland for the heating.

A1coke production is realized on the basis of Czech hard coals mined in the southern part of Upper Silesian Coal District. The coke production is operated in multi-chamber system with full recovery of chemical products (gas, raw tar, raw benzene, ammonium etc.). The future trend of smokeless fuel production in Czech Republic makes for to the non-recovery coke oven, it means to two-product processes (coke + reduction gas, coke + electricity and so on). Jewell–Thompson coke oven (hard coal) and Salem oven (lignites) represent nonrecovery nowadays. The possibility of its application in Czech Republic are discussed. Jumbo coking reactor system (European project No. 500 to the Eureka programme) produces primarily metallurgical coke. The strong Clean Air Act suspends the production of smokeless fuel in multi-chamber system also in Czech Republic for the future period 2010–2020.

PAPER

Smokeless fuels manufactured on the basis of brown and black coals exploited in the Czech republic have been made available in the local market more or less during the whole twentieth century. A solid fuel can be termed as smokeless, if it contaminates, while burning, the environment with much less dust and gaseous or liquid air polluting substances than the usual coal. It is evident, from Tab. 1, that the specific emissions of dust, SO_2 , NO_x , CO from fuel coke burning are much lower than those from brown or black coal burning. Emissions of organic substances do not practically occur when burning the fuel coke. The fuel coke has been a typical representative of smokeless fuels in the Czech market during the whole 20th century. The chemical composition and volatile matters in solid fuels predetermine, to the great deal, the quantity and composition of combustion products and thus also the emissions from the combustion process (Tab. 2).

Until the sixties, a typical smokeless fuel based on black coal in the Czech region has been the fuel coke from carbonization gasworks. Its production in vertical coke ovens culminated during 1953–1962, attaining 500 - 600 thousand tons annually (Tab. 3). The transfer from the gas provisionment of the Czech economy from carbonization gasworks towards imported natural gas and gas from brown coal conversion was the reason for the termination of production of gas coke (1970/1971). Already since the thirties and forties, a part of demands for the smokeless fuel has been substituted by metallurgical coke of small classes (10 - 20, 20 - 40 mm), manufactured in horizontal chamber ovens of the Czech mines and metallurgical plants. The coke production in Czechoslovakia (since 1993 in the Czech republic) and

shares of the fuel and exported metallurgical coke are illustrated in Fig. 1. From this figure, the increasing share of the fuel coke in the overall coke production during the last 50 years is evident. The fuel coke from traditional chamber coking has been (from 1970) so far practically the sole solid smokeless fuel in this local fuel market. However, its production, based on carbonization of hard coal in multichamber coke ovens, will not be able to continue for a long time (not beyond 2010) due to strict requirements of the environmental legislation. The reduction of emissions realized in Germany according to Nashan /1/ within 1983-1986 characterizes approximately also the possibilities of the actual chamber coking in the Czech Republic (Fig. 2). Further steps towards reduction of emissions from the carbonization, considering the general interest in maintaining the production of metallurgical coke, result in the construction of large-volume coking chambers (as in the coke plant Kaiserstuhl III, Germany) or giant coking reactors JCR (prospect: project Eureka 500). The JCR technology presents, by its two-product manufacture of coke and 80 % hydrogen (alternatively electric power), an acceptable solution of emissions of noxious substances (Fig. 3). The suggested solutions /1,2/ are intended to enable the production of lump metallurgical coke, which is a requirement of the blast-furnace production of pig iron. It should be noticed, in this connection, that the specific consumption of lump coke in blast furnaces decreases with the continuously increasing share of the blasted (blown-in) coal. However, while the high investment costs for large-volume coke ovens or JCR-units seem acceptable for the production of metallurgical coke, it is most probable that the mentioned technological processes will be unacceptable for the production of smokeless fuels.

A solution, for the manufacture of smokeless fuel by hard coal carbonization, could be found in the revival of the idea of the multi-step continuous production process of formed coke. The Japanese production process of formed coke /3/, which reveals a "new way" in carbonization (Fig. 4), proved to be controllable in pilot-plant scale. Its maximum carbonization temperature is 700 °C, coked are briquettes (their own tar used as binder) and 70 - 100 ~ of usual seam coal can be used for this production. The advantages are: continuous process, closed system and reduction of manpower. The production of semicoke would not mean (if used as fuel) a disadvantage. A compromising solution between the combustion of low rank hard coals (V^{daf} about 35 %) and burning of fuel coke is the Polish manufacturing process of thermobriquets /4/. The semicoke (A^d 14.0 %, v^{daf} 3.1 %) prepared by aut-thermic pyrolysis from seam coal (V^{daf} 35.2 %) is mixed and thermobriquetted with coking coal (V^{daf} 29.9 %). The smokeless fuel (thermobriquettes with acceptable ash content (A^d 10.9 %) and volatile matters (v^{daf} 14.0 %) has, compared with the original coal, a low smoke emission (Fig. 5). For the future production of black coal-based smokeless fuels, only coals from the southern part of the Upper-Silesian district (Czech Republic, Ostrava-Karvina) -Fig. 6 - can be considered. Other hard coal districts in Czech will terminate the exploitation until the years 2000/2005.

The brown coal-based semicoke has been produced, in Czechoslovakia, only in 3-zonal ovens Lurgi, till 1970. The carbonization of brown coal (W_t 30 %, A^a 9 %) from the North-Bohemian district (Most) at 550 °C resulted in the production of 38 % semicoke. The semicoke was mostly fine-grained 20 mm, with high ash content (A^d 15 - 19 %) and with high reactivity (self-ignition). It was therefore used mostly for gasification and only to a lesser degree for agglomeration of ores and generation of heating steam. The process of low-temperature carbonization Lurgi, is in Tab. 4, dealing with the structure of brown coal consumption, included in the position "for chemical processing".

It may be assumed that protective environmental legislation will prevent, within a not far prospect, the combustion of coal in small combustion chambers and fireplaces. This will open the room, in the Czech market after the year 2000, for a wider application of solid smokeless fuels. The most suitable raw-material locality would seem to be the North-Bohemian district (Fig. 6) and here namely the underground mines Centrum, Alexander and Kohinoor, and the giant open pit ČSA (Fig. 7). Good prerequisites of the localities /5/ are based on acceptable contents of sulphur and ashes (Tab. 5). In the giant open pit ČSA, the selective mining of lower-ash parts should be assumed. A significant contribution to the solution of ecological problems of Bohemia would be presented by the production of about 1 million annual tons of smokeless fuel - the browncoal semicoke.

Out of many processes for the production of brown-coal based smokeless fuels, we consider as most promising, e.g. the process of the American SALEM company /6/. The carbonization furnaces Salem, type Pancake (Fig. 8) proved successful also for the production of the fuel semicoke /8/. The basic layout of the equipment is illustrated in Fig. 9 /9/. The production capacity of such furnaces is 20 to 300 thousand tons of coke a year. The traditional equipment for processing the volatile products is omitted completely and the heating value of byproducts can be utilized for the steam or electric power generation, alternatively. Combustion gases in the stack are dust and smoke-free. The coal is carbonized in a thin layer on a plate-formed rotating hearth. Volatile products from coal degassing are withdrawn and - over the coal layer - partially or entirely burned in air. The heat is transferred through the wall or by the gas to the rotating coal layer and causes its de-gassing. The coal is overturned by rabbles at each revolution of the hearth, thus improving mechanically the heat transfer. This type of furnace is predetermined for coking of non-caking or weakly-caking coals at about 1000 °C. About 1 % of volatile matters (V^{daf}) still remain in the coke. The exhaust gas is withdrawn at the temperature of about 1000 °C and is then entirely burned with air in the secondary combustion chamber. The heat can be used for the generation of steam or electric power. The carbonization process SALEM with the Pancake-equipment has been applied namely in Germany, where it is used for degassing of the Rhine coal, with high power efficiency, which attains about 95 % for the whole process.

CONCLUSIONS

- 1) The production of smokeless fuels from the hard coal has been, and in the prospects till 2005/2010 will be, in the Czech Republic, substituted by finer coke classes from traditional metallurgical coke production in horizontal coking ovens.
- 2) The stricter environmental legislation in the European community and thus also in the Czech republic will induce the production of smokeless fuels in two-product systems (coke/semicoke + electric power, aft. coke/semicoke + heating steam).
- 3) The relatively low costs of the open-pit mining and the acceptable quality of brown coal from some mines or quarries, namely in the North-Bohemian district, are a good qualification for the use of selectively mined coals for the production of 1 million annual tons of smokeless solid fuels. Good prospect are given for the application of the Salem process, which is used, in Canada, for the manufacture of smokeless fuel.

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Table 1. Emission Factors (kg/G3 fuel) for Various Fuels at Combustion [9]

Emission type	Brown coal	Hard coal	Heating coke
Dust	3.878	0.553	0.313
SO ²	0.626	0.554	0.401
NO ^x	0.238	0.223	0.024
CO	2.324	5.84	1.459
Organic comp.	0.028	0.01	0
Total	8.094	7.18	2.197

Table 2. Volatile Matter and Chemical Composition of Solid Fuels

Parameter	Brown coal	Hard coal	Antracite	Heating coke
V ^{daf} [%]	48 - 58	12 - 38	8	1 - 2
C ^{daf} [%]	64 - 74	82 - 92	94	94 - 97
H ^{daf} [%]	5 - 6.3	4.2 - 5.3	3	0.3 - 0.7
O ^{daf} [%]	18 - 22	4 - 10	2	1

Table 3. Structure of Hard Coal Consumption (% real fuel) in Czechoslovakia

Consumption	1955	1960	1965	1970	1975	1980	1985	1989
power station	18.2	20.6	18.1	19.8	19.7	21.4	20.6	19.5
heating steam	15.8	13.5	17.4	19.3	19.0	20.0	21.7	20.7
carbonization	35.2	39.9	43.3	47.2	50.7	47.7	48.9	50.5
town 1) gasworks	3.1	2.7	1.4	0.1				
railroad	10.8	8.6	7.6	4.3	1.7	0.1		
inhabitants	2.9	3.5	2.3	3.1	3.3	4.4	4.0	4.5
total	100	100	100	100	100	100	100	100

1) vertical coke oven

Table 4. Structure of Brown Coal Consumption (% real fuel) in Czechoslovakia

Consumption	1955	1960	1965	1970	1975	1980	1985	1989
power station	22.6	29.4	32.1	38.2	47.6	50.6	52.4	49.0
heating steam	19.6	19.3	22.7	24.5	24.4	24.6	24.4	25.2
gasification			1.2	2.0	3.3	2.7	2.5	1.9
railroad	9.8	10.8	5.9	2.6	1.0			
briquetting	1.1	1.2	1.8	2.9				
chemical processing	8.4	7.0	4.6	3.6				
inhabitants	18.7	17.4	11.8	10.4	9.4	9.9	8.8	9.7
total	100	100	100	100	100	100	100	100

Table 5. Technological parameters of seams extracted in North Bohemian mines [5]

Company/mine	Seam (m)	Q_i (M; /kg)	A^d (%)	S_i^d (%)
MUS				
DUK Komotany				
ČSA	25.68	15.90	19.38	2.00
DJŠ	19.11	11.51	37.22	1.04
Mines Ležáky				
Vršany	26.10	10.77	39.80	1.23
Most-Kopisty		14.39	26.10	1.30
Mines Hlubina	23.14			
Alexandr		19.58	11.04	0.96
Centrum		17.70	7.40	0.80
Kohinoor	17.30 -22.50	18.92	11.09	1.00
SD	23.80			
Mines Nástup	15.33-18.34	10.80-11.47	29.72-34.29	2.47-2.97
Bilina	28.80	13.57	29.70	0.99
FUEL COMBINE				
Chabařovice	12.21	11.81	22.27	0.40

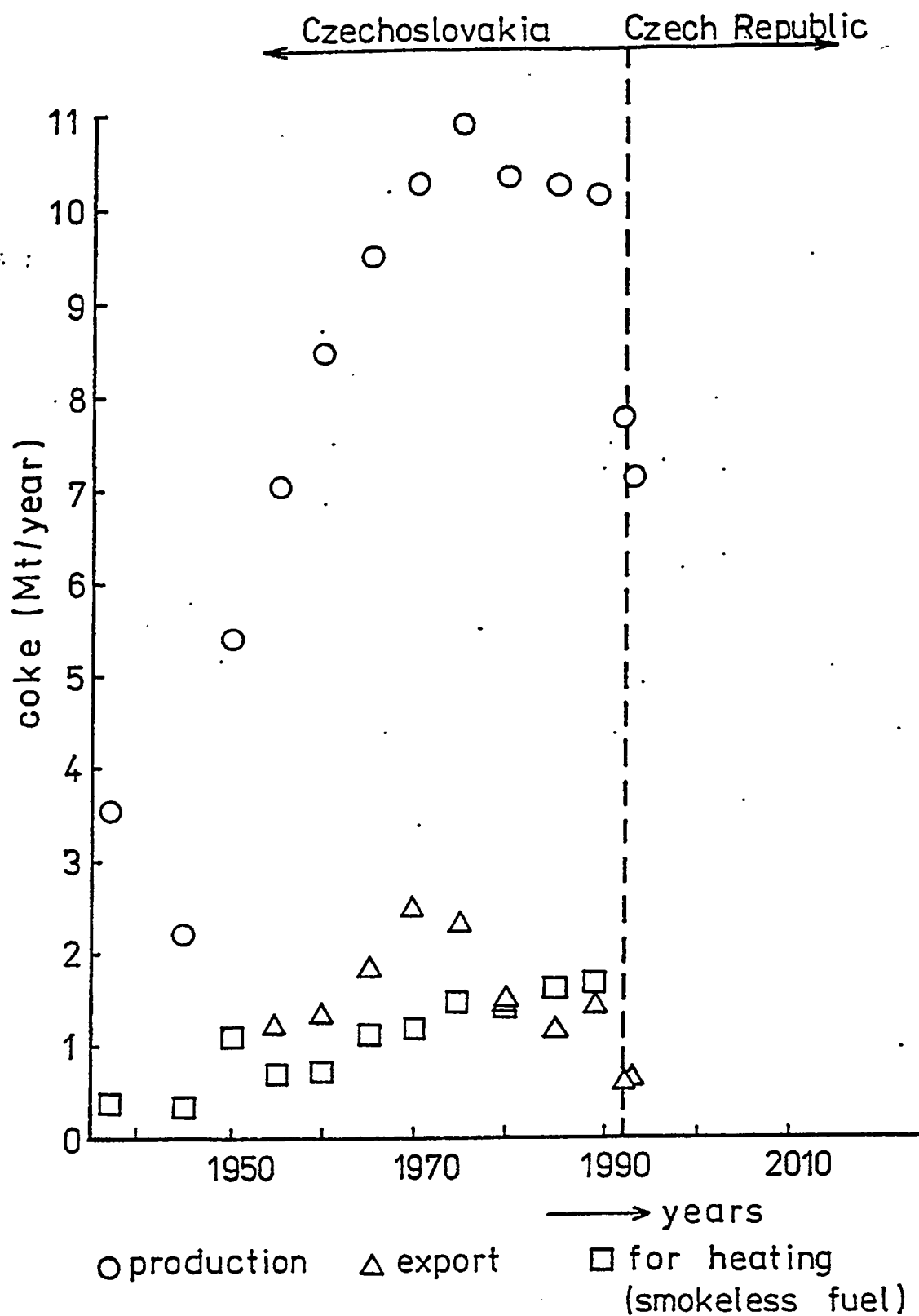


Figure 1. Coke production and utilization.

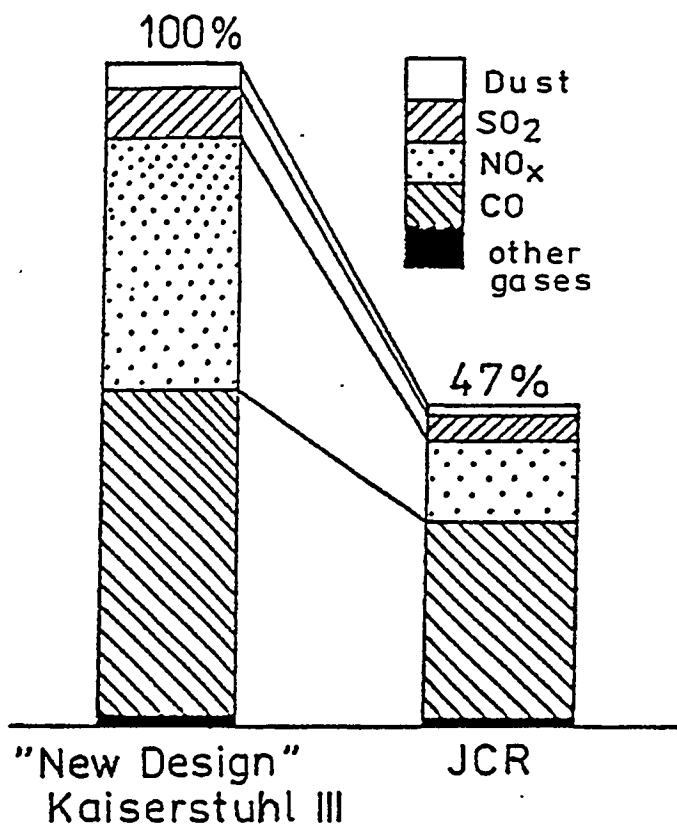
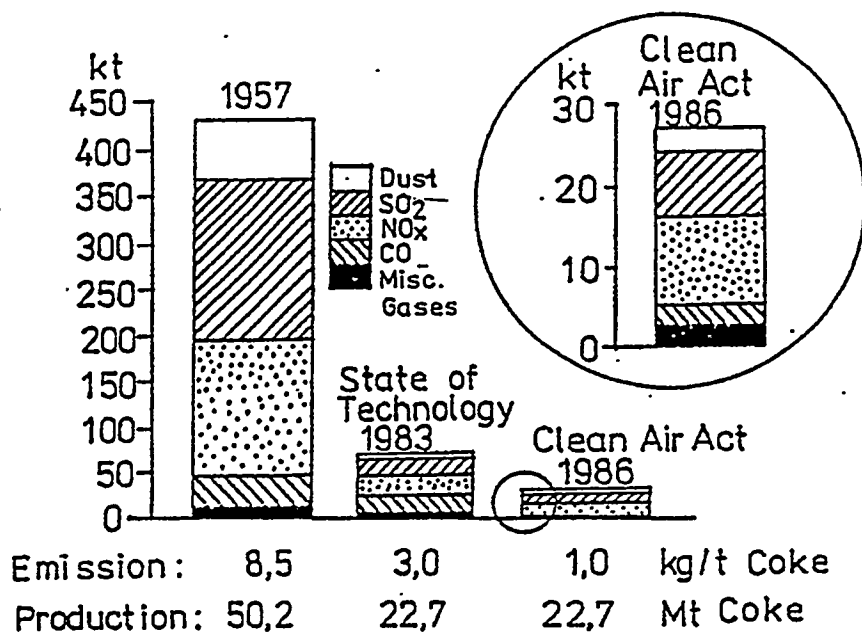


Figure 2. Development of the reduction of emissions in the coke plants of Germany [1,2].

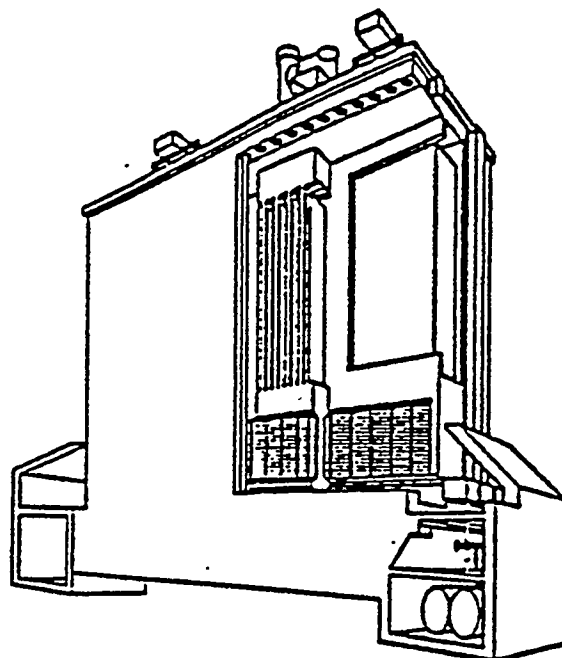


Figure 3. Jumbo coking reactor (JCR) – project Eureka 500.

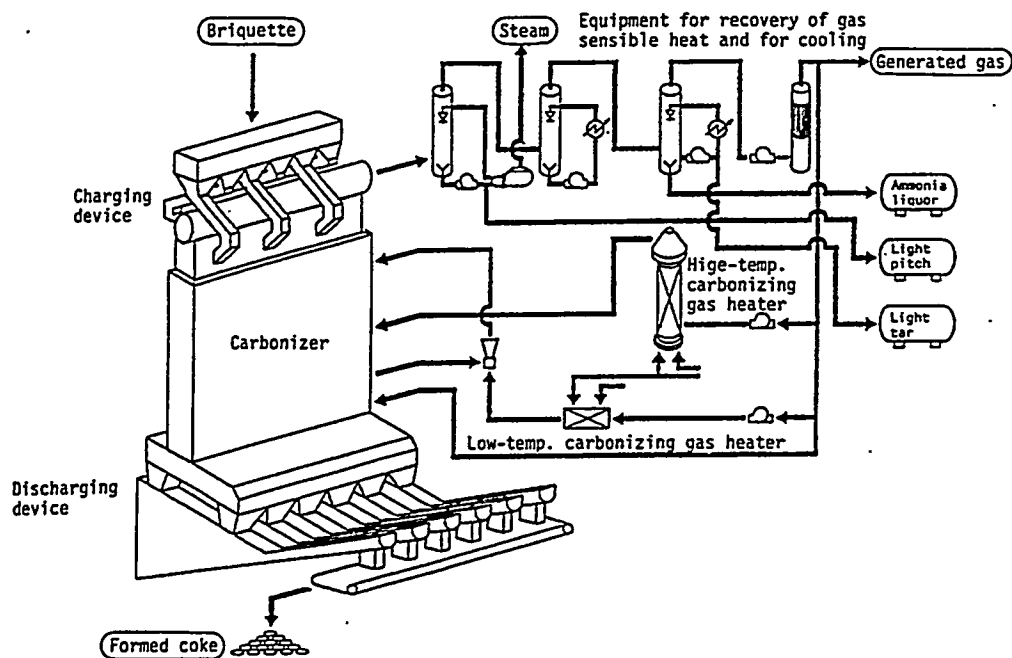


Figure 4. Japanese "new way" of formed coke production [3].

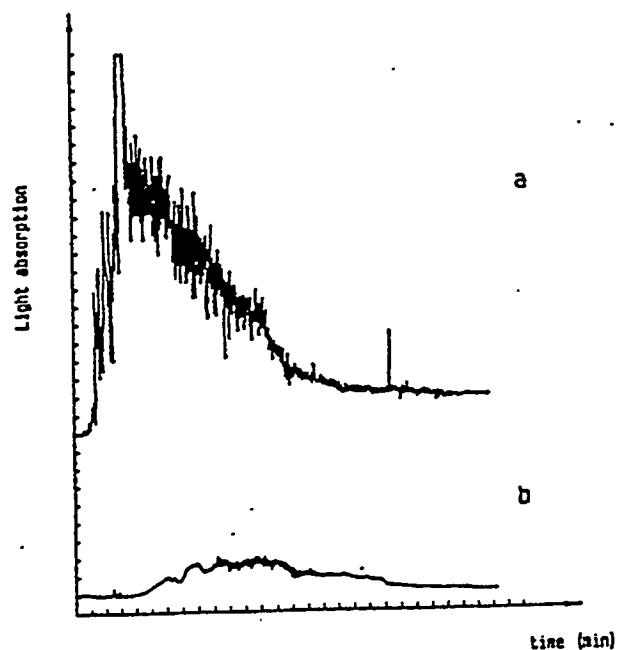


Figure 5. Smoke emission when burning coal and smokeless fuel a) coal and b) smokeless fuel.

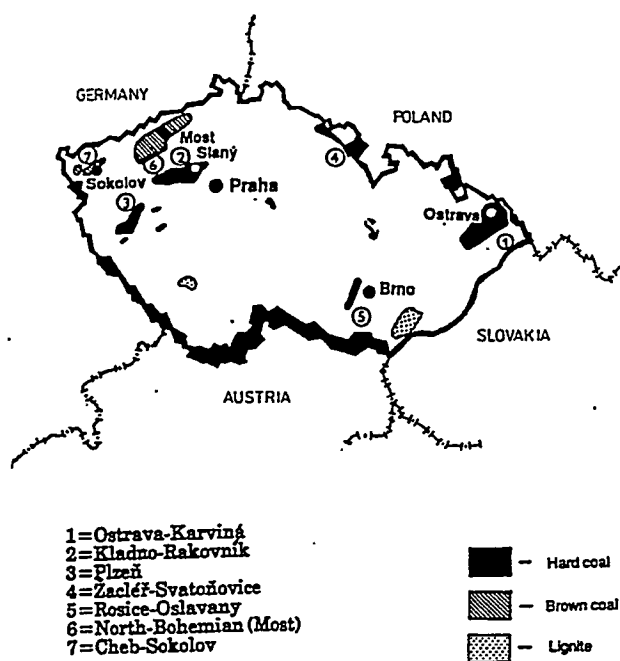


Figure 6. Location of coal districts in Czech Republic.



Figure 7. Location of open-pit and underground mines within the North-Bohemian brown coal district.

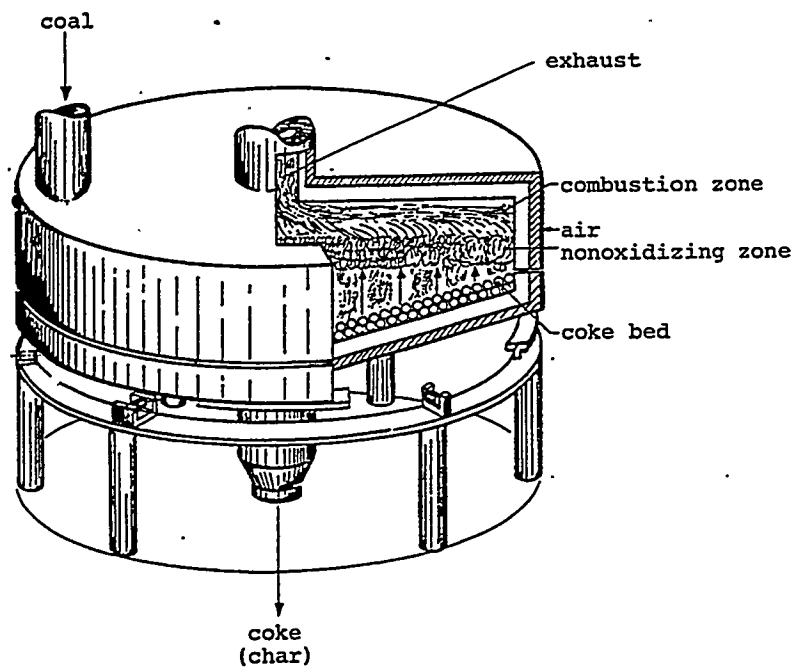


Figure 8. Hearth furnace Salem, Pancake type-section.

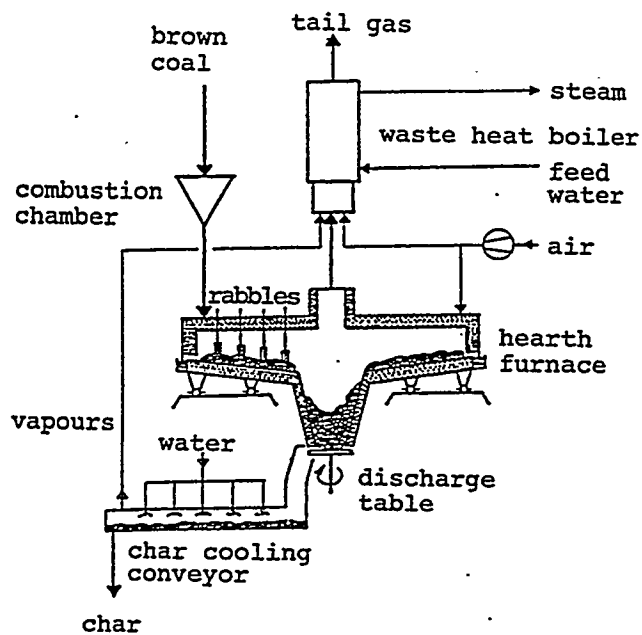


Figure 9. Rotary hearth furnace Salem for brown-coal carbonization.

ASSESSING THE EFFICIENCY VERSUS THE INEFFICIENCY OF THE ENERGY SECTORS IN FORMERLY CENTRALLY PLANNED ECONOMIES

Diana Vorsatz

Energy and Environment Division
Lawrence Berkeley Laboratory, MS 90-4000
University of California
Berkeley, California, USA

ABSTRACT

As much the extreme inefficiency of Eastern European energy sectors is emphasized, as little attention their relatively efficient aspects receive. Indeed, a few efficiency indicators show the highest global efficiencies for the formerly centrally planned economies, such as the overall primary to useful energy efficiency. These figures draw the attention to an underestimated feature of former socialist energy sectors and to crucial policy implications: in some respects central planning lead to a more efficient use of energy than the market economy. Consequently, if transitions from the central planning to the market economy are not managed carefully, further reductions in energy efficiency can be expected in some sectors of the economy.

INTRODUCTION

The high energy intensities of Eastern European economies are widely publicized. Primary energies necessary to produce unit economic output, measured in GDP or PPP (Purchasing Power Parity), are reported to be two to five times higher than in developed countries [1] [2]. Also well known are the low individual production, conversion, transmission, distribution and appliance efficiencies [3] [4] [5]. For instance, the lowest global fossil primary energy to final fuel efficiencies (for a definition of terminology used in this paper please see Table 1) for both natural gas (56%) and coal (75%) prevail in reforming economies; while biomass transformation into final fuels is also lowest in the world with as low efficiency as 20%. The generation of electricity is just as inefficient, it is often lower than 20% in economies in transition, compared to an about 36% average in market economies and a global average of 31%. The primary to final energy conversion efficiency with 69% in former socialist countries also reaches a worldwide low compared to the 74% world average. The lowest comparative conversion efficiencies in reforming economies are estimated to be in the final to useful energy conversion, where these countries achieve only a 30% efficiency level, while the market economies convert final energy 53% efficiently to useful energy [5].

TABLE 1

Definitions of Energy Forms [5]

- primary energy: energy gathered or recovered directly from nature; e.g. crude oil
- secondary energy: converted energy from primary; e.g. electricity, petrol
- final energy: energy delivered to the point of consumption; e.g. electricity for an appliance, petrol for a car
- useful energy: converted energy by end-use devices; e.g. heat, light

However, Nakicenovic reports that some indicators describing the *overall* performance of the energy sector are the highest in reforming economies. For instance, the conversion efficiency from primary to useful energy is 42% comparing to a 34 % world average [5]. This means, that former socialist economies produce approximately 8 units more of useful energy from 100 units of primary fuel than the world average. Representative values for a comparison of different conversion efficiencies are shown in Table 2.

TABLE 2

Representative Efficiencies of Conversion Among the Different Forms of Energy [5]

	OECD	Eastern Europe
Primary to Secondary Energy (Electricity Production)	36%	20%
Primary to Final Energy	80%	69%
Final to Useful Energy (Electricity End Use)	22%	11%
<i>Overall Primary to Useful Energy</i>	<i>36%</i>	<i>42%</i>

ANALYSIS

The reasons for the high energy intensity of the economy and for low individual conversion, distribution, transmission and appliance efficiencies in reforming economies originate from different aspects of the centrally planned economy and the socialist system. Mainly, the lack of market forces provided no penalty for inefficiency, or reward for efficiency. In some cases opposite incentives operated in a planned economy: since resource allocations for the next planning period were based on previous resource use, companies were often interested in the overconsumption of resources. Cold war militarisation relied on the highly energy intensive heavy industries, which contributes strongly to the high energy intensities of former socialist economies. Heavily subsidised energy prices, the lack of metering, uncontrollable heating systems and flat rates resulted in a large scale of energy wasting in the residential sector. Numerous other aspects of socialism, including corruption and inadequate environmental attitudes, contributed to the low efficiency of resource utilisation.

However, there were some aspects of the centrally planned economy that promoted the efficient use of energy. Socialism favored collective energy use, thus, the same energy provided service for more users than in the market economies. Two examples to represent this phenomena are the transportation and district heat sectors.

Transport Sector

When Eastern European transportation systems are compared to their Western counterparts, this dual nature in energy efficiency can be well identified. Although individual vehicle efficiencies in reforming economies are lower than those in OECD countries, due to the dominance of public modes of transportation, the same energy transports more people or freight to the same distance in former Centrally Planned Economies.

Chart 1 shows the comparison of the modal distribution of passenger travel between representative former socialist and OECD countries [2]. It is well demonstrated in the chart that organised ways of passenger transport dominated over individual modes in centrally planned countries (although this has been changing since the transitions), while it is automobile use that dominates passenger transport in industrialized countries.

Passenger Travel per Capita

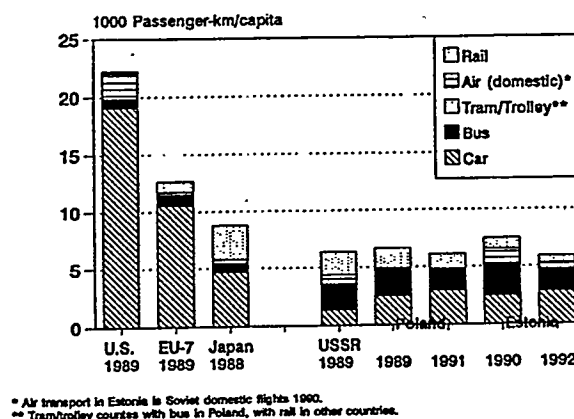


Chart 1. Comparison of Modal Distribution of Passenger Travel between the East and West. [2]

The result of the difference in modal distribution is demonstrated in Chart 2. Energy intensities of the total passenger transport sector are considerably lower in reforming economies than in industrialized

Energy Intensities of Travel

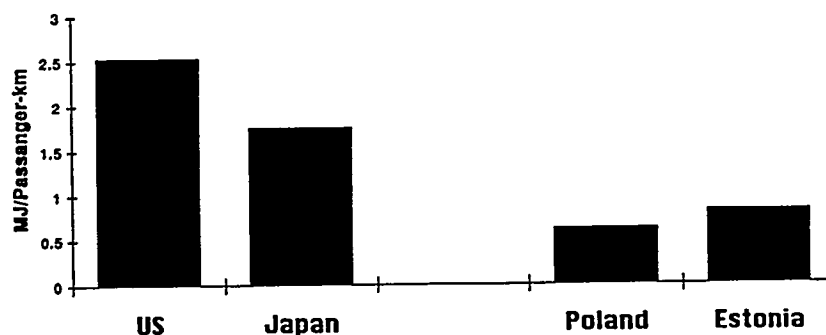


Chart 2. Comparison of Energy Intensities of Passenger Travel in Representative Industrialised and Former Socialist Countries [6] [5] [2]

countries, since central planning favoured collective transport. Thus, on the aggregate level, less energy is necessary to transport one person to the same distance. The same trend can be shown for freight transport as well.

Another example for the dual nature of energy efficiency is district heat. Although the transmission, distribution and use of district heat are highly inefficient in formerly centrally planned economies, the fact that they often originate from the waste heat of power generation or industrial processes enhances aggregate level energy efficiency. More concentrated settlement patterns in socialist countries allowed the utilization of such waste heat as district heat, while in industrialized countries the preference of single family type dwellings and individual heating systems enabled the utilisation of this usually lost heat.

These phenomena, the importance of which is usually underestimated if not neglected, is so substantial from the point of view of energy use, that it is able to compensate for the individual inefficient end uses on the aggregate level, resulting in the highest aggregate energy efficiency level globally in the reforming economies.

POLICY IMPLICATIONS

High efficiencies of energy use in some sectors resulting from the former central planning have major implications from the point of view of restructuring Eastern European economies. If transitions in such sectors are not designed in a way to attempt conservation of the features leading to higher relative efficiencies, Western modeled transitions might result in an actual loss in efficiency, and consequently further deterioration in environmental quality. Therefore, it is of crucial importance that these countries design their own development patterns incorporating the positive features inherited from the central planning system, wherever possible. One such sector with positive initial conditions is transportation. If Western models are adapted and current trends continue, large modal shift is expected to increase the use of individual modes of transportation significantly. This will result in further deterioration of air quality and other environmental problems.

FURTHER RESEARCH NEEDS

Besides public transportation, many sectors of the economy contain features where activity is more energy efficient or environmentally friendly than in the industrialized countries. It is most important to identify these "positive initial conditions", understand their reasons and strategies to conserve as much of them as achievable. Such areas to be assessed more in detail include:

- waste heat utilization in power plants and industrial processes;
- residential settlement patterns and district heating;
- freight transport, modal distribution;
- consumer behaviors (e.g.. attitude to packaging, bottle deposit system, etc.).

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APPENDIX

CURRENT ENERGY PERSPECTIVE: EAST CENTRAL EUROPE

This report entitled "Energy and Environmental Profile for Selected East Central European Nations," was prepared during the period spring 1994 through winter 1994.

The report covering Bulgaria, the Czech and Slovak Republics, Hungary and Poland, consists of a summary table organized by subject and country that displays a country profile; overall energy mix; key energy and environmental issues; energy resources, use, and trends; electrical generation, transmission, and demand; briquettes; district heating; and environmental regulations and trends, as well as supporting text.

The country profiles were based largely on information for the years 1991 and 1992, the most recent information readily available to the authors. In addition to the literature search, the following groups were contacted during preparation of the report: the U.S. Department of Commerce, the U.S. State Department, the U.S. Army, the Center for Economic Cooperation and Development, the U.S. Department of Energy, the International Energy Agency, and the embassies and ministries of the individual countries.

The report was distributed to authors prior to the conference in order to aid in their report preparation.

ENERGY AND ENVIRONMENTAL PROFILE FOR SELECTED EAST CENTRAL EUROPEAN NATIONS

D.J. Daly, Research Manager
E.A. Sondreal, Principal Research Advisor

Energy & Environmental Research Center
Grand Forks, North Dakota, USA

Eugeniusz Jedrysik

Central Mining Institute
Katowice, Poland

Wojciech Smolka

Institute for Chemical Processing of Coal
Zabrze, Poland

INTRODUCTION

The nations of East Central Europe regained their political and economic freedom in 1989, ending nearly a half century of centrally planned economies under the hegemony of the former Soviet Union (FSU). These nations are now emerging from economic conditions marked by price distortions and a focus on heavy industry, isolation from world markets, and a lack of occupational health and environmental safeguards. Economic recovery, environmental restoration, and political stability, as well as eventual entrance into the European Community (EC), require a reordering of policies and priorities, including those bearing on energy and the environment. This report, prepared as a background document for the Second International Conference on Energy and Environment to be held in Prague in November 1994, is composed of a summary table (Table 1) and supporting text and is intended to provide a concise review of issues related to energy and the environment for the Czech and Slovak Republics, Hungary, Poland, and Bulgaria. Organized by subject and country, Table 1 contains country profiles (Row A), information on the economy (Row B), primary energy consumption, environmental priorities, energy resources, production, and utilization (Rows C, D, F, G, H, and I), electrical generation and transmission (Rows J and K), district heating (Row L), briquettes (Row M), and environmental regulations (Row N). Pertinent policy goals, issues, and trends are noted. The report is based largely on a review of documents published by the International Energy Agency (IEA) and the U.S. Department of Energy (DOE), as well as selected sources obtained from the countries of the region. Reference citations are keyed to information presented in Table 1.

The report is based on the most recent published information available to the authors, mainly from 1991 and 1992. The evolving situation in the region will quickly outdate portions of the report. Because the report is intended as a summary, certain topics, including coal quality and specific characteristics of power plants and other facilities, were given very limited treatment, and the reader is referred to key sources in the bibliography for further information. For other topics, such as district heating and briquette manufacturing and use, the treatment here reflects the information available to the authors.

ECONOMIC TRANSITION

While in transition to democratic political structures and free markets (Table 1, Row B), the East Central European nations are emerging from postindependence recessions. Gross domestic product

(GDP) has declined since independence. The private sector share of GDP is low in Bulgaria and the Czech Republic but high (50%) in Poland. In 1993, Poland and Hungary respectively reported 7% and nearly 2% growth in industrial output. Inflation continues to be high, ranging from 11% in the Czech Republic to 35% in Poland and up to over 80% in Bulgaria. Outside the Czech Republic, unemployment also remains high, between 11% and 16%. Per capita foreign debt is high overall, ranging from \$594 in the Czech Republic to \$2121 in Hungary.

RESOURCES AND ENERGY SUPPLY

The economies of East Central European nations are highly energy intensive, with total energy use ranging from 1 to 1.8 tons of oil equivalent (toe) per US\$1000 GDP, compared to 0.3 tons for the OECD (Organization for Economic Cooperation and Development) countries as a whole (Table 1, Row C). All are net energy importers with very limited domestic resources of oil and gas, which were formerly supplied by the U.S.S.R. (Table 1, Rows F, G, H, and I). Total energy consumption ranges from 0.95 exajoules (EJ) in Bulgaria and 1.13 EJ in Hungary to 4.04 EJ in Poland. Energy use is down throughout the region since the peak in the late 1980s. Coal dominates the energy mix in the Czech Republic (54%) and Poland (78%), while the mix in Hungary and Bulgaria is more evenly divided between coal, oil, gas, and nuclear. Poland has no domestic nuclear energy capacity, while nuclear energy accounts for between 10% to 15% of the energy mix in the other countries.

Political and economic reforms have changed the focus of energy policy from one of interdependence within the sphere of the FSU to self-reliance and movement toward integration into the EC (Table 1, Row D). Subsidies and barter agreements among the East Central European nations have been largely discontinued. Demand for transportation fuel, in particular, is projected to increase dramatically, whereas energy demands for electricity, space heating, and heavy equipment are expected to remain level or show modest increases. Oil and gas imports from the FSU are troubled by regional political and economic uncertainty, declining production, and the aging production and transportation infrastructure. Upgrading and maintaining the oil and gas infrastructure and continuing exploration in the FSU will require a massive investment, mainly from foreign sources and estimated at over US\$10 billion dollars, in the near term. An important overall policy goal of the East Central European countries is to ensure a stable supply of oil and gas by diversification of sources, accelerated development of domestic resources, and upgraded infrastructure, including pipelines and processing and refinery units. Other high-priority goals include energy conservation, upgrading or decommissioning facilities (particularly older nuclear and coal-fired power plants), and retrofitting environmental control methods for remediating air, soil, and water pollution (Table 1, Row E).

East Central European governments have moved to support joint ventures with foreign investors in sectors requiring significant capital investment, such as upgrading or expanding existing facilities, including those for transportation fuels and service, as well as for high-risk enterprises such as oil and gas exploration and production. Governments have retained control over energy supply in matters such as pipelines, electrical transmission grids, and import agreements. Private domestic ownership has included mining cooperatives, marketing and service businesses (including vehicle service stations), and support industries.

As shown in Table 1, Row F, East Central European coal reserves indicate an adequate supply into the next century, particularly for low-rank coal (LRC). Reserves in Bulgaria, Hungary, and the Czech Republic are predominantly LRCs, whereas Poland has large reserves of hard coal along with significant LRC deposits. The former Czech and Slovak Republics (FCSR) have recoverable reserves of hard coal totaling 3330 Mt with an annual production of nearly 26 Mt in 1987. The Ostrava-Karvina region of the Czech Republic, in the southern extension of the Upper Silesian Basin, continues to dominate hard coal production. These coals, produced from underground mines, are anthracite or low-volatile, strongly caking bituminous coals containing low levels of ash,

moisture, and sulfur. Recoverable reserves of LRC (mainly brown coal) in the Czech and Slovak Republics total 8850 Mt with an annual production of around 100 Mt in 1987, mainly from surface mines. The principal reserves and production of brown coal are in Northern Bohemia in the Czech Republic, where the coals are moderate to high in ash (17%–30%), variable in sulfur (0.5%–3.0%), and highly variable in moisture content (30% average), with heating values from 9 to 18.6 MJ/kg. The Sokolov field, southwest of the Northern Bohemia region, is another significant LRC area. The Slovak Republic to the east contains only minor LRC deposits.

Poland has proven recoverable reserves of hard coal in excess of 28,700 Mt, two-thirds of which are of coking quality and all recoverable only by underground mining. Deposits in the Upper Silesian Basin in southern Poland, occurring in 1.5- to 2.5-meter-thick seams, account for 93% of reserves in developed deposits, over three-quarters of prospective hard coal reserves, and about 97% of hard coal production. Excellent average properties include a lower heating value of 23.3 GJ/t, a sulfur content of 0.75%, 30% volatile matter, 9.7% moisture content, and 16.7% ash content. Annual production in 1987 stood at 178 Mt. Production costs are high at many of the mines, and some mines are being closed. Maintenance of production capacity requires investment in new mines and the further development of existing mines. Recoverable reserves of LRC in Poland total 11,700 Mt, mostly exploitable by surface mining with bucket-wheel excavators. The Belchatów and Turow mines dominate production, having seams greater than 20 m in thickness (up to 60 m). Although LRC deposits are generally level or gently dipping, selective mining is often required because of local geological complexities. Production in 1987 stood at 73.2 Mt.

In Hungary, the proven hard coal reserves (100 Mt) are concentrated in the southwest portion of the country, at Pecs in the Mecsek Mountains, which provides Hungary's only domestic source of coking coal. Deposits are geologically complex and mining costs are high. Hungary's LRC reserves of 3650 Mt occur along the northern border with the Slovak Republic and are exploitable by surface mining. The Matraalja field, northwest of Budapest, containing six seams of 4 to 14 meter thickness, accounts for more than three-quarters of LRC proven reserves. Mining costs are competitive, and the potential for continued development is good. Matraalja lignite is characterized by moderately high moisture (45%) and ash (22%), low sulfur (1% daf), and a relatively low heating value (6.7 MJ/kg).

In Bulgaria, proven reserves include 30 Mt of higher-rank coal (mainly bituminous) which accounts for less than 1% of annual production. LRC reserves stand at 3700 Mt, of which two-thirds are available for surface mining. Half of the Bulgarian LRC reserves and three-quarters of the 35.3 million tons of LRC (mainly lignite) produced in 1988 are accounted for by the Maritsa East lignite deposit. The Maritsa East lignite bed, varying from 3-25 m in thickness, is high in moisture (49%–57%), ash (30%–45%), and sulfur (2.8%–4.1% dry) and has a lower heating value (5-7 MJ/kg).

With respect to oil and gas resources as shown in Rows G and H in Table 1, Hungary produces about a quarter of the oil it consumes, while production in the other East Central European countries is minimal. Hungary produces about 25% of its natural gas needs, while other countries import over 90%. There exists a potential for increased domestic gas production in all of the East Central European countries, and exploration is being accelerated by foreign investment and technical assistance. Natural gas supplies are also supplemented with coal gas. As shown in Row I in Table 1, uranium deposits have been mined in the Czech and Slovak Republics, Hungary, and Bulgaria, but most of the mines have production costs much higher than world prices and are, therefore, slated to be shut down.

ELECTRICAL GENERATION

The study countries in East Central Europe have a combined installed generating capacity of about 69 GW, which provides a per capita generating capacity of 0.94 kW (Table 1, Rows J and K). Net electrical production for the region compiled from selected sources in the period from 1990 to 1992 was about 274 TWh per annum, which equates to 3730 kWh per person annually. Generating capacity and

production per person are approximately two-thirds of those in Western Europe and one-third of the U.S. The Czech Republic has the highest per capita electrical use in the region, followed by Bulgaria, the Slovak Republic, Poland, and Hungary.

Taken as a whole, the region relies on coal for 74% of its electrical generation, followed by nuclear for 19%, oil and gas for 4%, and hydropower for 3%. The contribution of brown coal and lignite to electrical generation is estimated to be about 50% in the combined Czech and Slovak Republics, 36% in Poland, 35% in Bulgaria, and 8% in Hungary; the corresponding contributions of hard coal are estimated to be 11%, 60%, 18%, and 20% respectively. Reliance on coal for electrical power has declined during the 1980s as nuclear units were installed, except in Poland, which has no nuclear power. Most countries rely on domestic supplies of coal with the exception of Bulgaria, which imports some coal from the Ukraine.

Overall consumption of electricity is down because of the slowdown in the economy. Imports of electricity have decreased significantly during this time with a lesser decrease in domestic generation. Peak loads are being met in the region with the exception of Bulgaria, which has experienced power outages.

The burning of high-sulfur, high-ash coal and lignite for power generation is a leading cause of severe air pollution in some areas of East Central Europe. The problem is being addressed under phased-in emission regulations by both decommissioning some older coal burning plants and rehabilitating, retrofitting, and/or repowering other units with improved control systems, flue gas desulfurization (FGD), low-NO_x burners, electrostatic precipitator (ESP) enhancements, and fluidized-bed combustion (FBC)—atmospheric (AFBC) and circulating (CFBC).

Each of the study countries in the region is planning additional capacity using gas-fired combined cycle plants for peaking service in the period of 1995–2000. New baseload plants are typically needed only after 2000, with either coal or nuclear units likely to be selected. Some countries, most notably Poland, Bulgaria, and the Slovak Republic, have significant untapped hydroelectric potential, but expansion in capacity is limited by high capital cost and environmental concerns.

Czech Republic and Slovak Republic

Prior to 1990, the power industry in the Czech Republic was organized in a single state-owned company, the Czech Power Works (CEZ), which generated, transmitted, and distributed electricity from plant to end user. Since then, the industry has been decentralized and partially privatized with the establishment of eight regional distribution companies and other independently operated heat and cogeneration plants, leaving the CEZ (now 30% privately owned) with generation and transmission.

Power demand decreased by about 8% to 9% in the two republics from 1990 to 1992 after rising during the 1980s, but growth is expected to resume as the economy recovers. In the Czech Republic, the installed generating capacity of 14,500 MW is 77% coal-fired, 12% nuclear, and 11% hydropower. In the Slovak Republic, the 5600-MW total installed capacity is 39% coal and gas, 31% nuclear, and 30% hydro. Both republics have an ample margin of excess capacity. Nuclear facilities are the most fully utilized, supplying 21% of net generation in the Czech Republic (1992) and 50% in the Slovak Republic (1991). Hydro capacity is least utilized and is reserved for peaking service.

Nuclear power plants are currently operating at Dukovany in the Czech Republic (4 × 440-MW model V213 units commissioned between 1983 and 1987) and at Bohunice in the Slovak Republic (2 × 440-MW V230s, 2 × 440-MW V213s). The two older V230 type units at Bohunice are generally considered unsafe, and their decommissioning is planned for some time between 1995 and 2005. New nuclear plants are under construction at Temelin in the Czech Republic (2 × 100 MW) and at Mochovce in the Slovak Republic (4 × 440 MW). Although expansion of nuclear power is controversial, completion of those units that are already in an advanced state of construction is considered to be the least costly

option for reducing the environmental impacts of fossil fuel generation and for integrating with the West European power grid system (UCPTE).

Coal-burning power plants are the largest source of air pollution in the Czech and Slovak Republics, and they represent a particularly serious problem in Northern Bohemia in the Czech Republic, where high-sulfur content lignite is burned substantially without control of SO₂ emissions. Part of the planned solution is to shut down older coal units as new nuclear capacity becomes available, including, by the year 2000, 14 out of the 48 coal-fired generating units operating in the Czech Republic (1790 out of 7850 MW) and five of the 16 units in the Slovak Republic (550 out of 1760 MW). The remaining coal-fired units are being retrofitted with FGD or alternatively repowered with AFBC or converted to low-sulfur fuel. In addition, low-NO_x burners are being installed on some units.

Further development of hydroelectric power in the Slovak Republic was set back in 1990 when Hungary withdrew from the joint agreement to construct the Gabčíkovo–Nagymaros Dam because of environmental concerns. As a result, Slovakia will be forced to utilize its own dam and generating station at Gabčíkovo at well below design capacity.

The 220- and 440-kV transmission grids in the Czech and Slovak Republic are owned separately by the CEZ and SEP, but with significant interconnections that account for a net transfer of 6% from CEZ to SEP and 0.3% from SEP to CEZ measured in reference to their combined generation. The Czech Republic is interconnected with Poland and Germany, including former West Germany. The Slovak Republic is interconnected with, and is a net exporter of power to, both Hungary and the Ukraine.

Poland

Organization of the Polish power industry since the late 1980s has undergone dramatic changes that first reorganized the previously centralized system into an excessively large number of small independent operating units, including 32 generating companies and 33 transmission and distribution networks. A second round of restructuring is currently in progress to reconsolidate the power industry into a smaller number of joint stock companies under the Polish Power Grid Company (PPGC). The PPGC, itself established as a joint stock company in 1990, has overall responsibility for operating the power grid and developing plans for rehabilitating electrical generation and transmission systems. Plans for privatization envision a transition to a mix of state-owned and privately owned companies, starting with the privatization of the Kraków Heat and Power Plant as a pilot project. Demand for electricity in Poland declined by 15% between 1989 and 1992, with in-country generation dropping by 9% and imports falling far more substantially by 72%. Electricity production was 132.8 million kWh in 1992.

Thermal power, which is nearly all coal-fired, with only minor amounts of oil and no gas firing, accounts for over 90% of Poland's 32,000 MW of installed generating capacity. Almost 70% of this capacity is concentrated in 15 large coal-fired plants, including major stations at Bełchatów (4320 MW) and Tróćno (2000 MW) burning brown coal and stations at Kozienice (2600 MW), Dłona Odra (2600 MW), Polaniec (1600 MW), and Rybnik (1600 MW) burning bituminous coal.

Poland has over 100 small hydroelectric and pumped storage plants used for peaking service, which account for most of the 10% remainder of installed capacity—but only a small increment of production (2.9% in 1988). Poland's large hydroelectric potential of about 12 million kWh annually is only 13% exploited, due largely to the high capital cost of hydroelectric facilities.

Poland has no nuclear power plants, and all planned nuclear power projects have been cancelled, including the Żarnowiec project. However, a role for nuclear power is foreseen within the next 15 to 20 years.

Electrical generating capacity will be adequate for the next several years, owing to depressed economic growth and transition to a less energy-intensive economy. Near-term priorities are to complete

construction in progress on a new coal-fired plant (2160 MW) and pumped storage capacity (750 MW); to rehabilitate and retrofit aging coal-fired generating equipment (18 years average age) for improving availability, efficiency, and environmental control; and to reduce large losses of up to 10% in transmission and distribution. Flue gas desulfurization systems and low-NO_x burners are beginning to be installed on coal-fired plants, with 4000 MW estimated to be retrofitted by the year 2000 and 8600 MW thereafter. In addition, coal-washing plants are being installed at 18 mines to reduce the sulfur content of hard coal burned in power stations.

The Polish transmission grid consists of a 400-kV ring (not yet completed) with 220-kV branches linking power plants and 220-/110-kV substations. Interconnections include 220- and 750-kV lines to the Ukraine and 220- and 440-kV lines to the Czech Republic and former East Germany.

In 1992, Poland had net electrical imports amounting to 2.7% of demand, which represented a substantial reduction from the 8.9% imported in 1989. Poland is upgrading its interconnections with the Czech and Slovak Republics and Hungary as a step toward joining the West European power grid (UCPTE).

Hungary

The Hungarian Electricity Works (MVM), organized in January 1992 under the authority of the Ministry of Industry and Trade, provides for a first tier of eight regional generating and six regional distributing companies controlled by a second tier of financial holding and operating functions. The second tier includes responsibility for transmission grid operations, power dispatching, wholesale power purchase contracts, and electrical imports. A somewhat complex network of current ownership involving municipalities (1% to 5%), the MVM Holding Company and its parent State Asset Holding Company (45% to 49%), and the State Property Agency (50%) is intended to lead to a blend of private and state ownership under Hungary's liberal policies on privatization and foreign investment, although bureaucracy and pricing uncertainty have slowed this process.

Demand for electricity in Hungary peaked in 1989 at 41 TWh and has since declined by 18% to 33.5 TWh in 1993. In-country generation dropped by 11% between 1990 and 1992, whereas net electrical imports dropped 69%. Imports provided 29% of demand in 1990, compared to about 10% in 1992.

Hungary's total installed generating capacity of 7300 MW includes 2100 MW in lignite- and brown coal-fired plants (29%), 3300 MW in oil- and gas-fired plants (45%), 1840 MW at the Paks nuclear station (25%), and 48 MW from two larger hydroelectric plants on the Tisza river and 27 mini hydro systems (0.6%). Electrical generation by MVM in 1991 was 28% coal-based, 23% oil and gas, 48% nuclear, and 0.7% hydro. The generating mix has shifted over the last four decades, starting with construction of primarily small brown coal-fired plants in the 1950s and 1960s, followed by construction of a large lignite-fired plant in the early 1970s, oil and gas plants later in the 1970s, and a nuclear plant in the 1980s.

Hungary has a capacity margin about 25% above peak load (1991) and is placing a strong emphasis on demand-side management to maintain adequate reserve capacity in the near term. Some older coal-fired plants operating on high-cost coal will be decommissioned, and the use of coal for power generation is expected to decline in the future. Work is in progress to retrofit and repower other coal-fired boilers for life extension and emission control using technologies that include FGD, low-NO_x burners, flue gas recirculation, and AFBC. Two boilers at the Ajka Power Plant have been converted to a hybrid pulverized coal fluidized-bed combustion system. The Gagarin plant fired on lignite and the Oroszlany plant fired on hard coal have both undergone major rehabilitation. The immediate generating need before 1997 is for 800 MW of gas-fired combined cycle capacity for peaking service. New baseload units (2 × 900 MW) needed by about the year 2000 may involve either lignite, hard coal, or nuclear fuel. The public is strongly opposed to the expansion of nuclear capacity in Hungary, and earlier plans for construction of 2 × 1000-MW units at the Paks station were cancelled in 1989. No plans for expanding hydropower have been reported after suspension in 1989 of Hungary's participation in the Slovakian-Hungarian

hydroelectric project at Gabcikovo–Nagymaros. If hydro-, nuclear-, and coal-/lignite-based units are not selected, the future alternative will be greater reliance on imported oil and gas at escalating prices.

Bulgaria

Organization of the energy sector in Bulgaria prior to a November 1991 energy policy decree involved two vertically integrated government agencies for 1) oil and gas and 2) coal heat and electricity (the Committee on Energy [COE]). Since then a number of government-owned companies, including the National Electric Company (NEK), have been established. The NEK is responsible for the generation, transmission, and distribution of electricity throughout Bulgaria.

Bulgaria's demand for electricity decreased by 22% between the peak year of 1988 and 1992, reflecting a drop in industrial output, price increases, and capacity constraints. The installed generation capacity of 12,074 MW as of 1992 (53% thermal, 33% nuclear, and 16% hydro) should, in theory, provide a safe margin of excess capacity. However, the low operating reliability of coal-fired and nuclear plants and the reduced availability of hydropower in recent dry years have limited maximum load to about 60% of installed capacity, which is below the level of peak demand and has resulted in power outages.

The only nuclear plant, located at Kozloduy, consists of four 440-MW units, commissioned between 1974 and 1980, and two 1000-MW units, commissioned in 1988 and 1991. All units have pressurized light-water reactors operating on slightly enriched uranium. The four older units do not meet International Atomic Energy Agency (IAEA) standards due to lack of redundant cooling and containment, and they are slated for closure when alternative power generating capacity becomes available. The newer 1000-MW units meet international standards but require improvements in instrumentation and control. Necessary improvements in the Kozloduy plant are being funded by the European Bank for Reconstruction and Development (EBRD).

Bulgaria has four major coal-fired generating plants at Maritsa East (2780 MW), Bobov Dol (630 MW), Varna (1260 MW), and Russe (340 MW). The Maritsa East complex operates on large economic deposits of low-grade lignite containing very high levels of sulfur and ash. The Maritsa complex also produces briquettes for domestic heating, which are somewhat fragile and subject to breakage and contain high percentages of sulfur. Bobov Dol operates on low-quality subbituminous coal from uneconomic mines that are slated for eventual closure. Varna and Russe operate on uncertain supplies of low-volatile bituminous coal imported from the Ukraine. Over 60% of the coal-fired units have operated for over 20 years and are candidates for decommissioning or life extension. Coal supplies are limited in respect to both availability and quality. Uncontrolled sulfur emissions from plants burning high-sulfur lignite can reach levels of 18 grams of SO₂/Mcal (20 lb of SO₂/MBtu) or higher, requiring 96%–97% control to reach post-1995 requirements. The priority placed on sulfur control in the past has been low owing to the use of tall stacks for dispersion and lack of local health effects. Plants at present have no provision for controlling NO_x. Large boilers are equipped with ESPs for particulate control, but significant improvements are needed to meet emission standards. A major study on thermal power plant rehabilitation by Bechtel, Energoproekt, and TOTEMA completed in October 1993 under sponsorship of the U.S. Trade & Development Agency (USTDA) placed a high priority on improving unit reliability, selectively retrofitting units with advanced wet FGD or spray dryer methods for sulfur control, enhancing particulate control by ESP modifications or gas conditioning, constructing a CFB cogeneration boiler to supply steam for briquetting, and switching some units to higher-quality U.S. or Indonesian coals (Bobov Dol, Varna, and Russe). The Energy & Environmental Research Center is currently working with Energoproekt and TOTEMA to evaluate specific U.S. clean coal technologies to meet these needs, under sponsorship of DOE and AID.

Major hydropower plants are located at Chaira (735 MW), Rhodope (380 MW), and Arda (274 MW), with 84 smaller plants making up the remaining 580 MW of hydroelectric capacity. An additional 400 MW of capacity at Chaira is at or near commissioning. The availability of hydropower is estimated to be 1.9 TWh in dry years and 4.5 TWh with average precipitation, which represent only 11% and 26% respectively

of the annualized capacity (installed capacity $\times$ 8760 hours/year). The economically exploitable hydropower potential in Bulgaria is estimated to be 10 to 12 TWh.

Electrical transmission in Bulgaria consists of a 200- and 400-kV grid, interconnected with the Ukraine by 750- and 400-kV lines, and with Romania, Turkey, Greece, and Serbia by 400-kV lines. The largest interconnection, with the Ukraine—3150-MW capacity, carries relatively high cost power (5.1¢/kWh in 1991) both to Bulgaria and on to Romania. Peaking power of up to 400 MW is imported from a gas turbine combined cycle plant in Turkey. Power exchanges with Greece and Serbia are more limited due to differences in electrical standards for frequency and voltage regulation that disallow synchronization between the West European UCPT system and the East European IPS system, requiring power exchanges to operate on an "isolated island" principle.

DISTRICT HEATING PLANTS

Hot water for heating is supplied to significant portions of urban populations in the East Central European countries by central facilities that include cogeneration plants, central heating plants, and industrial heat sources (Table 1, Row L). District heating accounts for 28,133 Mtoe in the Czech Republic (72% coal), 44,960 Mtoe in Poland (98% coal), 4383 Mtoe in Hungary (71% gas), and 4120 Mtoe in Bulgaria (divided between coal, oil, and gas). Significant energy losses occur because of heat radiation and leakage, excess fluid temperature, inadequate metering, and distorted fee structures. Where coal is used, district heating plants are a major source of particulate and gaseous emissions, a particular problem in urban settings.

Policy goals include evaluation of district heating systems, elimination of subsidies, encouragement of individual heating systems, substitution of oil or gas for coal, and facility and infrastructure upgrading. Installation of cogeneration facilities based on advanced technologies are underway with the support of western governments and private industry.

BRIQUETTE FUELS

As shown in Row M of Table 1, briquettes made from LRCs are a potential source of energy mainly for domestic use. In addition, briquettes offer the potential for SO_x emission reduction. Two technologies are currently available for briquette production:

- Cold briquetting of HRCs with capture additives for harmful combustibles
- Hot briquetting of LRCs along with a binder or caking coal and additives for capture of harmful combustion products

In Poland, residential heating consumes more than 25 million tons of coal annually (9.5 million tons in household stoves and 8.4 million tons in residential heating systems). Coal use in heavily populated areas contributes up to 22% in total emissions of dust and 86% of SO₂. Since replacement of coal-based energy with electric or gas is not possible in the short term, coal will be replaced with less polluting coal-based briquettes. Although Poland supports no commercial briquette production at present, it is estimated that the country could sustain production of about 2.4 million tons, with about 0.4 million tons going for export.

In 1993, 650,000 tons of briquettes were made in the Czech Republic, all from pulverized lignite. The briquettes are used in small household boilers and stoves. Of the total, 50,000 tons was exported to Slovakia.

The Maritsa plant, east of Sofia, has a monopoly on production in Bulgaria with 1.5 million tons of briquettes produced from the high-sulfur lignite of the Maritsa East field. Briquettes are consumed domestically for household heating. Activities are underway to set environmental criteria for future production.

ENVIRONMENTAL ISSUES AND STANDARDS

Past disregard for environmental protection under the centrally planned economics of East Central Europe prior to 1989 resulted in very severe pollution of air, soil, and water caused by energy extraction and processing, power generation, district heating, heavy industry, and transportation. Many of these problems are related to the use of fossil and nuclear fuels, particularly coal.

Air pollution is the greatest overall cause of concern in the region, with certain areas representing crisis conditions. Total air emissions are greater in Poland (Table 1, Row N), where nearly half the SO_2 , a third of the NO_x , and a quarter of the particulate emissions result from coal-based power generation. However, sulfur dioxide emissions on either a per capita or per area basis are highest in the Czech and Slovak Republics and lowest in Poland; the regional average annual emission of about 0.1 ton SO_2 per person is roughly twice the 1989 level in Western Europe and 50% higher than the 1990 level in the United States. Taking into account transboundary transport of airborne pollutants, the annual average sulfur deposition per unit area is greatest in the Czech and Slovak Republics and in Poland—particularly in the areas of Northern Bohemia and Silesia bordering on the former East Germany. All of the study countries are signatories to the United Nations Economic Commission for Europe (UNECE) 1979 framework convention for long-range reduction of transboundary air pollution, and all are members of the related European Monitoring and Evaluation Program, which monitors emissions and transport of sulfur and nitrogen oxide, ammonia, volatile organic compounds, and photochemical oxidants. In addition, East Central European countries have moved toward much stricter source emission standards similar to those in Western Europe in order to form a basis for affiliation with the EC.

Emission standards vary considerably depending on the size of the source and whether the facility is new or existing or burning domestic or imported fuel. The standards given in Table 1 are the lowest published levels found for large coal-fired boilers where some values varied by information source. The East Central European standards for SO_2 and NO_x are similar to those of the EC, with the exception of the Bulgarian standards for plants existing before 1992. Particulate standards are less stringent in the East Central European countries, owing perhaps to the high level of ash in many of the coals being burned.

The coal mining and power generation industries are endeavoring to improve their handling of land reclamation after open pit mining, acid mine drainage, and disposal of coal preparation residues, combustion ash, and future FGD by-products. Problems of safety in nuclear power plants are being addressed under IAEA guidance, but problems of interim storage and permanent disposal of nuclear waste remain largely unresolved. In addition, municipalities and heavy industry are beginning to address the many sources of inadequately treated sewage and chemical or heavy metal wastes that are polluting many rivers and some agricultural lands.

The urgent need to remediate environmental problems is having to be balanced with other social and economic goals, including employment, energy supply, and privatization. Somewhat different policies and priorities are being followed in various East Central European countries, but all have adopted the underlying principle that the "polluter pays."

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TABLE 1

Energy and Environmental Summary for Selected Countries of East Central Europe

Energy and Environmental Summary for Selected Countries of East Central Europe								
	1		2		3		4	
	Former Czechoslovakia (unless otherwise noted)		Poland		Hungary		Bulgaria	
A Country Profiles	Czech Republic	Slovak Republic						
• Area, km ²	78,700	48,000	312,680		90,030		110,910	
• Population, million	10.4	5.3	38.5		10.3		8.9	
• Labor Distribution, %								
– Industry	38	33	34		30		33	
– Agriculture	8	12	27		16		20	
• Annual Per Capita Electrical Generation, kWh	5160	3770	3450		2800		4310	
• Currency	Koruna	Koruna	Zloty		Forint		Lev	
B Economy								
• 1991 GDP, US\$	• \$44.3 billion, \$2823 per capita	• \$54 billion, \$1409 per capita			• \$23.2 billion, \$2208 per capita		• \$21.4 billion, \$2436 per capita	3, 24, 29, 42, 43
• GDP Trends	• Year-end 1992, Czechoslovakia divided into two countries: industrial Czech Republic and agrarian Slovak Republic; GDP changes in 1993 – Czech Republic (+)1% – Slovak Republic (-)9.3%	• 1992 GDP growth of 1%, 1993 GDP growth of 4%, largest in region			• 1992 GDP declined 4.4%		• 1992 GDP decline of 5.6%, 1993 GDP decline of 2%	
• Foreign Debt/Investment	• Foreign debt \$9.3 billion in 1992, \$594 per capita	• Foreign debt \$48.1 billion in 1992, \$1249 per capita. Debt was reduced to \$33.6 billion (\$846 per capita) in agreement with Paris and London Clubs in spring 1994 (\$25.7 billion to state banks and \$7.2 billion to private banks). Half of trade is with EC countries.			• Foreign debt \$21.9 billion in 1992, \$2121 per capita		• Foreign debt \$12.1 billion, \$1366 per capita	
• Inflation	• 11% in 1992 (Czech 12.5%, Slovak 8.7%)	• 35% in 1993			• 23% in 1992		• Nearly 83% in 1992	
• Unemployment	• 3% Czech, 11.2% Slovak (January 1993)	• 15.6% (December 1993)			• Reached 13.3% in January 1993		• Nearly 16% in December 1992	
• Industry Output	• Industry output -22% (1991), early 1993 industry output -6.7% for Czech Republic	• Industrial production growth 7%, investment growth 3%			• Early 1993, industry output growing at 1.6%		• Early 1993, industrial output continues to decline (~10.9%)	
• Privatization	• Contribution of private sector to GDP in 1992 – Czech Republic 20% – Slovak Republic 20%-21%	• In 1993, as a result of privatization program, 50% of GDP, 60% of employment, and 33% of productive assets are located in the private sector.			• Contribution of private sector was estimated to range from 25% to 45% of GDP (according to source); by mid-1993 less than 10% of the state-owned industry had been privatized (main part of assets bought by foreign investors).		• Privatization of large, state-owned enterprises continues. Contribution of private sector to GDP 10%.	

Continued...

TABLE 1 (continued)

	1	2	3	4	Sources
	Former Czechoslovakia (unless otherwise noted)	Poland	Hungary	Bulgaria	8
C Primary Energy Supply (1992)					
• Consumption, exajoules (1 EJ = 10 ¹⁸ J)					
– Coal	1.44	3.15	0.27	0.32	33.2%
– Petroleum	0.48	0.56	0.31	0.28	29.3%
– Natural Gas	0.46	0.33	0.37	0.19	20.1%
– Nuclear	0.26	0	0.15	0.14	15.2%
– Hydropower	0.01	0.01	0.00	0.01	1.5%
– Electricity, net import/(-) export	0.01	-0.01	0.03	0.01	0.8%
Total	2.66	4.04	1.13	0.95	
• 1991 Energy Intensity, toe/\$k of GDP (calculated in 1987 US\$)	1.43	1.78	1.16	1.06	21
• 1991 Energy Use Per Capita, toe/person	4.05	2.51	2.56	2.58	
D Energy Trends					
• General	• Energy prices raised to market levels • The diversification of crude oil and natural gas and the strengthening of the strategic role of the two republics in European energy are of principal importance – Increase the use of Adria pipeline up to 4.5 Mtyear – Trans-Alpine oil pipeline from Ingostadt to Kralupy (15 Mtyear) – Schwechat-Bratislava oil pipeline (2-3 Mtyear) – Construction of new bunkers (0.6 Mt) and creation of a strategic crude oil reserve – Increase capacities of underground gas storage – The import of Iranian and Algerian natural gas through a new pipeline is considered	• The primary energy balance reshaping: – Elimination of coal monoculture by increasing the share of gas and oil. – Contract for construction of a gas pipeline to western Europe through Poland was signed with Russia in 1993. • Energy price adjustment • Increasing energy production and consumption efficiency	• The elimination of one-sided energy import dependence by import source diversification • The improvement of energy efficiency – Encouraging energy conservation – Restructuring of production • Establishment of market conditions in energy supply – Development of liberalized pricing policy reflecting international value • Public participation in decisions concerning the impact of energy development on whole society	• The reorganization of energy sector by establishing the operating entities as joint stock or limited liability companies, with the government as the sole shareholder • Price reform – Petroleum and gas prices are linked to world market – Prices of heat and coal are increased significantly	D1: 2, 17, 24, 32, 46 D2: 26 D3: 17 D4: 5, 6, 16, 25, 28, 30, 42, 43, 44, 45

Continued...

TABLE 1 (continued)

	1	2	3	4	Sources
	Former Czechoslovakia (unless otherwise noted)	Poland	Hungary	Bulgaria	
• Electrical supply	- Power generation in the nuclear plants is acceptable: - Completion of nuclear plant at Temelin - Necessity to establish definitive underground storage for highly radioactive waste and/or for the burnt-out fuel - Coal-based generation of electricity in northwest Bohemia will be gradually decreased, and desulfurization and denitrification equipment will be installed in those coal-fired plants that remain in long-term operation. - Thermal plants not meeting limits of 1991 Czech Clean Air Act by 1998 will be taken out of operation.	- Rehabilitating and retrofitting of existing power stations (4 GW up to year 2000 and 8.5 GW in the period 2001–2010) - The completion of projects in progress - Opole Power Plant utilizing hard coal (2600 MW) equipped with FGD - Hydro pumping storage plant (750 MW) - Improvement of the transmission system - Interconnection to West European UCPTE system no later than 1997 - Restructuring and privatization of Electricity System - Polish Power Grid Company is the sole transmission company. - Main thermal plants will be organized in seven major joint stock companies. - Central heat and power plants will operate as 15 independent joint stock companies. - All pumped storage power plants, as the only source of peaking power, will be organized within a single stock company. - A role for nuclear power is foreseen in the next 15–20 years.	- Expected interconnection to UCPTE in 1997–1998 - Construction of gas-fired combined cycle plants for peak demands at Kelenfod and Dunamenti; utilization of gas substituted for imported low-sulfur oil at existing dual-fired plants. - Construction of 4-bcwm per year pipeline link to the West through Austria - After year 2000, new power plants will be needed; nuclear or hard coal power plants are considered.	- Reduction of imported fossil fuels and improved utilization of nuclear capacity - Resolving safety concerns at Kozloduy nuclear power plant - Upgrading of coal-fired plant to improve efficiency, availability, and emissions control	
E Environmental Priorities	- Air, water, and soil pollution in Northern Bohemia from mining, industry, coal-fired power production. - Air pollution abatement is the highest priority. - Reclamation of coal and uranium mines	- Dispersed-source air emissions in upper Silesia - Kraków region restoration program - Transboundary SO₂ emissions - Surface water pollution from saline mining waters in South	- SO₂ and particulate emissions from coal-fired electrical generation - NO_x and hydrocarbon emissions, particularly from vehicles - Permanent and interim nuclear fuel disposal site areas	- Serious environmental problems in "hot spot" areas (12% of total area) - Air pollution - SO₂ and particulate emissions - Land pollution - Heavy metals contamination - Salinity and landfill problems	E1: 2, 24, 32 E2: 25 E3: 17, 22 E4: 13, 16, 45

Continued...

TABLE 1 (continued)

	1	2	3	4	Sources
	Former Czechoslovakia (unless otherwise noted)	Poland	Hungary	Bulgaria	
F	- High contribution to transboundary pollution in Europe - Storage capacity for spent nuclear fuel	Effective management of coal conversion wastes through improved disposal and increased utilization		- Water pollution - Steady contamination stream - Inadequate sewage systems	
Coal					
• % of energy supply/uses	52% (1990-1991) 50% (1992) (21% from high-rank coal [HRC], 33% from low-rank coal [LRC] in 1991)	78% (1990-1991) 76% (1992) highest in Europe	24.0% (1990-1991) 19% (1992), lowest in region	33% (1990-1991) 38% (1992) (32% from LRC) - Two-thirds for heat and power, one-quarter for industry, remainder for household	F1: 17, 46 F2: 26 F3: 17, 18 F4: 1, 5, 6, 7, 8, 14, 16, 44, 45
Consumption	102 Mt (1992) down from 143 Mt in 1984	227 Mt (1992) down from 294 Mt in 1988	17 Mt (1992), down from 28 Mt in early 1980s	39 Mt (1992), level since early 1980s	
Goals/special needs/trends	- Reduce coal use 44% (particularly low quality brown coal) by 2000, substitute nuclear energy and natural gas - Possibilities of delivery of coal by Danube-Main-Rhine Canal - Reserves in developed deposits, at present production rate, are about 80 years for hard coal and 40 years for brown coal.	- Reduce the high level of dependence on coal and diversify energy base - HRC, a valuable source of foreign currency, is produced mainly from underground mines; production is down by one-quarter from 1980 to 1990 because of cost/price squeeze; objectives are to close the 10% of the mining capacity with the highest costs while retaining flexibility to boost production for export, to use coal in short term for barter, and to reform costly regulations (example: requiring that all seams greater than 0.8 m in thickness be mined). Production projected to be 140 Mtyr next 20 years. After year 2000, export of 11 Mt is planned, and the import of 5-10 Mt of steam coal is under consideration to supply energy to the Baltic coast region. - LRC production has doubled since 1980 and is projected to remain level to 2010.	- All of Hungary's coal mining and preparation capacities are divided between eight regionally based companies: Mecsek, Veszprem, Orsolya, Tataanya, Dorog, Nograd, Borsad, and Matraajla. - HRC mining is uneconomical because the coal has a low calorific value, deep mining conditions are generally unfavorable, and productivity is low (average output from deep mines 1.54 t per shift, per worker). In September 1990, the Coal Mining Restructuring Center was established to reorganize companies to work toward financial viability.	- Underground HRC mines have unfavorable geology with high mining costs; policy is to reduce noneconomic production of bituminous and subbituminous coals depending on social needs. - Lignite surface mines are economical; production increase of 20% is possible without major investment, and policy is to increase production.	

Continued...

TABLE 1 (continued)

	1		2		3		4	
	Former Czechoslovakia (unless otherwise noted)		Poland		Hungary		Bulgaria	
• High-rank coal (HRC)								
– Total recoverable reserves/annual production	3330 Mt	25.7 Mt (1987)	45,040 Mt	193 Mt (1987)	100 Mt	2.1 Mt (1989)	30 Mt	0.4 Mt (1988)
– Main coal basin	Ostrava-Karvina field, southern extension of Upper Silesian Basin		Upper Silesia Coal Basin		Mecsek field, southwestern Hungary		HRC fields include the Balkan Basin, east central Bulgaria, and Dubrudza field in easternmost Bulgaria.	
– Recoverable reserves/annual production	–	22.6 Mt (1988)	39,900 Mt	188.5 (1988)	100 Mt	2.1 Mt (1989)		
– Proximate analysis								
Ash, wt% dry	15.1		11.05–16.21		Variable, weakly caking bituminous coal with high ash and sulfur; only domestic source of coking coal; deposits are steeply dipping and heavily disturbed; energy content variable 13.2–14.9			
Sulfur, wt% dry	0.6		0.86–1.99					
Moisture, wt% as mined	3.0		–					
Heating value, (MJ/kg)	25.5		28.70–32.10					
• Low-rank coal (LRC)								
– Recoverable reserves/annual production	8850 Mt	101 Mt (1987) (90% surface mined)	11,700 Mt (all surface minable)	73.2 Mt (1987)	3650 Mt (all surface minable)	18 Mt (1989)	3700 Mt (95% surface minable)	35.3 Mt (1988)
– Main LRC regions	• Most brown coalfield in North Bohemia, Czech Republic		• Belchatów field, central Poland		• Matraalja lignite field, northwest Hungary		• Maritsa East, south central Bulgaria	
– Recoverable reserves/annual production	5135 Mt	74.1 (1987)	–	–	2863 Mt	5.3 Mt (1989)	2110 Mt	27 Mt (1987)
– Proximate analysis								
Ash, wt% dry	26.0–44		37.0–40		39.5		30.1–45	
Sulfur, wt% dry	0.5–3		0.8–3		0.8		2.8–4.1	
Moisture, wt% as mined	30 average		18–45		45.3		49–57	
Heating value, MJ/kg	9.0–18.6		6.7–15		6.7		5.5–6.7	
• 1 seam, 40–150 m deep and 20 m thick, nearby Solokov brown coalfield has a capacity of 18 Mt/year.								
• Belchatów mine among largest in the world, single seam, 50–70 m thick, shallow and free of disturbance, design capacity 40–50 Mt/yr; nearby Konin field has a single seam 6–20 m in thickness.								
• 2 mines, 6 seams 4–14 m thick, bucket-wheel excavators for overburden removal, seam removal by power shovel or bucket-wheel excavator								
• 3 seams, main seam 3–25 m in thickness, overburden 30–110 m, high water content and variable ash content, among the lowest grade coals in use in the world								
• Bucket-wheel excavators with overburden to coal ratios of 4:1.								

Continued...

	1	2	3	4	Sources
	Former Czechoslovakia (unless otherwise noted)	Poland	Hungary	Bulgaria	
G Petroleum					8, 18, 32, 43, 44, 45, 46
• % of energy supply/uses	• 18.1% (1990-1991) • 17% (1992)	• 13.8% (1990-1991) • 12% (1992) lowest in Europe, down from peak of nearly 16% in 1980	• 27.6% (1990-1991) • 28% (1992)	• 29.3% (1990-1991) • 19% (1992)	
• Consumption	• 1992 consumption of 206 kbd (232 kbd in 1991) down from the peak of 320 in 1987	• 1992 consumption of 227 kbd (275 kbd in 1991) down from peak of 350 kbd in 1988	• 1992 consumption 140 kbd (23% domestic production) down from 161 kbd in 1991 and a peak of 227 kbd in 1985	• 1992 consumption 72 kbd, down from 118 kbd in 1991 and peak levels of 275-295 kbd in the mid-1980s	8
• Goals/special needs/trends	• Policy to diversify foreign supply • Per capita oil use lower than found in OECD because of fewer automobiles per capita and dominance of coal for heating	• Policy to diversify foreign supply, develop domestic resources (by licensing foreign companies to explore new deposits), expand, upgrade, and privatize supply and distribution infrastructure • Share of motor gasoline is increasing in product refining; 9.5 persons/passenger car vs. 1.7 in U.S., but number of autos is growing; increased demand (up 75% by 2010) projected for transportation and secondarily for industry (not for domestic heating)	• Policy to diversify foreign supply, develop domestic supply, and upgrade infrastructure and distribution • 5.9 persons/passenger car (1989) vs. 1.7 for U.S.	• Policy to diversify foreign supply, develop domestic supply, and upgrade infrastructure and distribution • Foreign companies acquiring and exploring onshore and offshore blocks • Provide licensing for foreign involvement in exploration production, refining, and distribution	G1: 24 G2: 26 G3: 22 G4: 45
• Proved reserves/production	15 Mb year-end 1993, down from around 20 Mb in the mid-1980s 2 kbd in 1993 400 producing wells 5 bd per well	36.8 Mb year-end 1993, down from 45.9 Mb year-end 1991 1993 production 3.4 kbd (about 1.2 Mb/yr) down 5.6% since 1992; production flat since decline in early 1980s (1981 production of 2.3 Mb/yr) 2302 producing wells 1.5 bd per well Production since the mid-1980s, but industry remains underdeveloped	139 Mb year-end 1993 1993 production 31.7 kbd (11.6 Mb/yr) down 5% from 1992, 1991 production 15.6 Mb 1776 producing wells 17.8 bd per well 4 rigs active	15 Mb year-end 1993 1993 production 1.0 kbd (0.365 Mb/yr) down from 0.423 Mb/yr in 1991 100 producing wells 10 bd per well	12, 36

Continued...

TABLE 1 (continued)

	1	2	3	4	Sources
	Former Czechoslovakia (unless otherwise noted)	Poland	Hungary	Bulgaria	
• Sources of supply	• 99% imported • CIS will supply 6 Mt oil to Czech Republic in near term in response to Czech purchases of North Sea natural gas from Western Europe (spring 1994). • Adria pipeline supply lost due to unrest in Yugoslavia.	• 98.5% imported • In 1990, CIS supplied 89% of petroleum by pipeline; by 1993, imports diversified, the Middle East is now key source. • 40% supply through port of Gdansk and by pipeline south. • Important domestic sources cited for 1992 include Nosowka field (discovered in 1988) with two wells producing 334 bd and Wysoka-Kanienska field (discovered in 1979) with four wells and 292 bd production.	• In 1993, 77% imported, 23% domestic • One-half domestic production (12% supply), one-third cumulative production, and two-fifths producing wells from Algyo field (discovered in 1965) in the southeast near Szeged	• 99% imported	G2: 35, 36
• Infrastructure/facilities/distribution	• 1990 refinery capacity (crude) 455 kbd (22.7 Mty) • 6 refineries: Bratislava (162 kbd crude), Kilin, Kralupy, Pardubice, Strazke, Zaluzi. Zvolen; Kralupy refinery is undergoing expansion and upgrading (spring 1994).	• 1990 refinery capacity 385 kbd (19.2 Mty) of crude • 9 refineries: major refineries include Plock (252.4 kbd crude, catalytic cracking 48.7 kbd, catalytic reforming 31.2 kbd; catalytic reforming construction spring 1994) and Gdansk (60 kbd crude, hydrotreater expansion and catalytic reformer construction spring 1994); minor facilities include Czechowice, Glinik Marlampolski, Jasto, Jealicze, Kralaty, L. Warynski, Trzebinia, Plock (remaining 73 kbd crude capacity). • Gdansk facilities changed from export to port of entry and Gdansk/Plock pipeline refitted to move product south into heartland; additional 40 Mb/yr=6 Mtyr refinery required in the south and additional oil and product pipelines required. • Distribution network for lubricants and vehicle fuels expanding with greater privatization in the distribution sector.	• 1990 refinery capacity 220 kbd (11 Mty) • 3 refineries: Szazhalombatta (150 kbd crude, 20 kbd catalytic cracking, 23 kbd catalytic reforming; undergoing construction for MTBE unit spring 1994), Leninvaros (60 kbd crude), Zalaegerszeg (10 kbd crude)	• Refining capacity 300 kbd crude • 3 refineries: Burgas (240 kbd crude), Pleven, Ruse	34, 37

Continued...

TABLE 1 (continued)

	1	2	3	4	Sources
	Former Czechoslovakia (unless otherwise noted)	Poland	Hungary	Bulgaria	
H Natural Gas					8, 18, 32, 43, 44, 45, 46
• % of energy supply/uses	• 17.3% (1990–1991) • 19% (1992)	• 8.2% (1990–1991) • 10% (1992)	• 32.7% (1990–1991) • 36% (1992)	• 20.1% (1990–1991) • 25% (1992)	
• Consumption (dry natural gas) (bcum = 10 ⁹ m ³) (bcuft = 10 ⁹ ft ³)	• In 1992, consumption 13.7 bcum (463 bcuft), down from peak of 15.0 bcum (530 bcuft) in 1990	• In 1992, consumption 10.3 bcum (363 bcuft, domestic) down from peak of 13.2 bcum (465 bcuft) in 1989	• 1992 consumption 9.7 bcum (342 bcuft) down from peak of 12.1 bcum (428 bcuft) in 1989	• 1992 consumption 5.6 bcum (198 bcuft) down from a peak of 6.8 bcum (241 bcuft) in 1990	8
• Goal/special needs/trend	• Diversify foreign supply, develop domestic supply, upgrade, expand, and privatize infrastructure • Projected to import 21 bcum of gas by 2005	• 40% residential; growth projected at 4%/yr through 2010; policy to diversify foreign supply, develop domestic supply, upgrade, expand, and privatize infrastructure	• Diversify foreign supply, develop domestic supply, upgrade, expand, and privatize infrastructure	• Diversify foreign supply, develop domestic supply, upgrade, expand, and privatize infrastructure	
• Reserves/production	14 bcum 696 Mcum (1990) fields at capacity	1300 tcm coal bed methane resource Domestic production 4 bcum (142 bcuft), 7.9 bcum in 1978	Remaining reserves 123 bcum (4349 bcuft), estimated additional reserves 223 bcum, 175 bcum recoverable 1992 production 2.46 bcum (170 bcuft) down from 4.8 bcum in 1985		H1: 25 H2: 27 H3: 23
• Sources of supply/ infrastructure/facilities/distribution	• About 93% of gas supplies are imported through Brotherhood and Transgas pipelines from FSU, approx. 3% are domestic conventional production, remainder are manufactured gas. • 1/93 agreement for 8 bcum/yr CIS gas pipeline across Czech Republic to Stegal-Midal pipeline in Germany; 2/94 FSU will supply 7 bcum (245 bcuft) to Czech Republic in response to competition from Western European suppliers. Increasing supply through Transgas pipeline system, 71% in 1991. • Underground storage capacity of 3 bcum	• 1991 Imports of 7.3 bcum (258 Bcuft) from FSU – CIS–Western Europe 101-cm pipeline – Construction underway on Yamal CIS–Western Europe pipeline via Poland; Polish purchase rights to 0.4 bcum (14 bcuft/yr, 3.5% 1992 consumption) of 1.9 bcum (67 bcuft/yr) shipments • Other potential foreign sources include North Sea gas via Germany or under the Baltic, as well as Algerian gas via Italy and Yugoslavia.	• In 1993, gas-processing capacity stood at 947 Mcuft/d and throughput at 520 Mcuft/d (down from 1078 Mcf capacity and 684 Mcf throughput in 1989). Major processing plants include the Szeged plant at Csongrad (318 Mcuft/d capacity, 254 Mcuft/d throughput), Ulies plant at Csongrad (160 Mcuft/d capacity, 70.5 throughput), Hajdusoboszo plant at Hajdu-Bihar (155 Mcuft/d capacity, 70.6 throughput) and the Endrod plant at Bekes (134 Mcuft/d capacity, 70.6 Mcuft/d throughput). Minor plants include Babosca, Barcs, Berekturdo, Demjen, Heves Ebes, Kiskunhalas, Szank, and Tazlar.		H1: 15 H2: 38 H3: 36
					3, 38, 42, 43

Continued...

TABLE 1 (continued)

1												
2												
3												
4												
Sources												
H1: 43												
H3: 33												
I1: 12												
I3: 17												
I4: 13												
9, 43												
• % of energy supply												
• 9.8% (1990-1991)												
• None is consumed within Poland. However, Poland participated in construction of nuclear power station in former Soviet Union; Poland now imports electric power from this source.												
• 13.3% (1990-1991)												
15.2% (1990-1991)												
• Six underground mines and 11 in situ leaching operations Yellowcake from domestic deposits was sold to the former Soviet Union until 1990. Operations are noncompetitive, and mine closings began in 1991.												
• Yellowcake from domestic deposits enriched in the former Soviet Union												
• The Mecsek uranium mine is noneconomical.												
• 34.8 TWh (1992), down 15% from a peak of 41 TWh in 1989												
• 38.2 TWh (1992), down 22% from a peak of 49.2 TWh in 1988												
J1: 17, 41, 43, 46												
J2: 8, 26												
J3: 17, 18												
J4: 1, 13, 43, 45												
8, 9, 11, 27, 43, 44												
• Generating capacity (GW, %)												
Czech Republic Slovak Republic												
10.17 77% 1.21 22%												
29.54 92%												
0.42 2%												
2.01 29%												
3.06 44%												
1.76 13%												
2.05 6%												
0.05 1%												
6.88												
11.09												
4.91 44%												
0.45 4%												
3.76 34%												
1.97 18%												
• Annual electric production (TWh, %)												
1991 1992 1991 1990												
Year												
Coal 40.4 75% 4.2 21% 129.2 97.3% 8.2 28% 20.3 53%												
Oil and gas (est.) 12% 0 6.6 23% 1.5 4%												
Nuclear 12.1 23% 2.4 59% 13.8 48% 14.7 38%												
Hydropower 1.2 2% (est.) 8% 3.6 2.7% 0.2 0.7% 1.9 5%												
Total 53.7 11.7 132.8 28.8 38.4												
• Imports (TWh)												
• No Information • 5.0 • 7.5 (net) • 2.7 (from Ukraine)												

Continued...

TABLE 1 (continued)

	1 Former Czechoslovakia (unless otherwise noted)	2 Poland	3 Hungary	4 Bulgaria	Sources
• Transmission	• 220 kV and 440 kV grids owned separately by CEZ and SEP; district companies operate lines <220 kV.	• Major lines 400 kV and 220 kV, 750 kV to former USSR	• Grid system with 750 kV, 440 kV, and 220 kV lines, connections with Serbia, Romania, and Slovak Republic (440 kV) and with the former USSR (440 kV and 750 kV)	• Grid system with 440 kV and 220 kV lines. Major connections with Romania and Turkey (440 kV) and (Ukraine 750 kV).	
• Goals/special needs/trends	• Electrical generation is thermal (coal) dominated; increased coal use is opposed on the domestic front because of concerns for land and air quality, while nuclear development is opposed by neighboring nations. World Bank study in favor of upgrading existing thermal plants and transmission infrastructure instead of nuclear. Czech consumption is projected to grow to 59–62 TWh by 2010; nuclear consumption has quadrupled since 1982, 12% (1992); nuclear expected to increase to 5.8 GW from 3.3 GW (1991) by year 2010 as a replacement for coal-based electrical energy. Tremelin (2000 MW) nuclear station was approved in March 1993 with Westinghouse (not CIS) supplying control technologies and fuel (\$320 million).	• Completely dominated by thermal (coal) generation. Nuclear imports amount to 1%, and there are no immediate plans to initiate nuclear plants.	• Electrical sector divided between thermal and nuclear; electrical need projected to increase to 52 TWh in year 2010 (Hungarian Electricity Board "realistic" scenario); nuclear and coal options are under consideration; nuclear capacity could double in the near term (two 1.0–GW plants).	• Domestic sector dominated by thermal (coal) with significant nuclear and hydro components; coal-based generation is expected to increase modestly while nuclear will remain level to 2010. Kozloduy reactor units 1–4 are designated the most deficient in region by IAEA (1991), but remain in operation due to lack of available replacement capacity.	• Power plants can provide only a maximum of 7.2 GW due to low availability of thermal and nuclear plants, coal production constraints, and irregular coal import from the Ukraine. In 1993, EBRD approved 250 million ECU grant to upgrade Kozloduy plant.

Continued...

TABLE 1 (continued)

	1	2	3	4	Sources
	Former Czechoslovakia (unless otherwise noted)	Poland	Hungary	Bulgaria	
• Actions/needs	• SEP is constructing second nuclear plant in Mochovce (880 MW by 1995 and 880 MW by 1997). • The strengthening of interconnections with neighboring countries is important to SEP in order to enhance the trade of electricity. • Surplus generating capacity of about 30% will delay new plant construction. Retrofitting of coal-fired plants for SO₂ and NO_x control is under way. Future plants will be either gas-fired combined cycle, lignite-fired AFBC, PFBC or IGCC, or nuclear.	• Upgrade coal-fired plants to meet emission standards by 1998. Improve plant efficiency and availability	• Implement demand-side management; retrofit or repower old coal-fired units with FGD or AFBC; install gas-fired combined cycle peaking capacity; plan for a new baseload power station of 2000 MW based on hard coal, lignite, or nuclear power by the year 2000.	• Eliminate high cost (\$0.05 kWh) imports from CIS and obtain peaking power from Turkey; complete 2x216-MW hydro units at Chaiira; decommission nuclear units #1 and #2 at Kozloduy but refit units #3 and #4; upgrade safety on all 2880-MW nuclear slated for continued operation; rehabilitate coal-fired plants for life extension, emissions control, and fuel switching	
K Coal-Fired Power Plants					
• Actions/needs	• Slovakia – Retrofit power plant complexes in Voljany, Novaky, and Kosice (FGD, fluidized-bed boilers, turbogenerators and de-NO_x units)	• Modernization is needed in order to improve reliability and reduce emissions. • By 2000 4 GW should be modernized, by 2010 next 8.6 GW. • By 2000 a new coal-fired plant in Opole (2160 MW) • 750-MW storage pump unit under construction	• Comprehensive program of coal-fired power station rehabilitation (10 stations with 59 units), date of completion: 1992.	• A study of thermal power plant rehabilitation was conducted in 1993 under USDA sponsorship addressing 2950 MW of coal-fired capacity. High priorities were given to the following: – Unit reliability – A cogeneration CFB boiler to supply steam for briquetting – Sulfur control by advanced wet FGD or spray drier methods – Particulate control enhancements – Fuel switching to higher quality imported U.S. or Indonesian coals	K1: 17, 41, 45 K2: 26 K3: 18 K4: 1, 14, 16, 45 5, 6, 43

Study implementation may be affected by decommissioning of the Kozloduy nuclear units (3760 MW).

Continued...

TABLE 1 (continued)

	1		2		3		4		Sources
	Former Czechoslovakia (unless otherwise noted)		Poland		Hungary		Bulgaria		
• Average age/general condition			• Most units >20 years old (average 22 years) • Generally no desulfurization units and NO _x control		• Most units > 25 years old		• Over 60% of major equipment has been operated for more than 20 years, decommissioning or life extension necessary.		
L District Heat (DH) and Combined Heat and Power (CHP)	DH	CHP	DH	CHP	DH	CHP	DH	CHP	24
• Fuels (1991, thousand toe)									
– Coal	7951	–	9675	34385	338	602	29	1171	
– Petroleum products	2507	–	381	179	773	274	1457	259	
– Gas	2543	–	334	6	2223	873	254	950	
Total fuel	13,001	–	10,390	34,570	3334	1749	1740	2380	4120
• Goals/trends	• In 1992, heat and CHP plants were separated from Czech Power Works, and privatized companies were created. District heating requires 3.5% of total natural gas (0.1% in OECD Europe). In 1992, coal was used to heat 35% of all dwellings due to its low price; 30% potential savings are identified in heat-only stations, heat transport and distribution by concentrating on cogeneration and reducing heat losses (15%–18% losses due to old piping network, high fluid temperature, and poor metering).		• 70% of dwellings in urban areas are supplied with heat and 50% with hot water; 45% of this energy is supplied by cogeneration in the power industry (this trend is assumed to continue); remaining heat is from industry surplus or heating plants. Some cogeneration plants are producing only heat due to low power demand. • District heating plants will continue to rely on coal except in central urban areas where natural gas will be used due to environmental concerns. • Major problems are severe pollution (from smaller plants particularly), heat losses due to radiation and leakage, and improper metering of energy.		• 635,000 apartments out of 3.9 million are supplied by 59 district heating companies; 170,000 apartments have central heating. Several DH companies have serious debt due to unpaid bills. Heat is generated in DH plants or purchased from CHP plants. • Most district-heated apartments have no metering or heat control. • Transmission losses assessed to range between 30%–40%. • Since 1992, prices have been controlled by municipalities.		• Three district heating plants require either life extension or conversion to natural gas; conversions are not foreseen in near term.		L1: 25 L2: 27 L3: 23 L4: 45

Continued...

TABLE 1 (continued)

	1	2	3	4	Sources *
	Former Czechoslovakia (unless otherwise noted)	Poland	Hungary	Bulgaria	
• Actions/needs	U.S. Trade Development Program granted \$1.5 million for power plant rehabilitation.	- World Bank loans \$250 million (\$60 million from EBRD) partially for DH upgrade, April 1990 \$340 million (\$50 million from EBRD) partially for modernization of DH, 1991 \$120 million to promote privatization of Kraków-Lęg Heat and Power Plant (1400 MW of thermal capacity) \$26 million for conversion of two coal-fired boilers in Kraków to natural gas - Elimination of energy subsidies and price liberalization (households paid less than industrial users for gas, electric, and district heating and hot water) - Reorganization of heat generation companies, commercialization of gas and heat distributors - Switch from coal stove heating to gas heating for individual households	- EIB energy project: combined cycle gas turbine (district heating), \$35 million of ECU - World Bank loans for energy/environment, \$125 million reconstruction and conversion of several gas-fired power stations to combined cycle cogeneration		
	- Assessment to determine which units could be converted into CHP, rebuilt, or reconstructed (to reduce energy demand by 30%). - Elimination of all subsidies (direct, indirect, and cross-subsidies)		- Several thermal power plants have been upgraded by installation of gas turbine CHP units (700 MW of additional electric capacity): Dunamenti, Kelenfold, Újpest, Debrecen, and Kispeszt. - Capital Investments in DH networks and heat plants - Modification of fees structure	USTDA \$650,000 grant to evaluate district heating plants in Sofia, Koslov, and Pernik.	
M Briquettes					M1: 29 M2: 40 M4: 4
• Production/consumption	1993 production of 650,000 tons from pulverized lignite, 50,000 tons exported to Slovakia.	- No current production - Potential production 2.4 Mt with 0.4 Mt for export - In the second part of 1994, Blachownia will start production of briquettes (assumed output: 200,000 tons per year).		1.5 Mt of Maritsa East lignite is used to make briquettes. - Consumed domestically for heating	
• Goals/issues/trends		Demonstration plant of smokeless fuel in Institute for Chemical Processing of Coal (Zabrze)		- Recommendation to modernize the briquetting process or switch to low-sulfur coal - Major source of urban particulate and SO_x emissions - Attempts to remove sulfur have been unsuccessful	
N Environmental Issues					
• Emission (thousands of tons)					

Continued...

TABLE 1 (continued)

	1	2	3	4	Sources
	Former Czechoslovakia (unless otherwise noted)	Poland	Hungary	Bulgaria	
SO ₂	2814 675	(1989) (1990)	2,760 600	1030 150	N1: 25 N2: 27
NO _x	—	(1990)	2524	1050	N3: 23,— N4: —
CO	221375		383000	—	
Particulates	1484		1420-193	808	
Organic	—	(1991)	0 (1990) 1231		
					2, 5, 6, 19, 2120, 26, 31, 32
• Lowest published emission standards for large coal-fired boilers ¹ Units: mg/m³ g/GJ lb/MBtu					
SO ₂	New and existing	New and existing after 1997		Coal source	Existing before 1992
	Over 300 MW			Over 50 MW	
EEC 400 144 0.30	500	555	400	650 234 b.4 8	3500 1260 2.59 2000 1260 1.48
>500 MW	180	200	144	domestic imported	
				650 234 b.4 8	
NO _x					
EEC 650 234 0.48	234	417	300	600 216 b.4 4	1000 350 b.74 1300 468 b.96
>500 MW	650	150	0.32	domestic imported	
				600 216 b.4 4	
Particulate	Over 50 MW				
EEC 50 18 0.037	100	194	No Standards	100 35 b.07 4	200 72 b.15 150 48 b.11
>500 MW	36	70	0.15	domestic imported	
				80 29 b.059	

Continued...

TABLE 1 (continued)

4				
1		2	3	4
Former Czechoslovakia (unless otherwise noted)		Poland	Hungary	Bulgaria
Sources				
• Goals/issues/trends	• Air pollution – Former CSFR is a major contributor to transboundary air pollution in Europe. – Serious pollution in Northern Bohemia and Northern Moravia – Two power generating plants among the top 25 emitters of SO₂ cause about 80% of the total SO₂ and NO_x emissions. – In 1990 the SO₂ emission per capita was 3 times more than OECD countries. – Former CSFR contributes 1.1% of total global CO₂ emission. – Transport is attributed with about 45% of CO emissions, 15% of organic, 15%–22% of NO_x, and 3% of SO₂ emissions. – By 1992 only ESPs and a few scrubbers are installed on large combustion units. • Serious problems are caused by open pit mining, acid mine drainage, and groundwater pollution. – 35,000 hectares of soil devastated and approximately 65,000 occupied by solid waste • Adverse environmental impacts result from nuclear fuel cycle. Sulfuric acid solutions from chemical leaching in situ threaten groundwater reserves (Straz-Northern Bohemia).	• "National Environmental Policy" since 1990 defines near-, mid-, and long-term goals • Close or retrofit the most polluting manufacturing plants • Reduce SO₂ emission to 2.9 Mt by year 2000 (achieved in 1992) – FGD units in Skawina, Belchatów, Polaniec, Opole – Coal-washing at 18 mines • Reduce NO_x emission to 1.3 Mt by year 2000 (achieved in 1990) • Reduce particulate emissions from industrial plants by 50% (compared to 1980s level) • Remediate pollution in Upper Silesia and other regions: – "Ecological disaster" area, the most polluted region of the country – U.S./Polish program of Kraków restoration (low emission) • Reduce pollutant discharge into rivers by 50%	• Priorities of Ministry of Environmental Protection and Regional Development (in 1991) • Vehicle emissions: – Particulate emission and unburned hydrocarbons from diesel buses and trucks – NO_x emissions from transport are a lower priority. – Introduce buses fueled by natural gas – Reduce lead content from 0.4 to 0.15 g/L in gasoline, to raise production of unleaded gasoline and reduce the sulfur content in diesel oil to 0.2% (DKV refinery in Szazhalombatta) – Promote cars with catalytic converter and four stroke engines (diluents reduction) • Reduce emissions of SO₂, NO_x, hydrochloric acid and toxic substances in highly industrialized regions – 12% of total area below standards of WHO (from Lake Balaton through Budapest to Miskolc)	• Serious environmental problems in "hot spot" areas devoted to heavy industry (12% of population affected). • High levels of air pollution, eroded agriculture lands, and heavy metal pollution occur in regions around the major cities (Sofia, Pernik, Burgas, Varna, and Plovdiv). • Air pollution – In 1991 SO₂ emissions were 9 times and NO_x twice those of the world average. – Significant air pollution due to traffic in cities (average age of cars, 14 years) • Land pollution – Heavy metals contamination (lead, zinc, copper, and arsenic) in regions of Srednogie, Plovdiv-Asenovgrad and Kardjali (47,000 hectares contaminated in excess of norm.) – Salinity affects about 40,000 hectares. – Landfill problems in most Bulgarian communities, which contributes to soil and groundwater pollution
	- N1: 24 - N2: 26 - N3: 22 - N4: 45 5, 22			

Continued...

TABLE 1 (continued)

1 Former Czechoslovakia (unless otherwise noted)	2 Poland	3 Hungary	4 Bulgaria	Sources
• Actions: – About 80% of CEZ investment in 1992–1996 to reduce environmental impact – Install FGD on Prunerov II, Prunerov I, Pocerady, Tusimice II, Melnik III (totally 3600 MW) – CEZ's Power and Environmental Project supported by the World Bank (air pollution) – By 1994 catalytic converters required in all new gasoline-fueled cars – "Polluter Pays Principle" since 1991	• Reduce saline water discharges from coal mines into surface waters by 50% • Increase waste reutilization (ash and slag from heat and power plants, metallurgical and chemical waste) • 10% of Polish debt (Paris Club) to be exchanged for environmental protection investment (April 1991) • "Polluter pays", (1991) 40% of expenditures on environmental protection came from charges and fines. • Privatization and environmental policies are in conflict.	• Reduce emission of SO₂ and NO_x from coal-fired power plants – Reduce SO₂ emission from electric power industry by 40% (in 1990 no power station equipped with FGD) – MVM plans to reduce NO_x emissions through modification of boiler designs – Hungary's goal was to reduce SO₂ emissions 30% by 1993 (from 1980 level) and limit emissions of NO_x to 1987 level after 1994. • Nuclear waste – Permanent and interim fuel disposal sites are required (the spent fuel pool at Paks is only for 2.5 years in 1991).	• Water pollution – Contaminant streams (chemicals, heavy metals, and sewage effluents) discharged into the rivers – Only minor number of sewage systems have adequate treatment facilities. – Only one river is considered clean; six rivers are seriously polluted with ammonia, oil, copper, and nitrate. • Nuclear – Spent fuel storage is needed since CIS no longer accepts spent fuel rods. – Management of low and intermediate level nuclear waste	
			• In coal-fired power stations: – FGD has not been a top priority due to tall (235 m) stacks, high retrofit costs, and lack of health impacts. – ESP's perform below design and require upgrade. – NO_x controls for high-moisture/ash lignites require site-specific study. – Large volume of ash from high ash coal may pollute water.	

¹ Values are approximate based on rounded conversion factors representing averages for high- and low-rank coals.

100 mg/m³ = 36 g/GJ – LHV

1 lb/MBtu = 476 g/GJ – LHV

100 mg/m³ = 0.074 lb/MBtu – HHV

Continued...

LIST OF ABBREVIATIONS

AFBC	Atmospheric fluidized-bed combustion
CEZ	Czech Power Works
CFBC	Circulating fluidized-bed combustion
CHP	Combined heat and power facility (cogeneration facility)
COE	Committee on Energy (Bulgaria)
DH	District heating facility
DOE	United States Department of Energy
ERBD	European Bank for Reconstruction and Development
ESP	Electrostatic precipitator
FBC	Fluidized-bed combustion
FGD	Flue-gas desulfurization
FSU	Former Soviet Union, geographical area includes the several "republics," of the former Union of Soviet Socialist Republics (USSR), including Russia; Commonwealth of Independent States (CIS) corresponds only to Russia
GDP	Gross domestic product
HRC	High rank coal, includes anthracite and bituminous coal
IAEA	International Atomic Energy Agency
IEA	International Energy Agency, an agency within the OECD
IGCC	Integrated gasification combined cycle
IMF	International Monetary Fund
LRC	Low rank coal, includes subbituminous or brown coal, and lignite
MTBE	Methyl tertiary-butyl ether
MVM	Hungarian Electricity Works
NEK	National Electric Company (Bulgaria)
OECD	Organization for Economic Cooperation and Development
PFBC	Pressurized fluidized-bed combustion
PPGC	Polish Power Grid Company
SEED	Support for East European Democracy Act of 1989 administered by the U.S. Agency for International Development
SEP	Slovak Power Works
UCPTE	West European Power Grid
UNECE	United Nations Economic Commission for Europe

USTDA United States Trade and Development Agency

WB World Bank

UNITS AND CONVERSIONS

b	barrel (42 U.S. gallons), gallon = 3.785 L
B	10^9 , billion, giga (G)
Btu	British thermal unit
cal	calories
cd	calendar day
cu	cubic
cum	cubic meter
daf	dry, ash-free
EJ	exajoules
ft	feet
g	gram, mg = milligram (10^{-3} grams)
GW	gigawatt, 10^9 watt
J	Joules
k	10^3 , thousand, kilo
kbd	thousands of barrels per day
m	meter
M	10^6 , million, mega
t	ton
toe	tons of oil equivalent
TWh	terrawatt (10^{18} watt) hours
V	volt

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