DEMONSTRATION PLANTS

MASTER

U.S. DEPARTMENT OF ENERGY

Division of Coal Conversion

QUARTERLY REPORT

January - March 1977

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Publication Date: December 1977

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JANUARY - MARCH 1977

U.S. DEPARTMENT OF ENERGY

Division of Coal Conversion

Washington, D.C. 20545

Publication Date: December 1977

FOREWORD

This document was prepared by the Energy Research and Development Administration (ERDA) prior to the activation of the Department of Energy (DOE) by P.L. 95-91 on October 1, 1977. Therefore, wherever ERDA is mentioned, it should be noted that its functions have been transferred to DOE.

The technical reviews contained in this document were prepared by Cameron Engineers, Inc., Denver, Colorado, based on information supplied by DOE and its various contractors. The reviews, as they appear herein, have been authorized for publication by representatives of DOE. Cameron Engineers, Inc. assumes responsibility for the accuracy of the reviews but not for the accuracy of the information provided by either DOE or its contractors.

CONTENTS

EXECUTIVE SUMMARY 1

I. CLEAN BOILER FUEL DEMONSTRATION PLANT 5
Coalcon Division, Union Carbide Corporation
E(49-18)-1736

II. DEVELOPMENT OF COAL FEEDERS FOR COAL GASIFICATION OPERATIONS 9
Foster-Miller Associates Inc.
E(49-18)-1793

III. DEVELOPMENT OF A CONTINUOUS DRY COAL SCREW FEEDER 11
Ingersoll-Rand Research Inc.
E(49-18)-1794

IV. COAL FEEDER DEVELOPMENT PROGRAM 15
Lockheed Missiles and Space Co. Inc.
E(49-18)-1792

V. ENGINEERING AND TECHNICAL SUPPORT 17
U.S. Army Corps of Engineers
E(49-18)-1759

VI. TECHNICAL ASSISTANCE SERVICES 19
The Ralph M. Parsons Co.
E(49-18)-1775

VII. CONCEPTUAL DESIGN FOR AN ADVANCED COAL LIQUEFACTION COMMERCIAL PLANT 23
Fluor Engineers and Constructors
EX-76-C-01-2251

GLOSSARY 27

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EXECUTIVE SUMMARY

The United States has more energy available in coal than in petroleum, natural gas, oil shale, and tar sands combined. Nationwide energy shortages, together with the availability of abundant coal reserves, make commercial production of synthetic fuels from coal vital to the Nation's total supply of clean energy. In response to this need, the Office of Fossil Energy of the Energy Research and Development Administration (ERDA) is conducting a research and development program to provide technology that will permit rapid commercialization of processes for converting coal to gaseous and liquid fuels and for improved direct combustion of coal. These fuels must be suitable for power generation, transportation, storage, and residential and industrial uses.

The technologies selected for development—gasification, liquefaction, and direct combustion—satisfy an urgent need for a particular type of fuel, are potentially feasible both technically and economically (in terms of the costs of research and development and the final product), and will not exceed the air, water, and solid pollution standards established by the Environmental Protection Agency (EPA). The emphasis given each technology varies, depending on such things as technical complexity, development stage (laboratory research, including bench-scale tests and experiments with process development units, and pilot plant design, construction, and operation), variety of uses for the fuel produced, and urgency of the need that the technology is designed to satisfy.

ERDA's demonstration plant program was started in 1974 by one of ERDA's predecessor agencies: the Office of Coal Research, U.S. Department of the Interior. The objective of the program is to establish the technical and financial feasibility of coal conversion technologies proven during pilot plant testing. Demonstration plants will minimize the technical and economic risks of commercialization by providing a near commercial size plant for testing and production. Thus, ERDA is sponsoring the development of a series of demonstration plants, each of which will be a smaller version of commercial plants envisioned for the 1980's. These plants will be wholly integrated, self-sufficient in terms of heat generation, and dependent only on feedstock of coal, water, and air.

Under the ERDA program, contracts for designing, constructing, and operating the demonstration plants will be awarded through competitive procedures and will be jointly funded. The conceptual design phase will be funded by the government, with the detailed design, procurement, construction, and operation phases being co-funded, 50 percent from industry and 50 percent from the government. The cost involved in building and operating a demonstration plant will probably be between $200 million and $500 million, depending on the size of the plant.

The processes to be demonstrated include the conversion of coal to liquid fuels, high-Btu gaseous pipeline fuels, and low-Btu fuel gas. Other processes will be demonstrated as they become available. ERDA awarded the first contract under this program to Coalcon Company in January 1975. Coalcon is to design, build, and operate a demonstration plant for converting high-sulfur coal to clean boiler fuel. Contracts involving the development of coal feeders were awarded to Foster-Miller Associates, Inc.; Ingersoll-Rand Research, Inc.; and Lockheed Missiles and Space Company, Inc. Engineering and technical support for demonstration plant design and construction and the procurement of equipment with long lead times is being provided by the U.S. Army Corps of Engineers, Department of the Army Readiness Command, and the Mound Laboratory. The Ralph M. Parsons Company is furnishing ERDA such technical assistance services as the development of conceptual designs of commercial plants for producing liquid and solid fuels from coal, and evaluations of pilot plant performance and unit operations for processing coal. Fluor engineers and constructors is currently developing a conceptual design for an advanced coal liquefaction plant.

The overall effort on the *Clean Boiler Fuel Demonstration Project (Coalcon)* was concentrated on completion of the Phase I preliminary process design for the demonstration plant. Cost estimates for equipment were completed for most sections of the plant and process flow diagrams and heat and mass balances were updated and readied for finalization. The testing efforts at the Tonowanda and South Charleston test facilities were terminated at the end of December 1976 and consequently, there was no activity planned in this area during the first quarter of 1977.

The testing of prototype feeders for the *Coal Feeders for Coal Gasification Operations* project was advanced during the quarter with runs made with the centrifugal and positive displacement feeders. The centrifugal feeder was operated at pressure differentials up to 70 pounds-per-square-inch. The Foster-Miller engineers encountered problems with maintaining reliable coal feed rates and consequently, tests were suspended in February for the remainder of the quarter so that modifications could be implemented.

The positive displacement feeder was successfully operated during March at pressures up to 200 psi. Evaluation of results will be made during the second quarter.

Development of Continuous Dry Coal Screw Feeder continued with testing of the 1.5″ diameter screw feeder. The tests were conducted with the machine in the extrusion mode with and without external heat and injection mode without external heat. During testing in the extrusion mode with external heat, it was found that coal delivery rate and specific power consumption are essentially constant when the plug length is varied by the axial position of the screw. Also, moisture content of the coal significantly affects the screw performance with respect to power consumption.

Results of tests in the injection mode without external heat showed that coal can be pumped continuously against elevated back pressure and that the specific power consumption of the screw feeder is significantly reduced with increase in moisture content of input coal.

Phase II testing of the *Coal Feeder Development Program* was delayed due to equipment problems and manufacturers delays and therefore, no tests were performed during the quarter. However, Lockheed engineers did continue to develop design procedures for selecting efficient ejector systems and exploring staging options and investigated these areas with the mathematical model.

Technical Assistance Services by The Ralph M. Parsons Company were directed toward completion of the conceptual commercial plants currently under study. The Oil/Gas plant and the Fischer-Tropsch plant design tasks were completed during the period. The Power, Oil, Gas and Other products plant activities included preparation of detailed material balances for a number of units in the plant. Parsons continued the investigation of sensitive environmental areas of coal conversion where additional information is to be developed regarding the formation of possible pollutants.

The Conceptual Design for an Advanced Coal Liquefaction Plant was advanced with a continuing design effort on the conceptual commercial plant. Equipment and process studies were conducted in each major area of the plant and minor changes to the process design were made. Heat and material balances were advanced and specification of non-proprietary equipment was continued. Efforts were also directed toward mine and plant site layout.

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I. CLEAN BOILER FUEL DEMONSTRATION PLANT

UNION CARBIDE CO., INC.
NEW YORK, NEW YORK

Plant Site:	New Athens, Illinois
Contract No.:	E(49-18)-1736
Total Funding:	$ 15,150,000*
Phase I:	$ 4,750,000**
Phase II:	$ 17,700,000**
Phase III:	$142,300,000**
Phase IV:	$ 72,472,300**

INTRODUCTION

The Coalcon Department of Union Carbide is under contract with ERDA to design a demonstration plant for producing clean boiler fuels from high-sulfur coal. The plant was to be fully integrated in all phases of processing, from receipt of coal to delivery of a finished product. The design was geared to be environmentally acceptable by cleanup of all waste streams, and energy efficient by recovery of all by-products. Coalcon was organizing financial support for the program in the form of a consortium of energy and power companies and public agencies that would provide funds for the 50-50 government/industry cost sharing portion of the program.

The overall objective of the project is to verify, through a demonstration size plant, the commercial economics, technical scale-up potential, and the physical and chemical feasibility of a process for producing clean liquid boiler fuel pipeline gas and other useful products in a commercial-size plant. The plant is to be designed to convert 3901 tons per-day of high sulfur coal into 2990 barrels per-day of heavy oil, 1192 barrels per-day of a gasoline fraction, 1088 MMSCFD of liquefied petroleum gases and 28.39 MMSCFD of high Btu pipeline quality gas. 126.6 tons per-day of elemental sulfur will also be produced.

*Present Year Dollars
**Original Planning

The project is to be conducted in four phases. Phases I and II are funded entirely by ERDA, while Phase III and IV were on a 50-50 cost sharing basis with ERDA and industry.

Phase I involves evaluation of various processes for commercial feasibility, process design of a commercial plant, preliminary commercial plant design, and preliminary process design for the demonstration plant. The preliminary process evaluation will be made in an effort to increase the potential for creating a clean boiler fuel industry. Variations to the basic concept will be evaluated to determine their impact for increasing production flexibility, improving cost effectiveness and reducing sulfur content in the primary products. Some of the variables that will be evaluated include:

- Size of plant, degree of modularization
- Coal type, size, mixture, composition, and cost
- Alternative process trains and steps
- Process operating conditions (e.g., temperature, pressure, residence time, thermal efficiency, etc.)
- Product quality and yield.

The purpose of the preliminary commercial plant design is to obtain a detailed process design based on maximum use of proven, commercially available components and equipment on which to base detailed cost estimates. The end use of this design will be to evaluate the economic and technical feasibility for commercial plants and to recommend changes to the overall commercial plant concept. The demonstration plant design will also be based on a system that will integrate commercially available components and equipment. This effort will include process flow charts and schematics for the plant, and for each major process train and subsystem. Major process and utility piping, electrical networks, process operating conditions, and mass and heat balances, will be a part of the effort.

Phase II work would have involved the preparation of the complete plant design, including drawings, specifications, and definitive cost estimates. A bid package for the construction of the plant was to be prepared from these data. Phase III, demonstration plant construction, will include site preparation, equipment purchases, construction and field erection of process equipment, and plant acceptance and checkout. Phase IV, the ultimate objective of the project, will be the operation of the plant. Experience gained during this period will be used to determine the technical and economic performance and assess the project with regard to the scale-up of the operation to a full scale commercial plant. The clean boiler fuel program schedule is illustrated in Figure I-1.

PROCESS DESCRIPTION

Initially, the coal is crushed, milled and classified under flue gas to decrease the moisture. The coal is then fed to the feed hopper before it is pressurized to the operating pressure of the system plus pressure to allow feed to the reactor. The coal is dropped from the lock hoppers to a fluidized feeder vessel. From the feeder vessel, the coal is fed by dense phase flow in hydrogen gas by one inch lines through a heater and to the reaction. The coal is fed at temperatures to 450° F. The hydrocarbonization reactor is fluidized by hydrogen and operates at 555 psi and 1040° F. The solid residence time is 35 minutes, the gas residence time in the bed is 42.5 seconds. The char from the reactor is removed from the top of the bed with provision at the bottom of the reactor for removal of agglomerates. The char is used to produce hydrogen for the reactor by means of a Texaco gasifier.

The gases existing in the reactor are laden with solids which are removed by two cyclones in series. The cleaned gas/vapor is sent to the fractionation system for cooling and separation. The basic purpose of the fractionation system is to cool the reactor products, to stop reaction and to split the reactor product into four streams.

- Overhead Gas (N_2, CO, CO_2, CH_4)
- Light Liquid
- Heavy Liquid
- Waste Water

The reactor product gases are initially cooled by a venturi quench which is fed by the cooled bottom of the primary tower. The products are further refined by successive operations.

The gas product is sent through acid gas removal (Shell Sulfinol), gas separation (cryogenic) and methanation. The cryogenic system separates LP fuel gas, synthesis gas and a hydrogen rich stream. The hydrogen rich stream is

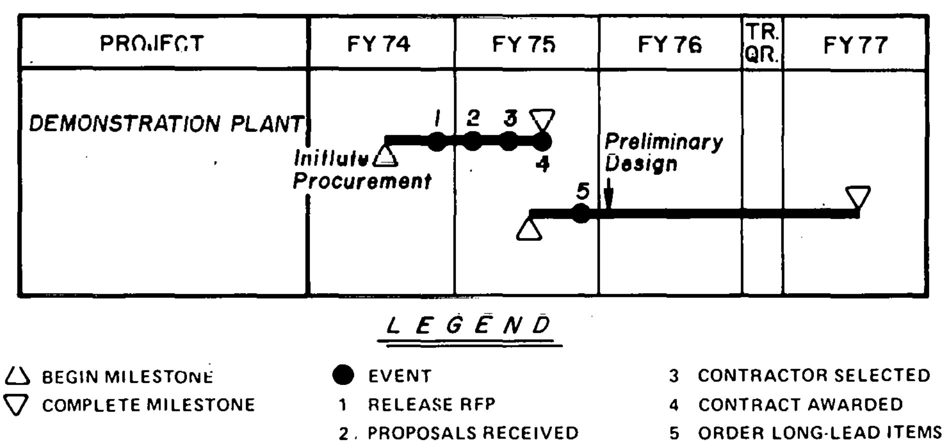

Figure I-1. CLEAN BOILER FUEL PROGRAM SCHEDULE recycled back to the hydrocarbonization reactor. The synthesis gas is sent to the methanation reactor for upgrading to high Btu pipeline gas. The LP fuel gas is also sold as a product. The process is shown in Figure I-2.

HISTORY OF THE PROJECT

Work under this contract was initiated in January 1975 when ERDA selected the Union Carbide Hydrocarbonization Process as the one to be used in ERDA's first demonstration plant project.

During 1975, work on the Clean Boiler Fuel Demonstration plant involved preliminary process design and engineering of a commercial plant. This effort included a review and evaluation of all hydrocarbonization subsystems to minimize capital investment and maximize subsystem operability and reliability. By early 1976, design and engineering for the commercial plant were complete. A process evaluation report was prepared and submitted to ERDA. This report included preliminary data on plant design and provided a basis for starting the design of the demonstration plant.

Work toward establishing the definition and design basis for the demonstration plant began late in 1975. Preliminary performance specifications were issued and work on the overall process design of the demonstration plant, analysis of the three coal types to be tested and development of process designs of plant subsystem were initiated.

Unfortunately, a number of technical problems plagued the Coalcon project throughout 1976. The lack of data needed to produce the process design for agglomerating coals delayed completion of the Phase I effort. Based on mid-year ERDA evaluations, and technical data produced in 1976, to that date, the Union Carbide technology for hydrocarbonization of agglomerating coals were determined to be a high risk technology. In addition, an economic analysis based on completed design data showed that the economics of a full scale commercial plant were marginal when compared to the projected economics of other processes currently under development. Because of these findings and associated technical problems, ERDA suspended project activity beyond the Phase I process design.

Union Carbide facilities used in support of the program included the Tonawanda, New York, and the South Charleston, West Virginia laboratories. The Tonowanda minitest facility was directing its work toward confirming kinetics and yield data for agglomerating high-sulfur bituminous coal. The South Charleston facility was being used to evaluate alternative

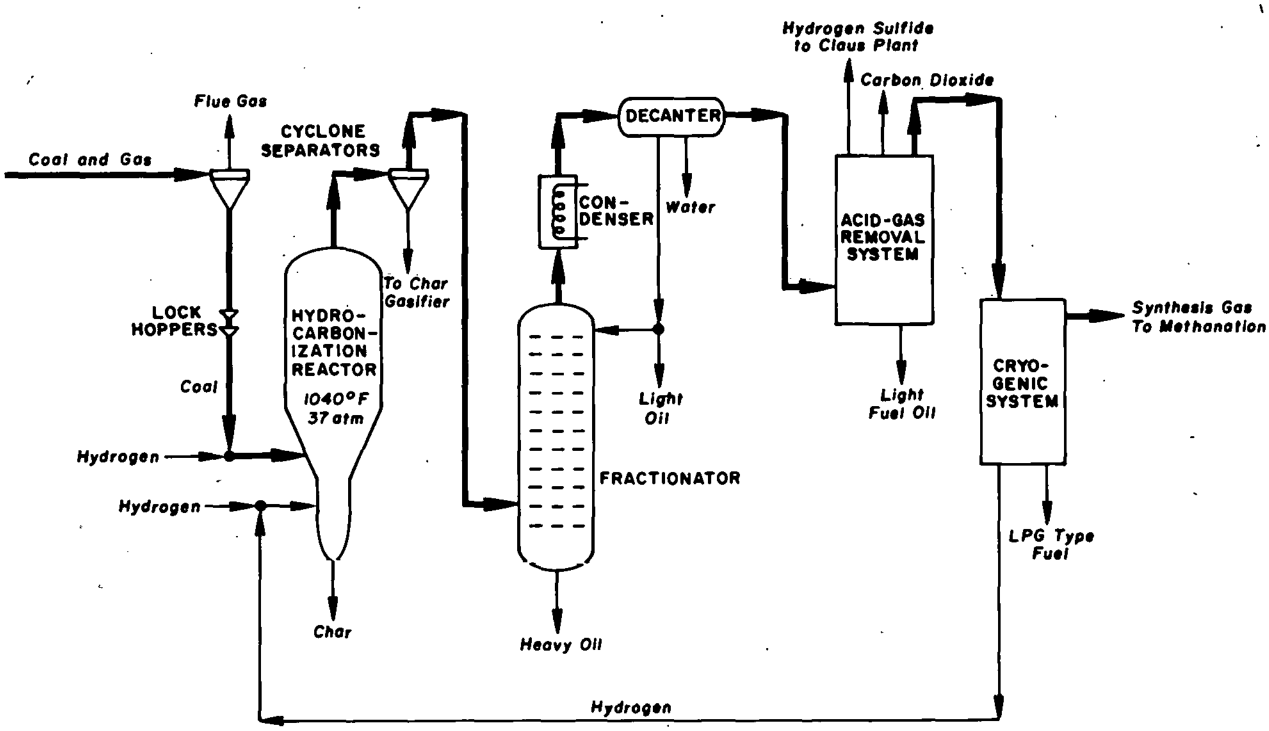

Figure I-2. HYDROCARBONIZATION PROCESS SCHEMATIC methods for deagglomerating high-sulfur bituminous coals in the hydrocarbonization process.

PROGRESS DURING JANUARY-MARCH 1977

The overall effort on the Coalcon project was concentrated on completion of the Phase I preliminary process design for the demonstration plant. The testing efforts at the Tonowanda and South Charleston test facilities were terminated at the end of December 1976 and consequently, there was no activity in this area during the first quarter of 1977. The status of the major engineering sections of the plant is outlined below.

Section 1—Coal Handling—Costing of equipment for this section is completed. Final design report documentation is ready for verification against final heat and material balance.

Section 2—Coal Preparation—Costing of equipment of this section is also 100 percent complete. Process flow diagrams, piping and instrumentation drawings and data sheets were marked up to accommodate preliminary heat and mass balance values.

Sections 3 and 4 — Coal Pressurization/Coal Heating—Costing of equipment is 80 percent complete for both sections. Final design report documentation is ready for verification against the final heat and material balance.

Section 5—Coal Hydrocarbonization—The process flow diagrams for the char recirculation concept has been completed. Work in the High Speed Injection concept is being finalized.

Section 6—Gas Cooling/Heavy Hydrocarbon Separation—The process flow diagram is complete, however, all other documents are in preparation, including the piping and instrumentation diagrams, equipment data sheets and layout plot plan..

Section 8—Sulfinol—The preliminary performance specification and equipment list have been completed and work was initiated on the equipment data sheets.

Section 10—Methanation—Efforts were initiated on the process flow diagram based on current heat and mass balance. The preliminary performance specification and equipment list were completed.

Sections 12A & 13—Claus, Aqua-Claus Plants—The pictorial flow diagrams for both sections were completed as were the preliminary performance specifications and equipment list.

Section 13—Char Cooling & Grinding—Piping and instrument diagrams, and plan and elevation drawings completed.

Section 14—Char Gasification—The signed agreement for use of the Texaco gasifier were finalized by ERDA on March 30, 1977 and delivered to Texaco development; Texaco started their review of the equipment data sheets.

II. DEVELOPMENT OF COAL FEEDERS FOR COAL GASIFICATION OPERATIONS

FOSTER-MILLER ASSOCIATES, INC.
WALTHAM, MASSACHUSETTS

Contract No.: E(49-18)-1793
Total Funding: $799,545
(100% ERDA)

INTRODUCTION

Under the sponsorship of ERDA, coal feeders for use in all coal gasification plants are to be developed through the pilot plant stage by Foster-Miller Associates, Inc. The project recognizes the coal feeder as one element common to all gasification processes. However, no currently available system can handle the quantities of coal, about 1,000 tons per hour, that will be used in commercial processes. These processes require the injection of coal, crushed to 1/8-inch and below, from an atmospheric-pressure hopper into a gasifier whose pressure may be as high as 100 atm.

Feed methods currently being used in pilot and demonstration plants depend on the coal size and gasifier pressure. Low-pressure units use lock hoppers, which must be operated at low temperature, with batch feeding of the coal. Slurry-feed techniques used in high-pressure gasifiers require energy to vaporize the liquid used to transport the coal. Both of these techniques are inefficient but can be tolerated in small-scale gasifiers. It will, however, be necessary to develop a technique to provide a continuous, high-pressure flow of coal to commercial-scale units at reasonable efficiencies and capital costs.

PROGRAM DESCRIPTION

The project to develop coal feeders was initiated in May 1975. It consists of three phases, all of which are to be completed by December 1977. In Phase I, Foster-Miller visited and studied gasification plants and consulted with ERDA personnel and consultants to prepare a list of coal feeder requirements for ERDA approval. Foster-Miller then prepared a report based on information concerning existing equipment and new conceptual designs. This report included a list of candidate equipment and an evaluation of that equipment.

In Phase II, critical components of the equipment selected in Phase I will be tested in the laboratory. Equipment of four different designs will be constructed, and each laboratory-scale feeder will be tested for approximately two months. These tests will be conducted to determine the ability of the equipment to control the flow of coal with accuracy, maintain stability, seal effectively against the gasifier pressure, provide economic operation in terms of equipment life and power requirements, and deliver to the gasifier coal having the desired characteristics. Data from laboratory research will be used to design feeders compatible with existing and projected pilot plant operations.

During Phase III, feeder concepts that have demonstrated a strong possibility of commercial-scale usage will be integrated into current and projected pilot plants as directed by ERDA. Feed rates will be in the range of three to five tons per hour. The final report of this phase will contain design specifications, assembly drawings and procedures, installation and functional test procedures, and operation and maintenance manuals.

A fourth phase, design of demonstration scale feeders, not part of this contract, will use the results of pilot plant testing. It is projected to include the development, design fabrication, and delivery to ERDA of coal feeders compatible with demonstration plant requirements. Feed rates in this phase are anticipated to be 50 tons per hour and greater.

PROJECT ACCOMPLISHMENTS

Foster-Miller Associates completed the Phase I program effort in March 1976, with the release of the Phase I report. The results from the evaluation of coal feeder requirements and existing feeders revealed that no suitable dry coal feeders were available that could operate at gasifier pressures above 20 atmospheres. As part of this initial effort, literature searches, patent reviews, and consulation with manufacturers were made to determine what particular concepts should be studied in Phase II. Results from these activities led to the selection of four methods:

- Coal plug feeders
- Centrifugal feeders
- Positive displacement feeders
- Conveyor feeder.

Evaluation of these concepts are currently being carried out during Phase II.

PROGRESS DURING JANUARY-MARCH 1977

Summary

Testing of prototype feeders continued throughout the quarter with runs being made with the centrifugal and positive displacement feeders. The centrifugal feeder was operated at pressure differentials up to 70 psi. The tests were plagued with problems maintaining reliable coal feed rates and tests were suspended in February so that modifications to the feeder supply system could be made. At the end of March, the modifications had not been completed.

The positive displacement feeder was successfully operated during March at pressures up to 200 psi. Some unusal results were obtained in that feed rate was not independent of back pressure as theory predicted. Evaluation of the results are currently underway to determine the cause of the discrepancy.

Pilot-Scale Coal Feeder Development

The assembly of the fluidized piston feeder prototype, which was initiated in November 1976, was completed in January. Installation of the feeder on the cold flow test loop continued throughout the month.

Only limited testing was made with the test loop during January since most of the month was taken up with test loop modifications to eliminate coal bridging problems in the feeder supply area. Testing was resumed at the end of the month, however, and a successful run with the centrifugal feeder against 40 psi back pressure was made.

The testing of the prototype centrifugal feeder unit continued in February. The unit was operated at pressure differentials to 70 psi with no detectable back leakage. Coal flow at this pressure was too low to measure. At differentials of about 25 psi the coal flow rate was 1,600 lb/hr. Testing of the centrifugal feeder has been plagued by problems in maintaining reliable coal flow to the eye of the feeder. At the end of the month testing of the unit was suspended while modifications to the feeder supply system were being evaluated.

Activity on the development of the centrifugal feeder was limited to the design and fabrication of feeder modifications during March. The modifications included:

- A redesign of the coal supply fluidization system to insure that the coal supply is maintained in a fluidized state until it enters the feeder sprues.
- Activation of the second set of feeder sprues to give a total of four passages.
- Redesign of the impeller to provide positive mechanical coal feed to the inlets of the feeder sprue.

Testing of the prototype positive displacement feeder was initiated during March. The unit was successfully operated at feeder back pressures at 200 psi. The feed material was 70 percent through 200 mesh eastern bituminous coal. The prototype feeder was operated at 10 cycles per minute and feed rates have ranged from 400 pounds per hour at 50 psi to 250 pounds per hour at 200 psi. In theory, the feed rate of the unit should be independent of back pressure. The test results are now being evaluated to determine why feeder output shows a decrease with increased back pressure.

The development of the coal plug feeder concept was terminated in favor of continued development of the sealed conveyor feeder concept. Currently, parts procurement for the system is underway.

III. DEVELOPMENT OF A CONTINUOUS DRY COAL SCREW FEEDER

INGERSOLL-RAND RESEARCH, INC.
PRINCETON, NEW JERSEY

Contract No.: E(49-18)-1794
Total Funding: $1,168,719
(100% ERDA)

INTRODUCTION

Development of a continuous dry coal screw feeder is being conducted by Ingersoll-Rand Research, Inc. through ERDA sponsorship. The feeders are to be developed through the pilot plant stage, with the engineering and economic viability evaluated throughout the development process. The end result of the research will be a recommendation by Ingersoll-Rand of coal feed injector equipment that will be compatible with projected demonstration plant requirements. The successful development of a continuous dry coal feeder would have a significant impact on coal processing. The equipment could be used in both high- and low-Btu gasification plants and also in coal liquefaction systems.

PROGRAM DESCRIPTION

Under the current contract with ERDA, started in July 1975, Ingersoll-Rand is conducting a three-phase development program to refine and scale-up a screw feeder that could be used in a demonstration plant. Tests initially conducted by Ingersoll-Rand indicated that screw feeders could be used in full size coal gasification and liquefaction plants in place of pressurized lock hoppers and slurry systems. The feeder currently being developed is a modified injection molding machine, operating like an extruder.

Phase I of the program involves the establishment of the coal feeder requirements imposed by the various processes being considered for commercial scale coal conversion operations. Literature searches, consultations with ERDA personnel and consultants, studies of plant operations, etc. will be used to obtain information on the feeder requirements. Using the information gathered, Ingersoll-Rand is to examine existing equipment and conceptually design new approaches to coal feeders.

In Phase II, critical components of the candidate equipment selected in Phase I will be tested. In addition, two laboratory scale, coal feeder prototypes, a Negri-Bossi V-12 injection molding maching and an IMPCO 1500, will be designed, fabricated, and tested. Among the characteristics to be investigated are:

- Feeder stability and degree of control
- Seal effectiveness
- Coal metering accuracy
- Life expectancy of critical components
- Mechanical power requirements
- Methods for reducing the feed coal size to meet process requirements.

The data resulting from laboratory testing will be used to design feeders for use in existing and projected pilot plant operations. Recommendations will be made to ERDA for further development of promising screw feeder concepts.

During Phase III, IMPCO screw feeder will be installed and operated in a pilot plant selected by ERDA.

Feed rates will be in the range of 0.5 to 5.0 tons per hour. A report will be prepared that will include design specifications, installation drawings, assembly procedures, installation and functional test guides, and operation and maintenance manuals. The performance of the feeder in the pilot plant tests will be assessed based on the test data. A final report will be prepared which will include the design of equipment sized for a demonstration plant.

A fourth phase, not part of the current contract, will use the results of pilot testing for development, design fabrication, and delivery to ERDA of coal feeders compatible with demonstration plant requirements. Coal feed rates in this phase will be 50 tons per hour or greater.

PROJECT ACCOMPLISHMENTS

Ingersoll-Rand Research developed, during Phase I, three conceptual designs for coal feeding. These concepts included a single-acting piston feeder, double-acting piston feeder, and a rotary valve piston feeder.

A comparative evaluation of coal feeder systems was completed, using the technical and economic criteria established during the fourth quarter of 1975. Existing coal feed systems, lock hoppers and slurry pumps were compared with new feed system concepts. The evaluation indicated that the piston feeders as a class seem to offer advantages over the lock hopper and slurry pump methods of feeding coal to high-pressure gasifiers. The screw feeder concept, although not as dramatic, also showed advantages over existing methods. A proposal is to be submitted for further evaluation of the piston feeder concepts.

ERDA received the Phase I report in March for review and comment.

PROGRESS DURING JANUARY-MARCH 1977

Summary

The 1.5″ diameter screw feeder development testing continued during the quarter. A number of tests were conducted with the machine in various modes which included extrusion mode with and without external heat and injection mode without external heat. During testing in the extrusion mode with external heat, it was found that coal delivery rate and specific power consumption are essentially constant when the coal plug length is varied by the axial position of the screw. Also, moisture content of the coal significantly affects the screw performance with respect to power consumption.

Results of tests in the injection mode without external heat showed that coal can be pumped continuously against evelated back pressure and the specific power consumption of the screw feeder is significantly reduced with increase in moisture content of input coal.

The 5.5″ diameter screw feeder development was limited to machine assembly and component testing, however, some tests were initiated towards the end of March and will be continued during the next quarter.

Laboratory Scale Feeder Development

1.5″ Diameter Screw Feeder (Negri-Bossi # V12) Development

Testing of the machine, which was initiated in 1976, was continued this quarter in three major areas. These included, extrusion mode, with external heat, extrusion mode without external heat and injection mode, without external heat.

Extrusion Mode, With External Heat

These tests were carried out to determine the effect of coal plug length on screw feeder performance. The increasing volume screw which showed the best performance during the configuration evaluation tests, was used during these tests. The screw rotational speed was maintained constant at 20 RPM and the coal was extruded against atmospheric pressure for each plug length. In addition to recording the usual test data, IR also recorded the operating time of each heater band to permit determination of the electrical heat input into the coal. The conclusions as reported by Ingersoll-Rand are as follows:

- For a given set of conditions (screw design, speed, coal, etc.) there is a minimum plug length below which a plug cannot be formed (3.55″ in this case) and there is a maximum coal plug length above which the screw can no longer pump, resulting in screw stalling (8″ in this case).
- The density of the extrudate increases (maximum 9%) with increasing plug length. This situation indicates that the coal plug length is compacted more with increasing plug length.
- Coal delivery rate is essentially independent of the coal plug length.

- The specific power consumption based on screw mechanical power is essentially constant above the 4.7" plug length and decreases slightly with increase in plug length.
- The mechanical power represents a small percentage of the total power. This condition is mainly due to the fact that a substantial part of the total power is required to evaporate the high percentage (8%) of moisture in the input coal. For efficient screw feeder operation the input coal should have a low moisture (~3%) content.

Extrusion Mode, Without External Heat

Testing was carried out with the machine operating as a conventional extruder and Illinois #6 coal as feed material. It was found that a mechanical restriction at the screw discharge end was necessary to assure formation of the cylindrical plug. Once in operation and the plug formed the mechanical restriction was removed at a predetermined screw tongue. Ingersoll-Rand observed that the barrel temperature increased continuously due to heat addition from internal friction and that the cylindrical plug could not be maintained. It was concluded that the condition indicated that the change in barrel temperature during operation changes the coefficient of friction between the coal and the barrel and as a result the stress distribution changed to a level where a compacted plug could no longer be formed. In an effort to control barrel temperature, a water jacket was fabricated and installed around the barrel. Following this modification, steady state operation against atmospheric conditions were achieved.

Testing was also conducted with 100 psig gas back pressure. However, the screw stalled in a short period of time. Ingersoll-Rand felt that the extrusion mode of operation was very senstive to coal plug length and that additional testing would be required to operate the machine satisfactorily in this particular mode.

Injection Mode, Without External Heat

Testing of the NB #V12 in this mode was carried out by operating the machine in a manner similar to that used for the Plastic Injection Molding Machine. Ingersoll-Rand Research Institute engineers explained the operation as follows.

"The coal flow was initially restricted on the discharge end (mechanically) to establish a compacted plug. When the compaction reaches a certain level the axial thrust force on the screw causes the screw to travel backwards. In the meantime, the coal is being conveyed toward the discharge end, forming the compacted plug. The mechanical restrictor was then removed and the coal plug was injected by ramming the screw forward. The above cycle was then repeated, without further use of the mechanical restrictor. The screw torque (hydraulic drive pressure) and the injection force (hydraulic ram pressure) were measured. The cycle was continued at atmospheric conditions until steady state operation was reached. A gas back pressure of 300 psig was then applied. The injection force slowly increased and leveled off. The test was continued until steady state operation was achieved. Figure 6 shows a typical curve of screw and injection pressure versus number of cycles (time) at atmospheric pressure and 300 psig gas back pressure.

The initial tests mentioned above, the injection and filling times were controlled manually. In order to more accurately control the operation, the machine was modified and a control circuit installed for automatic operation.

The second set of tests (automatic operation) were directed towards reducing the specific power consumption at atmospheric pressure. The following parameters were varied:

• Screw speed:	20-30 RPM
• Average plug length:	2"-2.75"
• Injection Stroke:	1-1/2"-2-1/2"

It was found that the specific power consumption was decreased by approximately 20% by operation of the machine at 20 RPM, plug length of 2.5", and injection stroke of 1-1/2 inches.

During testing with gas back pressure of 300 psig, back leakage developed due to an incompletely packed center core. Several modifications were made in an attempt to alleviate the problem. Tests were also carried out with different types of coal parameters such as moisture and size, at various gas back pressures. The analysis of these data indicate that specific power consumption is a strong function of the coal moisture. A 4.5% increase in moisture reduces the specific power consumption by approximately 33%. Testing with fine coal also indicated the same trend.

5.5" Diameter Screw Feeder (IMPCO 1500) Development

The major effort for the quarter was directed towards final assembly and component of testing on the machine. However, testing of coal was initiated towards the end of the quarter and will be continued during the second quarter of 1977.

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IV. COAL FEEDER DEVELOPMENT PROGRAM

LOCKHEED MISSILES AND SPACE COMPANY, INC.

SUNNYVALE, CALIFORNIA

Contract No.: E(49-18)-1792

Total Funding: $1,000,000
(100% ERDA)

INTRODUCTION

Lockheed Missiles and Space Company, Inc., a subsidiary of Lockheed Aircraft Corporation, is conducting a coal feeder development program under the auspices of ERDA. A need exists for this development effort because current lock hopper or slurry concepts for coal feeding are inadequate. The feeder system is a critical component of a coal conversion plant, affecting equipment and maintenance costs, plant efficiency, and down time. An improved coal feeder that is applicable to all processes using pulverized dry coal at reactor pressures up to 100 atm must be developed.

PROGRAM DESCRIPTION

Work under this three-phase program was initiated in July 1975. Phase I, which was completed in March 1976, involved the selection of candidate coal feeder injector concepts based on a detailed examination of the system requirements imposed by the various coal conversion processes.

The examination included:

- Screening potential candidates
- Investigating existing equipment
- Synthesizing feeder system designs
- Assessing problem areas
- Defining laboratory evaluation techniques
- Preparing a final report

Phase II studies will involve tests on four coal feeder systems. These include a fluid dynamic lock, kinetic extruder, ball conveyor, and an ejector. To establish a firm basis for the design of the coal feed systems for use in commerical plants, testing efforts for this phase will include:

- Laboratory tests, using simple bench-scale equipment, to answer questions pertinent to equipment design.
- Supporting analysis provided by mathematical models developed for optimizing equipment design, projecting operating efficiency, and updating economic data generated during Phase I.
- Design of test equipment
- Fabrication including procurement of materials.
- Installation of test equipment followed by testing as outlined in the test plan and data reduction and analysis.
- Documentation.
- Design, procurement, and installation of equipment for the test loop facility.
- Assurance that hardware is manufactured to applicable specifications and that all operations and specifications adhere to safety requirements.

During Phase III, candidate feeder concepts showing promise for commercial scale use will be designed and operated in current and/or projected pilot plants. Feed rates for these feeders are expected to be in the range of three to five tons per hour. As part of this phase, Lockheed will also prepare a report that will include design specifications, assembly and detail drawings, assembly procedures, installation and functional test procedures, and operation and maintenance manuals. The data obtained in the pilot plant tests will be analyzed, and a final report including an engineering design of equipment for a demonstration plant will be prepared.

A fourth phase, not part of this contract, will utilize the results of pilot plant testing, and is projected to include the development, design, fabrication, and delivery to ERDA of coal feeders compatible with demonstration plant requirements. Feed rates in this phase are anticipated to be 50 tons per hour and greater.

PROJECT ACCOMPLISHMENTS

Lockheed completed Phase I of the contract and issued the Phase I report in December 1975. Literature and patent searches were conducted which established fundamental principals used in the design of the feeder. Operating requirements were established via field trips to various coal conversion installations in the U.S. As a result of these efforts, various candidate concepts were selected for further evaluation and were segregated into low pressure and high pressure usage. Cost data were subsequently generated to compare the equipment and operating costs of each of the feed systems. For these studies, four feeder concepts emerged as the most promising for further laboratory testing. The four systems selected for Phase II investigation were:

- Ejector, based on the use of jet pumps
- Kinetic Extruder, a system based on the use of centrifugal force to reduce the permeability of the compacted coal to prevent net back flow of gases
- Ball Conveyor, using large metal balls snugly fitting into a standpipe and conveying coal in the interspace, designed to overcome net gas leakage by the downward motion of the column and the static pressure by the weight of the column. The return leg uses a liquid seal to prevent gas flow.
- Fluid Dynamic Lock, a system based on the use of a bladeless, disk type compressor.

To establish a firm basis for the design of the coal feed systems for use in commercial plants, Phase II will include:

- Laboratory tests, using simple bench-scale equipment, to answer questions pertinent to equipment design.
- Supporting analysis provided by mathematical models developed for optimizing equipment design, projecting operating efficiency, and updating economic data generated during Phase I.
- Design of test equipment.
- Fabrication, including procurement of materials.
- Installation of test equipment followed by testing as outlined in the test plan and data reduction and analysis.
- Documentation.
- Design, procurement, and installation of equipment for the test loop facility.
- Assurance that hardware is manufactured to applicable specifications and that all operations and specifications adhere to safety requirements.

PROGRESS DURING JANUARY-MARCH 1977

Due to equipment problems and manufacturers delays, testing of the Ejector and Kinetic Extruder has slipped. No tests were performed during this quarter. Testing will continue when the needed parts arrive.

During the reporting period, emphasis was placed on developing design procedures for selecting efficient ejector systems and on exploring staging options. The effect of using steam, higher stagnation temperatures, and higher molecular weight driver gases was investigated in the mathematical model. The studies indicate that the ejector is attractive as a topping stage in high-pressure systems and the use of steam as a driving fluid should be further investigated. System studies using the Kinetic Extruder in coal feed systems indicated that the performance of the device is closely tied to the properties of the feedstock. In general higher-pressure capability can be provided with fine coal grinds. Coarser grinds can be delivered at high pressure at increased coal feed rates. Lockheed determined that further testing is required to verify these predictions.

Lockheed has also concluded that the use of high temperature, high-molecular weight driver gases such as CO_2 increases the efficiency of the ejector. The studies have also indicated that steam is a desirable driving fluid.

V. ENGINEERING AND TECHNICAL SUPPORT

U.S. ARMY CORPS OF ENGINEERS,
HUNTSVILLE DIVISION
HUNTSVILLE, ALABAMA

Contract No.: E(49-18)-1759
Funded by Individual Task

INTRODUCTION

Under an interagency agreement between ERDA and the Office of the Chief of Engineers, U.S. Department of the Army, the U.S. Army Corps of Engineers is providing ERDA with engineering and technical support. This contract, initiated in mid-1974, involves the services of the Corps of Engineers engineering forces to provide technical services for demonstration plant design, construction, and related support for such projects and at such locations as requested by ERDA.

Demonstration plant assistance requests are made in the form of task assignment letters describing the scope of services desired. The task letter defines the specific function requested, the proposed location of the project, funding limitations, and designates the individual or office responsible for furnishing any requested ERDA direction. ERDA is billed by the responsible Field Operating Agency for actual expenses incurred.

PROGRAM DESCRIPTION

Under the current task letter, the Corps of Engineers is supporting ERDA in the areas of advance planning for several demonstration plants and preliminary engineering for the Clean Boiler Fuel Demonstration Plant (see Section I). The specific scope of services requested is as follows:

Advance Planning

- Assist in the preparation of requests for proposals (RFP) for three demonstration plants.
- Participate in the review and evaluation of proposals received in response to RFP's.
- Perform special studies, e.g., specific concept designs, relating to design and construction on a task basis.

Preliminary Engineering

- Review and/or prepare design criteria.
- Review preliminary engineering designs.
- Review and validate cost estimates and schedules.
- Review and/or assist in development of environmental impact statements.
- Review the results of site investigations and evaluations performed by contractors.
- Provide assistance in the development of reliability and quality assurance plans, configuration management plans, and computer programming for resource management.

The Huntsville Division was designated as the Field Operating Agency responsible for performing these tasks.

PROGRESS DURING JANUARY-MARCH 1977

The Corps of Engineers continued support activities for the Coalcon project, the Pipeline Gas Demonstration

Plant, the Fuel Gas Demonstration Plant, and the preliminary planning and engineering program.

Support for the Clean Boiler Fuel Demonstration Plant included review of coal tests and environmental analysis reports, a number of design documents, and completed engineering specifications for several areas of the plant. The Corps was also active in ERDA management and budget sessions and provided ERDA a review of the progress of the Coalcon project.

Activities related to the pipeline demonstration project included support to ERDA in negotiations of the contracts between ERDA and Conoco and the Illinois Coal Gasification Group. The effort on development of logic diagrams for both contracts continued throughout the quarter.

CE activity in the Fuel Gas Demonstration Plant Program was limited because of the near completion of the evaluation of proposals for a demonstration facility. CE did continue to monitor utility projects and provided assistance to ERDA as required.

Special task efforts performed under the preliminary planning and engineering program involved preparation of a Request for Proposals (RFP) for an Atmospheric Fluidized Bed Combustion Demonstration Plant.

VI. TECHNICAL ASSISTANCE SERVICES

THE RALPH M. PARSONS COMPANY
PASADENA, CALIFORNIA

Contract No.: E(49-18)-1775
Total Funding: $2,990,892
(100% ERDA)

INTRODUCTION

The Ralph M. Parsons Company is providing technical assistance services to ERDA with the objective of developing and demonstrating practical processes for producing liquid and/or solid fuels from coal. Under this program, initiated in 1972 and updated in 1974, Parsons is:

- Preparing conceptual designs and economic evaluations for commercial plants.
- Evaluating pilot plant performance and other experimental programs.
- Evaluating unit operations and processes for possible applications in coal processing, including design and construction of pilot plants.
- Evaluating proposals for new work and for changes in ongoing work.

The development of commercial design concepts and technical evaluations involve:

- Review of chemical, mechanical, and material problems associated with the design of large plants and equipment
- Identification of problems in sizing, safety factors, and instrumentation of equipment, which must be resolved before equipment is specified for manufacture
- Identification of equipment design problem areas, and development of programs for solution of those problems
- Identification of construction problems, including availability of materials, type of land base, and area required for construction, that must be solved before large equipment can be fabricated in the field
- Establishment of overall utility requirements. This effort will provide a common economic basis for comparing capital and operating costs of the processes. Ultimately, the commercial design concepts will serve as guides for selecting the best coal processes to be demonstrated in commercial-sized plants.

PROGRAM DESCRIPTION

Parsons has two primary tasks: (1) development of conceptual designs and economic evaluations of commercial plants and (2) technical evaluations.

Conceptual designs and economic evaluations of commercial-scale plants are being developed for the Char-Oil Energy Development (COED) process, an oil-gas process based on the Solvent-Refined Coal (SRC) process, the Fischer-Tropsch process, and a combined POGO (Power, Oil, Gas, and Other Products) process. The conceptual designs and economic evaluations are based on engineering data such as process yields, conversion efficiency, plant economics, and environmental analysis from pilot plant operations.

The overall objectives of the individual tasks are given below. The idea behind the Coal Mining/Coal Preparation task is to design and evaluate, as feed facilities to conversion plants, coal mine and preparation facilities for five geographic areas where conversion facilities are being studied. Plant capacities of up to 100,000 tons per day of coal feed are being considered.

Oil/Gas Plant efforts will be preliminary design and economic evaluation for a commercial plant to produce synthetic fuels and SNG from coal, and to define the maximum practical capacity of a single train plant using the selected process. The purpose of the Fischer-Tropsch plant task will be to develop a conceptual commercial plant design and economics for production of pipeline gas, motor fuel, distillates and other hydrocarbon fractions.

The objectives of the POGO (Power, Oil, Gas, and Other Products) plant design is to develo a preliminary design of a coal processing plant which will produce power, oil, gas, and other products. The chosen process will be based on economic evaluations of the candidate coal processes available. Other areas of effort will include the development of a model capable of calculating material and heat balances for a number of coal conversion processes using computer capability and to estimate the overall utility balance for the complex.

Parsons, is also developing a computerized process simulation program capable of estimating fixed capital investment, material and energy (utility) balances, and potential profitability of various coal conversion complexes. The program will be available to this project.

Among the technical evaluation activities is the development of functional and preliminary specifications for equipment and control apparatus required in the candidate conversion processes. All the components of a plant, from coal handling through production of fuel, are being considered, along with the associated units for power generation and waste treatment. Another technical evaluation activity is the investigation of materials for construction of equipment to determine which are preferred for use in coal conversion processes. Parsons is also defining facilities required to control air, water, and solid waste pollution to assure that plant operations are within applicable state and EPA environmental standards. Finally, Parsons is providing general support activities and preparing reports as appropriate or requested by ERDA.

PROGRESS DURING JANUARY-MARCH 1977

Summary

Efforts were continued toward completion of the conceptual commercial plants currently under study. Mine requirements and typical underground and strip mines were designed for the Southern Appalachian location. The design of a wet-jigging, screening and multipurpose cyclone coal preparation plant in support of the POGO design for the Eastern Interior region coal province was completed.

The Oil/Gas plant and Fischer-Tropsch plant design tasks were completed during this period. The POGO plant activities included preparation of detailed material balances for a number of units in the plant. Preliminary block flow diagrams for the multi-process demonstration facility were submitted to and discussed with ERDA. Parsons continued their investigation of sensitive environmental areas of coal conversion where additional information is to be developed regarding the formation of possible pollutants.

Conceptual Design of Commercial Plants

Coal Mining/Coal Preparation — Mine requirements and a mine plan for a Southern Appalachian location for the Power, Oil, Gas and Other Products were developed during the quarter. The mining plan consists of a combination of surface and underground mining for the first five years, with each type of mine producing half the coal requirements. All coal would be supplied from underground mines for the last 15 years of the 20-year project. The underground mine unit will produce 2 million short tons per year of run of mine coal. The strip mine unit has average capacity of 1 million short tons per year of run of mine coal.

The design of the wet jigging, screening and multistage cyclone coal preparation plant for the POGO design for the Eastern Interior region was completed. The plant will beneficiate high ash content coal to a clean coal product having an average of 7 percent ash on a dry basis. Sulfur pyrites will also be largely removed by the plant.

Oil/Gas Plant Design — the final design report was completed and sent to ERDA and NTIS. This completes this task assignment.

Fischer-Tropsch Plant Design — Approval to publish the R&D report was received from ERDA. This completes this task effort.

Power, Oil, Gas & Other Products Plant (POGO)

Basic process design activities continued on the major engineering sections of the plant. Preliminary flow sheets for the following process units were advanced:

- 12 — Solvent Refined Coal (SRC)
- 13 — SRC Atmospheric Distillation
- 14 — SRC Vacuum Distillation
- 15 — Pyrolysis
- 18 — Gasification
- 21 — Heavy Liquid Hydrotreating
- 25 — Naphtha Reforming
- 29 — Hydrogen Recovery and Purification

Multi-Process Demonstration Facility — A program plan was submitted to ERDA for design of the plant. Basically, the facility will be designed for a four phase construction program. The first phase will include coal handling, an ash blower, low Btu fuel-gas gasifier with a capacity to process 1,800 tons of coal per day, H_2S removal, and the necessary support facilities. The clean product gas would be supplied to an existing power boiler.

The second phase would have additional coal handling and preparation facilities, and oxygen blower medium pressure (400-600 psig) gasifier with a process capacity of 3,600 tons of coal per day.

The third phase would be a Fischer-Tropsch unit to convert synthesis gas to liquid fuels and substitute natural gas.

The fourth phase would provide additional modules for demonstration of other processes.

Equipment Development — Attempts continued to contact vendors regarding high temperature, and high efficiency cyclones. Investigations were also conducted on the practical efficiency of electrostatic precipitators for removal of char from synthesis gas streams. Ralph M. Parsons engineers confirmed that wet electrostatic precipitators are best suited for this application; and that dry units are also satisfactory but can be expected to vary in efficiency depending on the specific chars resistivity properties and the operating gas velocity.

Environmental Considerations — RMP initiated a dispersion modeling study concerning the air pollutants which could be released by the Multi-Process Demonstration Facility. The object of the study is to verify compliance with ambient air quality standards after air dispersion. The EPA developed PTMAX and PTDIS computer programs, providing maximum concentration of pollutants on the ground and contours of equal pollutant concentration from the source (ISOPLETHS) are being used for the study. Specific meteorological data pertinent to the geographical area studied will be obtained.

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VII. CONCEPTUAL DESIGN FOR ADVANCED COAL LIQUEFACTION COMMERCIAL PLANT

FLUOR ENGINEERS AND CONSTRUCTORS
IRVINE, CALIFORNIA

Contract No.: EX-76-C-01-2251
Total Funding: $1,906,800

INTRODUCTION

Fluor Engineers and Constructors are currently under contract to the Division of Major Facilities Project Management to prepare a conceptual design package for a commercial facility to produce liquid synthetic fuels by an advanced coal liquefaction scheme. The process currently under study is similar to the hydrogen donor solvent concept.

PROGRAM DESCRIPTION

The contract involves a series of closely related tasks which are expected to require about 18 months for completion. The initial task involves a screening study to select an overall plant configuration and liquid product slate. The objective is to establish a basis for design and selection of both basic and unit processes for the final design. The result of the effort will be an overall plant configuration plus an overall material and energy balance, capital and operating cost estimate. The technology to be used for each key step will have been identified. Following the initial screening study, the process design phase for the plant will commence. Material and energy balances will be developed and process flow diagrams prepared for non-proprietary units. In addition, utility consumptions, effluent streams, and catalyst and chemical requirements will be defined as well as specification of feed, product, and by-product streams.

The third task to be undertaken will involve equipment specifications for the plant. An outline of process duty specifications and dimensional drawings will be prepared for all mechanical equipment and vessels. Duty specifications will be written for conventional pre-engineered package systems such as water treating, insrument air, oxygen plants, and ash or slag handling. The specifications produced will not be complete in all details. However, sufficient information will be included so that a competent engineering contractor could complete the detailed engineering design without recourse to any substantial additional process design.

In addition to development of the basic engineering package, efforts will be expended in identification of those areas of process and mechanical design where additional development work is required before promising technology can be applied commercially.

After completion of the above tasks, a technical and economic evaluation will be made to determine the production rate and the number of parallel trains for each key unit within the commercial facility. The task also includes an evaluation to arrive at a recommendation for the size of a demonstration plant. In addition, a number of auxiliary studies will be carried out to supplement the plant design. These tasks include:

- Mine and plant site
- Environmental assessment
- Operating and maintenance instructions
- Final economic assessment

The mine and plant design activity cover a number of design functions which include:

- Preliminary engineering of a coal mine to be developed for a hypothetical typical coal deposit in the Appalachian region. Work will include a mining method, a mining plan for long term exploitation of the mine, a reclaiming plan, and a solid waste disposal plan.
- Transportation method from mine to plant.
- Coal storage and coal preparation.
- Plot plan development for mine and plant.
- Narrative specifications covering all support facilities.
- Preliminary single line electrical diagram
- Scale model of the proposed plant

The environmental effort will involve:

- Determination of applicable environmental regulations
- Identifications of all gaseous, liquid and solid effluents
- Determination of Procedures of processes for pollution abatement
- Preparation of descriptive material to demonstrate that the plant can meet the applicable environmental regulations

A complete plant description will be prepared which will include operating and maintenance instructions, flexibility and performance limits of plant operations, anticipated start up problems and critical areas of design and safety.

Finally, a capital cost estimate for the mine and plant will be developed. It will cover estimation of all fixed and operating costs and determination of product prices using discounted cash flow procedures.

PROJECT ACCOMPLISHMENTS

The process configuration tasks were completed during the sixth month of the contract. The processing scheme chosen by Fluor were determined to be as follows:

Extraction

Fluor developed a procedure for characterizing extract as a function of time and temperature in the extractor. As a result of this effort, extractor conditions were chosen at 700° F, 15 minutes residence time, and a 60 percent depth of extraction. The basic design consists of separate vessels, each with mechanical agitation.

Solids Separation

An extensive study was carried out to evaluate rotary precoat and horizontal leaf filtration, solvent deashing using an anti-solvent, and deashing by means of settling, by one or two stages. The results showed that single stage settling was the preferred route for the type of coal chosen for the project. The reduced capital cost, which is estimated to be several hundred million dollars, was the major incentive for selection of the system.

Low Temperature Carbonization (LTC)

The proposed design consists of a single vessel which is operated at 400 psig with oxygen addition. The incentive for this particular high pressure system is that it permits direct transport of char from the LTC to the gasifier which eliminates lock hoppers and other mechanical feeders.

The fluidized-bed, agglomerating ash process was incorporated into the processing scheme. An operating pressure of 400 psig was selected as a practical level since overall thermal efficiency is relatively insensitive to gasification pressure. The gassification of vacuum resid as an auxiliary feedstock to the gasifier was adopted. Fluor stated that gasifying resid rather than burning it provided added assurance that the plant would be environmentally acceptable for sulfur, nitrogen oxide and particulate emissions.

The total plant configuration was studied using a computerized technique developed by Fluor for determining overall and interunit material and energy balances. Conclusions reached by Fluor were listed as follows:

- Maximum gasoline should be produced with no production of either diesel or heavy fuel oil by-products
- Conventional coal cleaning procedures should be used rather than feeding ROM coal directly to the liquefaction process
- Depth of extraction has only a minor effect upon overall thermal efficiency
- The efficiency penalty resulting from the use of settling is small, since the extract contained in the underflow is converted to useful materials, char and gas

- There is no significant efficiency penalty associated with the use of water slurry vaporization (as a means of feeding LTC char to the gasifier) for producing hydrogen since the water is useful as shift steam. For fuel gas production, however, water slurry vaporization entails a substantial thermal penalty
- There is no advantage to coking of the vacuum resid. Since resid may be used either as an in-plant fuel or as a gasification feedstock, other streams must be found to replace any resid that is coked.
- Combined cycle gas turbines display the greatest overall efficiency and their use should be maximized

A summary of the product slate and process features selected to date and discussed previously are given below.

Product Slate:

Gasoline, 10 Reid Vapor Pressure

89 $\frac{R+M}{2}$	66,532	Barrels per Stream Day
SNG	68.5	Million Std. Cubic Ft. Day
Ethane	12.0	
Propane	8,089	
Butane	8,557	
Sulfur	1,193	Long Tons per Stream Day
Ammonia	240	Tons per Stream Day

Process Features:

Depth of Extraction - 60%

Solids Separation — Single stage settling

Solids Disposition — Converted to char in 400 psig LTC
Feed to H_2 Plant — LTC char plus vacuum resid
Extract Hydrogenation Conversion — 73.4%
Gasifier Type — Fluid Bed, Agglomerating Ash
Power Generation — Combined Cycle Gas Turbine

PROGRESS DURING JANUARY-MARCH 1977

Conceptual Plant Design

Process Design

The design phase for the conceptual commercial plant continued throughout the quarter. Various studies were conducted in each of the major areas and minor changes to the process design were made.

For each of the major areas, the heat and material balances were advanced and vendors of certain process were contacted concerning process design information. This task remains on schedule.

Specification of non-proprietary equipment required for the plant continued. Also, the mine and plant site design were advanced. Design data of greater detail will be provided as the engineering efforts on various plant sections near completion.

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GLOSSARY

absorption — an imprecise term suggesting the taking up of one substance by another by either a physical process or a chemical combination.

acceptor — calcined carbonate that absorbs carbon dioxide evolved during gasification, liberating heat.

acid gas removal — the process of selectively removing hydrogen sulfide and carbon dioxide from a gas stream.

activated carbon — carbon obtained by carbonization in the absence of air, preferably in a vacuum; has the property of absorbing large quantities of gases, solvent vapors; used also for clarifying liquids.

adiabatic — any process where heat is neither given off nor absorbed.

adsorption — the process by which the surface of a solid or liquid attracts and holds any atom, molecule, or ion from a solution or gas with which it is in contact.

agglomerate — assemblage of ash particles rigidly joined together, as by partial fusion (sintering).

anthracite coal — hard coal containing 86 to 98 percent fixed carbon and small percentages of volatile material and ash.

API — American Petroleum Institute.

API gravity — a scale adopted by the API for measuring the density of oils; $° \text{API} = \dfrac{141.5}{\text{Specific gravity, } 60°\text{F}/60°\text{F}} - 131.5$

aromatic hydrocarbon — a cyclic hydrocarbon containing one or more six-carbon (benzene) rings.

ash — solid residue remaining after the combustion of coal.

ASTM — American Society for Testing Materials.

autoclave — a vessel, constructed of thick-walled steel, for carrying out chemical reactions under high pressures and temperatures.

bench-scale unit — a small-scale laboratory unit for testing process concepts and operating parameters as a first step in the evaluation of a process.

binder — carbon products, tars, etc., used to impart cohesion to the body to be formed; a coal-extract binder may be used to prepare formed-coke pellets from non-coking coals.

bituminous coal — a broad class of coals containing 46 to 86 percent fixed carbon and 20 to 40 percent volatile matter.

blow down — periodic or continuous removal of water from a boiler to prevent accumulation of solids.

bottoming cycle — the lower temperature thermodynamic power cycle of a combined-cycle system.

Btu — British thermal unit, the quantity of energy required to raise the temperature of one pound of water one degree Fahrenheit.

BTX — benzene, toluene, xylene; aromatic hydrocarbons.

caking — the softening and agglomeration of coal as a result of the application of heat.

calcination — the process of heating a solid to a high temperature to cause the decomposition of hydrates and carbonates.

calorific value — the quantity of heat obtained by the complete combustion of a unit mass of a fuel under prescribed conditions.

carbon fiber — fine filaments of carbon about eight microns in diameter which are used in composite materials, being bound with resins.

carbonization — destructive heating of carbonaceous substances with the production of a solid, porous residue, or coke, and the evolution of a number of volatile products. For coal, there are two principal classes of carbonization, high-temperature coking (about 900°C) and low-temperature carbonization (about 700°C).

catalyst — a substance that accelerates the rate of a chemical reaction without itself undergoing a permanent chemical change.

centrifuge — an apparatus rotating at high speed which utilizes the centrifugal force generated to separate materials of different densities, e.g., undissolved residue from coal solution in the SRC process.

char — the solid residue remaining after the removal of moisture and volatile matter from coal.

Claus process — industrial method of obtaining elemental sulfur through the partial oxidation of gaseous hydrogen sulfide in air followed by catalytic conversion to molten sulfur.

coal — a readily combustible rock containing more than 50 weight percent and more than 70 volume percent of carbonaceous material including inherent moisture, formed from compaction and induration of variously altered plant remains similar to those in peat.

coalification — metamorphosis of vegetable debris into coal.

coke — strong porous residue consisting of carbon and mineral ash formed when bituminous coal is heated in a limited air supply or in the absence of air. Coke may also be formed by thermal decomposition of petroleum residues.

coke breeze — the fine screenings from crushed coke usually passing a 1/2 inch or 3/4 inch screen opening.

combined cycle — two sequential thermodynamic power conversion systems operating at different temperatures.

combustion gas — gas formed by the combustion of coal, e.g., burning.

combustor — a vessel in which combustion takes place.

coupon — a polished metal strip used to measure the rate of corrosion of the metal in a specific gaseous or liquid environment.

cracking — the partial decomposition of high-molecular-weight organic compounds into lower-molecular-weight compounds, generally as a result of high temperatures.

crude gas — impure gas produced in a gasifier.

culm — the waste or slack from anthracite mines or preparation plants consisting of fine coal, coal dust, and dirt.

cyclone separator — essentially a settling chamber to separate solid particles from a gas, in which gravitational acceleration is replaced by centrifugal acceleration.

degasification — a process for removing naturally occurring methane from coal seams.

delayed coking — a process wherein coal is subjected to a long period of carbonization at moderate temperatures to form coke.

demineralization — removal of mineral matter (ash) from coal by solvent extraction, usually under hydrogen atmosphere.

depolymerization — the change of a large molecule into simpler molecules usually accompanied by the substitution of hydrogen for oxygen in the molecular structure.

destructive distillation — the distillation of coal accompanied by its thermal decomposition.

desulfurization — the removal of sulfur from hydrocarbonaceous substances by chemical reactions.

devolatilization — the removal of a portion of the volatile matter from medium- and high-volatile coals.

diatomaceous earth — a yellow, white, or light-gray, siliceous porous deposit made up of opaline shells of diatoms; used as a filter aid, paint filler, adsorbent, abrasive, and thermal insulator. Also known as kieselguhr.

diatomite — See Diatomaceous Earth.

dissolution — the taking up of a substance by a liquid with the formation of a homogeneous solution.

distillation — a process of vaporizing a liquid and condensing the vapor by cooling; used for separating liquids into various fractions according to their boiling points or boiling ranges.

dolomite — a carbonate of calcium and magnesium having the chemical formula $CaMg(CO_3)_2$.

Dowtherm — trademark for a series of eutectic mixtures of diphenyl oxide and diphenyl used as high-temperature heat-transfer fluids.

ebullated bed — gas containing a relatively small proportion of suspended solids, bubbles through a higher density fluidized phase with the result that the system takes on the appearance of a boiling liquid.

economizer — heat exchanging mechanism for recovering heat from flue gases.

effluent gas — gas given off from a process vessel.

elutriation — the preferential removal of the small constituents of a mixture of solid particles by a stream of high-velocity gas.

endothermic reaction — a process in which heat is absorbed.

enthalpy change — the increase or decrease in heat content of a substance or system which accompanies its change from one state to another under constant pressure.

entrained bed (flow) — a bed in which solid particles are suspended in a moving fluid and are continuously carried over in the effluent stream.

eutectic — that combination of two or more components which produces the lowest melting temperature.

exothermic reaction — a process in which heat is liberated.

extraction — a method of separation in which a solid or solution is contacted with a liquid solvent (the two being essentially mutually insoluble) to transfer components into the solvent.

extractive coking — similar to delayed coking process, with the emphasis on high tar yields to produce liquids.

filter aid — finely divided solids used to increase efficiency of filtering.

filter cake — the moist residue remaining from the filtration of a slurry to produce a clean filtrate.

filtrate — a liquid free of solid matter after having passed through a filter.

filtration — the separation of solids from liquids by passing the mixture through a suitable medium, e.g., cloth, paper, diatomaceous earth.

Fischer assay — method for determining the tar and light oil yields from coal or oil shale; conducted in a retort under an inert atmosphere with a prescribed increase in temperature to 500°C.

Fischer-Tropsch catalyst — catalysts developed for the catalytic synthesis of liquid fuels from coal-derived synthesis gas; catalysts contain principally iron, cobalt, nickel, or ruthenium.

Fischer-Tropsch process — method of hydrogenating mixtures of carbon monoxide and hydrogen produced from coal, lignite, or natural gas by means of steam, at 1-10 atmospheres and 360-410°F to yield liquid and gaseous fuels, and a wide spectrum of industrial chemicals.

fixed-bed — stationary solid particles in intimate contact with fluid passing through them.

fixed carbon — the solid residue, other than ash, obtained by destructive distillation; determined by definite prescribed methods.

flash carbonization — a carbonization process characterized by short residence times of coal in the reactor to optimize tar yields.

flue gas — gaseous combustion products.

fluidization (dense phase) — the turbulent motion of solid particles in a fluid stream; the particles are close enough as to interact and give the appearance of a boiling liquid.

fluidization (entrained) — gas-solid contacting process in which a bed of finely divided solid particles is lifted and agitated by a rising stream of gas.

fluidized-bed — assemblage of small solid particles maintained in balanced suspension against gravity by the upward motion of a gas.

fly ash — a fine ash from the pulverized coal burned in power station boilers, or entrained ash carried over from a gasifier.

fractionation — distillation process for the separation of the various components of liquid mixtures.

freeboard — the space in a fluidized-bed reactor between the top of the bed and the top of the reactor.

free swelling index — a standard test that indicates the caking characteristics of coal when burned as a fuel.

Friedel-Crafts reaction — a substitution reaction, catalyzed by aluminum chloride in which an alkyl (R-) or acyl (RCO-) group replaces a hydrogen atom of an aromatic nucleus to produce a hydrocarbon or a ketone.

fuel cell — a galvanic cell in which the chemical energy of a conventional fuel is utilized to produce electricity.

fuel gas — low heating value (150-350 BTU/scf) product generally utilized on site for power generation or industrial use.

gasification of coal — the conversion of solid coal into a gaseous form by various chemical reactions with steam.

gasifier — a vessel in which gasification occurs, usually utilizing fluidized-bed, fixed-bed, or entrained-bed units.

heat capacity — quantity of heat required to raise the temperature of one pound of a substance one degree Fahrenheit.

high-Btu gas — a gas having a heating value of 900 to 1,000 Btu per standard cubic foot, which approaches the value for natural gas.

higher heating value (HHV) — the heat liberated during a combustion process in which the product water vapor is condensed to a liquid and the heat of condensation is recovered.

hydroclone — a small cyclone extractor for removal of suspended solids from a flowing liquid by means of the centrifugal forces set up when the liquid is made to flow through a tight conical vortex.

hydrocoking — coking of tars, SRC, etc., under hydrogenating conditions to form liquid products.

hydrocracking — the combination of cracking and hydrogenation of organic compounds.

hydrogasification — gasification that involves the direct reaction of fuels with hydrogen to optimize formation of methane.

hydrogenation — chemical reactions involving the addition of gaseous hydrogen to a substance in the presence of a catalyst under high temperatures and pressures.

hydrogen donor solvent — solvent, such as anthracene oil, tetralin (tetrahydronaphthalene), decalin, etc., which transfers hydrogen to coal constituents causing depolymerization and consequent conversion to liquid products of lower boiling range which are then dissolved by the solvent.

hydrotreating— a process to catalytically stabilize petroleum or other liquid hydrocarbon products and/or remove objectionable elements from products or feedstocks by reacting them with hydrogen.

ideal gas— any gas whose equation of state is expressed by the ideal gas law, namely PV = nRT where P is the pressure, V is the volume, R is the gas constant, T is the absolute temperature, and n = number of moles.

ignition temperature— the minimum temperature necessary to initiate self-sustained combustion of a substance.

industrial gas— see fuel gas.

inerts— constituents of a coal which decrease its efficiency in use, e.g., mineral matter (ash) and moisture in fuel for combustion.

in situ— in its original place, e.g., underground gasification of a coal seam.

intermediate-Btu gas— synthesis gas product with a higher heating value between 350 and 500 Btu per standard cubic foot.

lignite— brownish-black coal containing 65-72 percent carbon on a mineral-matter-free basis, with a rank between peat and subbituminous coal.

limestone— sedimentary rock containing 50 percent carbonate (CO_3) of lime or magnesia. Chemical formula (for calcite limestone) is $CaCO_3$.

liquefaction— conversion of a solid to a liquid; with coal, this appears to involve the thermal fracture of carbon-carbon and carbon-oxygen bonds, forming free radicals. These radicals abstract hydrogen atoms yielding low molecular weight gaseous and condensed aromatic liquids.

liquefied petroleum gas (LPG)— those hydrocarbons that have a vapor pressure (at 70°F) slightly above atmospheric (such as propane and butane); kept in liquid form under a pressure higher than 1 atm.

lock hopper— a mechanical device that permits the introduction of a solid into an environment of different pressure.

low-Btu gas— a gas having a heating value up to 350 Btu per standard cubic foot.

lower heating value— the heat liberated by a combustion process assuming that none of the water vapor resulting from the process is condensed, so that its latent heat is not available.

MAF— moisure and ash-free; a term that relates to the organic fraction in coal.

mesh— measure of fineness of a screen, e.g., a 400-mesh sieve has 400 openings per linear inch.

methanation— the production of methane (CH_4) from carbon monoxide or dioxide and hydrogen.

methane— CH_4, a colorless, odorless, and tasteless gas, lighter than air; the chief component of natural gas.

methanol— methyl alcohol, CH_3OH.

micron— a unit of length equal to one millionth of a meter; 10^{-6} meter.

moving bed— particlized solids in a process vessel that are circulated (moved) either mechanically or by gravity flow.

natural gas— naturally occurring gas extracted from sedimentary structures consisting mainly of methane and having a higher heating value of approximately 1,050 Btu per standard cubic foot.

noncoking coal— a coal that does not form coke under normal coking conditions.

olefinic hydrocarbon— a class of unsaturated hydrocarbons containing one or more double bonds and having the general chemical formula C_nH_{2n}.

open cycle— a thermodynamic power cycle in which the working fluid passes through the system only once and is then exhausted to the atmosphere.

peat— an unconsolidated, hydrophilic, yellowish-brown to brownish-black, carbonaceous sediment, formed by accumulation of partially fragmented and decomposed plant remains in swamps and marshes which retains more than 75 percent inherent moisture and less than 12 percent mineral matter in saturated natural deposits.

petrochemicals— those derived from crude oil or natural gas, or their coal-derived substitutes; they include light hydrocarbons such as butylene, ethylene and propylene, the raw materials for the production of plastics by polymerization.

phenols— a group of aromatic compounds having the hydroxyl (OH) group directly attached to the benzene ring.

pilot plant— a chemical process plant containing all the processes of a commercial unit, but on a smaller scale, for the purpose of studying the technical and economic feasibility of the process.

pipeline gas— a methane-rich gas that conforms to certain standards and has a higher heating value between 950 and 1,050 Btu per standard cubic foot.

plenum chamber— an enclosed space through which air is forced for slow distribution through ducts.

precoat— layer of suitable filtering medium, e.g., diatomaceous earth, laid down on a rotary filter cloth prior to operation.

prilling tower— a tower that produces small solid agglomerates by spraying a liquid solution in the top and blowing air up from the bottom.

process development unit— a system used to study the effects of process variables on performance; sized between a bench-scale unit and a pilot plant.

proximate analysis— analysis of coal based on the percentages of moisture, volatile matter, fixed carbon (by difference), and ash, using prescribed methods. Reported on different bases, such as as-received (or as-fired), dry, mineral-matter-free (mmf), and dry mineral- matter-free (dmmf).

purification— removal of a wide range of impurities present in gases from coal gasification.

pyrolysis— thermal decomposition of organic compounds in the absence of oxygen.

quenching— cooling by immersion in oil, water bath, or water spray.

Raney nickel catalyst— specially prepared nickel catalyst used in the hydrogenation of organic materials and the methanation of synthesis gas to methane.

raw gas— see crude gas.

reactivity— susceptibility to chemical change; for example, in coal liquefaction, the reactivity of the coal for conversion to liquid products is a function of the coal rank, among other things.

reactor— vessel in which coal-conversion reactions take place.

Rectisol process— a process for the purification of coal-gasification gas based on the capability of cold methanol to absorb all gas impurities in a single step; gas naphtha, unsaturated hydrocarbons, sulfur compounds, hydrogen cyanide, and carbon dioxide are removed from the gas stream by the methanol at temperatures below 0°C.

reducing gas— a gas which, at high temperatures, lowers the state of oxidation of other chemicals.

reforming processes — a group of proprietary processes in which low-grade or low molecular weight hydrocarbons are catalytically converted to higher grade or higher molecular weight materials; also applies to the endothemic reforming of methane, for the production of hydrogen, by the reaction of methane and steam in the presence of nickel catalysts.

refractory — a material capable of withstanding extremely high temperatures and having a relatively low thermal conductivity.

residence time — time spent by a typical particle in a particular zone.

saturated hydrocarbon — a carbon-hydrogen compound with all carbon bonds filled; that is, there are no double or triple bonds as in olefins and acetylenes.

scrubber — apparatus in which a gas stream is freed of tar, ammonia, and hydrogen sulfide.

seam coal — coal which is intermediate in rank between bituminous coal and anthracite; contains 8 to 22 percent volatile matter and from 91 to 93 percent carbon.

semi-water gas — a mixture of carbon monoxide, carbon dioxide, hydrogen, and nitrogen, obtained by passing an air-stream mixture through a hot bed of coke, having a higher heating value of about 120 Btu per standard cubic foot

sensible heat — that heat which results in only the elevation of the temperature of a substance with no phase changes.

shift conversion — process for the production of gas with a desired carbon monoxide content from crude gases derived from coal gasification; carbon monoxide-rich gas is saturated with steam and passed through a catalytic reactor where the carbon monoxide reacts with steam to produce hydrogen and carbon dioxide, the latter being subsequently removed in a scrubber employing a suitable sorbent.

sintering — the agglomeration of solids at temperatures below their melting point, usually as a consequence of heat and pressure.

slag — molten coal ash composed primarily of silica, alumina, iron oxides, and calcium and magnesium oxides.

slurry — a suspension of pulverized solid in a liquid.

solvation — the association or combination of molecules of solvent with solute ions or molecules.

solvent — that component of a solution which is present in excess; liquid used to dissolve a substance.

solvent extraction — selective solution of coal constituents from finely divided coal particles into a suitable solvent after intimate mixing, usually at high temperatures and pressures in the presence of hydrogen, with or without a catalyst, followed by phase separation.

solvent refined coal (SRC) — a coal extract derived by solvent extraction; a brittle, vitreous solid (m.p. 300°F to 400°F) containing about 0.1 percent ash and about 10 percent of the sulfur in the original coal feedstock; calorific value is about 16,000 Btu per pound; may be used as a clean fuel for power generation by combustion; utilized for the production of high-grade metallurgical coke, anode carbon, and activated carbon by coking, or hydrogenated to produce synthetic crude oil.

space velocity — volume of a gas (measured at standard temperature and pressure) or liquid passing through a given volume of catalyst in a unit time.

specific gravity — ratio of the weight of any volume of a substance to the weight of an equal volume of water at 4°C.

specific heat — heat capacity of a substance as compared with the heat capacity of an equal weight of water.

standard cubic foot (SCF) — the volume of a gas at standard conditions of temperature and pressure. The American Gas Association uses moisture-free gas at 60°F and 30 inches of mercury (1.0037 atm) as its standard conditions. The pressure standard is not universal in the gas industry: 14.7 psia (1.000 atm) and 14.4 psia (0.980 atm) are also used. The scientific community uses 32°F and 1 atm as standard conditions.

stoichiometry — the definite proportions in which molecules react chemically to form new molecules.

stripping — the removal of the more volatile components from a liquid mixture of compounds.

subbituminous coal — the rank of coal between bituminous and lignite, classified by ASTM as having a range of heating values between 8,300 and 11,000 Btu per pound on a moist mineral-matter-free basis.

substitute natural gas (SNG) — a gas produced from coal, oil sands, or oil shale conforming to natural gas standards.

superficial velocity — the linear velocity of a fluid flowing through a bed of solid particles calculated as though the particles were not present.

superheater — a heat exchanger which adds heat to the saturated steam leaving a boiler.

syncrude — synthetic crude oil; oil produced by the hydrogenation of coal, coal extracts, oil sands, or oil shale, which is similar to petroleum crude.

synthesis gas — a mixture of hydrogen and carbon monoxide which can be reacted to yield a hydrocarbon.

tail gas — a gas issuing from a gas-treatment unit which may be recycled to the process or exhausted.

tar (coal) — a dark brown or black, viscous, combustible liquid formed by the destructive distillation of coal.

therm — a unit of heat used as a basis for the sale of natural gas; equal to 100,000 Btu.

topping cycle — the higher temperature thermodynamic power cycle of a combined-cycle system.

turndown ratio — the minimum ratio of actual flowrate to design flowrate at which a process unit can be operated.

ultimate analysis — the determination by prescribed method of carbon and hydrogen in the material as found in the gaseous products of its complete combustion, the determination of sulfur, nitrogen, and ash in the material as a whole and the estimation of oxygen by difference; may be reported on different bases, such as as-received (or as-fired), dry, mineral-matter-free (mmf), and dry mineral-matter-free (dmmf).

Venturi scrubber — a gas cleaning device which involves the injection of water into a stream of dust-laden gas flowing at a high velocity through a contracted portion of a duct, thus transferring the dust particles to the water droplets which are subsequently removed.

volatile matter — those constituents of coal, exclusive of moisture, that are liberated from a sample when heated to 1750°F for seven minutes in the absence of oxygen.

water gas — gas produced by the reaction of carbon (in coal or coke) and steam to yield mixtures of carbon monoxide and hydrogen; similar to synthesis gas.

water gas shift — the reaction between water vapor and carbon monoxide to produce hydrogen and carbon dioxide or the reverse: $CO + H_2O \rightleftarrows H_2 + CO_2$

working fluid — a gas stream which directly does work, e.g., powering a gas turbine.

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