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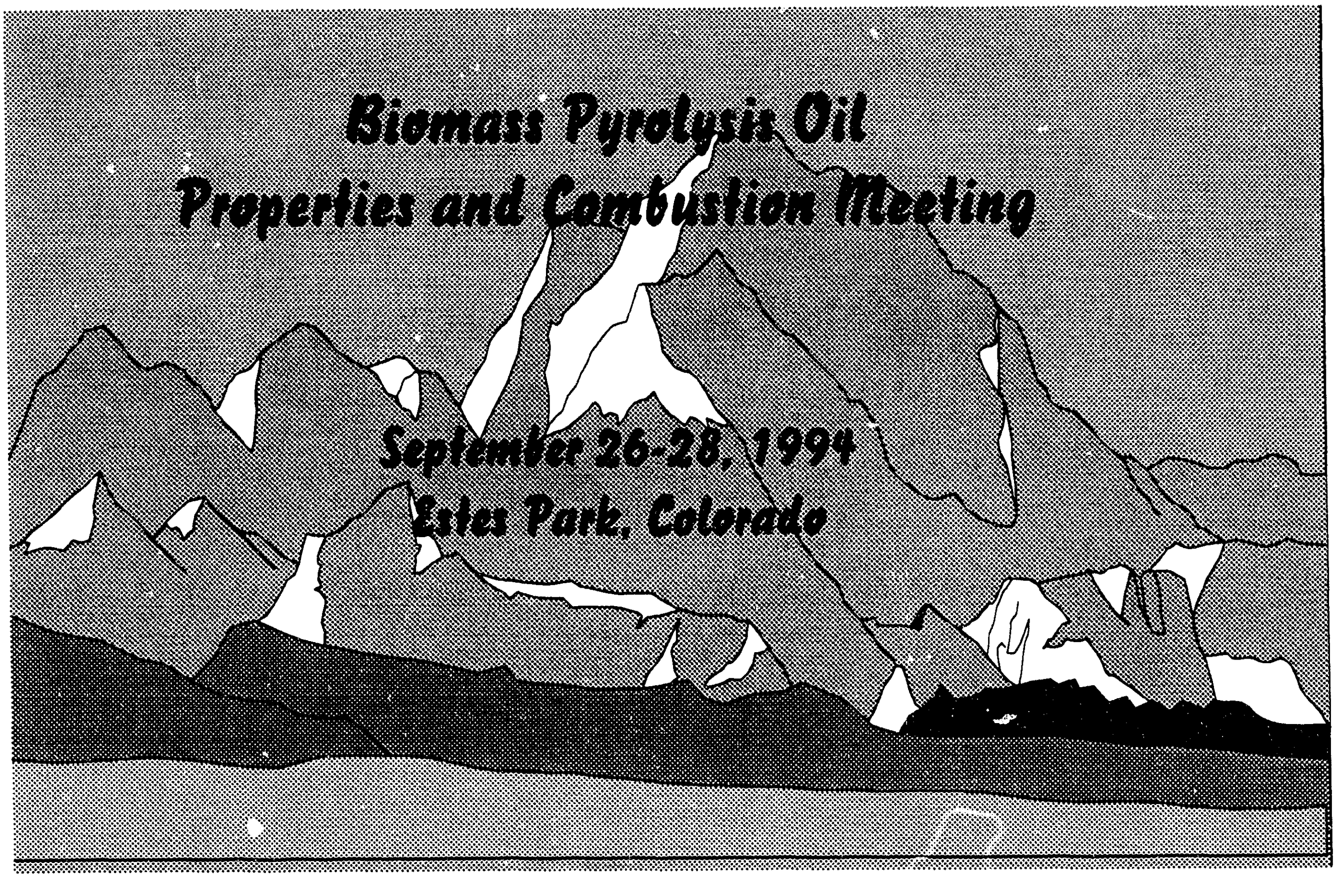
Program and Abstracts



Biomass Pyrolysis Oil Properties and Combustion Meeting

September 26-28, 1994
Estes Park, Colorado

sponsored by:
The U.S. Department of Energy, NREL, Natural Resources Canadaand
VTT Energy, Finland

MASTER

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Biomass Pyrolysis Oil Properties And Combustion

co-sponsored by the U.S. DOE, NREL, Natural Resources Canada (NRCan), and VTT Energy, Finland

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Preface

The increasing scale-up of fast pyrolysis in North America and Europe, as well as the exploration and expansion of markets for the energy use of biocrude oils that now needs to take place, suggested that it was timely to convene an international meeting on the properties and combustion behavior of these oils. A common understanding of the state-of-the-art and technical and other challenges which need to be met during the commercialization of biocrude fuel use, can be achieved.

The technical issues and understanding of combustion of these oils are rapidly being advanced through R&D in the United States, Canada, Europe and Scandinavia. It is obvious that for the maximum economic impact of biocrude, it will be necessary to have a common set of specifications so that oils can be used interchangeably with engines and combustors which require minimal modification to use these renewable fuels. Fundamental and applied studies being pursued in several countries are brought together in this workshop so that we can arrive at common strategies. In this way, both the science and the commercialization are advanced to the benefit of all, without detracting from the competitive development of both the technology and its applications.

This United States-Canada-Finland collaboration has led to the two and one half day specialists meeting at which the technical basis for advances in biocrude development is discussed. The goal is to arrive at a common agenda on issues that cross national boundaries in this area. Examples of agenda items are combustion phenomena, the behavior of trace components of the oil (N, alkali metals), the formation of NO_x in combustion, the need for common standards and environmental safety and health issues in the handling, storage and transportation of biocrudes.

The Technical Committee

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Wednesday Morning - Session #5: Combustion in Internal Combustion Engines

Combustion in Turbines

Biomass Pyrolysis Oil Properties and Combustion

Co sponsored by the U.S. DOE, NREL, Natural Resources Canada (NRCan) and VTT Energy, Finland

FINAL PROGRAM

Saturday and Sunday, September 24, 25, 1994

Hikes in Rocky Mountain National Park - Organized by Mike Antal and John Scahill	

Sunday, September 25, 1994

TIME	FUNCTION
5:00 - 7:00pm	Dinner served in cafeteria
7:00-10:00pm	Dessert Reception and Registration

MONDAY, SEPTEMBER 26, 1994

MORNING - SESSION #1

TIME	FUNCTION
7:00 - 8:00	Breakfast served in cafeteria
7:00 - 8:30	Registration
8:30-8:45	Welcome - Industrial Technology Division Welcome - Bill Marshall, Deputy Director for Operations, NREL
8:45 - 9:15	**Introduction and Overview of National Biomass Power Programs** Yrjo Solantausta (VTT), Ralph Overend (NREL), and Ed Hogan (NRCan)
	Fundamentals Discussion Leader: Don Scott University of Waterloo
9:15-9:45	*Cellulose Pyrolysis Kinetics: The Current State of Knowledge* Michael Antal (U. of Hawaii)
9:45-10:15	*Chemical Analysis of Biomass Fast Pyrolysis Oils* Doug Elliott (PNL)
10:15-10:45	Coffee Break
10:45-11:15	*Properties and Characteristics of Ensyn Bio-Oil* Narendra Bakhshi (U of Saskatchewan)
11:15-12:15	*Storage of Biomass Pyrolysis Oils* Stefan Czernik (NREL) *Inorganic Compounds in Biomass Feedstocks: Their Role in Char Formation and Effect on the Quality of Fast Pyrolysis Oils* Foster Agblevor (NREL) *Hot Gas Filtration to Remove Char from Pyrolysis Vapors Produced in the Vortex Reactor at NREL* Jim Diebold (NREL)
12:15-1:00	Lunch served in cafeteria
1:00 - 5:00	Afternoon - Free time, ad hoc group discussions
1:15 - 4:15	Park Service Walking Tour. Meet at Main Lodge at 1:15.
5:00 - 6:30	Dinner served in cafeteria

EVENING - SESSION #2 - Discussion Leader: Don Huffman (Ensyn)

	Fast Pyrolysis Oil Production and Economics -
7:00-7:30	*Engineering Developments in Fast Pyrolysis for Bio-Oils* - Tony Bridgwater (Aston University)
7:30-8:00	*Pyrolysis Oil Economics - Issues and Impacts* Cathy Gregoire (NREL)
8:00-8:30	*Flash Pyrolysis of Biomass in a Circulating Fluidized Bed Reactor* - Ionnis Boukis (CRES)
8:30-9:00	*The Production and Handling of WFPP Bio-Oil and its Implications for Combustion* - Angel Cuevas (Union Fenosa)
	Environmental Safety and Health and Fuel Specifications and Standards -
9:00-9:30	*Environmental Considerations in the Production and Use of Biomass Fast Pyrolysis Oils* - Doug Elliott (PNL)
9:30-10:00	*Results of Toxicological Testing of Whole Wood Oils Derived from the Fast Pyrolysis of Biomass* - David Gratson (NREL)

TUESDAY, SEPTEMBER 27, 1994

MORNING - SESSION #3 Discussion Leader: Don Hardesty (Sandia)

TIME	FUNCTION
7:00 - 8:00	Breakfast served in cafeteria
	Combustion in Boilers and Furnaces
8:30 - 9:00	*Specifications for Liquid Fuels in Boilers* (tutorial) - Scott Drennan (Coen Company
9:00 - 9:30	*Sprays and Spray Combustion* (tutorial) - John Daily (U. of Colorado)
9:30 - 10:00	*Formation of Nitrogen Oxides in Combustion Processes* (tutorial) - Mel Branch (U. of Colorado)
10:00 - 10:30	Coffee Break
10:30 - 11:00	*Single-Droplet Combustion of Biomass Pyrolysis Oils* Judy Wornat (Princeton)
11:00 - 11:30	*Baseline NO_x Emissions During Combustion of Wood - Derived Pyrolysis Oils* - Larry Baxter (Sandia)
11:30 - 12:00	*Combustion Characterization of Wood Derived Flash Pyrolysis Oils in Industrial-Scale Turbulent Diffusion Flames* - Alan Shihadeh (MIT)
12:00-12:30	*Alkali, Chlorine, SO_x and NO_x Release During Combustion of Pyrolysis Oils and Chars* David Dayton (NREL)
12:30 - 1:00	Lunch served in cafeteria
1:00 - 5:00	Afternoon - Free time, ad hoc group discussions, park visits on your own
5:00 - 6:30	Dinner served in cafeteria

EVENING - SESSION #4 Discussion Leader: Yrjö Solantausta (VTT)

	Combustion in Boilers and Furnaces (cont.) -
7:00 - 7:30	*Applied Bio-Oil Combustion* - Barry Freel (Ensyn)
7:30- 8:00	*Flash Pyrolysis Fuel Oil* - Steven Gust (NESTE)
8:00 - 8:30	*Bio-Oil Combustion Tests at ENEL* - Carlo Rossi (ENEL)
8:30 - 9:00	*Economic Development Through Biomass Systems Intergration* - Donna Johnson (Meetech)
	Integration of Bio-Oils into Utilities - Jerry Lonergan (Kansas Elec. Util Res. Program) (Abstract and Paper only.)
9:00 - 9:30	Discussion

WEDNESDAY, SEPTEMBER 28, 1994

MORNING - SESSION #5 Discussion Leader: Ralph Overend (NREL)

TIME	FUNCTION
7:00 - 8:00	Breakfast served in cafeteria
	Combustion in Internal Combustion Engines
8:30 - 9:00	*Comparative Study of Various Physical and Chemical Aspects of Pyrolysis Bio-Oils Versus Conventional Fuels Regarding their use in Engines* Jesus Casanova (U. of Polyt, Madrid)
9:00 - 9:30	*Use of Pyrolysis Oil as a Fuel in a Diesel Power Plant* Yrjo Solantausta(VTT)
	Combustion in Turbines
9:30 - 10:00	*Fuel-Specification Considerations for Biomass Liquids* (tutorial) Cliff Moses (SWRI)
10:00 - 10:30	Coffee Break
10:30 - 11:00	*Firing Fast Pyrolysis Oil in Turbines* R. Andrews (Hawker-Siddeley)
	Conclusion
11:00 - 12:00	*RD &D Needs and Plans, Wrap-up -* Ralph Overend (NREL)
12:00-1:00	Lunch served in cafeteria
1:00	ADJOURN

Monday, September 26, 1994
8:30 - 9:15 am

Introduction and Overview of National Biomass Power Programs

Discussion Leader -
Ralph Overend

Monday, September 26, 1994
8:45 am

Finnish Endeavours in the Field of Biomass Pyrolysis

Yrjö Solantausta
VTT - Finland

Finnish Endeavours in the Field of Biomass Pyrolysis

Kai Sipilä, Yrjö Solantausta
VTT Energy
P.O. Box 1601, FIN-02044 Espoo, Finland

Two R&D pathways related to biomass pyrolysis are being explored in Finland: Neste Oy is studying the replacement of fuel oil with flash pyrolysis oil, and Wärtsilä Diesel International Ltd. and Vapo Oy are exploring possibilities for using pyrolysis oil as diesel power plant fuel. Both of these ventures are supported by research at VTT Energy. In addition to the contributions of the companies themselves, the Ministry of Trade and Industry has been funding the work.

Neste is evaluating the supplementation of certain market segments, light fuel oils for heating large premises, with a biomass derived alternative. Pellet stoker boilers and grate boilers would be the more traditional solutions. Although the economics presently are uncertain, carbon tax or other related proposed measures may improve the competiveness. In addition to laboratory work on pyrolysis oil properties, Neste is conducting experiments in test boilers.

Extremely low-quality (high viscosity, high levels of metals) oils can be employed as fuels in medium and low speed diesel engines. One of the pioneers of the field, Wärtsilä, is developing a system that would tolerate such pyrolysis oils. Together with Vapo, a Finnish fuel producer, and VTT, an advanced biomass power plant concept is being developed.

VTT is carrying out supporting experimental work for these efforts. A 4-cylinder VALMET diesel engine has been modified for pilot-injection. The engine has been operated with pyrolysis oil for short periods. Work has also been carried out on both basic and applied aspects of pyrolysis oil production and oil analysis. Solids removal has also been studied. Experimental work on pyrolysis will be increased in volume during 1995.

Monday, September 26, 1994
8:55 am

U.S. Department of Energy Pyrolysis Related Activities
(by Richard Bain)

Presented by Ralph Overend
National Renewable Energy Laboratory

U.S. DEPARTMENT OF ENERGY PYROLYSIS RELATED ACTIVITIES

Richard Bain
National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, CO 80401

The U. S. Department of Energy (USDOE), with National Renewable Energy Laboratory (NREL) is involved in a number of biomass pyrolysis related activities. Studies are being performed through the Office of Utility Technologies (OUT) and the Office of Transportation Technologies (OTT), both of which are part of Energy Efficiency and Renewable Energy (EE). The USDOE programs have the goal of reducing the risks associated with commercializing new technologies and feedstocks for electricity, transportation fuels, and chemicals.

Studies are being performed as part of the OUT Biomass Power Program to determine the suitability of biocrude (pyrolysis oil) as a gas turbine fuel or diesel fuel for the production of electricity. To this end investigations of biocrude and char combustion studies are being performed by Sandia National Laboratories Livermore. Technoeconomic studies are being performed for pyrolysis-combined cycle electricity production systems. Laboratory studies are being performed using ablative pyrolysis and fluid-bed reactors to determine system modifications required to produce commercially acceptable fuels. For examples, hot-gas filtration apparatus is being used to reduce the alkali level of biocrude.

OUT's Hydrogen program is supporting investigations at NREL of the pyrolysis of lignocellulosic biomass and reforming of the pyroligneous oils for the production of hydrogen. Thermodynamic modelling and technoeconomic analyses of conceptual processes have indicated that a process of this nature has the potential to be cost effective with conventional means of hydrogen production. Catalysis research has been initiated for the development of novel catalytic systems for the reforming of pyroligneous oils.

OTT's thermochemical fuels program is sponsoring research for the production of oxygenated gasoline additive based on the ablative pyrolysis of biomass. Both pilot-scale research and supportive technoeconomic studies are underway. The concept being developed involves the production of pyrolytic vapors, followed by catalytic conversion of the pyrolytic vapors to intermediate species which can be reacted with an alcohol to form mixed ethers. NREL research is concentrating on producing a suitable feed stream to a commercial ether production unit. Evaluations are also being performed to assess the suitability of biocrude as a refinery feedstock, with efforts concentrating on using biocrude as a specific unit operation additive, and not as a refinery crude.

September 6, 1994

Monday, September 26, 1994
9:05 am

Overview of Thermochemical Biomass Conversion

E.N. Hogan
Natural Resources - Canada

OVERVIEW OF THERMOCHEMICAL BIOMASS CONVERSION

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Natural Resources Canada
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Ottawa, Canada
K1A 0E4

ABSTRACT

Thermochemical conversion technologies offer the potential of converting biomass feedstocks into liquids and chars for use either as fuels or as chemical feedstocks to replace the current dependence on fossil fuels. There have been considerable research, development, demonstration and commercialization activities underway in Canada over the past years in the promotion of pyrolysis and gasification technologies. This paper will highlight the technical developments and current status of these various thermochemical systems and describe future R & D directions. In the pyrolysis area, a major focus of the Canadian government is the generation of power from these bio oils through steam cycle systems, diesel engines or gas turbines and the current status of these projects will be discussed. Additionally, some work is underway on the production of value added chemicals from the pyrolysis oils and this will be discussed. An R & D project on the gasification of processed municipal solid waste will also be discussed.

Monday, September 26, 1994
9:15 - 12:15 pm

Session 1
Fundamentals

Discussion Leader:
Donald Scott
University of Waterloo

Monday, September 26, 1994
9:15 - 9:45 am

Cellulose Pyrolysis Kinetics: The Current State of Knowledge

Michael Antal
University of Hawaii

CELLULOSE PYROLYSIS KINETICS: THE CURRENT STATE OF KNOWLEDGE[†]

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Abstract

Recent advances in experimental methods and computer modeling have shed new light on the kinetics of cellulose pyrolysis. The rich slate of reaction products that evolve when cellulose is heated implies that the pyrolysis chemistry is exceedingly complex. Nevertheless, a simple, first order, high activation energy (ca. 238 kJ/mol) model accurately describes the pyrolytic decomposition of an extraordinary variety of cellulosic substrates. Secondary vapor-solid interactions are the main source of char formed during cellulose pyrolysis. When a whole biomass substrate is pretreated to remove mineral matter, the pyrolysis kinetics of its cellulose component are very similar to those of pure cellulose. Future work should focus on the effects of mineral matter on pyrolysis, and the secondary, vapor-solid reactions which govern char formation.

Monday, September 26, 1994
9:45 - 10:15 am

Chemical Analysis of Biomass Fast Pyrolysis Oils

Douglas C. Elliott
Battelle Pacific Northwest Laboratories

Chemical Analysis of Biomass Fast Pyrolysis Oils.

Douglas C. Elliott
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This paper will review the development of the field of chemical analysis of biomass fast pyrolysis oils. The techniques applied to pyrolysis oil analysis will be reviewed including proximate and ultimate analysis, chemical component analysis by various forms of chromatography and solvent separations, water (moisture) analysis, distillation and the related use of thermal gravimetry, and spectrophotometric analyses like infrared and ultraviolet. Advanced analytical techniques such as nuclear magnetic resonance and molecular beam mass spectrometry will also be discussed. This paper will review and compare the methods and the results of the analyses. The advantages and shortcomings of the various methods applied will be identified. Comparisons derived from the IEA Round Robin will be incorporated.

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[1] Operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830

Monday, September 26, 1994
10:45 - 11:15 am

Properties and Characteristics of Ensyn Bio-Oil

Narendra Bakhshi
Univ of Saskatchewan

PROPERTIES AND CHARACTERISTICS OF ENSYN BIO-OIL

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Catalysis & Chemical Reaction Engineering Laboratory
Department of Chemical Engineering
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Saskatoon, Saskatchewan S7N 0W0, Canada

Bio-oil produced by ENSYN using the RTP method was examined for its physical, chemical and stability characteristics. Its pH, specific gravity, viscosity and water content were 2.8, 1.16, 98 cP and 21 wt% of bio-oil, respectively. The elemental content (by CHN analysis) of the oil was 49.8 wt% C, 7.5 wt% H, and 42.7 wt% O. No nitrogen was detected by the CHN analysis. Its flash point was 76 °C and vapour pressure over the temperature range 33-72 °C was between 5-39 kPa.

Filtration (with screens, filter paper, fritted glass funnels) and separation (by centrifugation) showed that the bio-oil contained about 3.7 wt% char and 9.9 wt% tar. The ash (inorganics) content obtained from the char was 0.18 wt% and the total amount of ash in the bio-oil was 0.48 wt%.

The distillation characteristics of the bio-oil was studied at atmospheric pressure and under a vacuum of 172 Pa. The amount of distillate, up to 100 °C was 8.6 wt% of bio-oil, and at 108 °C, it was 25.0 wt% of bio-oil. The bio-oil consisted of 58.0 wt% low boiling fraction (<200 °C), 6.0 wt% high boiling fraction (200-450 °C) and 36.0 wt% non-volatiles (>450 °C). The distillate fractions were also analyzed using GC and GC/MS techniques.

The stability of the bio-oil was monitored by observing changes in its pH, density, viscosity and distillation characteristics over a 1 yr period. The viscosity increased from 98 to 194 cP and the amount of distillate decreased. However, the pH and density remained almost unchanged.

Upon gradual addition of water, the bio-oil was found to separate (about 17 g of water per 100 g bio-oil) into two fractions: a water-soluble fraction (WSF) and an organic fraction, termed, pyrolytic Lignin Fraction (PLF). At pH=2.8 and 23 °C, the yield of PLF was 54 wt% of bio-oil. The yield of PLF and its viscosity was significantly affected by the pH and temperature of bio-oil.

The miscibility characteristics of diesel with bio-oil (as is), bio-oil:solvent, PLF (as is) and PLF:solvent (termed feeds) was investigated at room temperature and 45 °C. The solvents were methanol, ethanol and acetone. The estimated maximum amount of diesel (per 100 g of feed) required to obtain a stable miscibility for a test period of 24 h were: 16 g in bio-oil, 21 g in bio-oil:methanol (9:1), 25 g in bio-oil:ethanol (9:1), 19 g in bio-oil:acetone (9:1), 6.5 g in PLF:Methanol (9:1), 12.2 g in PLF:Ethanol (9:1) and 10.8 g in PLF:Acetone (9:1). Increasing the temperature to 45 °C or the amount of solvent resulted in decreased miscibility.

Monday, September 26, 1994
11:15- 11:35 am

Storage of Biomass Pyrolysis Oils

Stefan Czernik
National Renewable Energy Laboratory

Storage of Biomass Pyrolysis Oils

Stefan Czernik
National Renewable Energy Laboratory
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An important advantage of liquid fuels is their storability. Storage procedures for petroleum fuels are well established. However, they cannot be directly applied to biomass pyrolysis oils because of significant differences in the physical/chemical properties of those liquids. Biomass pyrolysis oils are not yet standardized products and can exhibit a range of properties depending on the pyrolysis technology employed, process conditions, and feed materials. Nevertheless, they all contain components that can react to form higher molecular weight species. The oils are also corrosive to common storage tank construction materials (mild steel). Reactions between oil components and between the oil and tank materials are unfavorable and should be prevented (or at least minimized).

This paper describes how oak pyrolysis oil changes physically and chemically when stored under various conditions. The oils were generated in the National Renewable Energy Laboratory (NREL) vortex reactor system. Throughout the study which included temperature and time conditions, the oil remained in a single phase, and its pH was not affected by storage. However, the water content, viscosity, and molecular weight of the oil increased with time and the temperature of storage. Fourier-Transform Infra-Red (FT-IR) spectroscopy provided evidence that etherification or esterification reactions in the oil are responsible for these changes. The changes in the weight-average molecular weight and viscosity of the oil were successfully correlated using first order kinetics. The proposed method can be useful in estimating the influence of storage conditions on oil properties.

Other works demonstrated that carbon steel and aluminum are strongly corroded by wood pyrolysis oils, even at moderate temperatures. In this study, polyester resin and polyethylene, potential materials for constructing oil storage tanks, were evaluated for chemical resistance to oak pyrolysis oil. Only a slight swelling, less than that allowed by the standards, was observed in both materials which were exposed to the oil at 20°C and 60°C.

Monday, September 26, 1994
11:35 - 11:55 am

Inorganic Compounds in Biomass Feedstocks: Their Role in Char Formation and Effect on the Quality of Fast Pyrolysis Oils

Foster Agblevor
National Renewable Energy Laboratory

INORGANIC COMPOUNDS IN BIOMASS FEEDSTOCKS: THEIR ROLE IN CHAR FORMATION AND EFFECT ON THE QUALITY OF FAST PYROLYSIS OILS[1]

F.A. Agblevor, S. Besler, and R.J. Evans
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Abstracts

Inorganic compounds especially potassium, calcium, sodium, silicon, phosphorus, and chlorine are the main constituents of the ash in biomass feedstocks. The concentrations of ash in biomass feedstocks range from less than 1% in softwoods to 15% in herbaceous biomass and agricultural residues. During biomass pyrolysis, these inorganics especially potassium and calcium, catalyze both decomposition and char formation reactions. Decomposition reactions may either result in levoglucosan-rich or hydroxyacetaldehyde-rich pyrolysis products depending on the concentration of the ash in the feedstocks. Catalytic effect of the ash levels off above 1.5% concentration. Chars formed during these reactions invariably end up in the pyrolysis oils. A high proportion of the alkali metals in the ash are sequestered in the chars and leach into the pyrolysis oils. The presence of high concentrations of alkali metals in the biomass pyrolysis oils makes them unsuitable for combustion in boilers and in turbine operations. The highest concentration of alkali metals are found in herbaceous feedstocks and agricultural residue pyrolysis oils.

Sequential cold filtration of the oils using filters of varying size revealed that most of the alkali metals detected in the pyrolysis oils are indeed trapped in the chars. Leaching studies conducted on the chars suspended in the oils showed leaching of the alkali metals from the chars into the oils. Our data suggest that hot gas filtration of the oils can effectively reduce the alkali contents of the pyrolysis oils to acceptable levels to be used as turbine and boiler fuels.

Analysis of these pyrolysis oils for alkali metals and other trace elements is a challenging task because of the heterogeneity, unstableness, and lack of reference standards for these oils. The high moisture content of these oils make conventional atomic absorption (AA) spectroscopy and inductively coupled plasma (ICP) emission spectroscopic methods of analyses not very reproducible. The most promising method for alkali metals and chlorine analysis is the neutron activation method. This method has the advantage that no sample preparation step is required and several samples can be easily analyzed per run. However, the cost per analysis of sample is extremely high.

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[1] This paper will be presented at the *Specialists Workshop on Biomass Pyrolysis Oil Properties and Combustion*, Estes Park, CO. September 26-28, 1994.

Monday, September 26, 1994
11:55 - 12:15 pm

Hot Gas Filtration to Remove Char from Pyrolysis Vapors Produced in the Vortex Reactor at NREL

Jim Diebold
National Renewable Energy Laboratory

Hot-Gas Filtration
to Remove Char from Pyrolysis Vapors
Produced in the Vortex Reactor at NREL[1]

J.P. Diebold, S. Czernik, J.W. Scahill, S.D. Phillips, and C.J. Feik
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The absence of char in pyrolysis condensates is required for them to be considered to have value above that of a residual fuel oil because of the alkali content of the char. During pyrolysis, the alkali-containing ash is concentrated in the char. This paper discusses hot-gas filtration of pyrolysis vapors produced in a vortex reactor at temperatures above the apparent dew point of the vapors prior to condensation.

A customized baghouse was commercially fabricated which has four filters and the ability to backflush each bag individually with a pulse of compressed gas. The size of the compressed gas pulse has been small enough to allow backflushing to occur during pyrolysis operations without shutting down. The nominal gaseous residence time of this design is on the order of three to five seconds. This baghouse is relatively unique in its capability to use either flexible, woven NEXTEL ceramic bags made by 3M or rigid sintered stainless steel filters made by MEMTEC. Based on samples of char made in the vortex reactor and collected with a cyclonic separator, the baghouse manufacturer projected a collection efficiency of 99.9%.

The cyclonic separator was removed from the vortex reactor system at NREL and replaced with the baghouse. A series of runs were made to evaluate this char separation technique to filter the total pyrolysis stream produced by the vortex reactor. The tendency of the pyrolysis oils to crack to permanent gases under these conditions is discussed as a function of operating temperature of the baghouse, based on previously determined kinetics.

Removing the char from the pyrolysis gas stream was demonstrated to be superior to that previously obtained using a cyclonic separator, based on the oil changing color from black to brown, lower ash content, and lower alkali metal content. In the case of switchgrass, the alkali metal content of the oil was lowered by two orders of magnitude. At the low alkali metal content of these oils, the analytical technique has not been very reproducible and has been under development. Heterogeneity of the oils has been blamed for the lack of reproducibility of the analysis for the several parts per million of alkali present.

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[1] This paper will be presented at the Specialists' Workshop on Biomass Oil Properties and Combustion, Estes Park, CO, Sept. 26-28, 1994.

Monday, September 26, 1994
7:00 - 10:00 pm

Session 2

Discussion Leader:
Don Huffman
Ensyn

Monday, September 26, 1994
7:00 - 7:30 pm

Engineering Developments in Fast Pyrolysis for Bio-Oils

Tony Bridgwater
Aston University

Engineering Developments In Fast Pyrolysis For Bio-Oils

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ABSTRACT

Biomass pyrolysis is of rapidly growing interest in Europe while in North America, interest seems to have peaked a few years ago. This paper has two objectives:

1. To review the R.D&D in biomass fast pyrolysis in Europe supported by the European Commission.
2. To review the problems faced by the developers of fast pyrolysis, upgrading and utilisation processes which require resolution if the technologies are to be implemented.

Approximately US$ 5 million per year are being spent by the European Commission (EC) on R&D in thermal biomass conversion of which pyrolysis receives the lions share. Funding comes from a variety of EC R&D programmes (AIR, JOULE and APAS). The demonstration programmes (THERMIE and ALTENER) have yet to support any pyrolysis projects. A new 5 year Framework Programme started in January 1994 valued at US$ 15 billion in which bioenergy may receive over 150 US$million In addition most countries in the EC have their own bio-energy R&D programmes which are usually complementary to the EC programmes.

Aspects of design of a fast pyrolysis system are reviewed as follows:
Feed drying - is usually essential unless a naturally dry material such as straw is available. As moisture is generated in pyrolysis, bio-oil always contains at least about 15% water which cannot be removed.
Particle size - particles have to be very small to fulfil the requirements of rapid heating and to achieve high liquid yields. This is costly and reactors using larger particle have an advantage. The trade-off between reactor type and feed characteristics has not been evaluated.
Pretreatment - acid washing to de-ionise or hydrolyse, or addition of inorganic ions are practised to enhance production of speciality chemicals and liquid yields. Processing is by orthodox leaching type methods.
Reactor configuration - a wide variety of configurations have been tested showing considerable diversity and innovation in meeting the basic requirements of fast pyrolysis. The "best" method is not yet established.
Heat supply - the high heat transfer rate that is necessary imposes a major design constraint. Hot circulating solids are currently preferred for heat supply within the reactor. For ablative reactors, heat supply to the reactor is the major limitation on throughput.
Heat transfer - this is effected either by gas-solid heat transfer or solid-solid heat transfer. The latter is more effective and occurs to some extent in most reactors.
Heating rates - the low thermal conductivity of wood will prevent the very high claimed heating rates throughout the whole pyrolysing particle which therefore has to be sufficiently small.
Reaction temperature - total product yield is maximum at typically 500-520°C for most forms of woody biomass. Definition of bio-oil quality is needed to optimise reactor parameters.
Vapour residence time - this is widely considered crucial to the performance of fast pyrolysis which is true for some chemicals but is less important for fuels. The time-temperature window of the product vapours is more important than either individually.
Secondary cracking - Long vapour residence times and high temperatures cause secondary cracking of primary products reducing yields of specific products and overall liquids. This may not be disadvantageous.
Char separation - Some char is inevitably carried over from cyclones and collects in the liquid. Separation is difficult.
Ash separation - The alkali metals from biomass ash collect in the liquid and cannot be readily separated except by hot gas filtration which is still not proven.
Liquids collection - This has long been a major difficulty for researchers. Larger scale processing usually employs some type of quenching or contact with cooled liquid product which is effective. Careful design is needed to avoid blockage from differential condensation of heavy ends. Light ends are important in reducing liquid viscosity.

Monday, September 26, 1994
7:30 - 8:00 pm

Pyrolysis Oil Economics - Issues and Impacts

Cathy Gregoire
National Renewable Energy Laboratory

Pyrolysis Oil Economics: Issues and Impacts

Catherine E. Gregoire and Margaret K. Mann
National Renewable Energy Laboratory

The estimated cost to produce biomass-derived oil (biocrude) ranges from a low of $17/barrel of oil equivalent (boe) to over $50/boe. Differences in economic assumptions account for a portion of the variation in estimates, but do not tell the complete story. Process variations, plant size, and feedstock costs are also important cost contributors. In addition, the quality required for specific market applications can significantly affect the cost of the product.

Quantification of the cost elements for the production of biocrude must include factors specific to the feedstock, process, and final market. For a particular system, additional unit operations may be required to meet product specifications. A study was made of the cost contributions of different process sections in an effort to permit design of a facility to meet the needs of a variety of applications. The units may be combined in a number of configurations to provide an indication of the production cost for biocrude.

The biocrude production facility consists of five sections which will be incorporated into a particular process configuration selected from a number of available options. The sections examined in this study include Feed Preparation, Pyrolysis, Solids Removal, Condensation, and Product Treatment/Stabilization. Material and energy balances are calculated using the ASPEN process simulator. Cost figures for the selectable configurations in each section have been developed, and an overall cost of production can be determined for the selected facility.

Monday, September 26, 1994
8:00 - 8:30 pm

Flash Pyrolysis of Biomass in a Circulating Fluidized Bed Reactor

Ioannis Boukis
Center for Renewable Energy Sources

Flash Pyrolysis of Biomass in a Circulating Fluidized Bed Reactor.

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Low grade fuels such as biomass, RDF and solid wastes play an increasingly important role in the energy scene. In particular, biomass is readily recognized as the only renewable alternative fuel, its utilization for energy purposes being realized by direct use, as in combustion, or by upgrading into a more valuable and usable fuel. This upgrading may be by physical, biological, chemical or thermal methods to give a solid (char), liquid (ethanol, methanol or bio-oil) or gaseous fuel (biogas, low- and medium energy gas). Considering the upgrading options, pyrolysis processes aiming at maximizing liquid (bio-oil) yield are of particular interest, since liquid products are easier to handle in subsequent utilization schemes and better suited for retrofitting existing equipment. Biomass conversion methods to bio-oil include mostly thermochemical processes with characteristics such as high heat supply, rapid heating rate, modest temperature and short vapour residence time. Processes with similar characteristics, summarized under the term flash pyrolysis, are usually carried out in entrained or fluidized bed reactor configurations.

An interesting option for biomass flash pyrolysis could be a circulating fluidized bed (CFB), a bubble-free entrainment reactor type with recovery and recirculation of entrained and captured solids. This type of reactor could also best utilize the energy content of byproduct char, which is captured and recirculated with the inert heat carrier material in the bottom of the bed, while biomass is injected in the upper section of the bed. A novel reactor type for flash pyrolysis of biomass was conceived and a cold model for studying the hydrodynamics of the proposed system was constructed and tested. This reactor type, namely a circulating fluidized bed reactor, operates at relatively high velocities and utilizes the energy content of byproduct char by properly inserting it in a lower zone where it is combusted, while hot sand is circulating throughout the system as inert heat carrier material. Process parameters can be easily adjusted to match the desired high heat and mass transfer rates.

The results derived from cold model experiments, led to modifications of a hot unit of similar dimensions. These modifications include, oversizing the first cyclone to accommodate the increased solids charging of the gas stream as well as addition of a secondary cyclone, to allow fine sand and char capture. Moreover, the aeration gas supply to a non-mechanical valve was properly modified. Cold model operation has shown that the CFB hydrodynamics and stability favour the pyrolysis environment, though this is to be proven during hot runs.
The preliminary hot unit experiments showed that smooth reactor operation can be achieved but revealed that the downstream processing must be properly modified. The surface condensers used were proven very sensitive to plugging and are currently being replaced by liquid scrubbers followed (possibly) by a mist eliminator to retain the fine liquid droplets suspended within the entrained gas. Furthermore accurate on-line gas components measurement in different parts of the CFB reactor is planned in order to ensure that reducing conditions prevail in the pyrolysis section and to determine the optimum biomass feeding point.

Monday, September 26, 1994
8:30 - 9:00 pm

The Production and Handling of WFPP Bio-Oil and its Implications for Combustion

Angel Cuevas
Union Fenosa

The Production and Handling of WFPP Bio-Oil and its Implications for Combustion

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Union Fenosa has been operating and improving a pilot plant for the thermochemical conversion of biomass based on the Waterloo Flash Pyrolysis Process (WFPP) for some time. Valuable experience has been accumulated regarding the influence of the different parameters that can affect the production of the bio-oil. Bio-oil of relatively stable characteristics, in respect to physical and thermal aspects, has been achieved and is regularly produced. Work underway looks at clarifying the influence on the bio-oil characteristics, of some different feedstocks or modification of reaction parameters as well as stability and reliability of the operation, thermal and energy balances, and techno-economic assessment.

Some experiments in combustion, of limited consistency, were carried out in the past in collaboration with the Universidad Politécnica de Madrid. New programmes to further explore this aspect are underway.

Monday, September 26, 1994
9:00 - 9:30 pm

Environmental Considerations in the Production and Use of Biomass Fast Pyrolysis Oils

Douglas C. Elliott
Battelle Pacific Northwest Laboratories

Environmental Considerations in the Production and Use of Biomass Fast Pyrolysis Oils.

Douglas C. Elliott
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This paper will review the state of environmental regulations as they relate to the utilization of fast pyrolysis oils from biomass. Properties of the oils and components in the oils which are impacted by the regulations will be identified. Toxicological test results will be mentioned only as they impact on regulations. Potential environmental regulatory roadblocks will be discussed. Emphasis will be on U.S. federal regulations, which will be presented. The effects of state and local implementation of the regulations will be considered. Comparison to regulations in other countries will also be attempted.

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[1] Operated for the U.S. Department of Energy by Battelle Memorial Institute under Contract DE-AC06-76RLO 1830

Monday, September 26, 1994
9:30 - 10:00 pm

Results of Toxicological Testing of Whole Wood Oils Derived from the Fast Pyrolysis of Biomass

David Gratson
National Renewable Energy Laboratory

Results of Toxicological Testing of Whole Wood Oils Derived from the Fast Pyrolysis of Biomass

David A. Gratson
National Renewable Energy Laboratory
1617 Cole Boulevard, Golden, CO 80401

The National Renewable Energy Laboratory initiated toxicological testing for two whole wood oil samples (Southern Pine and Oak) produced in the vortex pyrolysis reactor at our facilities. This first phase of testing was performed to develop a toxicological profile, following a protocol appropriate for industrial compounds/products not intended to be used as consumer producsts. The tests conducted included dermal toxicity, eye irritation, inhalation toxicity and Ames mutagenicity and was done with the consultation of Mr. John Butala, Duquesne University. Results of this toxicological testing will be presented and compared with available data obtained from testing of similar material by other researchers. The results of NREL's testing showed that these materials may be handled safely with commonly used safe work practices and personal protective devices.

Tuesday, September 27, 1994
8:30 - 12:30

Session 3
Combustion in Boilers and Furnaces

Discussion Leader:
Don Hardesty
Sandia National Laboratory

Tuesday, September 27, 1994
8:30 - 9:00 am

Specifications for Liquid Fuels in Boilers

Scott Drennan
Coen Company

Submitted for presentation at the Biomass Pyrolysis Oil Workshop in Estes Park, Colorado, Sept. 26-28, 1994

SPECIFICATIONS FOR LIQUID FUELS IN BOILERS

Scott A. Drennan

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ABSTRACT

The wide variety of liquid fuels currently being used in utility and industrial boilers around the world require the atomizer/burner manufacturer to develop liquid fuel specifications in order to guarantee performance. This paper discusses the relevant specifications for liquid fuels and how they affect combustion and emissions performance in industrial and utility boilers. Liquid fuel combustion issues such as atomization, stability, and heat transfer are related back to the liquid fuel's chemical composition and physical characteristics. The various affects of physical characteristics such as viscosity, heating value, pour and flash points indicate how the fuel is handled, stored and what safety concerns are warranted up to the burner. The fuel's surface tension, viscosity, density and distillation characteristics affect the atomization and evaporation process and drive the designs of industrial atomizers. With the ever increasing concern and regulations on emissions from fossil fuel combustion, the chemical properties and pollutant reaction kinetics of liquid fuels are becoming the driving force for fuel choice in boilers. Emissions of concern such as nitrogen and sulfur oxides, soot, particulates, and volatile organic compounds are discussed in relation to liquid fuel specifications. These parameters are addressed and attention is given to the relevant issues for biomass pyrolysis oil usage in industrial and utility boilers.

Tuesday, September 27, 1994
9:00 - 9:30 am

Sprays and Spray Combustion

John W. Daily
University of Colorado

Sprays and Spray Combustion

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A presentation of the fundamentals of spray formation and combustion. Topics included in the discussion are basic atomization processes, drop size distributions, types of atomizers, typical atomizer performance, droplet evaporation and burning laws, and spray combustion characteristics.

Tuesday, September 27, 1994
9:30 - 10:00 am

Formation of Nitrogen Oxides in Combustion Processes

Mel Branch
University of Colorado

Formation of Nitrogen Oxides in Combustion Processes

Melvyn C. Branch
Center for Combustion Research
Mechanical Engineering Department
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Boulder, Colorado 80309-0427

Oxides of nitrogen may be formed during combustion processes in air by a "thermal" mechanism, by a "prompt" mechanism, or directly from nitrogen containing impurities in the fuel. Thermal NO_x formation refers to NO_x formed from nitrogen and oxygen in air by the extended Zeldovich mechanism. Nitric oxide formation with hydrocarbon fuels may exceed rates of formation attributable to the thermal mechanism because of reactions between CH_i species derived from the fuel and N_2. Finally, nitrogen which is chemically bound in the fuel or a fuel impurity can be rapidly converted to NO_x during the combustion process by direct oxidation. This review will summarize these mechanisms of NO_x formation, characterize the relative importance of the formation processes, and suggest means for ameliorating the formation of NO_x. The importance of NO_x formation and control associated with the combustion of biomass pyrolysis oil products will be emphasized.

Tuesday, September 27, 1994
10:30 - 11:00 am

Single Droplet Combustion of Biomass Pyrolysis Oils

Judy Wornat
Princeton University

Single Droplet Combustion of Biomass Pyrolysis Oils

Mary J. Wornat,* Bradley G. Porter, and Nancy Y. C. Yang

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Sandia National Laboratories, Combustion Research Facility and
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In an investigation of the combustion behavior of biomass-derived liquids, we have performed single droplet experiments with two biomass oils, produced from the pyrolysis of oak and pine. The experiments are conducted at 1600 K on 320-µm diameter droplets introduced into a laminar flow reactor, operating at O_2 concentrations of 14 to 33 mole %. *In-situ* video imaging of burning droplets reveals that biomass oil droplets undergo several distinct stages of combustion. Initially biomass oil droplets burn quiescently in a blue flame. The broad range of component volatilities and inefficient mass transfer within the viscous biomass oils bring about an abrupt termination of the quiescent stage, however—causing rapid droplet swelling and distortion, followed by a microexplosion. Droplet coalescence follows, and subsequent burning occurs in a faint blue flame with occasional smaller scale bursts of fuel vapor. At the late stages of biomass oil combustion, droplets are accompanied by clouds of soot, produced from gas-phase pyrolysis. Liquid-phase polymerization or pyrolysis of the oxygenate-rich biomass oils leads to the formation of carbonaceous cenospheres, whose burnout signifies the final stage of biomass oil droplet combustion. Oak and pine oils behave similarly during combustion, though differences in their physical properties cause pine oil to show more susceptibility to fragmentation during the microexplosion. Changes in oxygen concentration alter the timing of the events during biomass oil combustion—but not their nature. Comparison of the biomass oils with No. 2 fuel oil reveals vast differences in combustion mechanisms, which are attributable to differences in the physical properties and chemical compositions of the fuels. Despite these differences, the biomass oils and No. 2 fuel oil exhibit surprisingly comparable burning times under the conditions of our experiments. The swelling/microexplosion behavior of the oak and pine oils is contrasted to the burning of a poplar oil, which was subjected to a different filtration scheme.

Tuesday September 27, 1994
11:00-11:30 pm

Baseline NO_x Emissions During Combustion of Wood-Derived Pyrolysis Oils

Larry Baxter
Sandia National Laboratory

Baseline NO_x Emissions During Combustion of Wood-Derived Pyrolysis Oils

Larry Baxter and Bryan Jenkins[1]
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for presentation at the
Specialists Workshop on Biomass Pyrolysis Oil Combustion
September 26-28, 1994
Estes Park, CO

Abstract

NO_x emissions from two pyrolysis oils of similar origin and overall composition but differing nitrogen contents (0.12 and 0.32 % of dry fuel) are determined in a pilot-scale combustor. No NO_x reduction technology is employed in these tests, establishing the baseline or uncontrolled levels of NO_x. Measured effluent oxygen concentrations range from near 0% to near 21%, with stoichiometric ratios ranging from 0 to 1. NO and NO_x are measured separately and found to differ by insignificant (≈10-25 ppmv) amounts. Other relevant gas species (CO_2, CO, total hydrocarbons, and O_2) are also reported.

Peak NO_x emissions from these fuels vary from about 300 to around 650 ppmv, with lower levels associated with low nitrogen content fuels. Trends with stoichiometric ratio and fuel nitrogen content agree qualitatively with behavior from other nitrogen containing fuels, including biomass, coal, and petroleum oils. Nitrogen conversion efficiencies as a function of stoichiometric and fuel nitrogen content are observed to decrease with increasing fuel nitrogen content and increase with increasing oxygen content. Measurements of thermal, prompt, and fuel NO_x contributions indicate that total NO_x is the dominant formation mechanism for these fuels. These data suggest that NO_x formed during combustion of pyrolysis oil lends itself to many of the same control technologies as are used in other nitrogen-containing fuel.

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[1] On sabbatical leave from University of California, Davis Department of Biological and Agricultural Engineering.

Tuesday, September 27, 1994
11:30- 12:00 pm

Combustion Characterization of Wood Derived Flash Pyrolysis Oils in Industrial-Scale Turbulent Diffusion Flames

Alan Shihadeh
MIT

COMBUSTION CHARACTERIZATION OF WOOD-DERIVED FLASH PYROLYSIS OILS IN INDUSTRIAL-SCALE TURBULENT DIFFUSION FLAMES

Alan Shihadeh, Robert Manurung, Paul Lewis, and János Beér

The Combustion Research Facility
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An experimental investigation of two wood pyrolysis oils produced by the Ensyn and Waterloo flash pyrolysis processes was conducted in the combustion tunnel of the MIT Combustion Research Facility. The purpose of the experiments was to compare the pollutant formation and combustion characteristics of these pyrolysis oils to those of No. 2 fuel oil, and to identify the special requirements for utilizing pyrolysis oils in practical systems.

Furnace exit and in-flame measurements of gas composition, soot concentration, and temperature were made using intrusive traversing probes in 1 MW swirling turbulent diffusion flames. A high speed camera was used in the near burner field to record combustion instability, as well as the atomization difficulties that were encountered when burning the pyrolysis oils. Several fuel filtration, heating, and atomization configurations were tested with the pyrolysis oils.

The experiments showed that the Ensyn pyrolysis oil flames performed comparably to No. 2 fuel oil, producing slightly higher NOx and CO emissions (108 vs 80 ppm NOx, and 35 vs 13 ppm CO @ 3% O2). The Ensyn oil required more frequent filter changes, but otherwise could be used with the same fuel delivery system and operating procedure as No. 2 fuel oil. Soot concentration did not differ measurably for the two fuel types.

Operation with the Waterloo oil was problematic, and a steady operating condition could not be achieved. Fuel atomization remained poor over a range of fuel temperatures, and filter plugging in the fuel gun and upstream of the fuel gun cause frequent shut-downs. Filtration (230 micron) prior to the test runs did not remedy the problem. Filter plugging and atomization problems could be cured by mixing 15% ethanol with the oil; a 7% mixture was found to be inadequate.

Monday, September 26, 1994
12:00 - 12:30 pm

Alkali, Chlorine, SO_x, and NO_x Release During Combustion of Pyrolysis Oils and Chars

David C. Dayton
National Renewable Energy Laboratory

ALKALI, CHLORINE, SO_x, AND NO_x RELEASE DURING COMBUSTION OF PYROLYSIS OILS AND CHARS

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Biomass-derived pyrolysis oils must contain very low levels of alkali to become competitive fuels for use in turbine combustors for power generation. Based on standards set for traditional petroleum fuel oils, turbine manufacturers require total alkali (Ca+Na+K) levels in the sub-ppm range. Controlling NO_x and SO_x release during pyrolysis oil combustion must be considered to alleviate environmental concerns. Chlorine release from the combustion of pyrolysis oil will have important implications concerning corrosion of heat transfer surfaces in boilers and turbine blades in direct pyrolysis oil fired facilities. The transformation of nitrogen, sulfur, and chlorine during the production of biomass-derived pyrolysis oils is unknown. When pyrolysis oil is produced, the majority of the alkali present in the starting biomass material remains sequestered in the char fines. The alkali content of the oils, therefore, is thought to be predominantly a function of the amount of char fines suspended in the oil. Biomass-derived oils and chars were screened to investigate the fate of nitrogen, sulfur, and chlorine and alkali metal sequestered in the char during the production of pyrolysis oil from biomass.

We have used the molecular beam mass spectrometer (MBMS) system, constructed and operated at the National Renewable Energy Laboratory, to directly sample the hot gases liberated during the combustion of small pyrolysis oil and char samples in a variable temperature quartz tube reactor. The MBMS system is ideally suited for studying high temperature, ambient pressure environments such as those encountered during these screening studies. Chemical reactions are quenched and condensation is inhibited during the free-jet expansion of the high temperature combustion gases. As a result, reactive and condensable species remain in the gas phase at temperatures far below their condensation point. We have successfully used this experimental technique to identify alkali species released during the combustion of selected biomass feedstocks and have extended this previous work to monitor the release of nitrogen, sulfur, chlorine and alkali metal vapors during the combustion of pyrolysis oils and chars. Four of the pyrolysis oils screened in this study (two switchgrass oils, an oak oil and a poplar oil) were produced in the NREL vortex reactor. The other three oils screened (a switchgrass oil, a poplar oil, and a corn stover oil) were produced in a laboratory scale (2 inch diameter) fluidized bed combustor. The biomass chars were recovered from the hot filters on the NREL vortex reactor during pyrolysis oil production.

We will present results describing the release of NO_x, SO_x, chlorine, and alkali metal vapors during the combustion of biomass-derived pyrolysis oils and chars and compare these results with the combustion of the parent biomass feedstock where applicable. Comparisons will be made between the oils made by the two different processes. The relative amounts of NO, SO_2, and HCl released during pyrolysis oil combustion will be explored. We will also compare the amount of alkali metal released as potassium chloride during the combustion of switchgrass, switchgrass chars and switchgrass-derived pyrolysis oils.

Abstract submitted to the "Specialists Workshop on Biomass Pyrolysis Oil Combustion, Sept. 26-28, 1994 in Estes Park, CO

Tuesday, September 27, 1994
7:00 pm - 9:30 pm

Session 4
Combustion in Boilers and Furnaces (Continued)

Discussion Leader
Yrjö Solantausta
VTT

Tuesday, September 27, 1994
7:00- 7:30 pm

Applied Bio-Oil Combustion

Barry Freel
Ensyn

ABSTRACT

APPLIED BIO-OIL COMBUSTION

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As the conversion of biomass to liquid fuels via fast pyrolysis becomes an economic reality, interest is being focussed on applied bio-oil combustion. Research efforts are addressing storage and delivery systems, bio-oil/petroleum blending, burner modifications, and combustion optimization for emissions control.

A bio-oil pump/preheater skid has been assembled at Ensyn and preliminary atomization tests conducted. Combustion tests on bio-oil/petroleum blends have been carried out in a small scale flame tunnel.

Practical aspects of bio-oil combustion are presented based primarily on experience with the 20 MBTU/hour combustor located on the site of Ensyn's 25 tonne per day commercial RTP plant. Preliminary results from industrial burner tests being performed by Maxon Corporation are also provided.

ENSYN

Tuesday, September 27, 1994
7:30 - 8:00 pm

Flash Pyrolysis Fuel Oil

Steven Gust
NESTE

FLASH PYROLYSIS FUEL OIL

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ABSTRACT

Background

This project investigates the possibility of utilizing flash pyrolysis oil as a light fuel oil substitute for institutional customers such as schools, hospitals and small industry etc. where we currently market Tempera 15. Tempera 15 is priced and has technical properties between that of low sulphur heavy fuel oil and residential type fuel oil. It has viscosity of about 15 cSt at 20 °C, requires preheating to 50 °C and a storage temperature above 10 °C. It sells for about 1.3 mk/l (0.25 USD/l) which includes tax of 0.4 mk/l.

Results

Combustion. Flash pyrolysis oil from Ensyn was combusted in a district heat type, 2.5 MW boiler equipped with a dual fuel burner. The product was found to be difficult to ignite. A combustion chamber insert, warmed up with light fuel oil was necessary for self-sustaining combustion. The best results were obtained when flash pyrolysis oil was: filtered to <35 microns, preheated to 60-70 °C, atomized at pump pressure of 10-12 bar. The measured emissions in the initial tests were NOx < 150 ppm, CO < 90 ppm, particulates Bacharach number 6.

Properties. The flash pyrolysis oil tested at Neste contained char (2-3 wt%) and ash (0.1 wt%), had a heat content (LHV) of about 15 MJ/kg due to its water content of 24 wt%, and had pH of 2.8. The oil was unstable when exposed to air or high temperatures. Nozzle blocking occurred after burner shutdown due to formation of hard, black tar formation. Char in the oil was found to sediment out in the barrels during the 3 month storage time. Analysis for EPA-PAH compounds indicate levels similar to heavy fuel oil depending on source of crude. Both process improvements (char and ash reduction) plus some form of mild treatment (for stability, corrosiveness and lubricity) will be required to satisfy the technical requirements of target customers.

Costs. Economic analysis indicates that potential exists in Finland to profitably produce flash pyrolysis oil as a Tempera 15 replacement when: 1. the delivered price of woodchips is ≤ 45 mk/MWh (50 USD/dry tonne, Finnish Bioenergy Program goal) 2. flash pyrolysis oil (@17MJ/kg) is sold at 0.64 mk/kg (equivalent price to fuel oil at 1.3 mk/l on energy basis) 3. product as produced will not require costly upgrading to meet the requirements of the customers and 4. will be taxed at the same level as wood fuels today (=0).

Tuesday, September 27, 1994
8:00-8:30 pm

Bio-Oil Combustion Tests at ENEL

Carlo Rossi
ENEL- Thermal Research Center

Bio-oil combustion tests at ENEL

Carlo Rossi
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ENEL-Thermal Research Center (CRT) is involved in a research program aimed at assessing the feasibility of utilizing bio-fuels derived from flash pyrolysis of vegetable biomass as a fuel in furnaces, gas turbine combustion chambers and other energy applications.

In the past some preliminary combustion tests have been already performed by ENEL, firing bio-oil produced through a conventional slow pyrolysis process, in a commercial type burner for liquid fuel.

With the construction and operation of a 15 t/d flash pyrolysis plant in Umbria Region, next year ENEL will be able to carry out more comprehensive tests in this field.

In the meanwhile CRT has performed combustion tests utilizing relatively small quantities of bio-oils supplied by Spanish and Canadian producers.

These tests are aimed at investigating the atmospheric stationary combustion of crude bio-oil and the pressurized combustion of different bio-oil/ethanol mixtures, directly in a small gas turbine combustion chamber.

Tests include accurate bio-fuel chemical and physical characterization, flame investigation, combustion process assessment and characterization of flue gas.

A 0.5 MWth furnace and a 40 kWe gas turbine are the experimental facilities, located in the ENEL Experimental Area of Livorno, that are used for the execution of the above mentioned trials.

In parallel to these tests, ENEL has commissioned to MIT-Combustion Research Group of Boston, combustion tests on the same type of bio-fuels fired in Livorno, to be performed with a burner optimized for minimum NOx production, with a heat input ranging from 1 MWth to 0.25 MWth, to simulate turn-down.

The major part of research activities presented are conducted with the financial support of EEC.

The results of tests will be useful in particular to evaluate the potential and the limitations of direct crude bio-oil utilization, without complex and expensive upgrading processes.

Tuesday, September 27, 1994
8:30 - 9:00 pm

Economic Development through Biomass Systems Integration

Donna Johnson
Meetech

ECONOMIC DEVELOPMENT THROUGH BIOMASS SYSTEMS INTEGRATION IN NORTHEASTERN KANSAS

by

D.A.Johnson[1], W.D. Maclean[1], M. Asadi[1], R. Nelson[2], M. Langemeier[2],
P. Ohlenbusch[2], G. Naughton[2], D. Fjell[2], G. Krissek[3], J. Lonergan[4], and B. Mears[5]

In January 1994, the Department of Energy announced that 12 projects were chosen to study the feasibility of integrated production-conversion technologies for energy from biomass systems. The team represented by the authors was chosen for one project reflecting the Midwest region of the United States. The project site is Holton, Kansas (30 miles north of Topeka), a rural community which generates its own peaking power. Based on the results of Phase I and funding availability, some or all of the projects will be selected for demonstration projects.

Dedicated feedstocks for the facility are primarily herbaceous bioenergy crops. To date, the leading candidates are switchgrass, big bluestem/indiangrass, and brome hay. These feedstocks will be supplemented by waste wood from the region. The conversion facility is being designed to convert 100 bone dry tons per day of feedstock into biocrude oil via fast pyrolysis. Process flow diagrams, heat and mass balances and equipment costs are being determined. The oil produced will be shipped to the Holton power plant for electric production. The entire process will produce 3-4 MW of power.

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Tuesday, September 27, 1994

Integration of Bio-Oils into Utilities (No Oral Presentation)

Jerry Lonergan
Kansas Elect. Util Resources

Integration of Bio Oils into Utilities

Jerry Lonergan
Kansas Electric Utilities Research Program

The Kansas Electric Utilities Research Program (KEURP) is a cooperative venture of seven member electric utilities which operate in the State of Kansas. The goal is to "perform research to proactively seek and deliver technologies enhancing the value of electric services to its members, utility customers, and the State of Kansas." KEURP program activities are guided by two working committees. A Technical Committee comprised of research professionals from each utility and a representative from each regents institution directs the research and reviews proposals. An Executive Committee functions much as a Board of Directors and has final authority on all KEURP research. The Executive Committee is made up of the Chief Operating Officer, or their designee, from each member utility. Also, the Kansas Board of Regents appoints one member to the committee, the Chair of the Kansas Corporation Commission is the other member.

During 1994, KEURP developed a renewable energy and development research plan. A goal of this effort was to identify the most effective Kansas renewable resource(s) that, short term have the potential to be economically viable. A second activity, associated with the Biomass Pyrolysis Oil Combustion Workshop has been to discuss with members of the Executive Committee the processes involved with decisions to bring new technologies into an individual utility. Ideas presented should not be interpreted to represent the belief or policy of any individual member of KEURP or a policy of KEURP. The information is a collective interpretation, by the author, of informal conversations and comments and opinions expressed on an individual basis by Executive and in some cases Technical Committee members.

Risks are not easy to defend or justify in the current electric utility environment. As long as expectations are for long-term accountability for decisions made by utility companies; inventors, scientists, and advocates of various renewable sources or other emerging technologies should expect to be able to demonstrate the effectiveness and economics of individual technologies. For new ideas/methods to become a part of a utility's way of doing business, the driving factor has to be the economics of any project. Until the economic viability of a technology can be convincingly demonstrated, it will be difficult for advocates to have projects constructed by the utility industry. These prohibitive forces will have an even greater impact as competition grows among the utilities. Adoption of new, and somewhat riskier, technologies are even less likely without effective demonstration projects.

Wednesday, September 28, 1994
8:30 - 11:00 am

Session 5
Combustion in Internal Combustion Engines and Turbines

Discussion Leader
Ralph Overend
National Renewable Energy Laboratory

Wednesday, September 28, 1994
8:30 - 9:00 am

Comparative Study of Various Physical and Chemical Aspects of Pyrolysis Bio-Oils Versus Conventional Fuels Regarding Their use in Engines

Jesus Casanova
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Comparative Study of Various Physical and Chemical Aspects of Pyrolysis Bio-Oils Versus Conventional Fuels, Regarding their use in Engines.

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The objective is to present a comparative study of the physical and chemical characteristics of the bio-oils versus conventional fuels like petrol, fuel-oil, etc. From consideration of the bio-oil characteristics which most influence its use in engines (density, viscosity, water content, solubility, ash percentage, C, H, O %, HHV) a prediction of the performance of engines[redacted] fuelled with this product will be made. The most adequate types of engines will be discussed. Different alternatives to overcome the problems, and required modifications in engines, will be researched prior to bio-oil utilization at industrial scale.

Wednesday, September 28, 1994
9:00 - 9:30 am

Use of Pyrolysis Oil as a Fuel in a Diesel Power Plant

Yrjö Solantausta
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Use of pyrolysis oil as a fuel in a diesel power plant

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The diesel engine has numerous advantages in power plant service: High power to heat ratio (important in cogeneration), high efficiency also at partial load, fuel flexibility (natural gas, fuel oils, and even lower quality fuels), moderate specific capital investment, and low operating costs. Use of biomass flash-pyrolysis oils as diesel engine fuel is being considered because of the relative insensitivity of diesel engines to the contaminant levels found in these oils.

As pyrolysis oil has poor ignition properties, a pilot injection system has to be applied. In such a concept a small amount of pilot fuel with good ignition properties is injected prior to the main fuel to initiate combustion. Once combustion has started, the fuel with poor ignition quality may be injected as the main fuel. Such pilot-systems have been applied commercially to engines burning natural gas, alcohol and heavy fuel oil as the main fuel. Pyrolysis oils supplied by Ensyn Technologies Inc. have been tested at VTT Energy in a VALMET diesel engine (four cylinder, high-speed, turbocharged, max. power output 84 kW) equipped with pilot injection. The ultimate objective is to test pyrolysis oil in a large medium-speed power plant diesel engine.

Several potential problems have been identified in preliminary tests. These are related to pretreatment, injection, and combustion of the oil. Filtration of the wood-derived flash-pyrolysis oil is known to be difficult. It is necessary to remove solid particles larger than 10-20 μm from the oil prior to injection. A self-cleaning filtration device has been tested. Heavy wear and corrosion has been detected in the injection needle and the pump components of the engine. Some material testing has been carried out. Finally, high CO-emissions were analysed in the engine exhaust gas during the test. However, it will be possible to decrease the injection duration by installing a high-capacity main injection pump. The injection duration will then be reduced, and consequently CO-emissions should be diminished. The ongoing work at VTT Energy is addressing the identified problems.

Wednesday, September 28, 1994
9:30 - 10:00 am

Fuel- Specification Considerations for Biomass Liquids

Cliff Moses
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FUEL-SPECIFICATION CONSIDERATIONS FOR BIOMASS LIQUIDS

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There has long been a general feeling that gas turbines can burn any fuel, and certainly in comparison to piston engines, both spark ignition and compression ignition, this is true. It would be more correct to say that gas turbines can *be designed* to burn any fuel. However, once optimized for that fuel, or class of fuels, operation of the same gas turbine system on other fuel types may cause reductions in performance and/or durability. In some cases it is possible to derate an engine to make it more tolerant of certain fuel properties or to reduce the impact to acceptable levels. In more extreme cases, one can expect to have to modify or even redesign certain components in the fuel system or hot section to accommodate variant fuel properties. Generally these modifications can be made with confidence because empirical relationships have been developed between critical fuel properties and relevant design, performance, and durability parameters.

Such problems are controlled by the engine manufacturer with a fuel specification which describes the limits of critical fuel properties which are known to affect various aspects of fuel storage and handling as well as engine performance and durability. Such fuel specifications are developed as a balance of quality, availability, and cost.

Most gas turbines which are fired by liquid fuels use a clean, petroleum distillate fuel of low viscosity. A small number of gas turbine systems are fired with crude oil or residual fuels; however, special care is taken to address the problems caused by high viscosity, low hydrogen-carbon ratio, and high levels of contaminants, e.g., sulfur, vanadium, and alkali metals.

A review of the physical and chemical properties of various biomass pyrolysis oils suggests that they will be difficult to use in current gas turbine systems. Compared to distillate fuels, they are very viscous, have high density, high tar and alkali content, and may even contain significant amounts of char as an attempt to improve the overall energy efficiency of the pyrolysis process. Conventional methods employed with residual fuels such as heating to reduce viscosity and water washing to remove alkali will not be effective with biomass fuels because of their low thermal stability and high water solubility.

A new balance of fuel quality and engine design characteristics will have to found for the effective use of biomass liquids. Unfortunately, the values of many critical properties are quite far out of the range of experience with any distillate fuel, residual fuel, or alternate fuel such as coal liquids or shale oil. Furthermore, there appear to be some characteristics that are new and may require additions to the fuel specification. Some system testing with biomass fuels covering the range of properties will have to be done to develop relevant relationships before design modifications can be made to accommodate biomass fuels and for fuel specifications to be established.

Wednesday, September 28, 1994
10:30 - 11:00 am

Firing Fast Pyrolysis Oil in Turbines

Robert Andrews
Hawker Siddeley

Firing Fast Pyrolysis Oil in Turbines

Robert Andrews, Dr. P.C. Patnaik, Dr. Q. Liu and Dr. R. Thamburaj
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This presentation describes an international cost shared development program aimed at firing of fast pyrolysis bio-fuel in a gas turbine engine for power generation. Bio-fuel offers potential for direct use in gas turbines and commercial marketing of power generation systems worldwide. Hawker Siddeley Canada Inc., has over forty years experience in the industrial gas turbine industry and the capability to develop and market bio-fuel power generation systems.

The main objectives of the program are: to operate a small gas turbine on bio-fuel and to optimize the fuel production based on performance, emissions and practical commercialization. Although some technical limitations exist there are available techniques to address these limitations which are to be examined.

The turbine engine selected as the test vehicle is a 2.5 MW class - GT2500 engine designed and built by Mashproekt in the Ukraine. The standard operating conditions and layout of this engine provide flexibility in optimization of the combustion system to accept lower than conventional grade fuels.

Wednesday, September 28, 1994
11:00 - 12:00 pm

Discussion
RD &D Needs and Plans

Ralph Overend
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Biomass Pyrolysis Oil
Properties and Combustion Meeting

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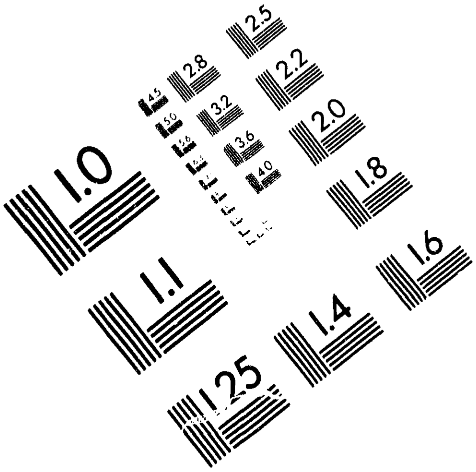

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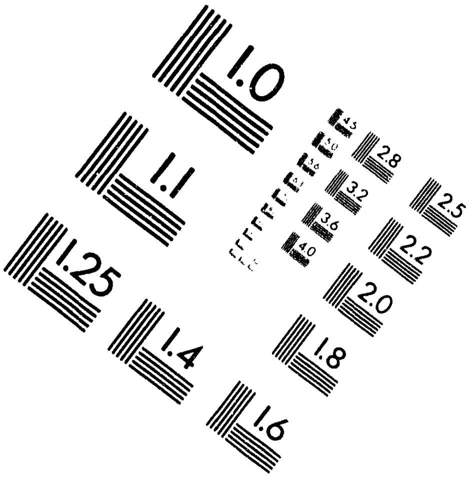

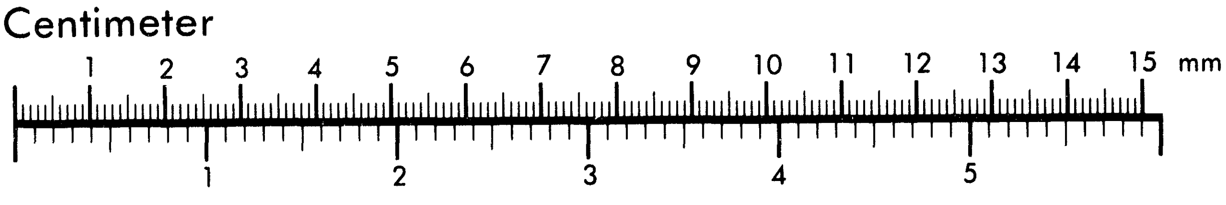

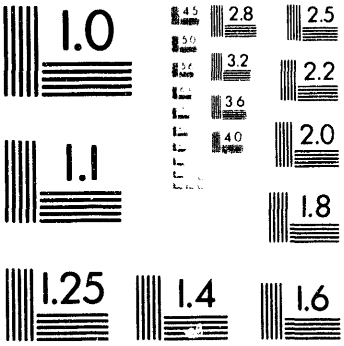

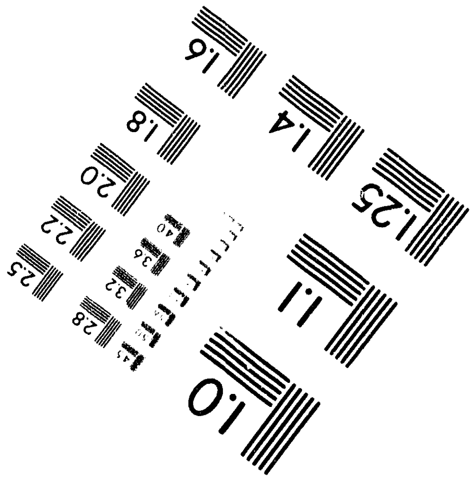

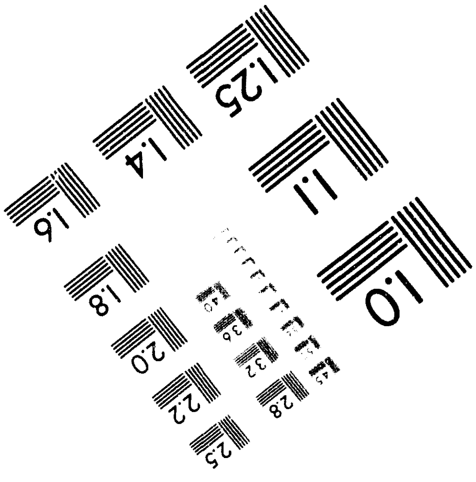

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