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COMBUSTION CHARACTERIZATION OF COAL FINES RECOVERED FROM THE HANDLING PLANT

Quarterly Technical progress report No.3.

Report Period: April 1,1995 to June 31,1995

By

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S.N. Dwivedi, Project Consultant

July 1995.

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For

U.S. Department of Energy

Pittsburgh Energy Technology Center

Pennsylvania.

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ABSTRACT

The main goal of this research project is to evaluate the combustion characteristics of the slurry fuels prepared from the recovered coal fines and plant coal fines. A specific study will include the combustion behavior, flame stability, ash behavior and emissions of SO_x , NO_x and particulate in a well insulated laboratory scale furnace in which the residence time and temperature history of the burning particles are similar to that of utility boiler furnace at 750,000 Btu/hr input and 20% excess air. The slurry fuel will be prepared at 60% solid to match the generic slurry properties, i.e., viscosity less than 500 cp, 100% of particles passing through 100 mesh and 80-90% of solid particles passing through 200 mesh. The coal blend is prepared using a mix of 15% effluent recovered coal and 85% plant fines. Combustion characteristics of the slurry fuels is determined at three different firing rates 750K, 625K, 500K Btu/hr. Finally a comparison of the results is made to determine the advantages of coal water slurry fuel over the plant coal blended form.

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

INTRODUCTION

During this period an agreement was drafted and signed by the officials of the University of North Dakota Energy & environmental Research Center (EERIE) and Prairie View A&M University to authorize the EERC to conduct the project experiments (see appendix E). The change of experimental site from PSDI(Productivity System Design Inc.) to EERC was arranged by PSDI and reported in the Progress report No. 2; January 1, 1995 to March 31, 1995 report period, which was approved by the DOE program coordinator Dr. Soung S. Kim, May 9, 1995.

EERC combustion test facilities require 2500lbs of clean coal (plant coal) and 500 lbs of recovered coal fines for the experiments. The Peabody coal company donated the above samples from Marissa mines in Marissa, Illonois and shipping expenses were billed to EERC. The Peabody has asked if we could share the test results:

COAL WATER SLURRY FUEL PREPARATION PROCESS

The plant coal will be comminuted at the EERC, first to a nominal 1/4 " top size using a William's hammer-mill crusher and then to a nominal 200-mesh (0.075 mm) top size using a Mikro-Pul 3 TH hammer-mill pulverizer. A representative sample of the comminuted plant coal, along with a representative sample of the recovered fines, will be subjected to proximate, ultimate, heating value (Btu) and high-temperature ash (HTA) x-ray fluorescence analyses. Further, the plant coal will be analyzed for particle size distribution (PSD) via malvern laser diffraction analysis and the recovered fines will be analyzed for PSD via wet sieve.

The recovered fines will be prepared into a slurry with deionized water, charged to a 500-gallon continuously agitated storage tank, and then subjected to a particle size adjustment using a Attritor 450 LB/hr wet ball mill. The size consist of the wet milled recovered fines will be periodically measured via Malvern laser diffraction particle size analysis; PSD control will be accomplished via adjustment of the wet mill residence time and the mill grinding speed. The target PSD is a maximum particle size less than 200 μ m and a mean particle size of 40 to 50 μ m. The milled-coal slurry will be collected in barrels and then transferred to the 500 gallon agitated storage tank.

Bench-scale evaluations using a HAAKE Rotovisco RV-100 Concentric Cylinder Viscometer will determine the optimum coal to water ratio (i.e. solids content) to prepare a slurry fuel with a 500 cp (centipoise) viscosity. A plant coal/recovered fines ratio of 85/15 by weight (dry basis) will be maintained during fuel preparation. The computer will provide the independent flow behavior for the fluid, viscosity, and yield stress values as each correlates to the Yield Power Law.

Subsequently, 2500 lb of bituminous coal-water fuel will be prepared by blending the pulverized plant coal/milled-coal slurry with deionized water. The fuel will be batch blended in 55-gallons barrels using a 6" marine-type propeller. The concentrated fuel will be stored in the 500-gallon agitated tank prior to combustion tests. Representative samples of the as-fired test fuel will be subjected to rheological, PSD, proximate, ultimate, Btu and HTA analyses.

PROJECT STATUS

During this period, test samples were shipped to EERC and experiments were planned and organized. Graduate and undergraduate student assistants continued their work on different aspects of the project and some of their observations are listed below.

Surender Rao Samudrala, (Graduate Research Assistant),

Had a chance to attend the Third Annual Historically Black Colleges and Universities/Private Sector/Energy Research and Development Technology Transfer Symposium at Atlanta and present the developments of the project.

He also worked on the literature related to

- Combustion test experiences and various factors effecting combustion efficiency
- Study of a process to recover the clean coal from coal preparation plant waste streams using a packed column also known as MTU static tube process
- Coal water mixture characteristics and basic requirements of CWM production process.

(See appendix A)

Omeir Mohannad, (Graduate Research Assistant),

Studied the various aspects of flame structure, flame propagation, types of flames and various variables affecting the behavior of diffusion flames . His findings are listed in appendix B.

Tamar C. Holley, (Undergraduate Research Assistant),

Studied the behaviors, methods and processes required to produce and combust the coal-water mixture fuel.

(See Appendix C).

Karen Jubert, (Undergraduate Research Assistant),

**Studied the combustion test results of coal-water-fuel used in Yukong's
Modified Boiler.**

(See Appendix D).

APPENDIX A

OBSERVATIONS MADE FROM THE PAPER ENTITLED COAL-WATER SLURRY COMBUSTION TECHNOLOGY AND ITS APPLICATION TO INDUSTRIAL FURNACES

This paper discusses the results of burning five different coal-water mixtures (CWM) in a combustion system developed by Beijing university of iron and steel technology (BUIST). Description of experiment furnace, CWS feeding system, burner, combustion test experiences and various factors effecting combustion efficiency are done.

Description of experimental setup

The test furnace consists of horizontal insulated chamber, a burner mounted in the center of front wall and has a feeding system where the CWS is fed by variable speed progressive cavity pump. The flowrate and pressure can be controlled by means of adjusting rotating speed of pump.

Electric air preheater is used to heat the secondary air. Ignition system consists of gear pump and control valves.

Burner consists of two parts atomizer and air register. The type of atomizer used is "Y" type jet, single hole and semi-internal mixing. A relative adjustable axial-vane swirl register is used and the intensity of the register can be varied in the range of 0 to .85.

Atomization of CWS is the most important factor for ignition, flame stability, and high carbon efficiency. A spray of fine particle sizes and reasonable particle distribution is required to obtain a high efficiency combustion.

Combustion Test

Cws was prepared using five different coals having solids loading about 65 to 75% (by weight) and viscosities in the range of 700 to 2000Cp (100 sec⁻¹). The observations made in the flame appearance are flame length increases gradually with the reduction of swirl intensity. When the swirl number is close to 0, the flame becomes unstable, and even extinguishable. When the swirl number is at .85 agglomeration at the burner throat is observed due to powerful recirculation which makes high temperature center close to the burner tip. The average temperature of CWS combustion gas within furnace chamber is about 1300°C which is needed for most of the industrial furnace.

Effects of droplet size and fineness of CWS spray

The factors accounting for atomization quality are fineness of the CWS spray droplet and its size distribution. Analysis of the test results of BUIST atomizer shows by reducing the CWS spray droplet size combustion efficiency increases. It is been observed from the literature that small droplets are easy to mix with oxygen and hence the heating time for devolatilization and ignition is greatly reduced. Also the burnout time is reduced due to the small droplet size. In order to have a high carbon conversion rate, the mean diameter should be less than 200µm and the percentage of droplets whose diameters are over 300µm should be restricted.

Considering the another important aspect, droplet distribution for large and medium capacity CWS burners atomizers with multihole and annular nozzle is the best fit. But for small capacity CWS burners single hole nozzle is still the best type as the nozzle diameter has to be ten times larger than top coal size in

order to avoid blockage. From the comparison of spray droplet distribution from single hole Y-jet and single hole cone-jet atomizer under same conditions showed the carbon conversion of Y-jet atomizer is 1.3 times more than cone-jet atomizer.

Effects of Cws properties

In order to study the effects of CWS properties on carbon conversion efficiency, test results obtained from combustion of five different Cws were analyzed and graphs were plotted. From the plots it showed that the carbon conversion efficiency increases with the increase in secondary air temperature. Also with the increase of excess air upto 1.4 combustion efficiency increased and then decreased slowly when excess air is increased above 1.4, when secondary air temperature was 120°C and CWS flow rate being 145 kg/h. At secondary air temperature of 120°C and excess air at 1.44 increase in furnace temperature caused an increase in the combustion efficiency.

Conclusions

BUIST has developed CWS burner appropriate for industrial furnace and have successfully demonstrated by applying the technology to Tunnel drying furnace and continuous reheating furnace for rolling mill.

It is observed that atomization quality and good combustion aerodynamic conditions are very important in the combustion of CWS.

The major factors affecting combustion efficiency are atomization quality CWS properties, secondary air temperatures, excess air rate and furnace temperature.

**DESCRIPTION OF BASIC REQUIREMENTS OF COAL WATER
MIXTURES (CWM)
PRODUCTION PROCESS AND CWM CHARACTERISTICS AS LISTED BY
M. MIYAZAWA, S. KANEKO, M. KINOSHITA, Y. UEMATSU,
H. YOSHIDA**

Basic requirements of CWM production process

Considering the application of CWM to large scale utility applications, the following are the basic requirements that has to be fulfilled .

1. Technical and economical feasibility of large scale CSF production facility
 - a. Large scale production of CWM is essential to keep the price of producing CWM low
 - b. The system must be applicable to a wide range of coals.
2. Optimization of slurry characteristics
 - a. Good combustion characteristics

In order to maintain a stable combustion and to minimize unburned carbon losses, good atomization and combustion characteristics are most essential. Also slurry rheology and elimination of coarse particles in CWM is very important.
 - b. High coal concentration in CWM

Water content in CWM must be minimized to achieve high boiler efficiency.
 - c. Long term storage capability without forming sedimentation of coal particles.
 - d. Good flow characteristics and minimum sedimentation are important factors for good transportation.

Governing factors of CWM characteristics

1. Particle size distribution

a. Dense packing effect

Filling the spaces between large particles with fine particles requires less water as a fluidizing agent which adds to high coal concentration.

b. Bearing effect of ultra fine particles

Large particles when coated with ultra fine particles created by smoothing off edges of large particles by attrition improves the fluidity.

c. Elimination of Coarse particles

The coarse particles over 150 and 500 microns needs to be eliminated.

d. Perfect mixing and dispersion

Due to strong agglomerating characteristics of ultra fine particles it is recommended that their production and dispersion with strong shear are performed simultaneously.

SUMMARY OF PAPER ENTITLED PROCESSING PREPARATION PLANT EFFLUENT USING A PACKED COLUMN

by
V. Choudary, L. Khan. D. Yang and D.D. Banerjee

This paper discusses the results obtained by using a packed column also known as MTU static tube process to recover the clean coal from coal preparation plant waste streams. The tests were conducted in two phases, the first being the testing of effluent samples collected from Illinois preparation plant which contains 50-60% ash in a lab scale column. The results being a clean coal containing 7-11% ash at BTU recovery of 91-98% and pyritic sulfur rejection levels of 61-74% are achieved. In the second phase prior to pilot-scale tests bench-scale confirmatory tests at Michigan Technological university using a 4-in. I.D. x 10-ft tall column are performed. Number of tests were performed in a 4-in. I.D. x 20-ft tall column to study the effects of primary variables(feed rate, percent solids and reagent dosage) and operating variables (air rate, wash water, and pulp level) using feed rates ranging from 20 to 108 lb/hr. The best results were obtained at a feed rate of 35.5 lb/hr, with a clean coal product containing 5.3% ash and 2.525 total sulfur at 32.8% yield. The pyritic sulfur rejection level for this test was 87% at 87% BTU recovery.

The main objectives are

- To recover the clean coal from preparation plant effluents using packed column and to study the ash and pyritic sulfur rejection levels.
- To study the effect of process variables such as feed rate, pulp density, and reagent dosage
- Study the effect of machine variables such as pulp level in column, air and waste water rate on packed column performance.

Prior to performing flotation tests characterization on four samples were done which include particle size analysis, proximate, ultimate and washability analysis. In phase two confirmatory bench scale tests were performed in a 4-in. I.D. x 10-ft tall column prior to performing pilot scale tests. Pilot scale tests were conducted on a 4-in. I.D. x 10-ft tall packed column. During these tests the conditioned slurry was then gravity-fed to the flotation column. The slurry flow rate and total slurry volume were monitored by flow meters. The pulp levels and depth of froth in column were controlled by moving tailings line up or down. Samples were collected periodically and analyzed for ash, sulfur, and Btu content. Using the product and tailing analyses reconstituted feed ash, total sulfur, and pyritic sulfur values were calculated. Based on these values, the percent ash rejection, pyritic sulfur rejection, and Btu recovery levels were calculated.

The criteria used to evaluate the performance of various tests are as follows

Selectivity index = % Btu recovery + % pyritic sulfur rejection -100

Efficiency index = % yield x % tailings ash + % product ash

Selectivity index is used in evaluating tests for pyritic sulfur rejection performance and efficiency index is useful in evaluating percent ash rejection and yield.

The results from the phase I bench scale column flotation indicate that all the samples achieved pyritic sulfur rejections of 65-75% at Btu recovery greater than 90%. From phase II bench scale tests it is found that clean coal containing 6-8% ash can be recovered at combustible matter recovery of 71-77%. Feed solids concentrations of 10-20% yielded product ash values of 6.5-7.5% at combustible matter recoveries of 74-77%. The best results were obtained at reagent dosage 6-12 lb/T using pine oil/fuel oil blend in the ratio of 1:1.

From the pilot -scale column flotation tests it is observed that high pyritic rejection levels of about 85-90% can be achieved at 75-80% Btu recovery. Clean coal containing less than 7% ash was recovered at Btu recoveries greater than 85%. At 5 and 12.5% feed solids concentrations, a clean coal ash content of less than 10% was achievable at 85-90% Btu recovery. It is observed that low (3-10 lb/T) to medium (between 10 and 20 lb/T) reagent dosages achieved better separations. Reagent dosages of 3 lb/T resulted in products with 11-17% ash contents at Btu recoveries of 85%. Considering the feed rate the tests indicate that the packed column can operate at feed rates comparable to other columns and the packing does not decrease the cell throughput rate. An optimum pulp level of 25 cm below the feed entry point for the selected data pairs is found. A decrease in performance is observed at both lower and higher pulp levels. From the test data it is found that an air rate of 25-30 l/min provided a high degree of separation. Also the efficiency index increased with increase in wash water content.

Conclusions from the test data are

7-10% ash levels were obtained at 80-85% Btu recovery and 80% PSR using feed rates of 32.6-40.8 lb/hr. The Product ash levels of less than 6% which is the best were consistently obtained at 33% yield and 80% Btu recovery at a feed rate of 35.5 lb/hr. At 5 and 12.5% slurry solids concentrations the best separation and high recoveries were obtained. At 5-10 lb/t reagent levels the best results were obtained. Performance was improved with the increase in wash water.

APPENDIX B

FLAME

Flame Propagation

When a mixture of gaseous are compressed, an electric spark is generated. That cause the mixture to ignite. Oxidation reaction is generated in the center and that called the flame center.

The ignition theory indicated that reaction of oxygen on the coal surface was not a major factor in this ignition process. However, others have identified surface oxidation as important in some coal dust ignition process.

Flame classification

Particle fame can be classified in several ways:

1-Flow types : Well stirred.

Recirculating.

2-Mathematical model complexity : Zero dimensional

One dimensional

Multi dimensional

3-Process type : Fixed bed

Moving bed

Fluidized bed

4-Coal particle size: large

Intermediate

Small

Classic Flame Types

1. Well-stirred Reactor. An example of a well-stirred reactor is ideal fluidized-bed combustor. This kind of idealized reactor is simple to describe , since fluid motion does not need to be described in detail.
2. premixed flame. A premixed coal dust flame may exist in a coal mine explosion. This type of flame can be very small , and very complex with diffusion, heat transfer and gas.
3. Diffusion Flame. A diffusion flame is characterized by injection of separate stream of fuel and oxidizer into the reactor. This type of flame is characterized by very complex fluid mechanics that may include recirculating and swirling flows.

Flame Variables

Major variables that influence the behavior of diffusion flame:

- 1-Reactor size and shape
- 2-Wall materials and temperature.
- 3-Coal type and size distribution.
- 4-Moister percentage and composition.
- 5-Ash percentage and composition.
- 6-Primary stream temp. , velocity and mass flow.
- 7-Secondary stream temp. , velocity and mass flow.
- 8-Burner configuration and location.

APPENDIX C

COMBUSTION STUDY OF COAL WATER MIXTURE (CWM)

Alternative energy sources has been in demand for over twenty years.

Introduction of coal as an energy source has been positively promoted. Using coal has presented several challenges, including its cost, and its negative contribution to the environment. A more improved product, coal-water mixture (CWM), has been developed. This research involves the study of its behaviors and the methods and processes required to produce it.

Coal-Water Mixture is a high concentration of water and coal (slurry). Its main attractions are its amenability to be handled as a fluid and the fact that its effect on the environment are negligible in such matters as spontaneous combustion and dispersion of coal dust.

CWM was used in various studies and tests to assess its transportation capacity, combustibility, storability, and environmental protection. The Coal Water Mixture was tested in several plants, including washing plants, and the initial product utilizing several different types of coal.

Using a 33 MW Himeji No. 1 Boiler, the tests performed to assess the behaviors of the Coal Water Fuel concluded that using a modified oil designed boiler is feasible, the combustion of the CWM is stable, and the operation is simple and reliable. The combustion was intensified and carbon conversion efficiency is increased by registering axial swirl in front combustion chambers. The No_x emissions were lower than that of the State Standard. Overall, the Coal Water Fuel is comparable to that of pulverized coal in most aspects.

The characterization, stability, and rheology was also assessed. The characterization component rated the physical, chemical and electrokinetic properties of the solid. The stability is investigated using sedimentation studies of experiments and measurements. The rheological components and the atomization are rated by the shear rate behavior using capillary tube rheometers to measure viscosity and vane geometry.

The preparation of the coal water mixture included coal beneficiation which improved the properties by removing sulfur and mineral matter from the coal. Other objectives include reducing the moisture level, improving grindability, improving the carbon burnout characteristics, and improving the CWF rheology. It was established that the requirements after beneficiation may result in high additive costs and adverse effects on CWF rheology, atomization, and combustion.

Fine coal waste, or utilizing the cheapest coal quantities in a feasible manner, was also researched. A study was conducted in a washing plant to assess the slurry cut from the coal of that plant, the beneficiation process of mechanical separation of the low ash coarse fraction and cleaning of the fine fraction, and formulation of Coal Water Mixtures. Under certain conditions, solid content may reach 70% of acceptable viscosity. It was established that it is feasible to prepare quality CWM using fine slurries from washing plants.

Finally, the combustion of the Coal Water Fuel was also judged using two methods, the In-situ Droplet Generation and the CWF Agglomerate Injection to introduce CWF droplets performed in a laminar flow reactor. The volatile combustion, particle rotation, ignition of char, char burnout, and fragmentation was all rated.

APPENDIX D

Summary of Combustion Test Results of Coal-Water-Fuel Into Yukong's Modified Boiler On a Commercial Basis at Yukong

Korea's largest total energy company has set forth a model project to develop a Coal-Water-Fuel (CWF) commercialization. Yukong Ltd. has completed the construction of a 600-BPD CWF plant and the modification of a 68-ton/hr oil designed boiler. It is known that CWF can be stored, transported, and burned like oil and is the most promising alternative fuel for general industrial application.

The following are some features of the Yukong CWF plant:

- The maximum design capacity of 750 barrels per day (i.e. 143 tons of CWF or 100 tons of dry coal or 33,300 tons of dry coal per year)
- Uses the wet technique for coal grinding
- Includes the beneficiation process
- Coal delivered by truck from Ulsan Coal Terminal
- Shipment of CWF by tank lorry to the boiler
- CWF storage capacity of 6550 barrels (275,000 gallons)

The following conclusions have been made as a result of the CWF-firing of 150,000 lb/hr in Yukong's Ulsan Refinery plant:

- CWF can be burnt satisfactorily in a commercial scale boiler without support fuel
- CWF can be readily transported and stored in conventional tank lorry with no significant degradation of quality
- Automated CWF supply system has a high degree of reliability
- Boiler reliability is not degraded by CWF firing with the proper selection of parent coals to

avoid any conventional slagging or fouling problems

- Good atomization can be achieved with a steam at a pressure as low as 120 psi with B&W

CWF burners and atomizer

APPENDIX E

Energy &
Environmental
Research
Center

UNIVERSITY OF NORTH DAKOTA

15 North 23rd Street — PO Box 9018 / Grand Forks, ND 58202-9018 / Phone: (701) 777-5000 Fax: 777-5181

May 24, 1995

Dr. H. Masudi
Prairie View A&M University
Mechanical Engineering Department
Prairie View, TX 77446

Dear Dr. Masudi:

Subject: Evaluation of a Coal-Water Fuel Project

Enclosed are two originals of the agreement for the above project that have been signed by an authorized official of the University of North Dakota Energy & Environmental Research Center (EERC). The agreement authorizes the EERC to perform services in the cost-reimbursable amount of \$30,000.

If the agreement meets with your approval, please have an authorized official of your organization sign both documents, retain one for your records, and return the second to my attention.

As we discussed, Jay Gunderson of the EERC will be contacting you regarding the testing schedule. Should you have any questions or require further information, please contact me at (701) 777-5271.

We look forward to working with you.

Sincerely,

Angela K. Lommen
Grants and Contracts Officer
EERC Financial Services

AKL/amf

Enclosures

c/enc: Jay Gunderson, EERC

c: Kaye Johnson, EERC
Steven Benson, EERC

AGREEMENT

This document sets forth the Agreement between the following parties: the University of North Dakota Energy & Environmental Research Center (EERC) and Prairie View A&M University (PRAIRIE VIEW).

WHEREAS the EERC is willing to conduct a Project entitled "Evaluation of a Bituminous Coal-Water Fuel" and PRAIRIE VIEW desires to receive the results of said Project.

THEREFORE, PRAIRIE VIEW and EERC agree as follows:

Article 1 - Scope of Work

The EERC agrees to perform the work as set forth in EERC Proposal No. 95-6272, entitled "Evaluation of a Bituminous Coal-Water Fuel" dated February 28, 1995, submitted to PRAIRIE VIEW as appended hereto and incorporated as APPENDIX A, Scope of Work. The EERC will use its best efforts to produce a coal blend of 15% recovered coal and 85% plant coal of the coals provided by PRAIRIE VIEW and will use its best efforts to produce a slurry mix of 60% coal blend and 40% water. Representatives of PRAIRIE VIEW will be advised of testing schedule and will be present for testing.

Article 2 - Period of Performance

The Agreement will become effective and will commence on the date this Agreement has been executed by both parties. The EERC shall use its best efforts to complete the Project within two months from the effective date of this Agreement.

Article 3 - Deliverables

The EERC shall use its best efforts to submit the reports/deliverables described in APPENDIX A, Scope of Work, in accordance with the time frames specified in same appendix.

Article 4 - Consideration and Payment

The total cost of the Project as described in APPENDIX A is estimated to be \$30,000. Of the estimated amount, PRAIRIE VIEW agrees to pay the EERC cost-reimbursable expenses not to exceed \$30,000.

Invoices for the project incurred shall be submitted to PRAIRIE VIEW for payment within 30 days of receipt of invoice. Invoice shall be submitted for payment on the following schedule:

Upon execution of Agreement	\$7500
Initiation of Sampling Effort	\$7500
Submission of Data	\$7500
Submission of Final Report	Balance

Costs shall be in accordance with the itemized budget appended hereto and incorporated as part of APPENDIX A. The EERC will, as dictated by the needs of the work, reallocate the budget amount among approved items or use the funds for other items directly related to the project, subject only to staying within the total amount authorized. As the source of funding

provided by this Agreement is federal, the EERC will follow the guidelines established in OMB Circulars A-21 and A-110.

Article 5 - Independent Contractor

The EERC is an Independent Contractor, not a partner or joint venturer, and shall not act as an agent for PRAIRIE VIEW, nor shall the EERC be deemed to be an employee of PRAIRIE VIEW for any purpose whatsoever. The EERC shall not have any authority, either express or implied, to enter into any agreement, to incur any obligations on PRAIRIE VIEW's behalf, or commit PRAIRIE VIEW in any manner whatsoever without PRAIRIE VIEW's express prior written consent.

Article 6 - Termination for Cause

If EERC shall fail to fulfill one or more of its obligations under this Agreement or breach any one or more of the terms and conditions of this Agreement, PRAIRIE VIEW may, upon its election, at any time terminate this Agreement by giving not less than thirty (30) days prior written notice of termination to EERC specifying any such breach or default. In the event of termination pursuant to this Article, EERC shall stop all work hereunder. No costs incurred after the effective date of a termination will be allowable, except 1) those costs which EERC could not reasonably avoid or eliminate, 2) which were otherwise authorized by the termination notice, or 3) those costs which were incurred in EERC's satisfactory fulfillment of its obligations under this agreement. In no event will the total of payments under this Agreement, if terminated, exceed the amount authorized by the PRAIRIE VIEW in Article 4 of this Agreement.

Article 7 - Notices

All notices, demands, offers, and other communications required or permitted hereunder shall be in writing and shall be deemed to have been given when received at the addresses noted below. Following are the separate addresses for technical and contractual concerns:

PRAIRIE VIEW

Name Dr. Houshang Masudi
Address Mechanical Engineering Dept.
College of Engineering & Arch.
P.O. Box 397
Phone Prairie View, TX 77446
Fax ph: 409/857-4023
fax409/857-2222

Technical MattersContractual Matters

EERC

Technical Matters

Contractual Matters

Name Jay Gunderson
Address Energy & Environmental
Research Center
University of North Dakota
PO Box 9018
Grand Forks, ND 58202
Phone (701) 777-5258
Fax (701) 777-5181

Sheryl Landis
Energy & Environmental
Research Center
University of North Dakota
PO Box 9018
Grand Forks, ND 58202
(701) 777-5124
(701) 777-5181

Article 8 - Miscellaneous

This Agreement shall be governed by, construed, and enforced in accordance with the laws of the State of North Dakota.

The headings in this Agreement are inserted for convenience and identification only and are in no way intended to describe, interpret, define, or limit the scope, extent, or intent of this Agreement or any provision hereof.

The terms of this Agreement are binding upon the inure to the benefit of the successors and assigns of the respective parties.

This Agreement, with attached APPENDICES, constitutes the entire agreement between the parties relative to the subject matter.

All changes, alterations, or modifications to this Agreement will be in writing and signed by the authorized officials of the parties hereto.

If one or more of the provisions of the Agreement shall be held to be invalid, illegal, or unenforceable in any respect, the validity, legality, and enforceability of the remaining provisions shall not in any way be affected or impaired thereby.

IN WITNESS WHEREOF, the parties hereto have executed this Agreement on the day and year last specified below:

PRAIRIE VIEW A&M UNIVERSITY

By _____
Name Dr. E. Joahanne Thomas-Smith
Title Interim Provost and Vice President
Date May 26, 1995

UNIVERSITY OF NORTH DAKOTA ENERGY & ENVIRONMENTAL RESEARCH CENTER

By David J. Bowen
Name Kenneth J. Dawes
Title Director, Office of Research and Program Development
Date 27 May 95

EVALUATION OF A BITUMINOUS COAL-WATER FUEL

1.0 INTRODUCTION

Currently, bituminous coal fines produced during normal operation of a pulverized coal-fired utility boiler are discarded at considerable cost. It has been proposed by PSDI to recover these fines and produce a stable coal-water fuel that may be fired to provide supplemental heat input to the boiler. Because these fines are normally disposed of in a pond, their recovery as a slurry product would be the most cost-effective approach.

Since the chemical properties of the fines are most likely different from those of the parent coal, their combustion and ash deposition properties are also expected to be different. Subsequent sections of this document outline the objectives of the proposed work, describe the facilities to be used, summarize the experimental approach, present a tentative schedule and estimated budget, and identify the key EERC personnel who will be involved.

2.0 OBJECTIVES

The overall objective of the activities outlined in this proposal is to complete an evaluation of the combustion behavior of a bituminous coal-water fuel. Specific goals include the following:

- Prepare a stable bituminous coal-water fuel and evaluate its rheological properties
- Determine the flame stability properties of the resultant fuel as a function of burner settings and firing rate
- Determine the combustion efficiency for the coal-water fuel as a function of residence time in the furnace and firing rate
- Perform a limited evaluation of the fuel's fouling potential at each firing rate
- Characterize emissions of SO_2 , NO_x , CO , CO_2 , and O_2

3.0 EXPERIMENTAL SYSTEM

The experimental system to be used to complete the proposed scope of work is referred to as the EERC combustion test facility (CTF). This pulverized coal-fired and coal-water fuel-fired combustor is vertically oriented and normally fires at a rate between 500,000 and 750,000 Btu/hr, generating between 120 and 160 scfm of flue gas. The primary function of this pilot-scale system for the past 20 years has been to address the flame stability and slagging and fouling tendencies of various fuels and fuel blends. More than 700 combustion tests of pulverized fuels and over 200 combustion tests of coal-water fuels have been completed on this test furnace. A more detailed description of the system is presented in Appendix A.

4.0 SCOPE OF WORK

The proposed scope of work is divided into two tasks. Task 1 will involve the preparation of the coal-water fuel and its rheological evaluation. Task 2 will involve completion of nine periods of flame stability testing: three burner settings at each of three firing rates. In addition, the fuel's fouling propensity will be investigated at each firing rate.

4.1 Task 1 - Preparation of the Bituminous Coal-Water Fuel

Fuel preparation will be achieved by thoroughly blending the as-received coal fines in water using a slurry preparation system consisting of a 500-gallon storage tank and two metering pumps. A 3-hp mixer assembly equipped with two 3-inch-diameter marine propellers will be used to ensure adequate blending during the process. An attritor mill will be used to achieve the appropriate size distribution (maximum particle size less than 200 μm , with a mean particle diameter between 40 and 50 μm) for the coal-water fuel. Rheological evaluation of the slurry fuel will determine the optimum solids content to achieve a fuel viscosity of approximately 500 cP. It is assumed that no additives will be used to stabilize the fuel prior to combustion. Once the fuel has been prepared, it will be transported by barrels and transferred to the storage tank located above the slurry feed pump used during combustion testing. Approximately 2500 lb of bituminous coal-water fuel will be prepared from the 1500 lb of dry fines received.

Analyses will be performed on the as-received coal fines to determine their proximate, ultimate, and heating value analyses. The product slurry fuel will also be analyzed for its proximate, ultimate, heating value, ash composition, particle-size distribution, and viscosity analyses.

4.2 Task 2 - Combustion Testing of Bituminous Coal-Water Fuel

The bituminous coal-water fuel will be fired over nine test periods (three burner settings at each of three distinct firing rates) to determine flame stability characteristics and combustion efficiency as a function of burner settings and firing rate. In addition, a limited evaluation of ash-fouling properties will be performed over three 5.25-hour test periods at each firing rate. These tests will be completed using a pilot-scale combustion system with an electrostatic precipitator (ESP) on the back end for particulate control. The combustor will be fired on natural gas to preheat the system to the desired operating conditions. The tests will be conducted over a 3-day period, firing at a different rate each day.

An International Flame Research Foundation (IFRF)-type secondary air swirl generator will be used during testing. The swirl burner is designed to achieve secondary air swirl numbers between 0 (no swirl) and a maximum of 1.9. Swirl is defined as the ratio of tangential momentum to axial momentum of the secondary air stream. A more complete description of the test protocol is included in Appendix A.

During the first day of testing, the bituminous coal-water fuel will be fired at a rate of approximately 750,000 Btu/hr. This rate should provide a furnace exit gas temperature at or above 2200°F at an excess air level near 20%, simulating full load operation. Burner settings will then be adjusted to determine the point at which the flame separates from the burner, indicating flame instability, and the point at which the flame is fully contained within the burner quarl, indicating stable conditions. Since these points will most likely change as the load level is adjusted in subsequent tests, a third (constant) swirl setting will be chosen so that performance may be correlated between each load test.

It is expected that up to 1.5 hours may be required to complete each test period. Data recorded at each burner setting will include a full gas analysis (CO , CO_2 , O_2 , SO_2 , and NO_x), the ratio of primary to secondary air, flame temperature at a single point in the furnace, and a measurement of furnace wall heat flux at this location. Flame temperature is determined by a high-velocity thermocouple, and heat flux is measured using a water-cooled probe. These measurements provide an indication of flame shape and intensity. A photograph of the flame at each burner setting will also be taken to provide a visual record of the flame. A small cyclone will be used to collect fly ash samples that will be analyzed for carbon content to determine the effect of burner settings and load on carbon conversion.

Once the flame stability evaluation has been completed, the burner will be set at a constant swirl setting, and the deposition probes will be inserted into the flue gas ductwork. Surface metal temperatures on each deposition probe will be controlled to approximately 1000°F with steam. Ash-fouling deposits will be collected over a 5.25-hour test period. During this test period, particulate will be extracted from the furnace proper at three elevations and analyzed for its carbon content. A portable gas analyzer will provide the flue gas concentrations of O_2 , CO , NO_x , and SO_2 at each location. CO_2 can be calculated based on the other gas constituents. The fouling deposits will be collected, weighed, and analyzed at the completion of this test period. An evaluation of deposit strength will also be performed using laboratory methods, provided the deposit has enough strength to withstand handling.

An electrostatic precipitator will be operated to collect bulk fly ash samples. These samples will be analyzed for carbon content, size distribution, and elemental oxide composition using x-ray fluorescence.

The furnace will be fired on natural gas between load tests on consecutive days to maintain system operating temperatures. The firing rate will be lowered to 625,000 and 500,000 Btu/hr for testing on Days 2 and 3, respectively. The test protocol described above for the first day of testing will be repeated at each load condition.

5.0 PROJECT SCHEDULE

Once the appropriate contractual paper work has been completed and the fuel received, EERC staff will begin work on Task 1 in order to prepare the coal-water fuel for combustion testing. It is expected that up to 2 weeks will be required to prepare the fuel and perform the rheological evaluation. During this time frame, the coal-water fuel feed system and the combustion system's gas analyzers will be calibrated.

Task 2 combustion testing is expected to occur over 3 days of operation in a single week. Once testing is completed, an additional 3 to 4 weeks will be required to analyze collected samples and reduce the operational data generated, for a total project duration of 6 to 7 weeks following receipt of fuel samples.

6.0 PROJECT BUDGET AND DELIVERABLES

A detailed budget for the proposed work was estimated on cost-reimbursable basis totaling \$30,000. Task 1 costs were estimated at \$6672 for fuel preparation and rheological evaluation. The estimated cost of combustion testing in Task 2 is \$23,328 for completion of nine flame stability test

periods and three ash-fouling test periods. The budget assumes that federal dollars will be used to perform the proposed work and uses the federal indirect cost rate of 42%.

The main project deliverable will be the slurry performance information and the operational data generated during each test period. The combustion data will be formatted such that all information can be incorporated into a Lotus or Quattro Pro spreadsheet. Interpretation of the data will be the responsibility of the proposal initiators. Copies of the pilot furnace log book and recorders will also be provided.

7.0 KEY PERSONNEL

Mr. Jay Gunderson will serve as the project manager and primary contact between the EERC project team and PSDI. As the project manager, Mr. Gunderson will be responsible for coordinating project activities on a daily basis and for the bulk of the data reduction activities. Assisting Mr. Gunderson with project activities will be Mr. Chris Anderson and Mr. Tom Moe.

Budget Removed at

Budget Notes

Energy & Environmental Research Center (EERC)

Background

The EERC is an independently organized multidisciplinary research center within the University of North Dakota. The EERC receives no appropriated funding from the state of North Dakota and is funded through federal and nonfederal grants, contracts, or other agreements. Although the EERC is not affiliated with any one academic department, university academic faculty may participate in a project based on the scope of work and expertise required to perform the project.

The proposed work will be done on a cost-reimbursement basis. Financial reporting will be at the total project level.

Salaries and Fringe Benefits

As an interdisciplinary, multiprogram, and multiproject research center, the EERC employs an administrative staff to provide required services for various direct and indirect support functions. Direct project salaries are estimated based on the scope of work and prior experience on projects of similar scope. Technical and administrative salaries are charged based on direct hourly effort on the project. Costs for general support services, such as grants and contracts administration, accounting, personnel, purchasing and receiving, as well as clerical support of these functions, are included in the indirect cost of the EERC.

Fringe benefits are estimated based on historical data. The fringe benefits actually charged consist of two components. The first component covers average vacation, holiday, and sick leave (VSL) for the EERC. This component is approved by the UND cognizant audit agency and charged as a percentage of direct labor on permanent staff employees eligible for VSL benefits. The second component covers actual expenses for items such as health, life, and unemployment insurance; social security matching; worker's compensation; and UND retirement contributions.

Travel

Travel is estimated based on UND travel policies, which include GSA daily meal rates. Travel includes scheduled meetings and conference participation as indicated in the scope of work.

Communications

Monthly telephone services and fax telephone lines are included in indirect cost. Direct project cost includes long-distance telephone including fax-related long-distance calls; postage for regular, air, and express mail; and other data or document transportation costs.

Project Office Supplies

General purpose office supplies (pencils, pens, paper clips, staples, Post-it notes, etc.) are provided through a central storeroom at no cost to individual projects. Budgeted project office supplies include items specifically related to the project: special research notebooks, binders, and other project organizational materials; duplicating, printing, special covers or paper, and binding of

reports; project data forms, transparencies or other presentation materials; literature searches and technical information procurement, including subscriptions; manuals, computer diskettes, memory chips, laser printer paper, and toner cartridges; and other miscellaneous supplies required to complete the project.

Data Processing

Data processing includes items such as computer use charges and computer software.

Supplies

Supplies in this category include scientific supply items such as chemicals, gases, and glassware supplies and/or nuts, bolts, and piping necessary for pilot plant operations.

Fees

Laboratory and analytical fees are established and approved at the beginning of each fiscal year and are charged based on a per sample or hourly charge depending on the analytical services performed.

Engineering support fees are based on an established per hour rate for drafting services related to the production of drawings as part of EERC's quality assurance/quality control program for complying with piping and pressure vessel codes.

Graphic services fees are based on an established per hour rate for overall graphics production such as report figures, poster sessions, standard word or table slides, simple maps, schematic slides, desktop publishing, photographs, and printing or copying.

Shop and operation fees are for expenses directly associated with the operation of the pilot plant facility. These fees cover such items as training, safety (protective eye glasses, boots, gloves), and physicals for pilot plant and shop personnel.

Professional staff clerical support fees provide part of the administrative infrastructure of the EERC. Fees are based on the hours directly charged by all EERC professional staff to specific research projects or indirect cost support functions.

Membership fees (if included) are for memberships in technical areas directly related to work on this project. Technical journals and newsletters received as a result of a membership are used throughout development and execution of the project as well as by the research team directly involved in project activity.

Indirect Cost

The indirect cost rate included in this proposal is approved by the Department of Health and Human Services. Indirect cost is calculated on Modified Total Direct Costs (MTDC). MTDC is defined as Total Direct Costs less individual items of equipment in excess of \$500 and subcontracts/subgrants in excess of the first \$25,000 for each award.