PENNSSTATE

**SUPERCLEAN COAL-WATER SLURRY COMBUSTION
TESTING IN AN OIL-FIRED BOILER**

Quarterly Technical Progress Report
for the Period 08/15/1989 to 11/15/1989

By

Bruce G. Miller, Co-Principal Investigator
Alan W. Scaroni, Project Manager

April 6, 1990

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Work Performed Under Cooperative Agreement No. DE-FC2289PC88697

For
U.S. Department of Energy
Pittsburgh Energy Technology Center
Pittsburgh, Pennsylvania

By
The Combustion Laboratory
The Pennsylvania State University
University Park, Pennsylvania

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1.0 INTRODUCTION

The Pennsylvania State University is conducting a superclean coal-water slurry (SCCWS) program for the United States Department of Energy (DOE) and the Commonwealth of Pennsylvania with the objective of demonstrating the capability of effectively firing SCCWS in industrial boilers designed for oil. Penn State has entered into a cooperative agreement with DOE to show that SCCWS (a fuel containing coal with less than 3% ash and 0.9% sulfur) can effectively be burned in oil-designed industrial boilers without adverse impact on boiler rating, maintainability, reliability, and availability. The project will provide information on the design of new systems specifically configured to fire these clean coal-based fuels. The project consists of three phases: (1) design, permitting, and test planning, (2) construction and start up, and (3) operations and disposition. The boiler testing will determine if the SCCWS combustion characteristics, heat release rate, slagging and fouling factors, erosion and corrosion limits, and fuel transport, storage, and handling can be accommodated in an oil-designed boiler. In addition, the proof-of-concept demonstration will generate data to determine how the properties of SCCWS and its parent coal affect boiler performance. Economic factors associated with retrofitting and operating boilers will be identified to assess the viability of future oil-to-coal retrofits.

The project consists of three phases as previously mentioned. Following is an outline of the project tasks that comprise the three phases:

Phase I: Design, Permitting, and Test Planning

- Task 1. Design
- Task 2. Permitting
- Task 3. Test Planning

Phase II: Construction and Start Up

- Task 1. Host Site Readiness/Boiler Retrofit
- Task 2. SCCWS Preparation
- Task 3. Performance Prediction
- Task 4. Shakedown Testing

Phase III: Demonstration and Evaluation

- Task 1. Test Burn
 - Subtask 1.a. SCCWS combustion performance
 - Subtask 1.b. Slagging/fouling propensity
 - Subtask 1.c. Erosion/corrosion characteristics
 - Subtask 1.d. Fuel transport, storage, and handling characteristics
- Task 2. Evaluate Retrofit Economics

Task 3. Final Report

Penn State began a coal-water slurry fuel (CWSF) research and development program in 1984 when business and government leaders in the Commonwealth of Pennsylvania were concerned about the lack of ongoing programs aimed at developing alternate fuels following a decline in oil prices. The ultimate goal of the project is to facilitate the replacement of petroleum-based fuel with a coal-based fuel in oil-fired (designed) boilers. Coal is the most abundant fossil fuel in Pennsylvania and a legislative decision was made to provide support for efforts to develop new uses and markets for this resource. Accordingly, Act 62 of the 1984 legislative session appropriated funds for the construction of a demonstration CWSF boiler of approximately 15,000 lbs steam/h on the main campus of Penn State at University Park. The project goal was to conduct a demonstration of the use of CWSF derived from Pennsylvania coal in an environmentally acceptable manner, while evaluating the effects on boiler performance of long-term firing with CWSF. From a commercialization viewpoint, the motivation for the project was to demonstrate the technical feasibility of retrofitting existing oil-fired units to burn CWSF, particularly in the commercial and light-industrial sectors. The project has progressed from the engineering design phase to the bidding phase and boiler construction is scheduled to begin in the first quarter of 1990. The SCCWS demonstration will be conducted on this boiler. Funding each year since 1984 has allowed for fuel procurement and the evaluation and installation of a research boiler (2 million Btu/h) to test candidate CWSFs and provide the necessary research support prior to start up of the demonstration unit.

The commercialization of CWSF use in Pennsylvania could become a reality if the legislature mandates the use of coal or coal-based fuels in State heating systems such as hospitals, schools, prisons, and office buildings. A bill to this effect was introduced in the 1987 legislative session and was referred to the Committee on Mines and Energy Management. This bill is still in Committee but should it pass, several oil-designed boilers may be retrofitted to fire CWSF.

The status of Phases I, II, and III are presented in Sections 2.0, 3.0, and 4.0, respectively. Section 5.0 outlines the activities planned for the next quarter. References are contained in Section 6.0.

2.0 STATUS OF PHASE I: DESIGN, PERMITTING, AND TEST PLANNING

2.1 Task 1. Design

Task 1, which involved the design of the installation has been completed. Appropriate equipment and diagnostic instrumentation were identified during this task. The majority of the facility design was completed for the Penn State CWSF demonstration

project by CDA International, Inc. and, therefore, was not repeated for the SCCWS program. Designs for the boiler and ash handling modifications have been completed. Equipment and diagnostic instrumentation unique to the SCCWS program have been identified. Equipment that must be designed or purchased to accomplish specific goals has been identified. Equipment for fuel storage, transportation, transfer, and blending is necessary for the SCCWS program. The present fuel handling design is inadequate for the scale required in the SCCWS demonstration. Necessary diagnostic instrumentation and sampling and testing equipment includes: probes or coupons for ash deposition and erosion and corrosion evaluation; on-line sensors for monitoring corrosive gas species, gaseous and particulate emissions, and heat flux variations due to deposition; and a viscometer for monitoring fuel properties. Equipment and diagnostic instrumentation that has been identified includes:

- SCCWS storage tank - Viatic Process/Storage Systems
 - CVF-144-16277-S RESIN-FAB reinforced plastic tank, 16,000 gallon capacity
- Large tank slow-speed mixer - "Lightnin Mixers"
 - Model 17Q7.5
- Lift frame - The lift frame will be constructed by a local machine shop or a University shop. A preliminary sketch of the lift frame is contained in Appendix A.
- 3,000-3,500 gallon tanktruck - Petroleum Equipment Trade Corporation
 - The final decision to acquire a tanktruck will be made after a SCCWS supplier is selected. Depending on the fuel supplier, the tanktruck may not be required.
- Transfer pump - Weinman Pump and Supply Co.
 - Warren Rupp Model SA2-A Type DN-3-A air operated diaphragm pump
- Hoses and fittings - PETCO
- High shear viscometer and computer - A viscometer from Brookfield Engineering/Laboratories Inc. was initially identified. Despite assurances from Brookfield that coal-water slurries have been successfully tested in their cone and plate viscometer, a test sample produced erratic results. Consequently, viscometer vendors were contacted and a viscometer from Bohlin Rheologi, Inc. has been identified as the candidate.
 - Viscometer
 - Bohlin Visco 88 BV Portable Laboratory Viscometer
 - Bohlin Visco Soft Software
 - Model RTE-110 Temperature Bath
 - Computer (From Macintosh)
 - Macintosh IICX
 - AppleColor High-Resolution RGB Monitor
 - Heat flux meter - Land Combustion

- Land Fluxdome Heat Flux Sensor Fluxdome
- Transmitter
- Power Supply
- On-line *in-situ* particle counter-sizer-velocimeter - Insittec
PCSV-P
 - PCSV-P Optical System
 - PCSV-P Signal Processor
 - Water or air-cooled probe housing
 - Software
 - 3-day installationComputer (From IBM Corporation)
 - IMB PS/2 Model 30-286 85-30-E31
 - IBM Color Display
 - IBM 6157 Tape Drive
 - IBM 6157 Adapter
 - Proprinter IIIAuxiliaries
 - Oscilloscope
 - Reticle Standard
- Multicyclone - Sierra Cascade
 - SE285-K Six-Stage In-Stack Cascade Cyclone Sampler Kit
 - SE280C Carrying Case
- On-line flue gas analyzers - Beckman Industrial
 - Model 880 NDIR SO₂ analyzer
 - Model 880 NDIR CO analyzer
 - Model 870 NDIR CO₂ analyzer
 - Model 755 Oxygen analyzer
 - Model 951A NO/NO_x Chemiluminescence analyzer
- On-line spectroscopic analyzer
 - The milestone deadline for spectroscopic analyzer design and specification is 10/01/1990.

2.2 Task 2. Permitting

Permits for the project are required from the Commonwealth of Pennsylvania Department of Environmental Resources Bureau of Air Quality Control (DER). CDA International, Inc. was responsible for applying for the initial permit which requested approval for construction. Approval has been granted. This plan approval also serves as a temporary operating permit. When the baghouse installation is completed or near completion and start up is anticipated, DER must be notified. During the term of this temporary operating permit, DER personnel will inspect the operation of boiler. In addition, any testing required by DER will be conducted at that time.

A regular DER operating permit will then be issued if: (1) the special conditions incorporated within the plan approval have all been fulfilled (the special conditions are listed below); (2) it has been demonstrated to DER's satisfaction that the construction,

modification, reactivation, or installation was carried out as proposed in the application, and that the operation of the source and any air pollution control equipment conforms with the operational information stated on the application; and (3) it has been demonstrated to DER's satisfaction that the air contaminant emissions from the source are in compliance with the requirements specified in, or established pursuant to, all applicable Rules and Regulations of DER.

Special plan approval conditions as detailed by DER are:

- This plan approval is issued for the construction of a Keeler/Dorr-Oliver DS-15 (or equivalent) coal-water slurry-fired boiler, the air contaminant emissions from which shall be controlled by a CE Air Preheater Ray Jet model 12-9 size 61214-9 fabric collector.
- Pursuant to the best available technology provisions of Chapter 127 of the Rules and Regulations, a particulate matter emission limitation of 0.1 pound/million Btu of heat input is established for this boiler. The sulfur oxide emissions shall not exceed the 4.0 pounds/million Btu of heat input limitation specified in Section 123.22 of DER's Rules and Regulations and additionally shall not equal, or exceed, a total of 40 tons per year.
- The University shall maintain comprehensive accurate records of the number of hours the boiler is operated, the amount of slurry fired in the boiler, the amount of coal in the slurry, and the sulfur content of the coal and shall make these available to DER upon request.
- Issuance of an operating permit for the boiler is contingent upon the boiler and associated fabric collector being constructed, and subsequently maintained and operated, as specified in the application and supplemental materials submitted for plan approval as well as in conformance with all conditions contained herein and upon satisfactory demonstration that any air contaminants emitted from the boiler are in compliance with the requirements specified in all applicable rules and regulations in Article III of the Rules and Regulations of DER as well as all conditions contained herein.
- The University shall keep on hand a sufficient quantity of spare fabric collector bags for the fabric collector associated with the aforementioned source in order to be able to immediately replace any bags requiring replacement due to deterioration resulting from routine operation of the source and fabric collector.
- The University shall immediately notify DER of any malfunction of the source or associated air cleaning device which results in, or may possibly be resulting in, the emission of air contaminants in excess of the limitations specified in, or

established pursuant to, any applicable rule or regulation contained in Article III of the Rules and Regulations of DER.

- This plan approval shall also serve as a temporary operating permit in accordance with the provisions of Section 127.23 of Chapter 127 of the Rules and Regulations of DER. This temporary operating permit is valid for a period of 120 days from completion of construction to allow for startup and debugging, provided that notification of completion of construction is given to DER within five (5) working days of the completion date. Should a period longer than 120 days be needed, a temporary operating permit renewal shall be obtained.

2.3 Task 3. Test Planning

Task 3, Test Planning, consists of three efforts. This includes developing SCCWS specifications, identifying appropriate operating procedures, and preparing a detailed test plan. Task 3 was initiated and nearly completed.

2.3.1 Develop SCCWS Specifications

Specifications for SCCWSs capable of being fired in boilers designed for oil were developed and coal sources capable of being beneficiated and slurried to meet required specifications were identified.

Specifications for superclean coals and the coal-water slurries formulated from them depend on an in-depth knowledge of how each critical property affects boiler performance and lifetime. Since much of this information is presently unknown, especially with regard to operation with SCCWS, specifications can only be general, at best. The basic properties of interest can be defined and certain values associated with them projected. This was been done by DOE in the Program Opportunity Notice (1) and through discussions between DOE and Penn State. The resulting specifications are indicated below are for boilers designed for residual oil:

Coal Parameter

Ash Content	less than 3.0%
Slagging Index (B/A x %S)	less than 0.6
Fouling Index (B/A x Na ₂ O)	less than 0.2
Sulfur	less than 0.9%
Ash Softening Temperature (Reducing atm.)	greater than 2400°F
Chlorine	less than 0.25%
Na ₂ O in ash	less than 0.5%
Fe ₂ O ₃ in ash	less than 10.0%
Silica/alumina ratio in ash	less than 2.0
Coal grind size	less than 95% minus 45 µm
Particles larger than 200 µm	less than 0.5%
Volatile Matter	greater than 25 weight percent

Characteristics of superclean coal-water slurry (SCCWS)

Solids Loading	greater than 50%
Heating Value, Btu/lb	greater than 6,500
Viscosity:	
100°F & 50/sec	less than 1,000 cp
100°F & 5,000/sec	less than 200 cp
Stability	greater than six month storage without significant impact on slurry properties

Atomization Requirements

Although separate from the coal and slurry specifications, atomization criteria are important to ensure adequate combustion and system reliability. The atomizer should have a tip life greater than 4,000 hours and the droplet mass median diameter (MMD) should be less than 80 μm .

The aforementioned parameters are discussed in the paragraphs below. An explanation of the limiting factors is presented and uncertainties noted.

Cleaned Coal

Ash Content

The mutual effects of ash content, ash chemistry, coal particle size, and slurry droplet size distribution on allowable convective pass velocity is not well defined. Experiments by Combustion Engineering indicate that tube erosion can be reduced by more than a factor of four with effective atomization of a micronized coal-water mixture (CWM) with 64% solids, as compared to tube erosion from the combustion products of a standard 75% minus 200 mesh CWM. However, ineffective atomization and/or high solids loading indicate similar or increased erosion with the micronized CWM. Estimates made by Burns & Roe indicate that minimum derating can be achieved by limiting the ash content in SCCWS to less than 3% for boilers designed for residual fuels. Other analyses indicate that these limits should be tightened to 1.5% to keep derating to less than 10%.

Because of the uncertainties existing due to insufficient data, a limit of 3% is being recommended for slurry firing in a residual boiler. This value is likely to vary for specific coals, ash chemistry, grind sizes, and atomization techniques.

Slagging/Fouling Indices

These indices are set to ensure a low potential for slagging and fouling based on the Halfinger method and work by Winegartner. The combination of ash content and the

slagging factors indicated in the specifications should result in very low steam and auxiliary requirements for soot blowing.

Sulfur

The sulfur limits have been set to meet existing emission limits consistent with gas/oil firing.

Chlorine

When chlorine content exceeds 0.25%, tightly bonded fouling deposits can be expected even when other fouling indices are low.

Ash Composition

Sodium oxide, iron oxide, and the silica/alumina ratio of the ash influence the erosiveness and bonding potential of the ash. The values listed indicate a balance between conventional practice and measured values in successful experiments.

Coal Grind Size

Coal grind size requirements are a consequence of the processing necessary to remove sulfur and ash to reach acceptable levels and to obtain particle sizes consistent with high combustion intensity and the formation of small ash particles. In addition, a particle size distribution must be achieved which facilitates atomization of the slurry and minimizes pulverization energy costs. Experiments have shown that a grind size between 70 and 95% minus 325 mesh is adequate for good combustion and atomization. The requirements for coal cleaning will depend on the parent coal chosen and the process utilized. The coal grind size requirements will be relaxed (smaller grind size accepted) if required to meet ash and sulfur specifications.

Volatile Matter

In order to facilitate ignition and achieve rapid combustion of the coal-water slurry droplets, the supercleaned coal should have a volatile matter content of at least 25%; however, 30% volatile matter content would be desirable.

Coal-Water Slurry

Solids Loading

Solids loading in the slurry should be as high as practical in order to minimize water injection which results in a loss of boiler efficiency and increased mass flow and velocity in the gas passages. Unfortunately, increasing solids loading often results in increased slurry viscosity. Results from experiments performed by Combustion Engineering indicate that a solids loadings of approximately 67% or less, for the coal tested, was required to keep the viscosity below 1,000 cp. The 1,000 cp value is that viscosity normally set to keep pump power requirements at a reasonable value.

Based on this and similar data from other slurry rheology tests, a goal of 50% or higher solids loading has been set.

Heating Value

Based on the 50% solids loading indicated above and with an essentially ash, sulfur, and moisture free coal heating value of 13,500 Btu/lb, the slurry heating value should be in excess of 6,500 Btu/lb. It would be desirable, however, for the heating value to be greater than 6,500 Btu/lb.

Viscosity

The viscosity of coal-water slurries is normally specified at 1,000 cp at low shear rates. This limits pumping power to reasonable levels. At high shear rates, typically incurred during atomization, the viscosity should be no more than 250 cp, to ensure that the droplet size specified below can be obtained.

Stability

Storage requirements will depend on site specific factors such as duty cycle and storage capacity. In commercial practice, the slurry may need to be stable for at least a six month period and any settled material should be easily resuspended by either recycling or mixing.

Atomization

Atomizer Tip Life

Ultrafine particle sizes and the relatively heavy solids content of the slurry will result in significant erosion of the atomizer unless adequate design and materials are utilized.

Droplet MMD

Experiments have shown that agglomeration of the coal particles can negate the potential benefits of fine pulverization and increase the time required for combustion. Results from Combustion Engineering indicate that combustion intensity is acceptable with droplet MMD of 80 μm or less.

2.3.2 Identify Operating Procedures

Operating procedures were to be identified this quarter. Procedures for fuel storage and handling, boiler operation including boiler startup, steady-state SCCWS firing, and shutdown, and sample collection and analyses (fuel, flyash, gaseous and particulate emissions, and deposits) were to be detailed. The operating procedures were not identified this quarter, they will be detailed once the construction project is closer to completion and more detailed information on the actual equipment (boiler and auxiliaries) in the facility is available.

Procedures for collecting and analyzing samples during the demonstration have been established. The techniques and sampling frequency are contained in the detailed test

plan (see Section 2.3.3) and include such samples as bottom ash, flyash, deposits from the deposition probe, deposits/scale and metal interface from the full-scale erosion testing probe, and gaseous emissions.

2.3.3 Prepare Detailed Plan

A detailed test plan was prepared and submitted October 12, 1989. A schedule for the demonstration test was constructed. The test plan identified the timing of the deposition testing, corrosion/erosion testing, and the samples to be collected and analyzed.

3.0 STATUS OF PHASE II: CONSTRUCTION AND STARTUP

3.1 Task 1. Host Site Readiness/Boiler Retrofit

The boiler was let for bids on October 18, 1989. The closing date for receipt of bid was initially set as November 14, 1989, but the deadline was extended one week to November 27, 1989. The date for the opening of the bids was extended because several (fifteen) specification changes were added to the original package. A copy of the bid package is not included in the quarterly report. A complete bid package was previously sent to DOE (John Winslow) by CDA International, Inc.

3.2 Task 2. SCCWS Preparation

3.2.1 Identify Coal Sources

The coal to be used for the production of the SCCWS will be from a Pennsylvanian mine. Three potential SCCWS suppliers were asked to identify the coal source(s) they would use to produce a fuel meeting the specifications discussed in Section 2.3.1. The suppliers will not be identified by name, but will be referred to as Vendors A, B, and C. Vendors A and C identified coal seams and mines while Vendor B identified only the coal seam. A summary of the coal seam(s) and/or mines identified by the fuel producers follows:

SCCWS Vendor A

Vendor A identified five mines extracting coal from the Brookville and Lower Kittanning seams. Vendor A believes that Upper Freeport coal would be a marginal candidate for fuel selection. Previous washability data for several different samples indicated that although the sulfur was generally reduced to between 0.6 and 0.8%, ash reduction to 3.0% was somewhat more difficult. Vendor A would feel more confident in using Upper Freeport coal if the coal ash specification was relaxed to 3.5-4.0%. The coal sources identified by Vendor A are:

Brookville Seam

- James Scott Coal Co.
Philipsburg, PA
Centre County

- Ambrosia Coal & Construction Co.
Edinberg, PA
Lawrence County
- Sunbeam Coal Corp.
Boyers, PA
Butler County

Lower Kittanning Seam

- C&K Coal Co.
Clarion, PA
Clarion County
- Barnes & Tucker Co.
Barnesboro, PA
Cambria County

SCCWS Vendor B

Vendor B identified eight coal seams from Pennsylvania from which they stated they can make a SCCWS meeting the required specifications. The seams that were identified are Pittsburgh, Upper and Lower Freeport, Upper, Middle, and Lower Kittanning, Clarion, and Brookville. In discussions with DOE, Vendor B learned that the Upper Freeport coal has been used successfully by DOE in coal-water slurry projects; therefore, Vendor B proposes to use Upper Freeport coal for SCCWS production.

SCCWS Vendor C

Vendor C has identified two coals from the Pittsburgh seam. They are:

- U.S. Steel Company; Maple Creek Mine
New Eagle, PA
Washington County
- Bethenergy Mines; Marianna 58 Mine
Eighty Four, PA
Washington County

After the coal sources were identified, two of the potential SCCWS producers informed Penn State that they will not be supplying the fuel for the demonstration. Vendor B has decided not to get involved with the project as a direct result of the recent Pittston coal strike. In addition, Vendor A informed Penn State in November, 1989, that they will not supply SCCWS. There are an additional two or three options for procuring the SCCWS. Two (and possibly three) consultants have contacted Penn State and will be

submitting proposals to Penn State in the next two months for producing the SCCWS for the demonstration.

3.2.2 Produce SCCWS for the Demonstration

SCCWS Vendors A and C have shipped SCCWS for combustion, atomization, and rheological testing. Vendor A shipped three barrels of fuel; however, this fuel will not be considered for final fuel selection due to Vendor A's decision not to supply fuel for the demonstration.

Vendor C shipped one barrel of SCCWS. The analysis of the fuel, as supplied by Vendor C, is contained in Appendix C.

The atomizer that the Combustion Laboratory currently uses when testing CWSFs in the two million Btu/h water-tube research boiler is an internal mix twin-fluid atomizer. Standard grind coal-water slurries can be successfully atomized and burned; however, micronized CWSFs do not satisfactorily atomize due to their dilatant nature. Previous tests conducted with a micronized fuel resulted in poor combustion efficiency (2). A viscosity insensitive prefilming atomizer was ordered from Parker Hannifin Corporation to test dilatant fuels. The new atomizer will be used in the fuel selection process to properly compare different fuels during the atomization and combustion testing.

4.0 STATUS OF PHASE III: OPERATIONS AND DISPOSITION

4.1 Task 1. Test Burn

Task 1, Test Burn, was initiated this quarter. Activities involving slagging/fouling propensity, erosion/corrosion characteristics, and fuel transport, storage, and handling characteristics are summarized in the following sections.

4.1.1 Subtask 1b. Slagging/Fouling Propensity

Subtask 1b., Slagging/Fouling Propensity, was initiated. The deposition test plan was completed and is contained in Appendix B.

4.1.2 Subtask 1c. Erosion/Corrosion Characteristics

Subtask 1c., Erosion/Corrosion Characteristics, was initiated. The erosion and corrosion test plan was completed and is contained in Appendix B. The on-line *in situ* particle counter-sizer-velocimeter (PCSV) which will be used for real time, nonintrusive particle concentration and size distribution measurement was ordered.

4.1.3 Subtask 1d. Fuel Transport, Storage, and Handling Characteristics

Subtask 1d., Fuel Transport, Storage, and Handling Characteristics, was initiated. A viscometer was identified, details of which are given in Section 2.1. Purchase of the viscometer is being performed by The Pennsylvania State University Purchasing

Department , which is currently conducting the mandatory bidding process. It is anticipated that this will be completed the second week in December.

5.0 NEXT QUARTER ACTIVITIES

The building and boiler construction and installation contracts will be awarded during the next quarter.

The viscometer will be purchased, Parker Hannifin Corporation's atomizer will be received, and the fuel evaluation process will begin. The atomization, combustion, and rheological characteristics of the SCCWS from Vendor C will be determined. In addition, should any other fuels be received, they will be tested as well.

It is anticipated that two and maybe three proposals will be received for SCCWS production.

Tests evaluating the application of the surface layer activation technique for erosion measurements will begin next quarter. This method will be evaluated through preliminary measurements during small-scale trials in the research boiler to determine if it is suitable for measurement of erosion rates during the 1,000 hour test on the demonstration boiler.

Design of a boiler deposition probe and a suction pyrometer will begin next quarter. They will be designed after the boiler manufacturer and boiler specifications are known.

The PCSV will arrive next quarter and preliminary tests will be conducted.

6.0 REFERENCES

- 1) Program Opportunity Notice for Superclean Coal Water Slurry (SCCWS) Combustion Testing in Oil-Designed Industrial Boilers, PON No. DE-PS22-88PC88697, U.S. Department of Energy, Pittsburgh Energy Technology Center, 1989.
- 2) Miller, B.G., R.T. Wincek, A.W. Scaroni, W.P. Kinneman, and R.G. Jenkins, "Combustion of CWSF in a 1000 lb/h Steam Water-Tube Boiler," 13th International Conference on Coal & Slurry Technology, Denver, Colorado, April 12-15, 1988.

APPENDIX A. SKETCH OF LIFT FRAME

SKETCH OF LIFT FRAME

APPENDIX B. VENDOR C FUEL ANALYSIS

VENDOR C FUEL ANALYSIS

Summary:

Number of Drums 1 (#1171)
Pounds of Slurry 476
Pounds of Coal 236 (at 49.61% solids)
Gallons of Slurry 50

Proximate Analysis:

<u>Drum #</u>	<u>% Solids</u>	<u>% Ash</u>	<u>% V.M.</u>	<u>% F.C.</u>	<u>% Sulfur</u>
1171	49.61	1.09	35.29	63.63	0.69

Viscosity (cp) at Shear Rate (Sec⁻¹):

<u>Drum #</u>	<u>346</u>	<u>490</u>	<u>692</u>	<u>979</u>	<u>(Sec⁻¹)</u>
1171	48	52	67	92	

Particle Size Distribution:

<u>Diameter (μm)</u>	<u>Mass Percent</u>	
>11.5	4.6	
11.5	1.7	
10.5	2.8	
9.5	3.2	
8.5	4.6	
7.5	5.0	D ₅₀ = 3.8 μm
6.5	7.0	
5.5	7.5	
4.5	10.4	
3.5	13.6	
2.5	15.2	
1.5	18.3	
0.5	6.2	

<u>Analysis Type</u>	<u>Mean</u>	<u>SD</u>
Coal Heating Value	15,028	395
Ash Content	0.83	0.11
Sulfur Content	0.73	0.10
Volatile Content	36.52	1.19
Carbon Content	84.76	1.65
Nitrogen Content	1.69	0.14
Hydrogen Content	5.37	0.36
Oxygen Content	6.64	1.49
Chlorine Content	0.07	0.07
Ash Fusion Temp. (it red.)	2103	61
Ash Fusion Temp. (it ox.)	2335	46
Silica	32.59	2.54
Alumina	27.41	1.63
Ferric Oxide	20.51	2.42
Calcium Oxide	5.12	0.80
Potassium Oxide	1.47	0.11
Sodium Oxide	1.16	0.06
Particle Size (top)	17	4
Particle Size (D ₅₀)	2.91	0.44
Solids Content	50.41	0.53
Viscosity (100/sec)	34	10
Viscosity (1,000/sec)	83	20

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