PENNSSTATE

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

Semiannual Technical Progress Report
for the Period 08/15/1995 to 02/15/1996

By

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June 3, 1997

Work Performed Under Cooperative Agreement No. DE-FC22-89PC88697

For
U.S. Department of Energy
Federal Energy Technology Center
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EXECUTIVE SUMMARY

The Pennsylvania State University is conducting a coal-water slurry fuel (CWSF) program with the United States Department of Energy (DOE) and the Commonwealth of Pennsylvania to determine the viability of firing CWSF in an industrial boiler designed for heavy fuel oil. Penn State and DOE have entered into a cooperative agreement to determine if CWSFs prepared from cleaned coal (containing approximately 3.5 wt.% ash and 0.9 wt.% sulfur) can be burned effectively in a heavy fuel oil-designed industrial boiler without adverse impact on boiler rating, maintainability, reliability, and availability. Information will also be generated to help in the design of new systems specifically configured to fire these clean coal-based fuels.

The project consists of four phases: (1) design, permitting, and test planning, (2) construction and start up, (3) demonstration and evaluation (1,000-hour demonstration), and (4) expanded demonstration and evaluation (installing a CWSF preparation circuit, performing baseline tests firing No. 6 fuel oil, and conducting additional CWSF testing). The boiler testing and evaluation will determine if the CWSF combustion characteristics, heat release rate, fouling and slagging behavior, corrosion and erosion tendencies, and fuel transport, storage, and handling characteristics can be accommodated in a boiler system designed to fire heavy fuel oil. In addition, the proof-of-concept demonstration will generate data to determine how the properties of a CWSF and its parent coal affect boiler performance. The economic factors associated with retrofitting boilers will also be evaluated.

The first three phases (i.e., the first 1,000-hour demonstration) have been completed and the combustion performance of the burner that was provided with the boiler did not meet performance goals. A maximum coal combustion efficiency of 95% (compared to a target of 98%) was achieved and natural gas cofiring (15% of the total thermal input) was necessary to maintain a stable flame. Consequently, the first demonstration was terminated after 500 hours. The second CWSF demonstration (Phase IV) will be conducted with a proven CWSF-designed burner.

Prior to starting the second demonstration, a CWSF preparation circuit was constructed to provide flexibility in CWSF production. The circuit initially installed involved single-stage grinding. A regrind circuit was recently installed and will be evaluated.

A burner was installed from ABB Combustion Engineering (ABB/CE) and will be used to generate baseline data firing No. 6 fuel oil and CWSF. A temporary storage system for No. 6 fuel oil was installed and modifications to the existing CWSF handling and preheating system were made to accommodate No. 6 oil.

1.0 INTRODUCTION

The Pennsylvania State University is conducting a coal-water slurry fuel (CWSF) program with the United States Department of Energy (DOE) and the Commonwealth of Pennsylvania with the objective of determining the viability of firing CWSF in an industrial boiler designed for heavy fuel oil. Penn State and DOE have entered into a cooperative agreement to determine if CWSFs prepared from cleaned coal (containing approximately 3.5 wt.% ash and 0.9 wt.% sulfur) can be burned effectively in a heavy fuel oil-designed industrial boiler without adverse impact on boiler rating, maintainability, reliability, and availability. The project will also provide information to help in the design of new systems specifically configured to fire these clean coal-based fuels.

The project consists of four phases: (1) design, permitting, and test planning, (2) construction and start up, (3) demonstration and evaluation (1,000-hour demonstration), and (4) expanded demonstration and evaluation. The boiler testing and evaluation will determine if the CWSF combustion characteristics, heat release rate, fouling and slagging behavior, corrosion and erosion tendencies, and fuel transport, storage, and handling characteristics can be accommodated in a boiler system designed to fire heavy fuel oil. In addition, the proof-of-concept demonstration will generate data to determine how the properties of a CWSF and its parent coal affect boiler performance. The economic factors associated with retrofitting boilers will also be evaluated.

The project consists of four phases as previously mentioned. Following is an outline of the project tasks that comprise the four 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. CWSF Preparation

Task 3. Boiler Performance Prediction

Task 4. Shakedown Testing

Phase III: Demonstration and Evaluation

Task 1. Test Burn

Subtask 1.a. CWSF combustion performance

Subtask 1.b. Slagging/fouling propensity; corrosion characteristics

Subtask 1.c. Erosion characteristics

Subtask 1.d. Fuel transport, storage, and handling characteristics

Task 2. Evaluation of Retrofit Economics

Task 3. Project Report

Phase IV: Advanced System Tests

- Task 1. Install Burner
- Task 2. Construct CWSF Preparation Facility
- Task 3. Generate Baseline Data Firing No. 6 Fuel Oil
- Task 4. CWSF Testing
- Task 5. Final Report

Penn State began a coal-water slurry fuel (CWSF) research and development program in 1984 with the ultimate goal of facilitating the replacement of petroleum-based fuels with coal-based fuels in fuel oil-fired (designed) boilers. The Pennsylvania legislature appropriated funds in 1984 for the construction of a demonstration CWSF boiler with a capacity of approximately 15,000 lb steam/h at 300 psig on the University Park campus of Penn State. The project goal was to conduct a demonstration of the use of CWSF derived from Pennsylvania coal. The boiler performance was required to be environmentally acceptable and the testing was to evaluate the effect on boiler performance of long-term firing with CWSF. From a commercialization viewpoint, it was considered necessary to demonstrate at the industrial scale the technical feasibility of retrofitting existing fuel oil-fired units to burn CWSF, particularly in the commercial and light-industrial sectors. State funding was also provided for the installation of a 1,000 lb steam/h (nominally rated) Cleaver-Brooks A-frame watertube research boiler (Kinneman et al., 1988) to investigate: the effect of boiler operating parameters on combustion performance (Miller et al., 1988); automation of the firing of CWSF, particularly with respect to start up and shutdown procedures but also for optimizing boiler performance (Wincek et al., 1989); testing candidate CWSFs (Miller et al., 1991); and providing the necessary research support and operator training prior to start up of the demonstration unit. The CWSF demonstration program is being conducted on the 15,000 lb steam/h demonstration boiler.

The approach used in the program was as follows:

1. Install a natural gas/fuel oil-designed package boiler and generate baseline data firing natural gas.
2. Shake down the system with CWSF and begin the first 1,000 hours of testing using the burner/atomizer system provided with the boiler. The first 1,000-hour demonstration was to consist of boiler optimization testing and combustion performance evaluation using CWSF preheat, a range of atomizing air pressures (up to 200 psig as compared to the 100 psig boiler manufacturer design pressure), and using steam as the atomizing medium.
3. If the combustion performance was not acceptable based on the combustion efficiency obtained and the level of gas cofire necessary to obtain flame stabilization, then low-

cost modifications were to be implemented, such as installing a quarl and testing alternative atomizers.

4. If acceptable combustion performance was not obtained with the low-cost modifications, then the first demonstration was to be terminated and the burner system replaced with one designed specifically for CWSF.
5. Perform 750 hours of testing firing CWSF and 250 hours with No. 6 fuel oil with the newly installed, multifuel burner.

The first three steps (i.e., the first demonstration) have been completed and the combustion performance of the burner that was provided with the boiler did not meet the targeted performance goals. Consequently, the first demonstration (Phases I-III) was terminated at 500 hours and the results have been presented elsewhere (Miller et al., 1994). Phase IV work is underway with modifications to the CWSF Preparation Facility and baseline testing firing No. 6 oil.

The status of Phases I through III and a summary of Phase IV are presented in Sections 2.0 through 5.0, respectively. Miscellaneous activities and activities planned for the next semiannual period are given in Sections 6.0 and 7.0, respectively. References are contained in Section 8.0 and acknowledgments are given in Section 9.0.

2.0 PHASE I: DESIGN, PERMITTING, AND TEST PLANNING

Phase I was completed on February 15, 1993 and the results have been presented previously (Miller et al., 1994).

3.0 PHASE II: CONSTRUCTION AND START UP

Phase II was completed on October 10, 1992 and the results have been presented previously (Miller et al., 1994).

4.0 PHASE III: DEMONSTRATION AND EVALUATION

Phase III work was completed on June 21, 1993 and the results have been presented previously (Miller et al., 1994). Drafts of a project report covering the first three phases were submitted to DOE on June 21, 1993 and August 15, 1994.

5.0 PHASE IV: ADVANCED SYSTEM TESTS

During this reporting period, the statement of work for Phase IV was modified to reflect current issues regarding CWSF combustion in oil-designed boilers. The original statement of work included procuring and installing a burner designed for CWSF, installing a superheater tube and advanced flue gas emissions component (in conjunction with another program (Cooperative Agreement No. DE-FC22-92PC92162), and conducting a second demonstration of 1,000 hours in length. The modified statement of work includes: (1) preparing CWSF in quantities sufficient for approximately 750 hours of testing, with at least one non-Pennsylvania coal tested; (2) installing and testing a burner that has been designed or modified to fire CWSF; and (3) firing No. 6 fuel oil for ~250 hours to provide baseline performance data.

A superheater with ancillary components was designed for the boiler convective pass, and the convective pass was modified when manufacturing the boiler to accommodate a superheater tube. However, as a result of ash deposition during testing over the last two years, the steam sootblower located in the convective pass was modified to control ash deposition. Consequently, a superheater can not be installed in the boiler.

An advanced flue gas treatment system, initially to be identified and provided by DOE, was to be tested on a slipstream. Flue gas treatment systems for SO₂, NO_x and particulates are currently being designed as part of another program (DOD/DOE; Cooperative Agreement No. DE-FC22-92PC92162) and will be in place for testing as part of that program.

The milestone schedule for Phase IV is shown in Figure 1, and Table 1 contains the milestone description for the entire project.

5.1 Task 1. Installation of a Burner

Penn State recently completed a program in which it was the host site for testing a dry, micronized coal (DMC) burner for ABB Combustion Engineering (ABB/CE; DOE Contract No. DE-AC22-91PC91660). The results were encouraging and so the burner platform was selected for use in the CWSF testing. ABB/CE will provide the burner, atomizers, and engineering support for the CWSF testing.

5.2 Task 2. Construction of CWSF Preparation Facility

The installation of single-stage grinding circuit for CWSF preparation was completed during the previous reporting period. This circuit was used to produce CWSF for another program (DOD/DOE; Cooperative Agreement No. DE-FC22-92PC92162). Activities this reporting period included installing a regrind circuit using a stirred ball mill (Morehouse Mill). The regrind circuit will be used to manipulate the coal particle size by regrinding a portion (up to ~30%) of the ground coal from the 4 x 8 ft ball mill. A schematic diagram of the CWSF preparation circuit is shown in Figure 2. Activities conducted during this reporting period include:

- Installed piping from the pump located under the product tank to the stirred ball mill;
- Installed piping from the stirred ball mill to the surge tank;
- Installed conduit and electrical wires for the pumps located under the product tank and surge tank;
- Installed inverters to operate pumps;
- Charged stirred ball mill with grinding medium;
- Installed flowmeters with bypass capabilities;
- Installed auxiliary piping for the flush tank;
- Fabricated a transition piece for the coal feed screw;
- Removed the spool piece between the weight-belt feeder and the TCS mill and installed the screw feeder to the 4 x 8 ft ball mill inlet;
- Installed conduit and electrical wires to the screw feeder; and
- Installed a drainage line for the rotary drum vacuum filter.

5.3 Task 3. Generate Baseline Data Firing No. 6 Fuel Oil

The boiler being used in this program is an oil-designed boiler which is capable of firing natural gas and has been retrofitted to fire coal-based fuels. Baseline data firing natural gas were obtained during Phase II of the program. However, baseline data firing heavy fuel oil were not obtained. Since CWSF is a more likely a replacement for heavy fuel oil, rather than natural gas, the boiler system was modified to accommodate heavy fuel oil and baseline data firing No. 6 fuel oil will be generated. This involves installing fuel oil storage, handling, and atomizing equipment. Approximately 250 hours of fuel oil testing will be conducted in March and April 1996.

The fuel oil will be stored in an asphalt tanker that has steam heat capabilities. The tanker, with a capacity of 6,500 gallons, was delivered and integrated into the CWSF piping system. Steam (maximum of 75 psig) was piped to the tanker in order to preheat the oil. The oil passes from the tanker to the burner pump through a 15' long, 3" diameter hose by gravity flow. From the burner pump, the oil is pumped through the existing CWSF piping through the CWSF (oil) preheater to the burner. The CWSF piping was modified at the burner front to circulate the oil back to the tanker through a 3/4" hose when it is not being introduced into the burner. Additional modifications include installing steam and compressed air purging capabilities for the 3 and 3/4" hoses, oil gun, burner pump, and piping from the pump to the burner.

5.4 Task 4. CWSF Testing

Two coals, one from Pennsylvania (Middle Kittanning seam) and one from Virginia, or ones with similar properties, will be tested. The CWSF produced from the Pennsylvania coal will be used for initial testing and optimization after the burner is installed, and will be used to investigate the effect of coal particle size, atomizer type, and operating conditions on combustion and boiler performance, deposition, and emissions. A total of ~500 hours of testing will be conducted with this CWSF.

The non-Pennsylvania coal (Taggart seam) will be obtained as a filter cake from AMAX Research and Development Center's advanced coal cleaning program and will be prepared into a CWSF using a paddle mixer system which is currently being designed. This CWSF will tested for approximately 250 hours to investigate the effect of coal particle size and ash content on combustion and boiler performance, deposition, and emissions.

5.5 Task 5. Final Report

No work was scheduled or conducted in Task 5.

6.0 MISCELLANEOUS ACTIVITIES

The statement of work was modified during this reporting period.

7.0 NEXT SEMIANNUAL PERIOD ACTIVITIES

During the next reporting period, Phase IV will be completed and will include:

- Generating baseline data firing No. 6 fuel oil;

- producing CWSF from the Pennsylvania coal for regrind testing;
- installing the paddle mixer system and producing CWSF with it; and
- preparing the final report.

8.0 REFERENCES

Kinneman, W.P., R.T. Wincek, B.G. Miller, A.W. Scaroni, and R.G. Jenkins, "Conversion of a 1000 lb/h Steam Boiler to Fire Coal Water Slurry Fuel," *Thirteenth Int. Conf. on Coal and Slurry Tech.*, Denver, Colorado, p.725 (April 12-15, 1988).

Miller, B.G., R.T. Wincek, A.W. Scaroni, W.P. Kinneman, and R.G. Jenkins, "Combustion of CWSF in a 1000 lb Steam/h Watertube Boiler," *Thirteenth Int. Conf. on Coal and Slurry Tech.*, Denver, Colorado, p. 119 (April 12-15, 1988).

Miller, B.G., J.L. Morrison, J.T. Elston, P.M. Walsh, H.H. Schobert, and A.W. Scaroni, "Superclean Coal-Water Slurry Combustion Testing in an Oil-Fired Boiler," Semiannual Technical Progress Report for the Period 08/15/1990 to 02/15/1991, Pittsburgh Energy Technology Center, Pittsburgh, Pennsylvania, May 15, 1991, DE-FC22-89PC88697.

Miller, B.G., A.W. Scaroni, S.A. Britton, D.A. Clark, J.L. Morrison, S.V. Pisupati, R.L. Poe, P.M. Walsh, R.T. Wincek, and J. Xie, "Coal-Water Slurry Fuel Combustion Testing in an Oil-Fired Industrial Boiler, Technical Report for Phases I-III", Pittsburgh Energy Technology Center, Pittsburgh, Pennsylvania, August 15, 1994, DE-FC22-89PC88697.

Wincek, R.T., W.P. Kinneman, B.G. Miller, A.W. Scaroni, D. Shefet, and F. Kal, "Combustion Control System for a Coal-Water Slurry Fuel-Fired Boiler," *AIChE Spring National Meeting*, Houston, Texas (April 2-6, 1989).

9.0 ACKNOWLEDGMENTS

The authors acknowledge the following personnel for their contributions to the project during this reporting period:

- Michael Anna - Research Technologist
- David Bartley - Research Technologist
- Glenn Decker - Research Technician
- Howard Glunt - Research Technician
- Robert Klemz - Research Technologist
- Ruth Krebs - Research Assistant
- Bradley Maben - Research Technician
- Joel L. Morrison - Senior Research Assistant
- Ronald Wincek - Research Assistant

Table 1. Milestone Description

<u>Milestone</u>	<u>Description</u>	<u>Planned Completion Date</u>	<u>Actual Completion Date</u>
Phase I			
Task 1, No. 1	Identify equipment and diagnostic instrumentation	09/15/89	09/15/89
Task 2, No. 1	Review present permit	09/15/89	09/15/89
Task 3, No. 1	Develop CWSF specifications, identify operating procedures, prepare detailed test plan	10/15/89	02/15/93
Phase II			
Task 1, No. 1	Building/boiler construction and installation let for bids	10/18/89	10/18/89
Task 1, No. 2	Building/boiler construction and installation awarded	12/31/89	03/23/90
Task 1, No. 3	Prepare site, install boiler and auxiliary equipment	04/01/91	01/31/92
Task 2, No. 1	Identify coal for CWSF preparation	09/30/90	09/30/90
Task 2, No. 2	Prepare CWSF for demonstration	04/01/91	10/13/92
Task 3, No. 1	Predict boiler performance	06/15/91	02/01/92
Task 4, No. 1	Shakedown boiler and auxiliary equipment	04/31/91	06/30/92
Task 4, No. 2	Generate baseline data on gas	05/31/91	09/30/91
Phase III			
Task 1, No. 1	Perform demonstration		
Subtask 1a, No. 1	300-hour demonstration milestone	07/31/92	07/31/92
Subtask 1a, No. 2	500-hour demonstration milestone	10/31/92	11/13/92
Subtask 1a, No. 3	Redefine CWSF specifications	01/15/93	01/15/93
Subtask 1b, No. 1	Develop deposition and corrosion test plan	10/15/89	10/15/89
Subtask 1b, No. 2	Design suction pyrometer	06/01/90	08/01/90
Subtask 1b, No. 3	Construct suction pyrometer	10/01/90	10/01/90
Subtask 1b, No. 4	Deposition characterization equipment design and specification	01/01/91	02/15/91
Subtask 1b, No. 5	Acquisition of baseline data for spectroscopic analysis of deposits; acquisition of baseline data for corrosion of tubes by ash components	08/31/91	08/15/92
Subtask 1b, No. 6	Coupon testing in boiler	10/31/92	11/13/92
Subtask 1b, No. 7	Complete deposition and corrosion testing	01/15/93	01/15/93
Subtask 1c, No. 1	Develop erosion test plan	10/15/89	10/15/89
Subtask 1c, No. 2	Complete research boiler erosion evaluation	08/01/90	08/01/90
Subtask 1c, No. 3	Full-scale erosion technique decision	10/01/90	10/01/90
Subtask 1c, No. 4	Design probe for full-scale erosion study	01/01/91	02/15/91
Subtask 1c, No. 5	Construct erosion probe	05/01/91	10/15/91
Subtask 1c, No. 6	Complete erosion modeling	01/15/93	06/15/93
Subtask 1d, No. 1	Identify viscometer	10/15/89	10/15/89
Subtask 1d, No. 2	Complete preliminary viscosity and stability tests	08/15/90	09/15/90
Subtask 1d, No. 3	Complete viscosity and stability tests	11/30/92	11/30/92
Task 2, No. 1	Complete economic evaluation	01/15/93	01/15/93
Task 3, No. 1	Complete project report	03/01/93	06/21/93
Phase IV			
Task 1, No. 1	Install Burner	02/21/96	02/21/96
Task 2, No. 1	Complete construction of Fuel Preparation Facility	08/31/93	08/31/93
Task 2, No. 2	Install and shake down CWSF preparation circuit with single-stage grinding circuit	01/31/95	01/31/95
Task 2, No. 3	Install regrind circuit	03/08/96	03/08/96
Task 2, No. 4	Install paddle mixer system	06/15/96	
Task 3, No. 1	Obtain baseline data firing No. 6 fuel oil	04/05/96	
Task 4, No. 1	Complete testing of CWSF produced using regrind circuit	06/15/96	
Task 4, No. 2	Complete testing of CWSF produced from filter cake	07/15/96	
Task 5, No. 1	Complete final report	08/01/96

Figure 1. PHASE IV MILESTONE SCHEDULE (Second Demonstration)

Figure 2. SCHEMATIC DIAGRAM OF THE CWSF PREPARATION CIRCUIT

M98051254

Report Number (14) DOE/PC/88697--T14

Publ. Date (11) 19970603

Sponsor Code (18) DOE/FE, XF

JC Category (19) UC-101, DOE/ER

DOE