PENNS STATE

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

Quarterly Technical Progress Report
for the Period 11/15/1989 to 02/15/1990

By

**Bruce G. Miller, Co-Principal Investigator
Peter M. Walsh, Faculty Associate
John T. Elston, Research Technician
Alan W. Scaroni, Project Manager**

**RECEIVED
DEC 08 1997
OSTI**

April 6, 1990

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

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

MASTER

[DTIC QUALITY INSPECTED 3]

19980401 098

"U.S. DOE Patent Clearance is NOT required for the publication of this document".

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.

PENNSTATE

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

Quarterly Technical Progress Report
for the Period 11/15/1989 to 02/15/1990

By

**Bruce G. Miller, Co-Principal Investigator
Peter M. Walsh, Faculty Associate
John T. Elston, Research Technician
Alan W. Scaroni, Project Manager**

April 6, 1990

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

DISCLAIMER

This report was prepared as an account of work sponsored by the United States Government. Neither the United States Government nor the United States Department of Energy, nor any of their employees, nor any of their contractors, subcontractors, or 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.

TABLE OF CONTENTS

	<u>Page</u>
1.0 INTRODUCTION	1
2.0 PHASE I: DESIGN, PERMITTING, AND TEST PLANNING.....	2
3.0 PHASE II: CONSTRUCTION AND START UP	3
3.1 Task 1. Host Site Readiness/Boiler Retrofit	2
3.2 Task 2. SCCWS Preparation	3
3.2.1 Identify Coal Sources	3
3.2.2 Produce SCCWS for the Demonstration.....	3
4.0 PHASE III: DEMONSTRATION AND EVALUATION.....	4
4.1 Task 1. Test Burn	4
4.1.1 Subtask 1b. Slagging/Fouling Propensity	4
4.1.2 Subtask 1c. Erosion/Corrosion Characteristics	4
4.1.3 Subtask 1d. Fuel Transport, Storage, and Handling Characteristics	5
5.0 NEXT QUARTER ACTIVITIES	5
6.0 REFERENCES	6

APPENDIX A. DESCRIPTION OF THE ATOMIZATION TEST FACILITY

APPENDIX B. SCHEMATIC DIAGRAM OF PARKER HANNIFIN
VISCOSITY INSENSITIVE PREFILMING ATOMIZER

APPENDIX C. DESCRIPTION OF 300,000 BTU/H DOWN-FIRED
COMBUSTOR

APPENDIX D. SCHEMATIC DIAGRAM OF FURNACE TEST SECTION

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 determine if 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 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 legislature 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 Penn State campus 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 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.

Accomplishments this quarter are presented in Sections 2.0, 3.0, and 4.0 for Phases I, II, and III, respectively. Section 4.0 outlines the activities planned for the next quarter. References are contained in Section 6.0. The status of the project schedule is given in Figures 1 through 3 with a description of the milestones contained in Table 1.

2.0 PHASE I: DESIGN, PERMITTING, AND TEST PLANNING

No work was conducted this quarter on Phase I. Phase I has been completed with the exception of identifying operating procedures (portion of Task 3). These will be formulated when the facility construction is near completion.

3.0 PHASE II: CONSTRUCTION AND STARTUP

3.1 Task 1. Host Site Readiness/Boiler Retrofit

Bids for the boiler project were received by the Pennsylvania Department of General Services on November 22, 1989. Based on the evaluation and recommendation of the Office of the Minority and Women Business Enterprise, and accepted by the Deputy Secretary for Public Works, the acceptable total of the low bids (general construction; heating, ventilating, and air conditioning; and electrical construction) amounted to \$1,263,876.00 or \$460,869.00 over the allocation of \$803,007.00. The bids were to expire on January 10, 1990; however, this date was extended to March 12, 1990 in order for Penn State to formulate plans for providing the necessary funds for the project to continue. Penn State has committed the necessary funds from Contract Administration with these funds to be reimbursed from future operating funds obtained by the College of Earth & Mineral Sciences for the CWSF boiler facility. The winning contractors are: General Construction - Haranin Construction Co., Bellefonte, Pennsylvania; Heating, Ventilating, and Air Conditioning - KirCon-Breco, Inc., Johnstown, Pennsylvania; Electrical Construction - G. M. McCrossin, Inc., Bellefonte, Pennsylvania. The two main subcontractors to KirCon-Breco, Inc. are Tampella Keeler, Williamsport, Pennsylvania, to provide their DS-15 package boiler and Control Techtronics, Inc., Harrisburg, Pennsylvania, to provide the boiler control package.

3.2 Task 2. SCCWS Preparation

3.2.1 Identify Coal Source

Penn State has received an additional quotation from another potential SCCWS supplier to produce 1,000 tons of SCCWS. Vendor D (potential SCCWS suppliers are not identified by name) is the fourth company to submit a proposal to Penn State. Vendors A and B asked to be withdrawn from consideration as discussed in a previous quarterly report (for the period 08/15/1989 to 11/15/1989). Therefore, there are currently two companies interested in supplying SCCWS - Vendors C and D. A copy of the proposal from Vendor D has been sent to John C. Winslow, the DOE project manager, for review.

3.2.2 Produce SCCWS for the Demonstration

Each company proposing to supply fuel for the demonstration has been requested to supply two to three drums of candidate SCCWS for testing to be conducted by Penn State and the U.S. DOE/PETC as part of the final fuel selection process. The fuels will be evaluated for composition, stability, rheology, atomization, and combustion.

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 (1). A viscosity insensitive prefilming atomizer was ordered from Parker Hannifin Corporation to test dilatant fuels. The atomizer was received this quarter. The new atomizer will be used in the fuel selection process to properly compare different fuels during the atomization and combustion testing. A schematic of the atomizer is contained in Appendix A. Testing did not begin this quarter because the atomization test facility (ATF) was moved from the Combustion Laboratory to another location. Utility hookups (water, compressed air, and electricity) were completed and the ducting is nearing completion. A description of the ATF is contained in Appendix B. The ATF uses a Malvern 2600C Particle and Droplet Sizer to measure droplet size. The measuring technique is similar to others that have utilized the Malvern instrument for sizing.

4.0 PHASE III: DEMONSTRATION AND EVALUATION

4.1 Task 1. Test Burn

4.1.1 Subtask 1b. Slagging/Fouling Propensity

The design of a boiler deposition probe and suction pyrometer were to begin this quarter. The designs have been postponed pending discussions with the boiler manufacturer concerning boiler accessibility.

4.1.2 Subtask 1c. Erosion/Corrosion Characteristics

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 and is nearing the final stages of construction. The PCSV is scheduled to arrive in March. A new furnace section for Penn State's 300,000 Btu/h down-fired combustor has been designed to allow insertion of the PCSV into the hot environment of a combustor. The combustor has a series of ports along its length which are 3 inches in diameter. The outside diameter of the PCSV is 3.75 inches and the new section which is being constructed contains two 4-inch diameter ports. Appendix C contains a description of the down-fired combustor. A schematic of the new furnace section is contained in Appendix D. The watertube research boiler will not be used to evaluate the PCSV because the ports are only 3 inches in diameter whereas the PCSV needs 4 inch ports for access into the boiler.

Testing was to occur on the research boiler this quarter to evaluate the surface layer activation technique for measuring tube erosion. The evaluation has been postponed. Inspection of the convective section of the Penn State Combustion Laboratory's research boiler, which has accumulated many hours of operation while firing approximately 1,750 gallons of CWSF, revealed that all of the heat transfer surface was coated with loose

deposits of unsintered ash. No evidence of scouring was visible anywhere, indicating that the detection of erosion is likely to be even more difficult than anticipated. This is not meant to imply that erosion is not important, just that it will be limited to regions where unexpected conditions lead to unusual acceleration or concentration of ash, just as in pulverized coal-fired units. Such a situation is likely to become obvious only after many thousands of hours of operation with SCCWS.

For the evaluation of the economic impact of switching from oil to CWSF, a quantitative measure of the erosive potential of coal ash is still needed. Penn State proposes to accomplish this by constructing a probe to be placed in the convective section. Erosion of the probe will be enhanced by directing a jet of air at its surface, the principle being that the jet will entrain particles and increase their erosivity by increasing their impact velocity, just as a sootblower does in a pulverized coal-fired boiler. In this way, it is anticipated that sufficient erosion to be detected using a micrometer can be observed in a test lasting about eight hours. The method has the advantage that all convective section conditions except velocity will be undisturbed (even temperature will be little changed provided the tube surface is not too close to the jet nozzle). A probe with which to test this concept in the research boiler will be designed.

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

A viscometer was ordered and received from Bohlin Rheologi, Incorporated. The viscometer is of cup and bob geometry and is programmable. The system, which includes the viscometer, temperature bath, and an IBM PS-2, has been set up and tested. Several CWSFs and viscosity standards were analyzed to debug the system and the viscometer is working satisfactorily.

Two papers were prepared for the Coal & Slurry Technologies Conference to be held April 23-26, 1990 at Clearwater, Florida. The papers are:

- 1) "The Pennsylvania State University Superclean Coal-Water Slurry Demonstration Program" by Bruce G. Miller and Alan W. Scaroni.
- 2) "Calculation of Carbon Conversion During Combustion of Coal-Water Fuel in Industrial Boilers" by Peter M. Walsh.

5.0 NEXT QUARTER ACTIVITIES

The building and boiler construction and installation contracts will be awarded next quarter. Penn State will meet with the boiler manufacturer to discuss the possibility of adding a superheater section and boiler penetration locations for observation and sampling.

Parker Hannifin Corporation's atomizer will be tested. The atomization, combustion, and rheological characteristics of the SCCWS from Vendor C will be determined. In addition, should additional fuels be received, they will be tested also.

A probe to study tube erosion in the convective section of the research boiler will be designed and tested next quarter.

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

The PCSV is scheduled to arrive next quarter and a preliminary evaluation will be conducted. This will include setting up the instrument, calibrating the PCSV with a reticle supplied by Insitec, and testing the performance of the PCSV in a hot combustion environment. The PCSV performance evaluation will be conducted in the down-fired combustor. The new furnace section for the down-fired combustor will arrive and the refractory will be cast prior to the testing. The PCSV may also be tested in one of the University's coal-fired boilers, depending on boiler accessibility.

6.0 REFERENCES

- 1) 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.

TABLE 1

MILESTONE DESCRIPTION

<u>Milestone</u>	<u>Description</u>	<u>Planned Completion Date</u>
Phase I		
Task 1, No. 1	Identify equipment and diagnostic instrumentation	09/15/89
Task 2, No. 1	Review present permit	09/15/89
Task 3, No. 1	Develop SCCWS specifications, identify operating procedures, prepare detailed test plan	10/15/89
Phase II		
Task 1, No. 1	Building/boiler construction and installation let for bids	10/18/89
Task 1, No. 2	Building/boiler construction and installation awarded	12/31/89
Task 1, No. 3	Prepare site, install boiler and auxiliary equipment	04/01/91
Task 2, No. 1	Identify coal for SCCWS preparation	09/30/90
Task 2, No. 2	Prepare SCCWS for demonstration	04/01/91
Task 3, No. 1	Predict boiler performance	06/15/91
Task 4, No. 1	Shakedown boiler and auxiliary equipment	04/31/91
Task 4, No. 2	Generate baseline data on gas (oil?)	05/31/91
Phase III		
Task 1, No. 1	Perform demonstration	03/01/92
Subtask 1a, No. 1	300-hour demonstration milestone	07/31/91
Subtask 1a, No. 2	600-hour demonstration milestone	09/30/91
Subtask 1a, No. 3	1000-hour demonstration milestone	11/30/91
Subtask 1a, No. 4	Redefine SCCWS specifications	01/15/92
Subtask 1b, No. 1	Develop deposition test plan	10/15/89
Subtask 1b, No. 2	Design suction pyrometer	06/01/90
Subtask 1b, No. 3	Construct suction pyrometer	10/01/90
Subtask 1b, No. 4	Spectroscopic analyzer design and specification	01/01/91
Subtask 1b, No. 5	Acquisition of baseline data for spectroscopic analysis of deposits	07/31/91
Subtask 1b, No. 6	On-line deposition analysis	11/30/91
Subtask 1b, No. 7	Complete deposition testing (auxiliary spectroscopic testing)	01/15/92
Subtask 1c, No. 1	Develop erosion and corrosion test plan	10/15/89
Subtask 1c, No. 2	Complete research boiler erosion evaluation	08/01/90
Subtask 1c, No. 3	Full-scale erosion technique decision	10/01/90
Subtask 1c, No. 4	Design probe for full-scale erosion study	01/01/91
Subtask 1c, No. 5	Construct erosion probe	05/01/91
Subtask 1c, No. 6	Acquisition of baseline data for corrosion of tubes by ash components	07/31/91
Subtask 1c, No. 7	Accelerated corrosion testing	09/30/91
Subtask 1c, No. 8	Coupon testing in boiler	11/30/91
Subtask 1c, No. 9	Complete erosion/corrosion modelling	01/15/92
Subtask 1d, No. 1	Identify viscometer	10/15/89
Subtask 1d, No. 2	Complete preliminary viscosity and stability tests	08/15/90
Subtask 1d, No. 3	Complete viscosity and stability tests	01/15/92
Task 2, No. 1	Complete economic evaluation	01/15/92
Task 3, No. 1	Complete final report	03/01/92

FIGURE 1. 1989 Milestone Schedule

FIGURE 2. 1990 Milestone Schedule

FIGURE 3. 1991 and 1992 Milestone Schedule

APPENDIX A. DESCRIPTION OF THE ATOMIZATION TEST FACILITY

DESCRIPTION OF THE ATOMIZATION TEST FACILITY

Fuel Spray Characteristics

In any liquid fuel combustion system, once an appropriate burner/atomizer design has been selected, the next step is the optimization of its performance during testing in the combustor. With each new fuel, it becomes necessary to repeat the procedure. Since combustion testing involves a complex interaction of several variables, it is desirable to perform some preliminary optimization of the fuel spray characteristics.

The spray angle is an important parameter. The fuel droplets should be ejected at an appropriate angle such that they are entrained in the swirling combustion air stream (and thus brought into contact with oxygen in the preheated air as well as with the hot recirculated products of combustion; particles follow a helical path, which lengthens their residence time - ie. retains them in the combustor for a longer time). Droplets ejected at too wide an angle may strike and burn on the refractory quarl (if any) and those emanating at too narrow an angle may escape entrainment in the air vortex and pass instead through the relatively slow-moving recirculation zone and out of the flame region. Droplet momentum is also crucial since, even with the desired angle, those particles having excessive momentum risk escaping entrainment and may even strike the walls. The simultaneous measurement of mass (inferred from droplet size and density) and velocity (eg. from double spark photography or high-speed cameras) allows verification of the desired momentum. As implied above, a hollow conical spray pattern is preferable to a solid cone from the point of view of entrainment in the combustion air vortex. It is therefore desirable to verify the spray pattern (using for example, a patternator) to estimate the deviation from a hollow cone - ie. how much fuel is being sprayed into the solid angle, which should be avoided. It has been shown that the spray pattern of certain atomizers (eg. the y-jet) acquires a degree of asymmetry under certain modes of operation. Uneven wear of nozzle discharge orifices or improper centering of the pintle or cone (in designs featuring an annular discharge orifice) can also lead to asymmetric spray patterns and this can be determined by appropriate measurements.

In many applications of liquid fuel combustion, it is important that the fuel be finely atomized in order to maximize the surface area exposed to convective and radiative heating. It is also important for droplet volumes to be minimized to effect rapid fuel burnout. Fineness of atomization may be the single most important parameter affecting the extent of fuel conversion - this being especially crucial in the case of slow-igniting (high-moisture), low-reactivity fuels such as micronized CWSFs. Atomization quality also affects ignition stability, turndown, and indirectly (if burnout is insufficient and fly ash size subsequently

large) impacts on slagging, fouling, erosion, and the effectiveness of particulate removal systems.

The Atomization Test Facility - "ATF"

Spray quality can be expressed in terms of the droplet size distribution or in simpler terms, as the top size (or more realistically, as the volume fraction of droplets above some level - typically 300 μm) in conjunction with the volume median diameter (vmd) or the Sauter median diameter (smd). Half of the volume of the entire population of droplets exiting a nozzle consists of droplets having diameters greater than the "vmd" while the other half consists of droplets of sizes smaller than the vmd. The "smd" is more commonly applied for liquid droplets. It is the diameter of a hypothetical group of droplets of uniform size, having the same total surface area and total volume (but not necessarily the same number of particles) as the sample being measured. This definition is derived from the realization that for a given quantity (volume) of fuel, the total surface area available for heatup, evaporation, and other processes to a large degree controls the rate of combustion.

An atomization test facility has recently been assembled. It has the capability of measuring the efficiency of atomization of a liquid fuel. Central to the facility are a spray chamber and peripheral equipment dedicated to the measurement of the droplet size distribution of any liquid spray pattern.

A sketch of the salient components of the ATF is given in Figure 1. The spray from the fuel gun is intersected by the laser beam from a Malvern Laser Diffraction Particle and Droplet Sizer; the latter includes a micro-computer which calculates the droplet size distribution and other pertinent data, stores the data on disk, and outputs selected results on a dot-matrix printer. The spray enters a chamber where most of the large droplets settle to the floor and are collected. Most of the remaining fine droplets are then removed in the demister. The induced draft fan provides a constant sweep of air which ensures that few droplets pass through the laser beam measurement volume more than once. The exhaust air contains very fine droplets alone and is vented to the atmosphere.

For a given fuel/nozzle combination, optimization of the operating parameters consists of determining the minimum flow rate and pressure of atomizing air (an indication of the amount of energy used in the atomization process) needed to achieve sufficiently fine spray quality. This minimum is measured as a function of fuel flow rate (ie. nozzle turndown). The fuel pressure needed to force any given flow rate through the discharge orifice increases with flow and also with the amount of resistance offered to the fuel by the atomizing medium (this applies to internal-mix nozzles; fuel and air interact external to the nozzle in external-mix designs). The fuel pressure should be recorded since it may influence discharge characteristics of the fuel pump. As a corollary to the above, although

air flow rate is a function strictly of air pressure when no fuel is flowing in the nozzle, it becomes dependent also on the fuel flow rate due to the interaction of the two fluids in an internal-mix nozzle.

ATF Plumbing

Details of the ATF plumbing are shown in Figure 2. Atomizing air is available from either a 7.5 hp building controls compressor capable of delivering continuously, 31 SCFM of air at 125 psig (150 lb/h), or from a 75 hp unit located in an adjoining laboratory and capable of providing 204 SCFM (987 lb/h) of air at 350 psig. The latter is equipped with a 1000 gal storage tank. The 6-stage Moyno Progressive Cavity pump can pump up to 1 gpm of fuel at pressures of up to 300 psig. For a slurry of density 10 lb/gal and higher heating value of 10,000 Btu/lb, this corresponds to a mass flow rate of 600 lb/h and heating rate of 6 MBtu/h. The pump capacity therefore limits the size of nozzles that can be tested, to around this level. The minimum flow the pump is capable of delivering is 0.1 gpm. Turndown below this can be achieved by bypassing and returning a portion of the flow to the storage tank, using the pinch valves shown in Figure 2. Fuel storage is in a 55 gal conical-bottom polyethylene tank. Water flush of the fuel line is provided before and after the pump for cleaning the lines before shutdown and prewetting them before startup on CWSF. Agitation is used for homogenization and resuspending particles settled out, after a period of time during which the facility was idle. It is accomplished using either recirculation (as indicated in Figure 2) or a portable, pneumatically-powered drum stirrer run at low speeds. A 250 psig burst pressure rupture disc seated in a special safety head (which lacks dead spaces where particles could accumulate) protects the fuel delivery system against overpressures resulting from nozzle plugging, etc. In the event of disc rupture, fuel is returned to the tank as indicated. The fuel is strained (1 mm openings) via an in-tank screen and then through disc strainers arranged in duplex (for switching during operation) to protect the atomizer against plugging by oversized coal or extraneous material. It is then metered (using a D40 MicroMotion mass flow meter) and its pressure and temperature are measured just prior to atomization. Atomizing air is filtered and the pressure is reduced to the required level using a regulator. It too is metered using a MicroMotion mass flow meter (model D25) and its pressure and temperature are measured just prior to the nozzle. A flow check valve protects against the unlikely event of fuel backflow. The droplet size distribution is measured using a Malvern 2600C Particle and Droplet Sizer with range lenses of focal lengths : 63, 100, 300, and 1000 mm. The overall particle size range that can be measured is thus 0.6 - 1880 μm . Both the EASY SIZER and MASTER SIZER software packages can be used to perform droplet size distribution calculations.

FIGURE 1

FIGURE 2. ATF PLUMBING

**APPENDIX B. SCHEMATIC DIAGRAM OF PARKER HANNIFIN
VISCOSITY INSENSITIVE PREFILMING ATOMIZER**

DESIGN	FUEL FLOW #/HOUR	ATOMIZING MEDIA	FLOW RATE #/HOUR	ATOMIZING MEDIA SUPPLY PRESSURE PSIG	TEMP °F	FURNACE PRESSURE ATMOSPHERE	FUEL	WITH SHROUD AIR
M8	250	AIR	170	90	100*	I	M.C.W.S.	NO

**APPENDIX C. DESCRIPTION OF 300,000 BTU/H
DOWN-FIRED COMBUSTOR**

Down-Fired Test Combustor

Introduction

A down-fired test combustor is available at Penn State to investigate pulverized coal and coal-water fuel (CWF) combustion. The combustor is used to study gaseous and particulate emissions, evaluate enhanced combustion techniques, assess performance of sorbents for reducing SO₂ emissions, and investigate the mineral transformations that the inorganic constituents undergo during combustion and subsequent cooling.

General Description

A schematic diagram of the system is shown in Figure 1. The combustor has a nominal firing rate of 300,000 Btu/hr. The burner depicted in Figure 1 is for pulverized coal combustion. The top section of the combustor can be replaced with an alternate section containing a burner for CWF combustion.

When firing pulverized coal, the fuel is screw fed into a venturi and transported to the burner by a small quantity of combustion air (primary air). The air-entrained fuel is premixed in a water-cooled burner with secondary air and the mixture is introduced into the top of the combustor. The secondary air can be preheated to 600°F.

The refractory-lined combustor is 9 feet high with an internal diameter of 18 inches. The main body of the combustor is modular in design consisting of five sections 18 inches in height. The maximum flame temperature is 2800°F and the gases exit the combustor at 1800°-2200°F. The combustor contains nine pairs of 3-inch ID opposed ports for particulate sampling.

The products of combustion pass from the combustor into a 6-inch refractory-lined duct, a 6-inch stainless steel pipe with water spray to cool the flue gas to 500°F, a cyclone for particulate removal, an induced draft fan, and exit through the stack.

The products of combustion can be monitored with an instrument package consisting of online O₂, CO₂, CO, NO_x, and SO₂ analyzers. Ash sampling can be performed at various locations throughout the system with a water-cooled isokinetic probe.

Figure 1. Down-Fired Test Combustor

APPENDIX D. SCHEMATIC DIAGRAM OF FURNACE TEST SECTION

FURNACE PROBE SECTION SKETCH

M98051255

Report Number (14) DOE/PC/88697-- T15

Publ. Date (11) 19960406

Sponsor Code (18) DOE/FE, XF

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

DOE