DOE/PC/88697--T9

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

Semiannual Technical Progress Report
for the Period 08/15/1993 to 02/15/1994

By

Bruce G. Miller, Co-Principal Investigator
Joel L. Morrison, Research Assistant
Roger L. Poe, Research Assistant
Alan W. Scaroni, Project Manager

Novmber 30, 1994

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

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

By
Energy and Fuels Research Center
The Pennsylvania State University
University Park, Pennsylvania

DISCLAIMER

DISCLAIMER

TABLE OF CONTENTS

EXECUTIVE SUMMARY

The Pennsylvania State University is conducting a coal-water slurry fuel (CWSF) program for 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 (installing a CWSF preparation circuit, conducting an additional 1,000 hours of testing, and installing an advanced flue gas treatment system). 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 CWSF demonstration program is being conducted on the 15,000 lb steam/h demonstration boiler located at Penn State.

The approach used in the program was as follows:

1. A natural gas/fuel oil-designed package boiler was installed and baseline data firing natural gas generated.
2. The system was then shaken down with CWSF and 1,000 hours of testing was conducted using the burner/atomizer system provided with the boiler. The 1,000-hour demonstration consisted of boiler optimization testing and combustion performance evaluation using CWSF preheat, a range of atomizing air pressures (up to 200 psig), and the use of steam as the atomizing medium.
3. If the combustion performance was not acceptable based on the combustion efficiency obtained and the level of gas support necessary to maintain 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 of proven CWSF design.

5. In addition to the advanced burner system, a superheater tube and advanced flue gas cleanup system were to be installed for the second 1,000-hour demonstration.

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 has been determined to be unacceptable. Consequently, the first demonstration has been concluded at 500 hours and the results are summarized in this report. The second demonstration (Phase IV) will be conducted after a proven CWSF-designed burner is installed on the boiler.

Prior to the second demonstration, a CWSF preparation circuit is being constructed. During this reporting period, the construction of the fuel preparation facility that will contain the CWSF preparation circuit (as well as a dry, micronized coal circuit) was completed. The CWSF preparation circuit will be completed by July 1,1994.

Proposals were from potential suppliers of the flue gas treatment systems were reviewed by Penn State and DOE. Penn State is working with DOE in conjunction with another program (Cooperative Agreement No. DE-FC22-92PC92162) in selecting the flue gas treatment system.

1.0 INTRODUCTION

The Pennsylvania State University is conducting a coal-water slurry fuel (CWSF) program for 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 (additional 1,000 hours of 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 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. Procure and Install Burner and Superheater

Task 2. Construction of a CWSF Preparation Facility

Task 3. Installation of an Advanced Flue Gas Treatment System

Task 4. 1,000-Hour Test

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 effects of long-term firing with CWSF on boiler performance. 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 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 support necessary to maintain 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 of proven CWSF design.
5. In addition to the advanced burner system, a superheater tube and advanced flue gas cleanup system were to be installed for the second 1,000-hour demonstration.

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 has been determined to be unacceptable. Consequently, the first demonstration (Phases I-III) has been concluded at 500 hours and the results have been presented elsewhere (Miller, et al 1993). The second demonstration (Phase IV) will be conducted after a proven CWSF-designed burner is installed on the boiler.

A summary of Phase IV is presented in Section 2.0. Section 3.0 summarizes the miscellaneous activities that were conducted. Activities planned for the next semiannual period are given in Section 4.0. References are contained in Section 5.0 and acknowledgments are given in Section 6.0. The milestone schedule for Phase IV is shown in Figure 1, and Table 1 contains the milestone description for the entire project.

2.0 ADVANCED SYSTEM TESTS

2.1 Task 1. Procurement and Installation of a Burner and Superheater

Burner procurement started this reporting period in conjunction with another program (Cooperative Agreement No. DE-FC22-92PC92162). The burner is being procured from Energy and Environmental Research Corporation and will have the capability of firing natural gas and CWSF or dry, micronized coal. It is a low-NO_x burner and a sectional view is shown in Figure 2. The burner will be installed prior to the Phase IV test (Fall of 1994). The burner design specifications are: high carbon conversion; >3:1 turndown; <30% excess air; combustion air temperature <400°F; burner pressure drop < 8 inches water column; capable of using air or steam as the atomizing medium; and erosion resistant design of the atomizer.

No work was conducted on the procurement and installation of the superheater this reporting period. The cavity in the boiler where the superheater will be installed is currently occupied by a deposition probe. The deposition probe will be removed and the superheater will be installed prior to the Phase IV test.

2.2 Task 2. Construction of CWSF Preparation Facility

The construction of the fuel preparation facility that will contain the CWSF preparation circuit and a dry, micronized coal (DMC) circuit was completed during the previous reporting period (Miller et al., 1993b). Figure 3 is a schematic diagram of the CWSF preparation circuit.

The installation of the CWSF circuit is being conducted in conjunction with another program (Cooperative Agreement No. DE-FC22-92PC92162).

The CWSF preparation circuit is in the final design stage. The process flow sheet has been completed and the engineering design is nearing completion. Major pieces of equipment have been identified and quotations for them have been obtained. Final cost determinations of the CWSF circuit are now focused on obtaining bids for supplying miscellaneous materials (*e.g.*, pipe, fittings, conduit, wire, regulators, etc.) and labor necessary to assemble the circuit. Final costing of the CWSF circuit is scheduled for completion by April 1, 1994.

Performance data have been collected for the rotary drum vacuum filter which will be used in the water treatment portion of the circuit. CWSFs prepared with and without dispersants were tested by the manufacturer.

2.3 Task 3. Installation of an Advanced Flue Gas Treatment System

Proposals received from potential suppliers of flue gas treatment systems were reviewed with DOE. Penn State is working with DOE in conjunction with another program (Cooperative Agreement No. DE-FC22-92PC92162) in selecting the flue gas treatment system. A preliminary selection has been made and Penn State is working with the supplier of the flue gas treatment system to ensure compatibility with the boiler system and applicability to industrial boilers in general. Specifics of the flue gas treatment system will be presented after the vendor and system are finalized.

3.0 MISCELLANEOUS ACTIVITIES

A program review for the U.S. Department of Energy, Pittsburgh Energy Technology Center's Coal Utilization Division was attended on November 10, 1993. A summary of the results from Phases I-III was presented.

4.0 NEXT SEMIANNUAL PERIOD ACTIVITIES

During the next reporting period, the following will be completed:

- Installation and shakedown of the CWSF preparation circuit;
- Installation of the burner; and
- Installation of the superheater.

5.0 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, June 21, 1993a, DE-FC22-89PC88697.

Miller, B.G., J.L. Morrison, R.L. Poe, and A.W. Scaroni, "Coal-Water Slurry Fuel Combustion Testing in an Oil-Fired Industrial Boiler," Semiannual Technical Progress Report for the Period 02/15/1993 to 08/15/1993, Pittsburgh Energy Technology Center, Pittsburgh, Pennsylvania, September 24, 1993, 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).

6.0 ACKNOWLEDGMENTS

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

- Michael Anna - Research Technologist
- David Clark - Senior Research Technologist
- Samuel Gross - Senior Research Technologist
- Michael Hill - Research Technologist
- Ruth Krebs - Research Assistant
- Scott Lyons - Research Technician
- Christopher Snyder - Research Technician

Table 1. Milestone Description

Milestone	Description	Planned Completion Date	Actual Completion Date
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	Procure and install burner	04/15/94	
Task 1, No. 2	Procure and install superheater	08/01/94	
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	07/01/94	
Task 3, No. 1	Install flue gas treatment system	07/01/94	
Task 4, No. 1	Complete 1,000-hr test	12/31/94	
Task 5, No. 1	Complete final report	03/01/95	

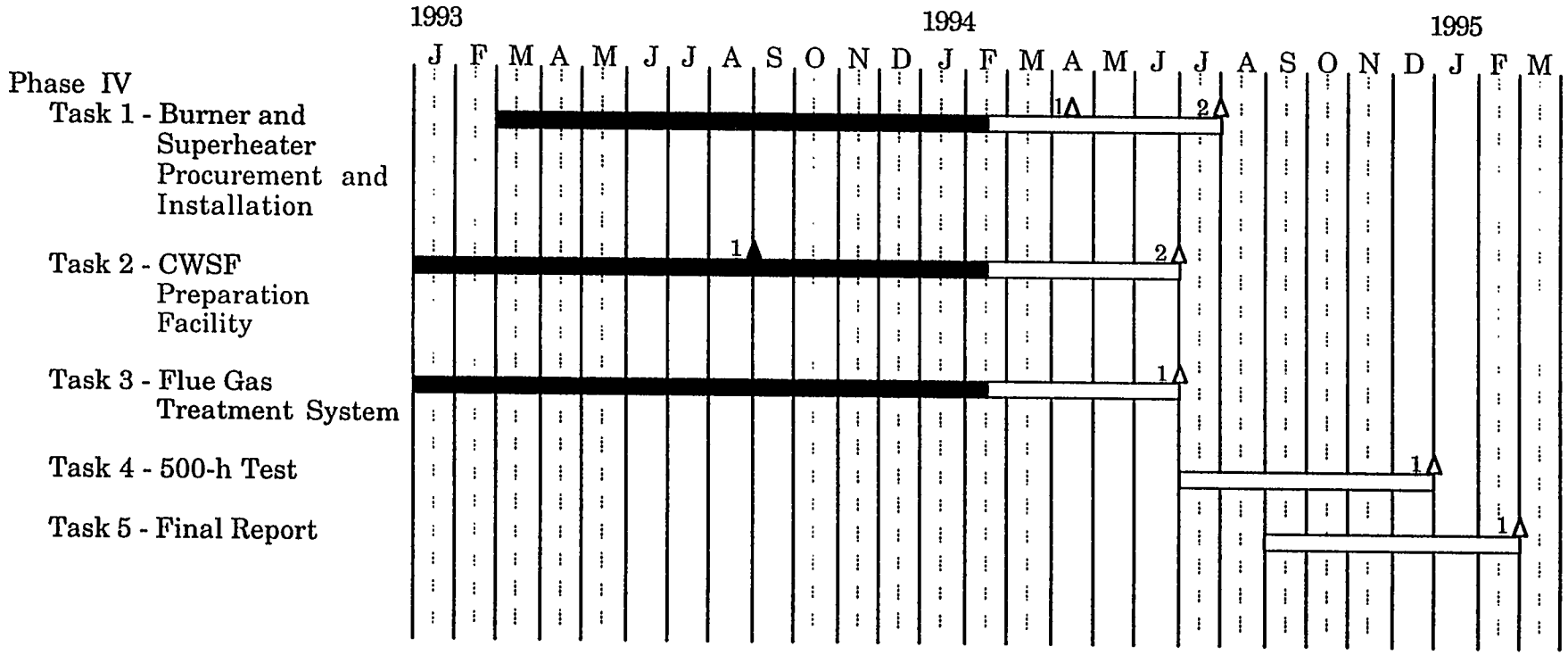

Figure 1. PHASE IV MILESTONE SCHEDULE (Second Demonstration)

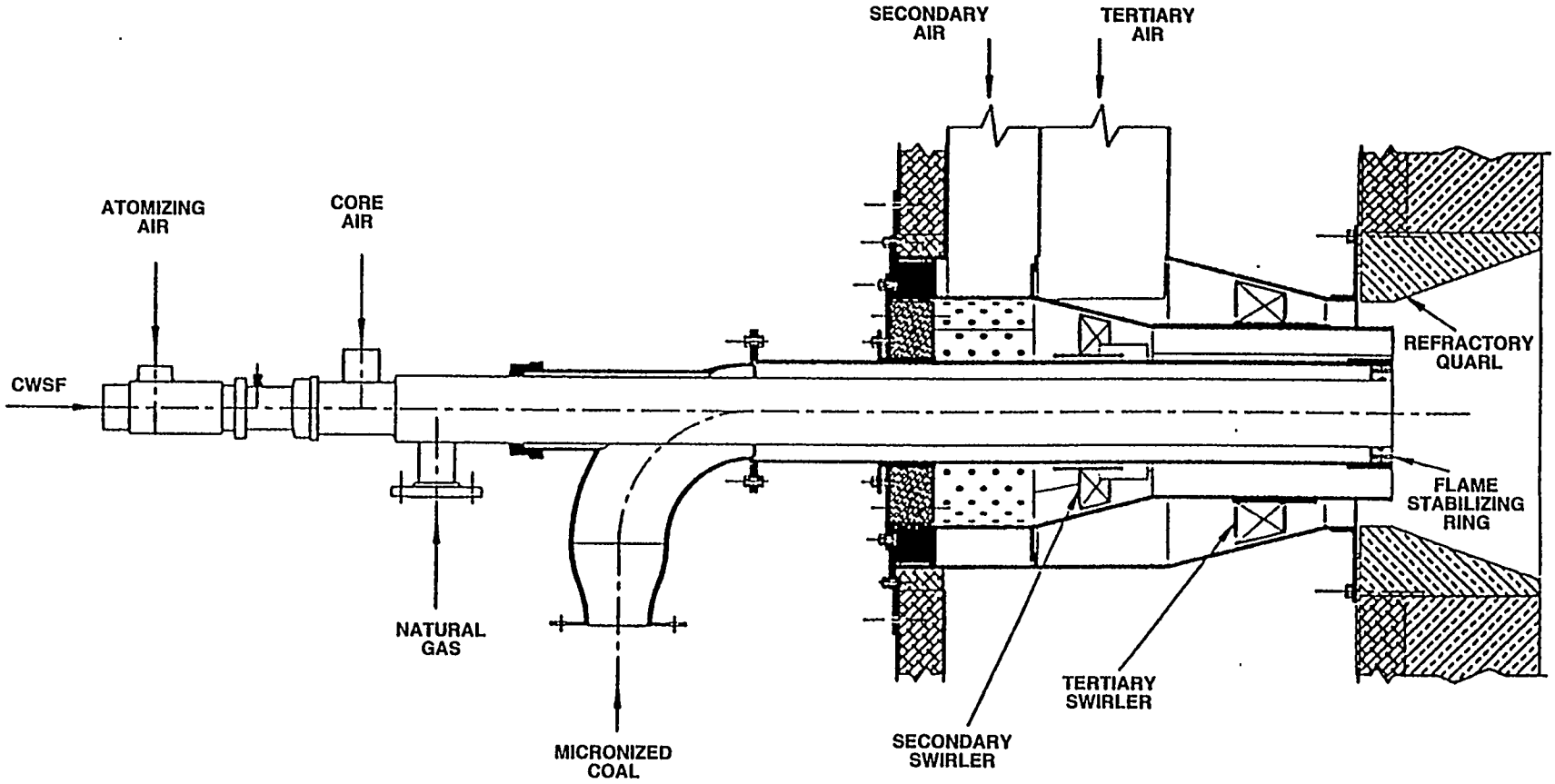

Figure 2. BURNER SECTIONAL VIEW

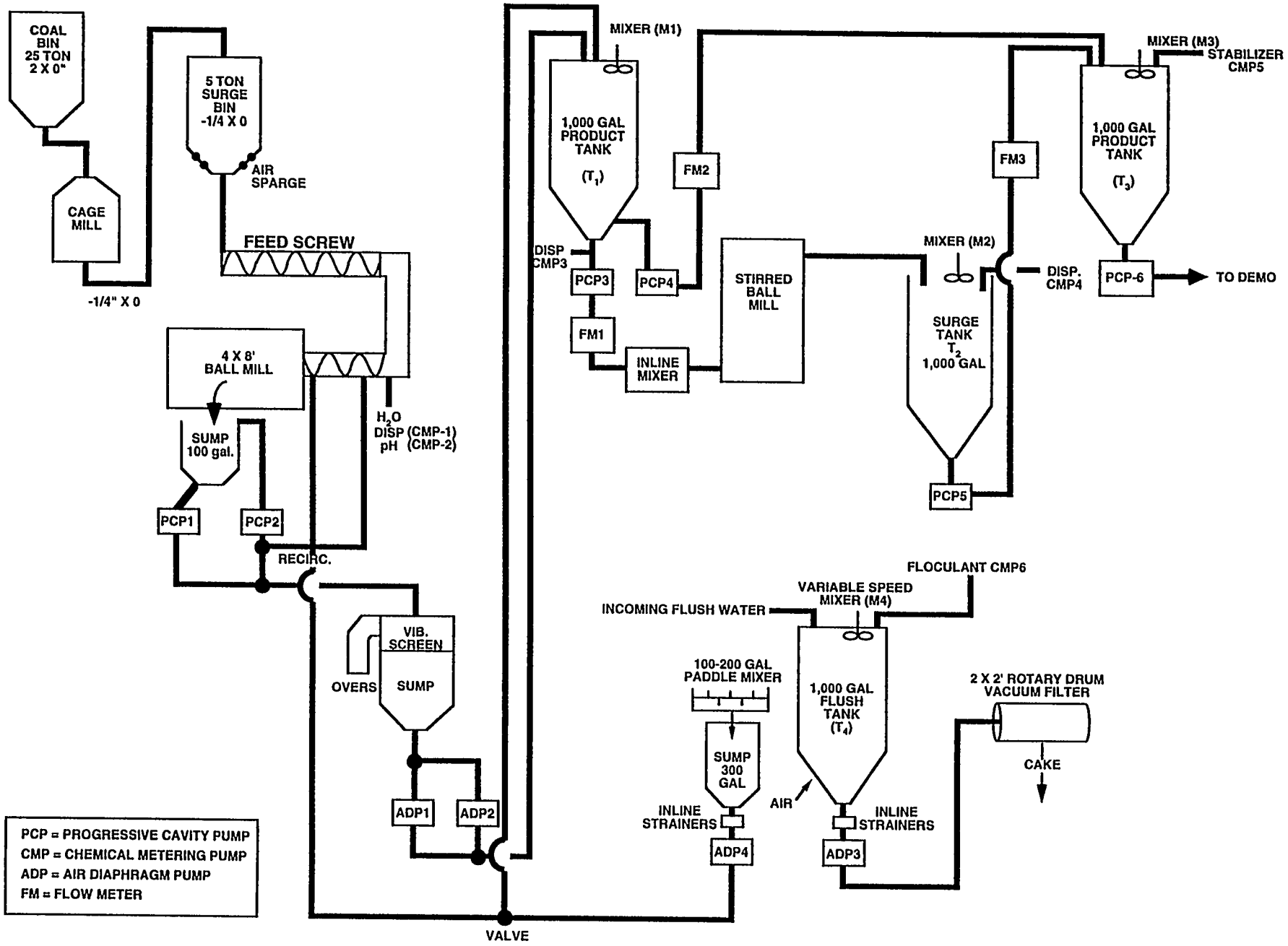

Figure 3. SCHEMATIC DIAGRAM OF THE CWSF PREPARATION CIRCUIT