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

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

By

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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. 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 CWSF preparation circuit (as well as a dry, micronized coal circuit) continued. The CWSF preparation circuit will be completed by November 1,1994.

Additional activities included receiving a coal-designed burner and installing it on the demonstration boiler; and working with DOE in selecting pollution control systems to install on the boiler.

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. Activities planned for the next semiannual period are given in Section 3.0. References are contained in Section 4.0 and acknowledgments are given in Section 5.0. 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

During this reporting period, a burner was procured from Energy and Environmental Research Corporation (in conjunction with another program (Cooperative Agreement No. DE-FC22-92PC92162) that has 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. Details of the burner were given in the previous semiannual report (Miller et al., 1994). Currently the burner is being operated in its dry, micronized coal mode for another program (Cooperative Agreement No. DE-FC22-92PC92162). The atomizer will be installed prior to the Phase IV test (first and second quarter of 1995).

No work was conducted on the procurement and installation of the superheater this reporting period. The superheater will be installed prior to the Phase IV test.

2.2 Task 2. Construction of CWSF Preparation Facility

Construction of the CWSF preparation circuit continued during this reporting period. 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).

Items that have been, or are in the process of being, installed or constructed are listed below:

- Water lines and nozzles (to clean the pipe trench) have been installed in the pipe trench;
- CWSF tank stands were constructed for Tanks T1 and T4;
- Tanks T1 and T4 were mounted on the stands;
- Mixer mounts were constructed for Tanks T1 and T4 and a mixer was mounted on Tank T1;
- Electrical conduit was installed and the mixers were wired;
- Piping for compressed air and water lines was installed to the areas in the Fuel Preparation Facility (FPF) where each major piece of equipment (pumps, tanks, sand mill, etc.) will be sited;
- CWSF lines were installed in the FPF and from the FPF to the boiler room;
- A flush water (water/coal mixture produced from purging lines in the boiler room) return line was installed from the boiler room to Tank T4;
- Piping for the sand mill was started;
- Moyno pumps that were received from OXCE Fuel Company were identified for Tanks T1 and T4 and put into place;
- Refurbishing of the 4 x 8' Centrix ball mill has begun. Allis Mineral Systems of York, Pennsylvania is currently fabricating a new main bearing for the ball mill. Orders for a new lubrication system and 50 hp motor have been placed. Installation of these components and controls for the ball mill will be subcontracted to the Beitzel Corporation;
- Pneumatic valves for tanks T1, T2, T3, and T4 have been ordered;
- Material was received for, and construction began on the sump for the ball mill;
- The hydraulic system for the Morehouse Mill, which was donated by OXCE Fuel Company, could not be repaired and a new hydraulic system was ordered;
- The Quality Assurance (QA) room was set up which included mounting cabinets, installing a sink, and setting up a computer; and
- A ladder was constructed and installed for access to a storage area above the QA room.

Orders have been placed for the remaining major pieces of equipment (tanks, moyno pumps, mixers). These equipment will be installed upon receipt.

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

It was the original intention of this task was to integrate an advanced flue gas treatment system with the boiler. However, after receiving proposals from potential suppliers and reviewing them with DOE, it became apparent that there were not any advanced systems that were both technically and economically viable for installation on industrial boilers. Consequently, it was decided to install commercial NO_x and SO_2 systems on the boiler. Work started in identifying the appropriate emissions control technologies.

3.0 NEXT SEMIANNUAL PERIOD ACTIVITIES

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

- Installation and shakedown of the CWSF preparation circuit, and
- Installation of the superheater.

4.0 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.

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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 08/15/1993 to 02/15/1994, Pittsburgh Energy Technology Center, Pittsburgh, Pennsylvania, March 28, 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).

6.0 ACKNOWLEDGMENTS

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- David Bartley - Research Technologis
- Howard R. Glunt - Research Technician
- Ruth Krebs - Research Assistant
- Scott Lyons - Research Technician
- Bradley Maben - Research Technician
- Joel L. Morrision - Research Assistant
- Roger L. Poe - Research Assistant
- 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	05/09/94
Task 1, No. 2	Procure and install superheater	12/31/94	
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	11/01/94	
Task 3, No. 1	Install flue gas treatment system	12/31/94	
Task 4, No. 1	Complete 1,000-hr test	06/30/95	
Task 5, No. 1	Complete final report	09/01/95	

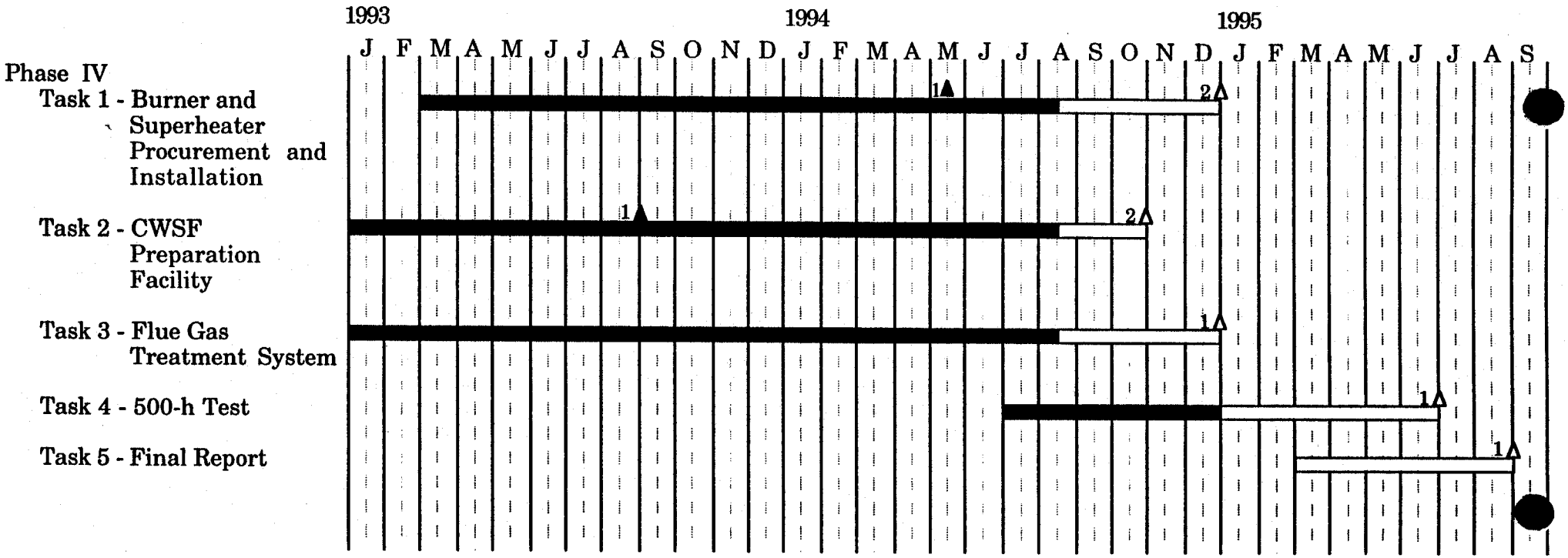

Figure 1. PHASE IV MILESTONE SCHEDULE (Second Demonstration)

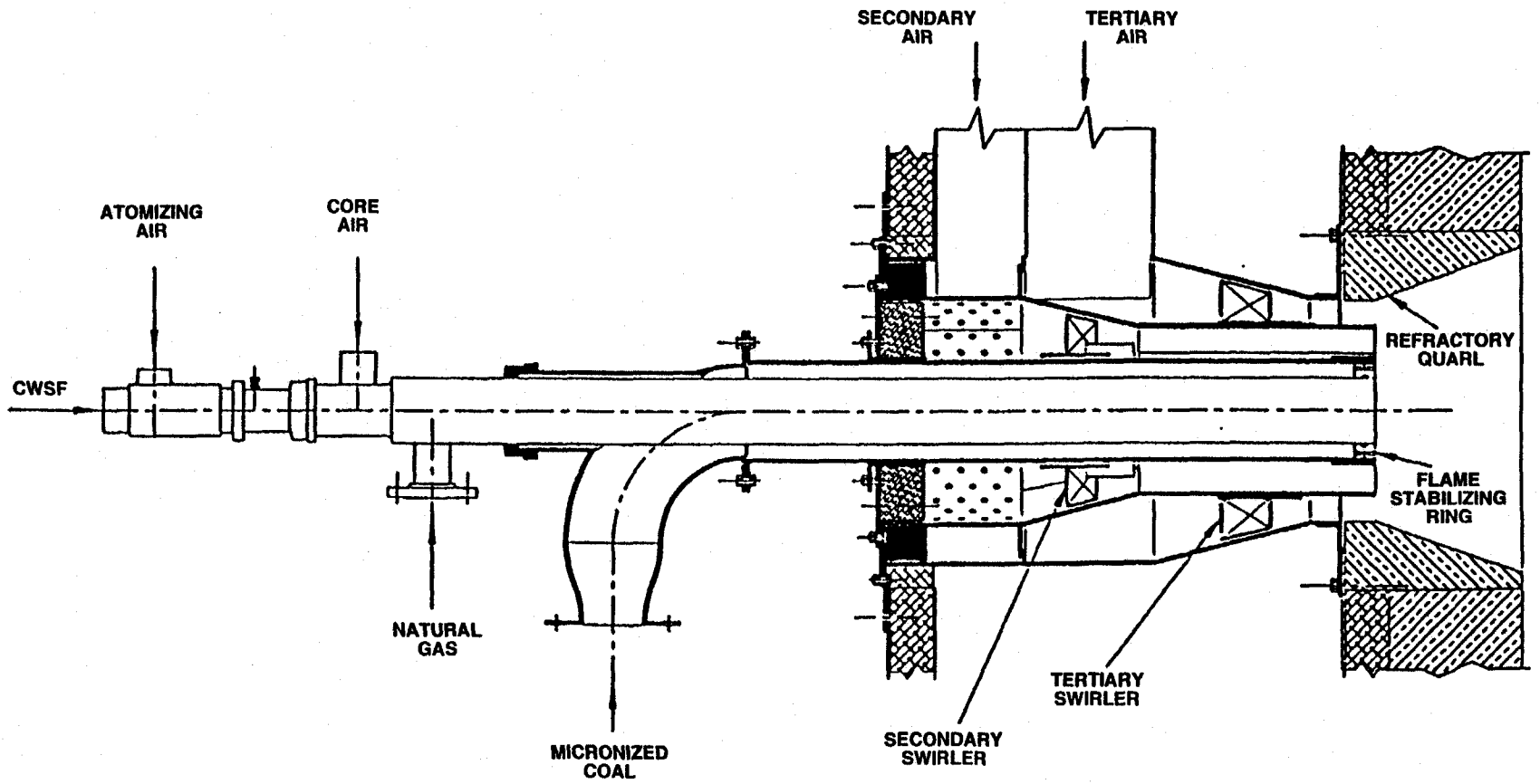

Figure 2. BURNER SECTIONAL VIEW

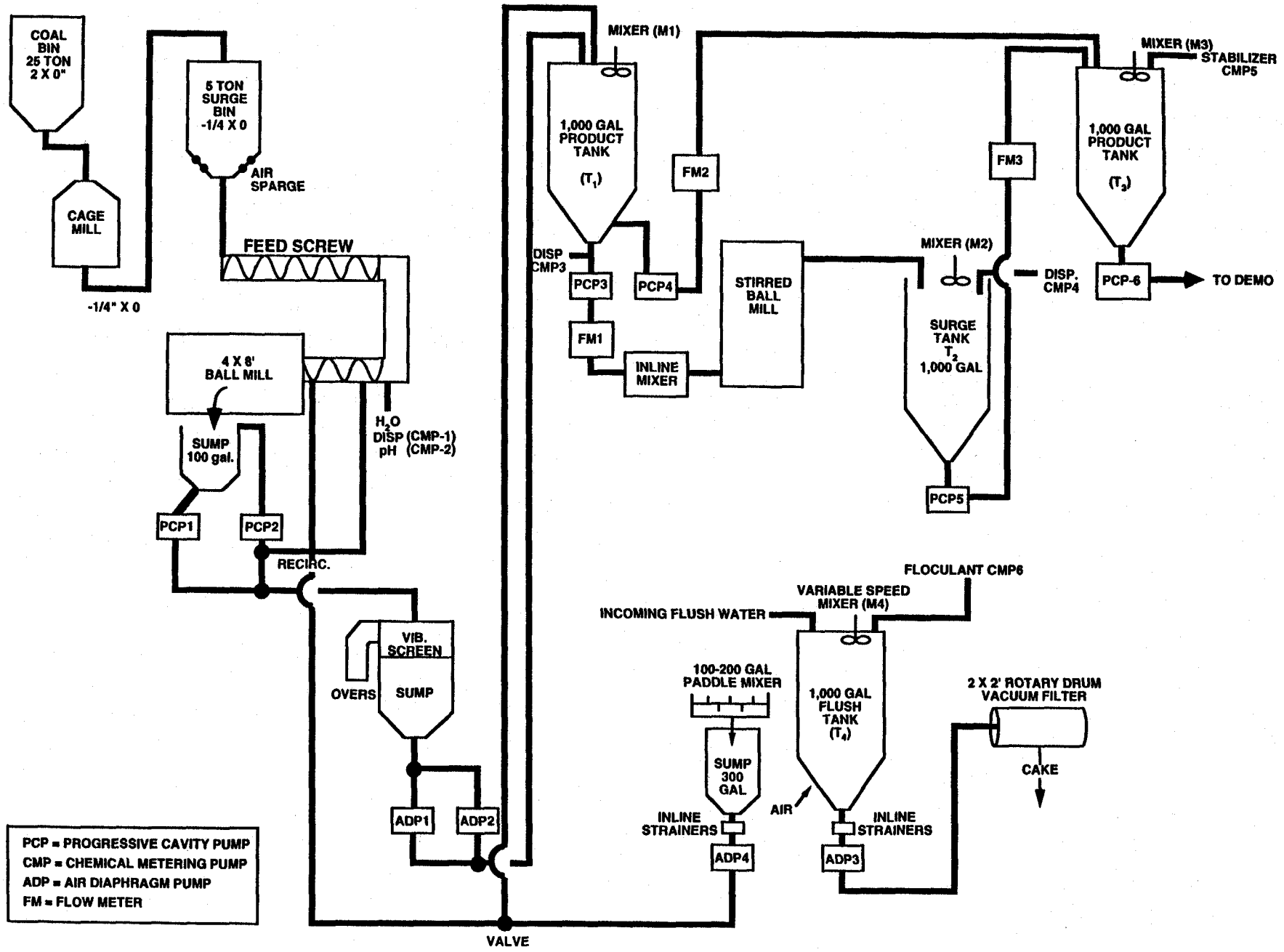

Figure 3. SCHEMATIC DIAGRAM OF THE CWSF PREPARATION CIRCUIT