Status Or Proof-Of-Concept Testing At The Cfff

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STATUS OF PROOF-OF-CONCEPT TESTING AT THE CFFF*

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ABSTRACT

This paper will summarize the results of POC testing at the DOE CFFF during CY 1989. At the end of this period, more than 1,500 hours of testing had been completed. Major efforts for the period included continued evaluation of the baghouse (BH) and Electrostatic Precipitator (ESP) in removing particulate under parametrically varied conditions.

Results of the redesigned superheater test module (SHTM), which provides more flexibility to meet desired test temperatures, increased the number of sootblowers and increased tube spacing will be covered.

The status of facility modifications will be detailed. This includes the provision of a high pressure air system for sootblowing tubes with molten tube deposits, installation of an automated ash/seed handling system and the engineering investigations into modification of the coal processing system to handle western coal. The latter capability is needed in FY-91 for the beginning of the scheduled 2000 hours Proof-of-Concept (POC) testing with western coal.

Performance of test components and improvements made during the year will be summarized.

Plans for the balance of FY-90 and the remaining years in the POC program will be presented.

INTRODUCTION

The University of Tennessee Space Institute (UTSI) located in Tullahoma, Tennessee operates the Coal Fired Flow Facility (CFFF) for the Department of Energy. This facility was dedicated in 1981, and shakedown was completed in 1982. Since that time, UTSI personnel have accumulated 1563 hours of coal-fired operation, including 1295 hours of Proof of Concept (POC) Testing. Four hundred and thirty nine of those hours were added in 1989.

The facility was designed and testing was planned to evaluate technology and materials that were used in commercial boilers, insofar as possible. The major components were designed to simulate combustion gas side conditions, since these conditions are much different from conventional coal-fired systems. The emphasis has been to provide technology related to corrosion, ash deposition, seed recovery and properties, control of gaseous (NO_x, CO, SO_2) and priority pollutants and particulate emissions, heat transfer, waste identification and management, environmental effects and system integration. Our work since the shakedown tests has concentrated on these aspects. We have reported on effective NO_x, SO_2, particulate and organic priority pollutant control in past SEAM meetings. We have also reported on the other technology aspects listed above. Testing in these areas is continuing to provide a better data base for design data to scale to commercial systems, including retrofit designs. Although complete data are not yet available, our design and operating conditions were established to be representative of early retrofit designs, as they are being evolved. During the last year, evaluation of the superheater test section tubes continued and additional time was accumulated on tubes not removed for metallurgical examinations. Ash deposition assessment also continued as did the study of the baghouse and electrostatic precipitator performance under variable operating conditions.

This paper will also describe three major facility modifications that are underway. These modifications include: addition of a high pressure air compressor system to provide higher pressure air for sootblowing; installation of an automated ash/seed handling system and the initial efforts on a coal processing system to handle a high moisture, reactive western subbituminous coal (Rosebud). The western coal processing capability will be required to begin the scheduled 2000 hours of POC testing with western coal.

SUMMARY OF TESTING

Three tests were completed in 1989 while firing Illinois Seam 6 coal. Testing continues to emphasize corrosion, ash deposition and pollution control. Additional data were obtained on heat transfer, and tests were run on candidate materials for a high temperature air heater.

LMF4-Q - The primary objectives of this test were to evaluate the redesigned superheater test

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module (SHTM) air heater and new sootblowers, and to continue to accumulate exposure hours on corrosion sections. More than 22,000 pounds of solids were collected from the flow train. The primary objectives were met, even though the test was shorter (40.5 hours) than planned because of a crankshaft failure on the process air compressor.

LMF4-R - This test was conducted in August 1989, and a major primary objective was to successfully complete the State of Tennessee particulate emissions compliance tests. This objective was successfully completed, and a report was issued to state officials. Four additional primary objectives were met, including operation for at least 260 hours. Actual test time was 263 hours. More than 145,000 pounds of solids were collected from the flow train during and after the test. One objective that was not met was the evaluation of the ESP at various specific collection areas (by changing gas flow rates). Ash deposition was well controlled, even with nominal K_2S ratios of 1.3 during the last 50 hours of the test.

LMF4-S - This test was completed in December, 1989, with four (4) primary objectives set. A second State of Tennessee Compliance Test, for sulfur dioxide was accomplished during this test. Tennessee limits are liberal for small equipment, but we achieved emission levels under much stricter NSPS rules. This test achieved the most successful start for the LMF, with more than 80 hours of operation accumulated without interruption after startup. The test was interrupted because of extremely cold weather (average December temperature set a record low in Tennessee). The SHTM and sootblower modifications continued to give excellent results with respect to ash deposition. Sootblower cycles were increased to eight (8) hours for two cycles before the end of the test, with no apparent adverse effects. These blowing cycle times are more typical of commercial practice. The K_2/S ratio varied somewhat and was higher than the goal for much of the test. This probably contributed to deterioration of the performance of the ESP, which could not be evaluated at various flow rates. During and after this test, more than 51,200 pounds of solids were collected.

Details of the results are given below.

SUMMARY OF TEST RESULTS

Ash Deposition

One of the major low mass flow (LMF) train revisions completed in 1989 was the tube bank/heating surface. This change was made to achieve gas temperature distributions at superheater test sections that simulated expected temperatures in retrofit designs. Based on the expected retrofit conditions and on airheater tube and baghouse/electrostatic precipitator inlet temperature limitations gas temperature goals were established. These were 2250°F at the Test Section 1 (TS1) inlet, 1750°F at TS2 inlet, 1350°F at TS3 inlet, 600-800°F at AH inlet and 350-400°F at the SHTM exit. The surface change also included widening gas lanes to reduce ash deposition severity. Four additional retracting sootblowers, as used in commercial coal fired systems, were also added to improve deposit removal capability. These changes were effective in achieving gas temperature goals, as shown on Figure 1. This figure shows that SHTM inlet and outlet temperatures were satisfactory. The temperature at TS2 was sufficiently high to achieve desired metal temperatures. Additional adjustment is also possible through judicious soot blowing schedules, as is also shown on Figure 1. However, even with this flexibility, the temperatures entering TS3 were sufficiently low that additional cooling surface was removed just upstream of this test section. The revised configuration will be in place for LMF4-T.

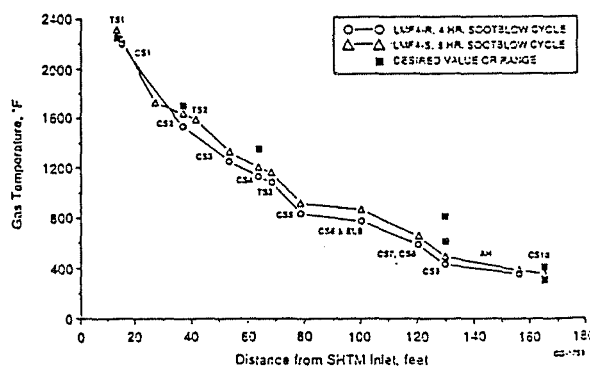

Figure 1. Gas Temperature Distribution Through LMF

The surface changes and additional retracting sootblowers were also very effective in reducing the ash deposition throughout the superheater test module. Sootblower frequency has been reduced throughout the test series as techniques were developed and equipment added to reduce ash deposition. Post-test inspections showed very clean conditions throughout the system except for TS1. The deposition was controlled even though high K_2/S ratios were used, which had caused problems with the past configuration and operating procedure. After the most recent changes, the interval between blowing cycles was increased to 8 hours. This frequency is more typical of power plant practice, depending on the deposition severity. Additional testing is required to confirm these results for longer periods of 8-hour cycles, and perhaps longer intervals between blowing cycles. The TS1 deposition has not resulted in gas lane pluggage, but provisions are being made to reduce deposition. This will assure long term continuous operation.

Corrosion

Half of the test section (TS) tubes were removed from the SHTM after 500 hours of exposure on coal and examined microscopically. This half is of the same materials as the tubes remaining, and the tubes removed were replaced by new tubes, also of the same materials. This will provide data for 500 h, 1500 h and 2000 h of operation with Illinois No. 6 coal. Measurements of the tube external corrosion scale thickness and depth of intergranular sulfide penetration are shown in Figures 2 and 3 for TS1. Of the

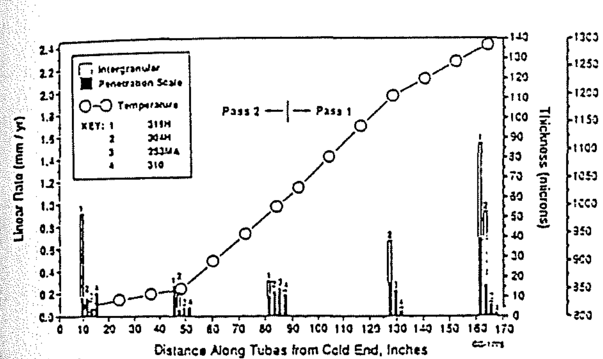

Figure 2. 500 Hour TS1 Front-of-Tube Corrosion

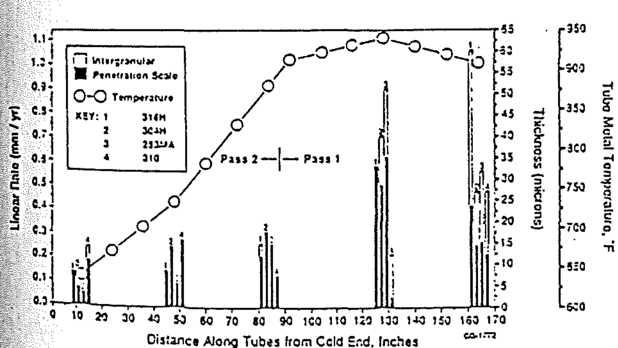

Figure 3. 500 Hour TS1 Back-of-Tube Corrosion

4 alloys, 304H, 316H, 253MA, and 310, tested, 310 had generally the least attack. On the first (hot) pass of TS1, the depth of sulfur penetration was similar to the corrosion scale thickness. The location of the maximum attack around the tubes was variable among the tubes, some being at the front and some at the back. Maximum TS1 tube linear attack rates as measured by the sum of scale thickness and penetration were about 2.3 mm/yr for 316H, 0.9 mm/yr for 304H, 0.9 mm/yr for 253MA, and 0.5 mm/yr for 310. If 0.5 mm/yr is taken as an acceptable limit, all the measured maximum loss rates were at or above this limit. The 316H and 304H alloys had bilayer scales, the inner layer being Cr-rich oxide/sulfide and the outer being Fe-rich oxide. The 310 and 253MA had single Cr-rich oxide scales with small amounts of sulfide. Despite lower gas temperatures at TS2 than at TS1 (1600°F vs. 2250°F), resulting in powdery rather than hard, dense deposits, the TS2 corrosion attack was not less than at TS1. Maximum metal temperatures were the same. Measurements of the tube external corrosion scale thickness and depth of intergranular sulfide penetration are shown in Figures 4 and 5 for

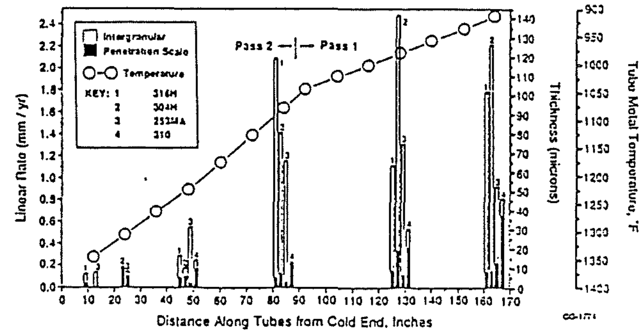

Figure 4. 500 Hour TS2 Front-of-Tube Corrosion

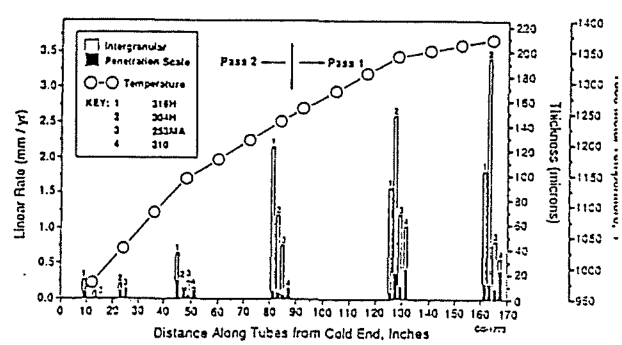

Figure 5. 500 Hour TS2 Back-of-Tube Corrosion

TS2. Corrosion scale thicknesses were in some cases greater for TS2 than for TS1, and the depth of intergranular attack was substantially greater, particularly at the downstream side. The nature of the TS2 intergranular attack was different in that it was associated with pitting. If this intergranular attack is omitted as not associated with normal operation, the maximum TS2 linear attack rates obtained from the scale thicknesses alone were 0.25 mm/yr for 316H, 0.37 mm/yr for 304H, 0.40 mm/yr for 253MA, and 0.40 mm/yr for 310, all below the 0.5 mm/yr limit criterion. The typical 316H scale/penetration morphology exhibited the same bilayer scale as at TS1 but with different mode of intergranular attack. Corrosion rates are typically higher when multiple operating cycles are experienced. Analyses of test section materials is continuing by UTSI, Argonne National Laboratory (ANL) and Babcock & Wilcox (B&W). Details will be discussed in other papers.

Baghouse (BH) and Electrostatic Precipitator (ESP)

The BH was operated during all CY 89 tests. The filtration velocity through the baghouse was nominally set at 2 ft/min, but this velocity was increased to as high as 2.4 ft/min. Cleaning cycles (reverse gas with sonic assist) were initiated when the pressure drop across the bags exceeded 10 inches water column. Residual pressure drops (measured immediately after cleaning) ranged from 2 - 3 inches wc. The time between cleaning cycles generally averaged 2 hours or longer at a filtration velocity of 2 ft/min. Operating with a filtration velocity of 2.4 ft/min reduced the time between cleaning cycles to approximately 70 minutes. Collection efficiencies under all conditions were normally an order of magnitude greater than required by NSPS standards.

One source of operating difficulties resulted from acid condensation and subsequent failure of steel top caps which hold tension on the bags. The reverse gas ductwork located atop the BH tends to condense acid gas which then drips onto the top caps of the bags. During LMF4-Q, these caps caused several bags to rip as the cap failed under load. Examination of the bag material by the Gore Company showed good bag permeability and burst strength (Tables 1 and 2), and the permeability was equivalent to a bag tested 3 years earlier which indicates no measurable blinding of the bag material. The burst strength of a new bag normally declines by 50% within the first two weeks of service. The acid attack is currently being reduced by 1) using stainless steel top caps, 2) placing drip plates under the reverse gas ductwork, and 3) insulating the reverse gas ductwork to increase the flue gas temperature.

Table 1.
Permeability Data for Gore-Tex Bags
(CFM/FT^2 @ 0.5" H_2O)

Description	Average	% Increase
As Received	4.2	----
After Light Brushing of Front Surface	4.2	0
After Vacuuming Front Surface	4.4	4.8
After Vacuuming Back Surface	4.7	6.8

Table 2.
Mullen Burst Test Results
for Gore-Tex Bags (psi)

New Mat	Top	Middle	Bottom	Average	%Loss
450	228	242	261	244	46

The ESP was operated at selected specific collection areas (SCA) which varied between 375 and 550. During conditions of molar potassium to sulfur ratios below 1.0, the ESP performance was similar to previous tests. Under these conditions, the ESP will meet NSPS at an SCA of approximately 400, although performance is erratic. However, under testing conditions with K_2/S = 1.3, the performance declined rapidly. Increasing the SCA and thereby reducing the gas flow rate through the ESP did improve the collection efficiency.

The ESP performance cannot now be predicted from gas flow alone. Efforts are underway to determine the cause of the degraded performance, especially under high K_2/S ratios. Although no definite cause has yet been determined, possibly an increase in total potassium into the combustor leads to an increase in the number and concentration of particles under one (1) micrometer. Figures 6 and 7 show the ash/seed particle size distribution for K_2/S ratios of <1.1 and <1.3. These data iondicate higher concentration of fines for the higher K throughputs. The data are reported as number or weight per dry normal cubic meter (DNCM) divided by the log differences in diameters (DLOGD). The concentration of particles entering a field can exceed the ability of the ESP to charge them (ion quench) which causes lower collection efficiencies (see Figures 6 and 7). This impactor data was normalized by dividing by the logarithmic differences in diameters of the individual cut points. More data collection is planned in the upcoming CFFF tests to verify these early findings.

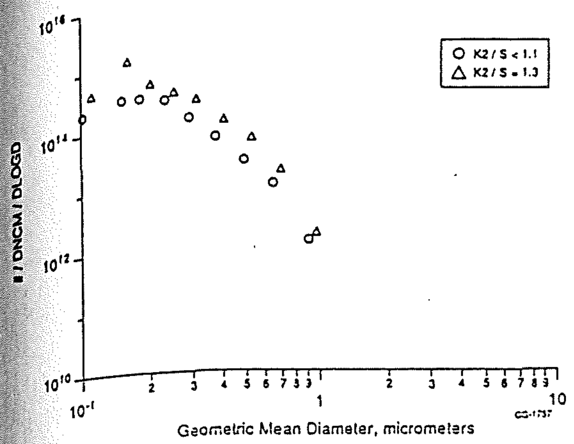

Figure 6. Differential Number Size Distribution of Particles Entering the ESP

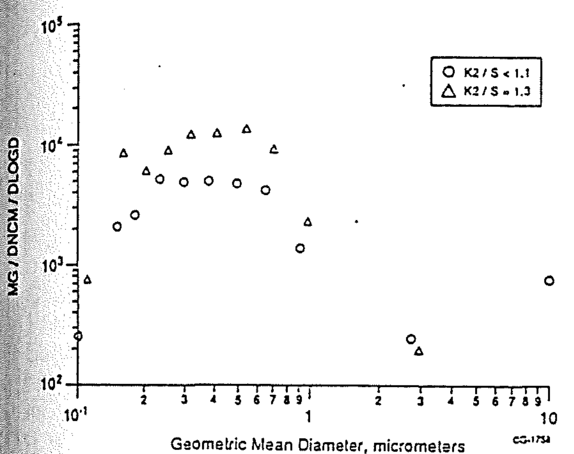

Figure 7. Differential Mass Size Distribution of Particles Entering the ESP

Pollution Control/Tennessee Compliance Test

The State of Tennessee requires an operating permit for the CFFF. The facility must pass selected criteria to obtain the permit. In general, the criteria are less stringent than NSPS and self-imposed limits. However, they do require a significant testing effort to document the results. Testing for SO_2 and particulates was completed in 1989. The results are shown in Table 3 and Figure 8. Permit limits were met for both SO_2 and particulates. The particulate emissions are based on stack measurements and include the totals through the baghouse, electrostatic precipitator and the gas which bypasses the loosely fitting damper controlling flow through the venturi scrubber. Measurements to determine the BH and ESP performance are made just before and after each piece of equipment.

Table 3.
Particulate Emissions Compliance Test*

Run 1	Not Completed
Run 2	0.0547 lb/MMBtu
Run 3	0.0647 lb/MMBtu
Run 4	0.0398 lb/MMBtu
Run 5	0.0461 lb/MMBtu
Run 6	0.0605 lb/MMBtu

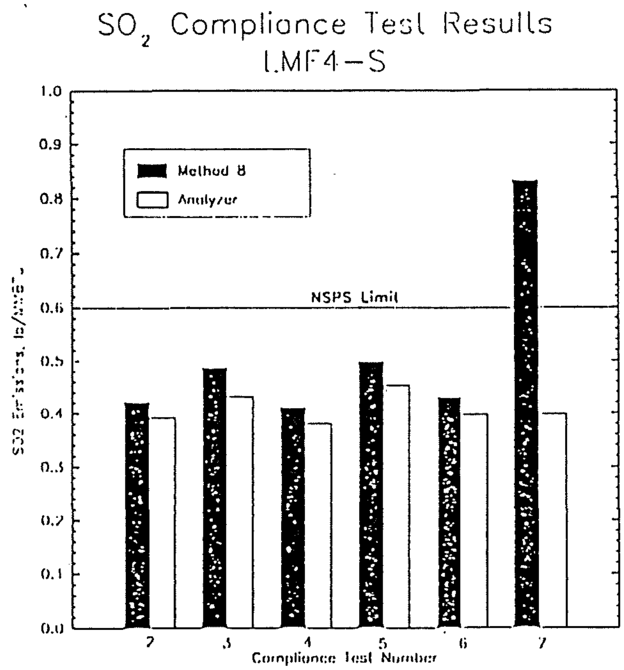

Figure 8. Compliance Test Results for LMF4-S

High Temperature Air Heater

UTSI personnel began limited work on materials that potentially may be used in a high temperature air heater, which will increase the efficiency of an MHD system. The preliminary work led to the conclusion that our effort should be directed toward evaluating materials that could be used in a recuperative heat exchanger. Thirty-eight specimens have been tested in the last four LMF tests. The specimens included a variety of compositions.

Two materials were identified that are worthy of further consideration. The most tolerant to corrosion and temperature was a zirconia tube provided by Norton Company. Although the zirconia was able to endure the most severe conditions (near the exit of the diffuser) it was subject to repeated cycles of thermal shock which resulted in fissures throughout the tube. Composite materials using zirconia on the outside are being considered.

The other material, while slightly less tolerant to temperature and corrosion, was seemingly unaffected by thermal shock. This was a tubular component of silicon carbide particulate reinforced alumina composite made via the Lanxide DIMOX (TM) directed metal oxidation process and purchased from Du Pont Lanxide Composites, Inc. This is a new process, and only very limited production capabilities are now available. Currently the manufacturer is able to make almost any shape in lengths up to 40 inches. Shortly, they expect to produce eight foot lengths.

The possibility of a recuperative heater led to the consideration of a concept proposed by Way[1] and Seehausen[2] for metallic heat exchangers. Some very preliminary ideas have been considered, substituting refractory materials for the metal tubes suggested in their concept (Figure 9).

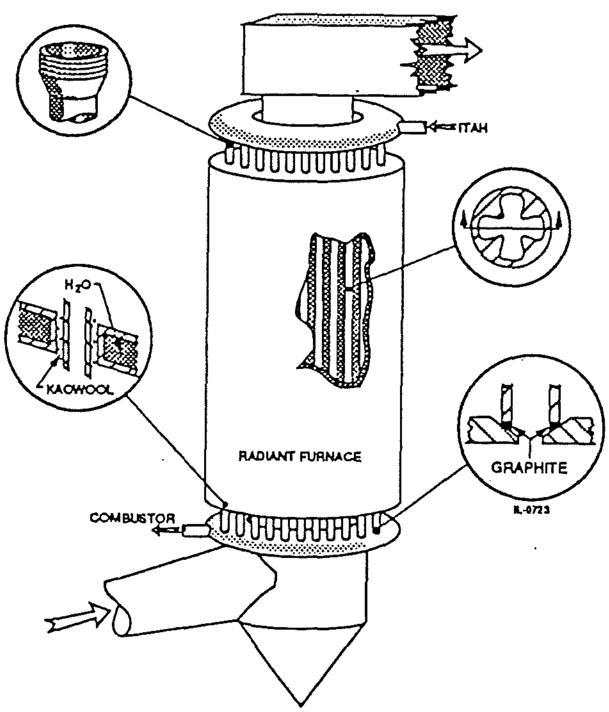

Figure 9. Recuperative HTAH Concept

FACILITY MODIFICATIONS

High Pressure Sootblower System

As noted earlier, the sootblower system is being upgraded for greater effectiveness. Detailed design and procurement of materials for a higher pressure sootblower system for the SHTM were pursued during 1989. The sootblowers on the west leg of the SHTM, which includes the three superheater test sections, will be supplied from a new 400 psig, 650 ICFM capacity air compressor system. This system, including the necessary motor control center and switchgear, was specified, procured and delivered during 1989. A new compressor shelter, with appropriate foundation and ventilation details, was also designed and specified during 1989. Excavation for the compressor shelter began in late 1989 and the shelter is now complete. Installation of the new compressor system and replumbing of the west leg sootblowers for higher pressure service is underway and the system is expected to be available for the May/June test.

Automated Ash/Seed Handling System and Western Coal Modification

As part of the "Integrated MHD Bottoming Cycle" contract, UTSI worked with Hudson Engineering Corp. (Houston, Texas) and B&W to develop capabilities at the CFFF for automated handling of seed/ash and for the processing of high moisture, reactive western coals. This work was continued from 1987 when the original contract was negotiated. During January 1989, ECP received and reviewed the Critical Design Review Report, prepared by Hudson Engineering, on the Seed/Ash Handling System. The Critical Design Review was held at UTSI on February 14, 1989, and included representatives from DOE, Hudson Engineering, B&W, and Gilbert Commonwealth.

In March responsibility for completion of the Integrated MHD Bottoming Cycle contract (both Ash/Seed Handling System and Western Coal Modifications) was turned over to UTSI. The Critical Design Review Report became the basis for in-house design efforts necessary to procure the remaining materials and install the automated seed/ash handling system. This effort was on-going through 1989 with an expected shake-down test of the CFFF during the test in May/June 1990. A schematic showing some of the key components of this system is shown on Figure 10.

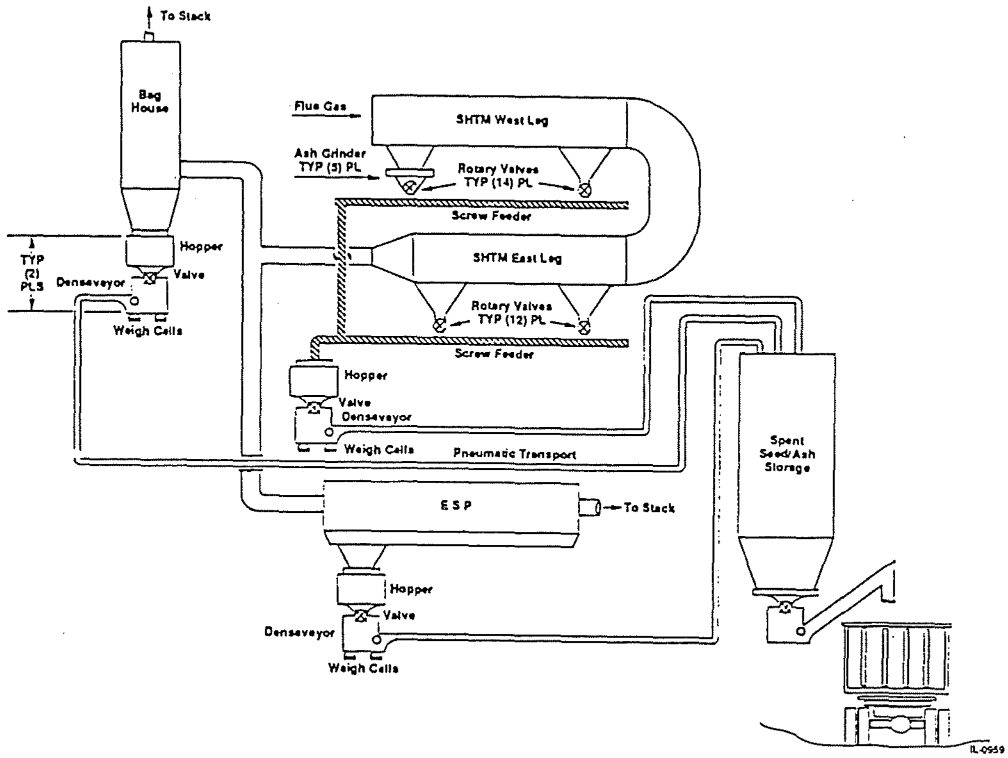

Figure 10. Ash/Seed Removal System

The preliminary Design Review for the Western Coal Modification was held at UTSI on February 15, 1989. The Preliminary Design Review Report prepared by Hudson Engineering proposed a system including a separately heated "tray dryer" manufactured by the Wyssmont Company. This equipment was felt to be necessary to achieve the 3 to 5% moisture level criteria specified for pulverized western coal in the CFFF. Later analysis demonstrated a severe economic impact of a gas-fired scaled-up version of the Wyssmont dryer on the proposed MHD retrofit plant. Activities during late 1989 included review of alternate coal drying and pulverizing schemes to achieve higher moisture levels, small scale testing of the drying characteristics of western coal, and the development of plans for the actual drying, pulverizing and feeding western coal with existing CFFF coal processing equipment.

A shipment of approximately 25 tons of Montana Rosebud coal (29% moisture) was received at the CFFF for flow testing. This coal was stored in the feed tank to the pulverizer under a nitrogen blanket. Tests were conducted with and without potassium carbonate mixing. Flow of nitrogen to the pulverizer (to prevent combustion) was set at 20,000 lb/hr. The maximum primary nitrogen temperature entering the pulverizer was limited to 550°F due to temperature limitations of the E-35 mill. Pulverizer exit temperature was maintained at 165°F for all tests.

Raw coal was fed to the pulverizer where grinding and drying occurs. Grab samples were taken at the pulverizer exit. The nitrogen conveys the pulverized coal to the baghouse where the solids are separated from the gas stream. This coal is collected in reservoir tanks until the pulverization has been completed (approx. 10,000 lb) when it is gravity fed into the feed tank and pressurized with nitrogen.

The first test was conducted without mixing potassium carbonate (seed) with the coal. Moisture at the pulverizer exit averaged approximately 14%, while the feedtank moisture was only 7% (see Figure 11). Drying

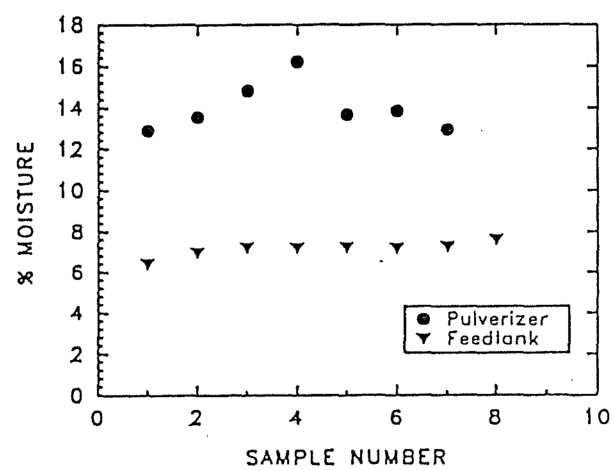

Figure 11. Moisture of Montana Rosebud Coal Pulverized at CFFF Without K_2CO_3

does occur from the pulverizer exit to the feedtank, especially since dry nitrogen was used, but some of the observed difference may be caused by sampling technique. Probably the pulverizer exit sample is high due to condensing moisture from the gas as the sample is collected. Two samples were collected for size analysis. These samples were approximately 77% through 200 (74 μm) mesh for a raw coal feed rate of 4500 lb/hr to the pulverizer (see Figures 12 and 13).

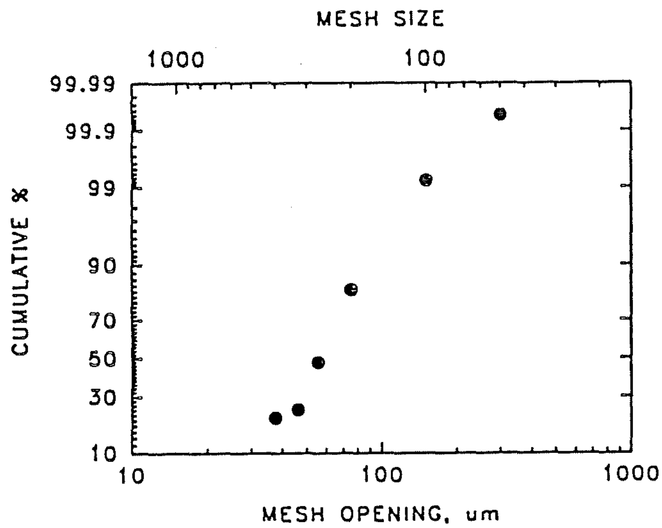

Figure 12. Size Analysis of CFFF Pulverized Montana Rosebud Coal Without K_2CO_3 (Sample 1).

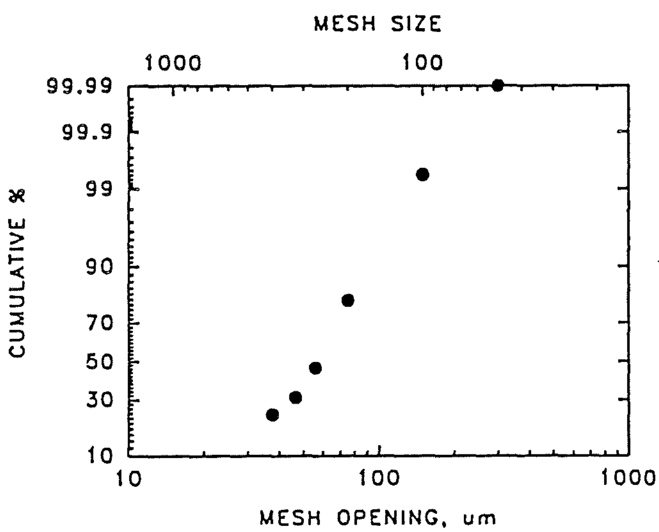

Figure 13. Size Analysis of CFFF Pulverized Montana Rosebud Coal Without K_2CO_3 (Sample 2).

In the second test sequence, potassium carbonate was mixed with coal in the pulverizer such that the dried mixture contained approximately 10% K_2CO_3. During the first portion of the test, the raw coal feed rate was 4500 lb/hr with an indicated 7 lb/min seed flow. During the last third of the pulverization, the raw coal feed rate was increased to 5000 lb/min. Pulverized coal moisture for the pulverizer outlet and the feedtank averaged approximately 15% and 6%, respectively (see Figure 14). Size analysis of pulverized coals averaged 81% through 200 mesh for both 4500 and 5000 raw coal feed rates (see Figures 15 and 16).

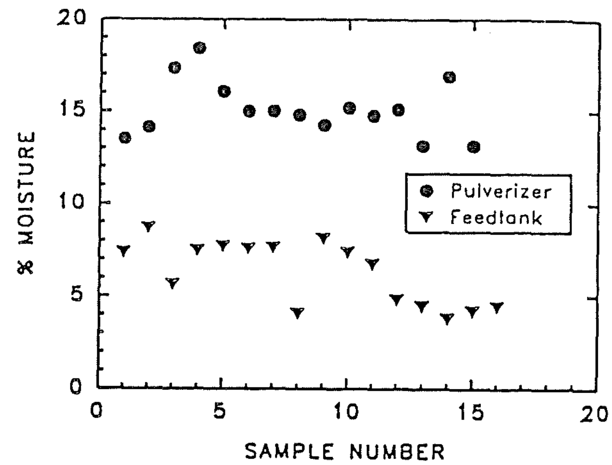

Figure 14. Moisture of Montana Rosebud Coal Pulverized at CFFF with 10% K_2CO_3

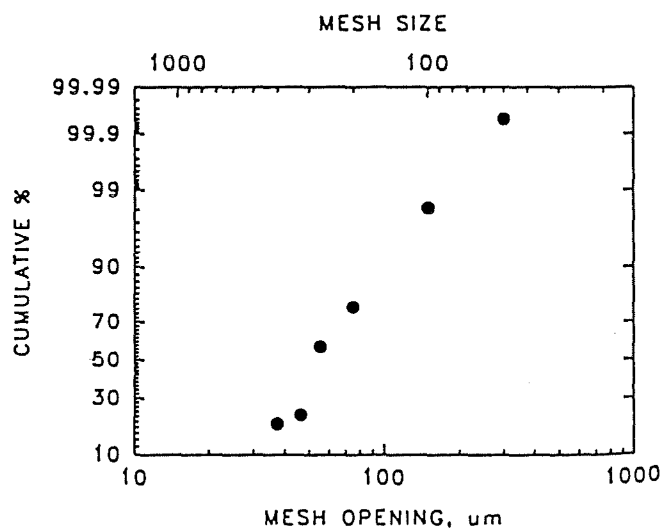

Figure 15. Size Analysis of CFFF Pulverized Montana Rosebud Coal With 10% K_2CO_3 (4,500 lb/hr raw coal feed rate).

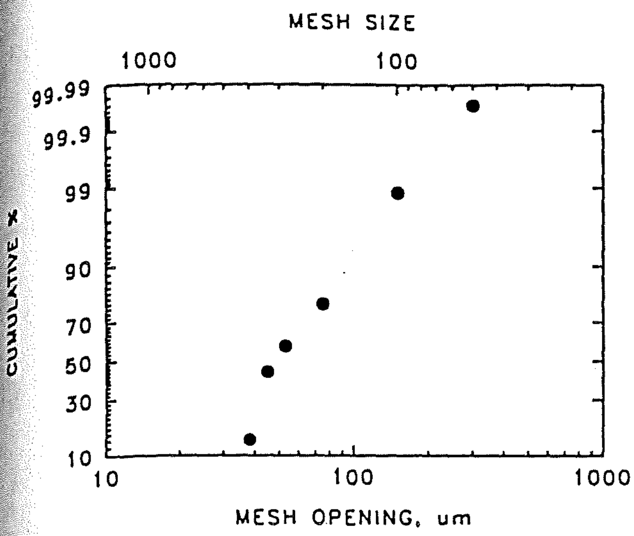

Figure 16. Size Analysis of CFFF Pulverized Montana Rosebud Coal With 10% K_2CO_3 (5,000 lb/hr raw coal feed rate).

Subsequent flow tests at the CFFF of the pulverized coal were very successful with no flow stoppages. Flow smoothness was observed to be comparable with that of Illinois #6 coal. Flow rates were varied from 0.8 to 1.5 lb/sec with no observable control problems.

In preparation for specifying and procuring a system at UTSI, six different process options were developed to dry Montana Rosebud coal at the CFFF. Based on a number of factors (capital cost, operating cost, installation schedule, simplicity, etc.), one option was selected and recommendations were given to PETC. The option selected (see Figure 17) has a closed-loop inerted gas system which is heated indirectly with an oil or gas fired burner. The heated gas is used to dry the coal and carry the coal to the baghouse. The moisture in the gas exiting the baghouse is removed by a water-cooled condenser. The water supplied to the condenser is tentatively cooled with a chiller. The dried gas (dewpoint of 90°F) from the condenser then returns to the heater, thus completing the loop. Oxygen contained in the inert gas loop is maintained below 7%, with nitrogen make-up. Because the primary 'air' to the pulverizer will be 650 to 700°F, the existing E-35 mill will require an EL modification.

PLANS

During the next year several major activities are planned:

1. Conclude the 2000 hour program on Illinois No 6 coal, including exposure of superheater corrosion specimens for 2000 hours.
2. Complete and evaluate high pressure sootblowing system and ash/seed removal system.
3. Complete design and installation of an intermediate temperature air heater.
4. Complete installation of the western coal preparation modification and initiate western coal tests.
5. Complete 1300 hours of POC testing on eastern and western coals.

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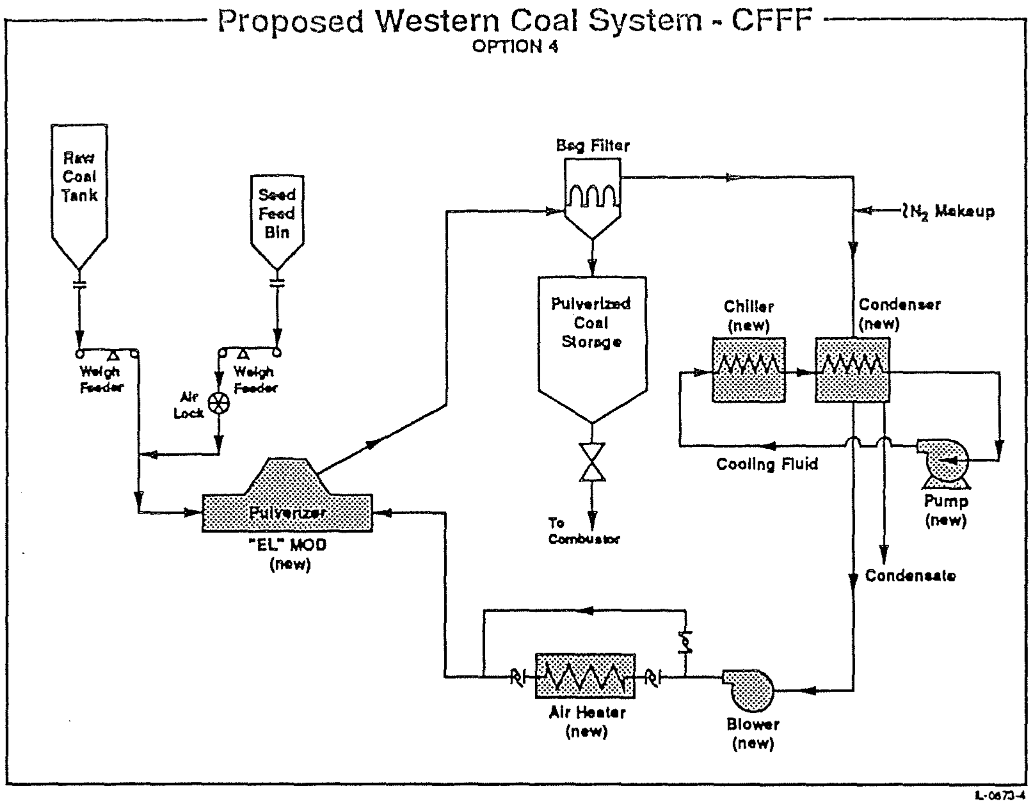

Figure 17. Proposed Western Coal System - CFFF