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ADVANCED SLAGGING COAL COMBUSTION SYSTEM, ASCCS

Final Report, Volume 1

Test Task Results

June 1989

Work Performed Under Contract No. AC22-84PC60422

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

By
TRW Space and Technology Group
Redondo Beach, California

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PREPARED FOR:

UNITED STATES DEPARTMENT OF ENERGY
PITTSBURGH ENERGY TECHNOLOGY CENTER
PITTSBURGH, PA 15236

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ABSTRACT

TRW has developed an advanced slagging coal combustor for the conversion to coal of coal-, oil-, and gas-fired boilers, furnaces. kilns, and other heat utilization equipment. The U. S. Department of Energy, Pittsburgh Energy Technology Center, has sponsored research for the establishment of a broad, commercially acceptable, engineering data base to advance coal as the fuel of choice for these retrofit conversions.

A partially developed, slagging combustor was characterized at a thermal power level of 10 MM Btu/hr with Eastern and Western pulverized coals, and an Eastern coal water mixture. Scaling and Performance verification testing was performed on a full scale 50 MM Btu/hr combustor. The TRW 50 MM Btu/hr combustor was then mated with a TRW supplied boiler simulator to investigate combustor interaction effects with downstream heat utilization equipment.

This final technical project report presents the results of a three year effort to develop a data base for coal conversions. Significant contributions have been made in coal mineral matter removal (90%+), NOx control through combined fuel and oxidizer staging (to 250 ppmv), and characterization of the combustor particulate effluent (4 micron mean diameter, 5% above 10 microns). Fair SOx control was achieved at the 30% to 40% reduction level. The ability to use coal water mixtures as a fuel delivery option was met with limited success.

EXECUTIVE SUMMARY

Historical Background

TRW became involved in coal combustion Research and Development in 1975 with a design study for magnetohydrodynamic (MHD) applications. TRW turned the preliminary design concepts into reality in 1976 when sizable company funds were expended in early experiments with various coals and the erection of a 10 megawatt thermal (MWt) experimental test facility. A total of 242 combustion experiments were conducted and 55 tons of coal were consumed in these early experiments. As a point of reference, this 10 MWt combustor was the only continuously operating MHD coal combustor of its size in the U. S. during its development testing which spanned 2 years.

In 1978, TRW received a DOE contract to demonstrate a 20 MWt high pressure coal combustor in competition with two other combustor designs. At the same time, TRW in its commitment to coal combustion research and development, planned, designed and constructed a multi-million dollar fossil energy test facility to conduct the necessary research for this type of program. This facility, designated FETS (Fossil Energy Test Site), has been expanded, upgraded and has been used for the majority of TRW's coal combustion R&D activities.

After two years of extensive testing, TRW was selected as the winner of the competition. TRW continues to be the leading MHD coal combustor contractor in the U. S.

Due to the diminishing oil and natural gas availability, especially following the Arab oil embargo in 1973, TRW, in 1974 began to seriously consider expanding the industrial and power generation usage of our most abundant natural resource: coal. It was TRW's intent to become involved in the research and development and ultimate commercialization of industrial and utility coal combustors for gas- and oil-fired boiler retrofits. To this end, and using corporate resources, TRW began to develop the atmospheric slag rejecting coal combustor. Based upon the MHD technology which existed at the time, TRW began development of retrofit coal combustors in 1976 with tests of a single stage, slag rejection combustor at low pressure, low air preheat and substoichiometric conditions. This testing, design and system studies resulted in a proposal by TRW to DOE in 1979 for an industrial boiler retrofit combustor. That procurement, however, was delayed until the emergence of the Notice of Program Interest for "Innovative and Partially Developed Concepts in Coal Combustion Systems" in 1982. The work which this final report describes was a direct result of that NOPI. A contract was awarded to TRW in early 1984.

From early 1979 to the present TRW has been progressing along two paths towards commercialization of complete coal combustion systems for the application to industrial and utility boilers, process heaters, and furnaces.

Path one has been primarily concerned with the technical advancement of slagging coal combustors with respect to basic technology issues and the definition of technical requirements directly related to their application. To this end, a 17 - inch diameter coal combustor was constructed and placed into test by TRW early in 1981. This combustor was dedicated to near ambient pressure operation for boiler retrofit applications and tested with a wide variety of coals and over a wide range of operating conditions. This development work was intensified during 1981 and 1982, bringing the retrofit technology to a "partially developed status." TRW was awarded a contract by DOE/PETC in 1984, entitled Advanced Slagging Coal Combustion System (ASCCS), to establish a broad, commercially acceptable engineering data base for the advancement of coal as the fuel of choice for boilers, furnaces, and heaters.

Simultaneously, TRW was in the process of scaling the 17 - inch diameter combustor to a firing rate of 50 MM Btu/hr to obtain scaling data for a single vectored project directed at retrofitting a small industrial boiler located in Cleveland, Ohio. The ASCCS project was directed at ascertaining the overall technical capabilities of the slagging coal combustor to meet retrofit requirements constrained by environmetal issues.

In the early 1980's, as part of path two of the general effort underway, TRW teamed with Stone and Webster, an East Coast engineering and construction corporation with extensive experience in boilers, power plants, and coal combustion and handling systems. This path began with extensive technical and market analyses for the commercialization of TRW's slagging coal combustion technology. That path has culminated in the first field endurance demonstration of a nominal 50 MM Btu/hr commercial prototype slagging coal combustor. The endurance test was highly successful and provided the technology base for submitting a Clean Coal Program proposal for the retrofit of a small utlity boiler. A contract with DOE has been recently negotiated and this program is currently also underway.

The slagging coal combustors share a common heritage from the early MHD combustors and the 17 - inch diameter atmospheric combustor. All combustors have a two stage precombustor, a slagging stage for molten ash removal, and varying methods for introducing the final combustion air in a host boiler, process heater, or furnace. The Cleveland Demonstration Project combustor is based upon a workhorse 34 - inch diamter unit located at TRW's Capistrano Test Site (CTS). The workhorse combustor was extensively used for the ASCCS test phases. The Cleveland combustor is TRW's first generation commercial prototype unit. The Demonstration Endurance Test objectives were to accummulate reliability and maintainability data over a 4,000 hour firing time. The R & M data included all plant systems from coal receiving to stack exhaust. The 4,000 hour test was successfully completed. Test results during commercial operation confirmed earlier performance characteristics obtained with the workhorse unit. Overall plant performance exceeded expectations. Carbon conversion exceeded 99.5%, and NOx emissions were well within acceptable industry limits. The system was operated under a variance from the State of Ohio relaxing the requirements for SOx control, as this combustor does not have SOx control capability. The combustor availability was over 90%. Long-term tube erosion and corrosion characteristics were well within acceptable industry limits. A post-test boiler inspection revealed no indication of any change. Water walls and convection tubes remained leak tight, and the refractory floor and lower walls were still in good condition.

The Cleveland Demonstration combustor system is currently being used to evaluate TRW's method of in-furnace sulfur emission control (Secondary Air Sorbent Injection, SASI). This work is being sponsored by the Ohio Coal Development Office (OCDO) and ESEERCO (Empire State Electric Energy Research Corporation). Data obtained from this activity will be fed into the Clean Coal Program. The system has also been used to test the applicability of high ash, and low volatile material coals to support the TRW Combustion Unit's commercialization activities.

TRW's Clean Coal Technology Program with the Department of Energy is focusing on a multiple combustor (4) retrofit of a small utility boiler operated by Orange and Rockland and located in Pearl River, New York. The unit has a plate rating of 69 MWe, and will be retrofitted with four, 160 MM Btu/hr slagging combustors. These combustors have been designated as second generation commercial prototypes as design improvements have been incorporated as a result of the Cleveland Demonstration Test. This program is the first retrofit of the TRW slagging combustor for utility applications. Particulate control is primarily achieved by the slagging stage, and ultimately by a bag house. NOx control is achieved by staged combustion and the judicious use of overfire air within the host boiler. Sulfur control is external to the combustor and takes place within the host boiler by TRW's SASI method. The results of the ongoing sulfur control work in Cleveland will provide input data for implementation. The technical issues of multiple combustor installation, operation, and performance will be delineated as a result of this program. The retrofit installation and plant start-up activities are currently scheduled to occur during the third quarter of calendar year 1990.

<u>Summary of Results</u>

A two-phased approach was utilized in performance of the Advanced Slagging Coal Combustion System Development Project. Phase I concentrated on further characterization testing of the sub-scale, 17 - inch combustion system to obtain scaling correlation data for the 50 MM Btu/hr combustor. Following these tests, the 50 MM Btu/hr combustor was subjected to scaling and performance verification testing on Western and Eastern pulverized coals, and an Eastern coal water mixture (CWM). Schematics of these combustors are shown in Figure ES-1, and Figure ES-2. The precombustor of the 50 MM Btu/hr combustor is not shown for clarity purposes. A total of 28 tests were run on the 10 MM Btu/hr sub-scale combustor, and 53 tests were run on the 50 MM Btu/hr combustor.

The major results are grouped in the following performance categories:

1. Carbon utilization
2. Slag Recovery
3. Pressure drop correlation
4. Cooling load characteristics
5. Minimum air preheat requirements
6. Particulate carry-over characteristics
7. NOx emissions
8. SOx emissions

In general, the performance of the larger combustor was superior in all aspects to that of the sub-scale combustor. The single most important aspect of the combustion process was identified with the operation of the precombustor. A properly operating precombustor drives the entire downstream combustion process by locking combustion in the head-end of the combustor which produces very high carbon utilization efficiencies and attendant slag removal efficiencies. The carbon conversion efficiency is best measured by analysis of the exit gas composition, rather than by a measurement of carbon in the slag tank effluent. Carbon utilization efficiencies of 99% + were measured for the 50 MM Btu/hr combustor at slagging stage stoichiometries of 0.75 and above. Comparable efficiencies for the sub-scale combustor required slagging stage stoichiometries of 0.85 and above.

The precombustor exit temperature played a large role in the overall combustion process. Western coals, which have higher volatile material contents, require minimum outlet temperatures of 1600 F to achieve slag recoveries of 80%. An increase to an outlet temperature of 1850 F raises the slag recovery to 94%. Eastern coals, due to their lower volatile material content, require outlet temperatures in the range of 1850 F to 2200 F to achieve comparable slag recoveries. The slagging characteristics and slag recoveries were considerably improved with the larger combustor. This was a beneficial effect of scale. The larger combustor would also perform well with a minimum air preheat temperature of 275 F, whereas, the sub-scale combustor required a minimum preheat of 500F.

A similar effect of scale was observed in the operating pressure requirements. The nominal system operating pressure for the 50 MM Btu/hr combustor was 40 to 45 inches of water; the corresponding system operating pressure for the sub-scale combustor was 60 inches of water.

The overall cooling load for the 50 MM Btu/hr combustor was reduced when compared to the sub-scale combustor, i.e., from 22% to 17% at nominal stoichiometries of 0.75 to 0.80. Approximately 60% of the cooling load is taken out after the slagging stage baffle. Long transition ducts will have overal system cooling load integration implications.

The range of particulate size distributions for the combustor operating without a boiler simulator indicated acceptability for oil- and gas-fired retrofits, i.e., @ 10% of the particles greater than 10 microns diameter. The Phase 2 test results, described subsequently, further clarified this aspect.

The emission of oxides of nitrogen was found to correlate with the level of fuel bound nitrogen in the coal. Typical NOx emissions were 350 ppmv to 450 ppmv for Eastern coals, and 250 ppmv to 450 ppmv for the Western coals. The NOx emissions were found to be very sensitive to the slagging stage stoichiometry and moderatly sensitive under turndown conditions. NOx would increase under higher stoichiometries and decrease at reduced load. The above numbers were for operation without a boiler simulator, which are higher than one finds with a boiler simulator or in actual practice.

Attempts at removing sulfur by the direct injection into the slagging stage were met with disappointing results. A maximum range of 30% to 40% sulfur removal was measured, depending upon the operating parameters. Similar results were obtained with both combustors. The combustors operating with coal-fired precombustors yielded lower capture results than they did when operating with oil-fired precombustors. A considerable amount of effort was expended on trying to elucidate the reasons for these poor results. It was determined that at slagging stage stoichiometries conducive for high carbon conversion and slag recovery, and low system NOx, the thermochemical conditions were unfavorable for high sulfur capture in a reducing regime. Conversely, under conditions for high sulfur capture, low carbon utilizations and low slag recoveries would occur. It was therefore concluded that the simultaneous control of NOx, SOx, and particulates could not be achieved within the slagging stage without advanced development of a device for sulfur emission control.

A limited amount of testing was performed with an Eastern CWM and a TRW designed CWM injector. Stable slagging stage combustion was achieved with low CWM feed pressures (20 psia), and low air to CWM atomization ratios (0.15 to 0.2). A total test time of 11 hours was accumulated with the longest test being 4 hours. Carbon utilization efficiencies and slag recoveries were lower than with pulverized coal due to incomplete combustion and problems in obtaining good combustion in the precombustor stage. The use of CWM with the slagging combustor appears feasible, however, a higher level of effort is required to realize the full potential.

As part of the Phase I effort, a System Studies Task was initiated to develop complete conversion retrofit designs from the physical boiler modifications to the balance of plant requirements. To this end TRW subcontracted to Stone and Webster Engineering Corporation, and Foster Wheeler Energy Corporation to assist in developing the retrofit application designs. Four retrofit application cases were chosen for analysis. These included a small kiln, an industrial package boiler, an industrial field erected boiler, and a utility boiler. The study was completed during Phase II. The major results of the study indicated that the combustor cooling load required careful integration into the combustion air preheat system or boiler steam cycle. System derating was not required due to the indication that the flyash carry-over would not adversely affect the heat utilization equipment surfaces. A simple payback analysis was made for the retrofit conversions which indicated that the following paybacks would be achievable for a fuel price differential of $3/MM Btu (premium fuel price less retrofit fuel price) and with the system operating at a conservative capacity factor of 70%:

1. 70 MM Btu/hr kiln, 2.5 years

2. 50 MM Btu/hr industrial boiler, 40,000 lb steam/hr, 3.5 years

3. 300,000 lb steam/hr field erected industrial boiler, 4 - 100 MM Btu/hr combustors, 2.1 years

4. 410 MWe utility boiler, 16 - 250 MM Btu/hr combustors, 1.4 years.

The above analysis, however, assumes the use of compliant coal, as no provisions have been incoroprated for sulfur control. The payback periods will increase when sulfur control equipment is added. One part of the study examined the consequences of requiring flue gas desulfurization equipment to be added (FDG). The economic ramifications would make the retrofit application with existing FGD control technology unattractive.

Phase II of the project was concerned with the interaction of the products of combustion with heat utilization equipment. To this end TRW supplied a boiler simulator consisting of a furnace section and a convective pass section. A commercial secondary air windbox and injector was purchased from Peabody Engineering. The full-up combustion test train is shown in Figure ES-3. Secondary combustion characteristics and convective tube pass deposition were investigated during short term testing.

Secondary combustion characteristics were smooth and confined to a short flame (typically 6 to 8 feet). The FEGT (furnace exit gas temperature) typically ran between 1800 F and 2000 F. Simulated convective pass tube temperatures were maintained at 1000 F. Post-test analyses of the tube deposits revealed high friability indicating that normal soot blowing would be adequate for tube cleaning. A significant result was the morphology of the deposits. Spherical particulate deposits were observed. The size distribution, as determined in a micromerigraph, revealed that less than 10% of the deposited particles were greater than 20 microns, the distribution having a mean particle size of 5 microns. The flyash entering the convective pass section had a mean particle size of between 3 and 4 microns and only 6% of the particles were greater than 10 microns.

Figure ES-1

10 MM Btu/hr Combustor

TRW

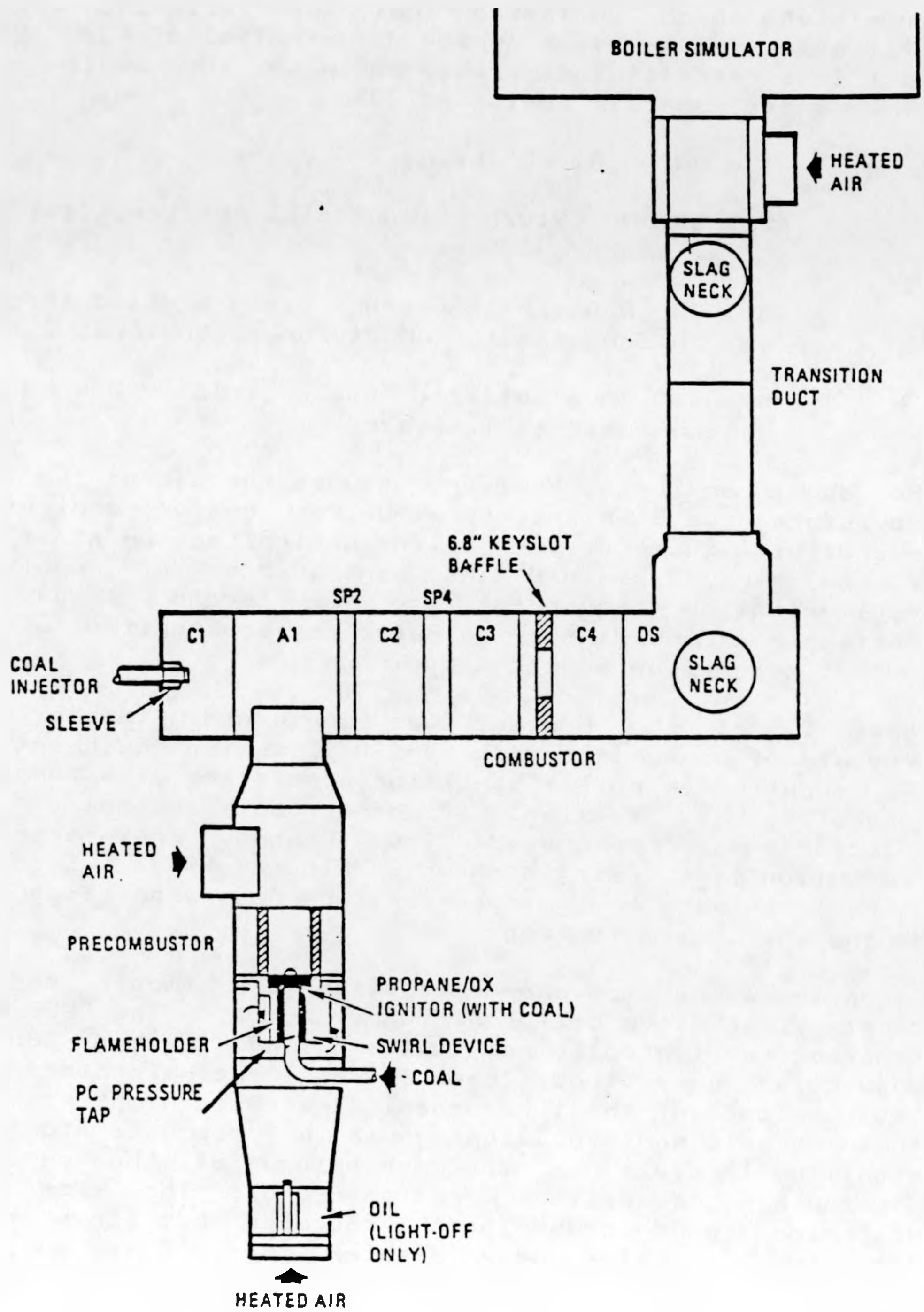

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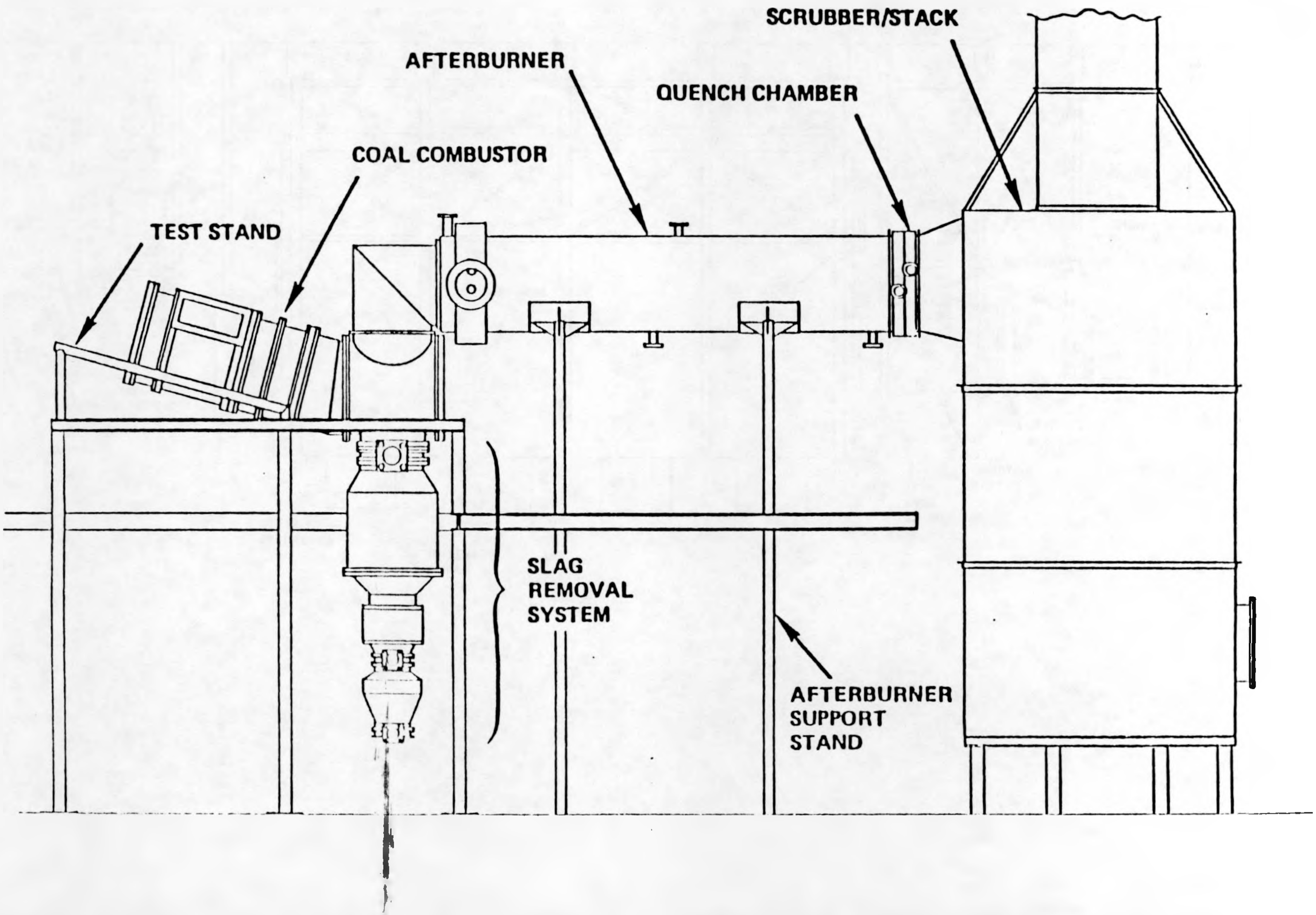
Figure ES-2

50 MMBtu/hr Combustor System



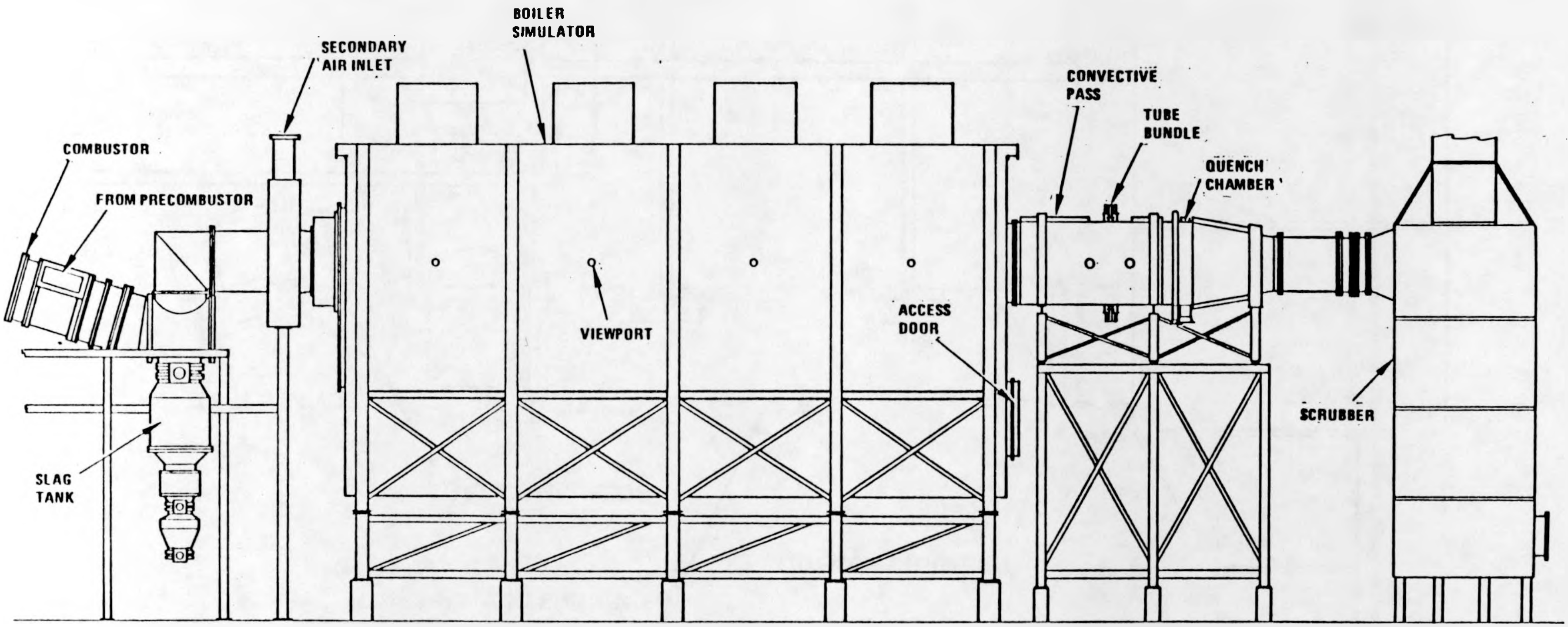


Figure ES-3. Combustion System Schematic

These data substantiated the predictions that little to no derating would be required for retrofit applications, and that long term tube erosion should not be encountered.

The system NOx levels were further reduced by the secondary combustion occurring within the furnace section rather than in a a high intensity "afterburner" type device. The less intense secondary combustion resulted in less thermal NOx generation with overall levels being lowered by about 50 ppmv.

Summary of Conclusions

The major conclusions resulting from the DOE sponsored work are:

1. The scaling criteria used by TRW in going from a nominal 10 MM Btu/hr combustor to a 50 MM Btu/hr combustor have been verified.

2. A direct benefit of scale has been observed. Carbon conversion efficiencies and slag recovery values have increased at equivalent stoichiometries.

3. The combustion system can operate at environmentally acceptable NOx levels for industrial applications.

4. The slagging combustor concept is applicable to a wide range of coals and the preliminary feasibility of firing with a coal water mixture has been shown.

5. Sulfur removal by direct injection into the slagging stage is not feasible.

6. Derating of furnaces, boilers, and other heat utilization equipment is not anticipated due to the low level of particulate matter escaping the combustor and the small size distribution of that particulate matter.

7. The economic coversion analyses reveal retrofit applicability to a range of small kilns and boilers up to full size utility boiers. The economic recovery periods are acceptable at fuel price differentials of $3/MM Btu and becomes even more attractive as the size of the retrofit application is increased.

Summary of Recommendations

There are two major recommendations which, when implemented, will greatly enhance user acceptability of the TRW slagging coal combustion concept for retrofit applications:

1. An intensified effort is required in order to develope a method for the simultaneous control of NOx, SOx, and particulates. This effort is anticipated to introduce advanced sulfur emission control technology to a point where commercial acceptance could be achieved.

2. More development work is required with the combustor/ coal water mixture fuel combination. Only a partial understanding of the combustor operation with CWM was achieved. The technology issues for CWM firing require additional delineation.

CONTENTS

CONTENTS (CONTINUED)

1.0 INTRODUCTION

The Pittsburgh Energy Technlogy Center (PETC) has implemented a number of research and development projects that will lead to the establishment of a broad, commercially acceptable engineering data base for the advancement of coal as the fuel of choice for boilers, furnaces, and heaters. This includes new installations and those existing installations that were orginally designed for oil or gas firing. The data generated by these projects should be sufficient for private sector decisions on the technical, economic, and environmental feasibility of using coal as the prime fuel of choice. It is also intended that this work will provide incentive for the private sector to continue and expand the development, and application of these combustion systems.

TRW was one of several corporations selected by the U. S. Department of energy to participate in advancing coal combustion system technology. TRW had taken a slagging coal combustor concept and partially developed it to the point where advanced development was deemed feasible. The Advanced Slagging Coal Combustion System Development Project, Contract DE-AC22-84PC60422, was initiated in February 1984, and was concluded in June 1987.

The partially developed combustor, rated at 10 MM Btu/hr, was further characterized on Eastern and Western pulverized coals, and an Eastern Coal Water Mixture (CWM). Data were obtained to determine: scaling parameters to a full-scale, 50 MM Btu/hr combustor; the potential for meeting particulate, NOx, and SOx emission standards. A TRW provided 50 MM Btu/hr combustor was tested for scaling and performance verification parameters. These tests demonstrated that the slagging combustor stage could reject 90% of the coal mineral matter as slag, and reduce NOx emissions to the 250 ppmv to 350 ppmv range. Sulfur reduction testing by the direct injection of appropriate sorbents into the slagging stage indicated emission reductions of 30% to 40%.

The same combustor, i.e., 50 MM Btu/hr, was then mated to a TRW provided boiler simulator consisting of a furnace section and a convective pass test section. Secondary burner characteristics and downstream heat utilization equipment interaction effects were investigated. Pulverized, Eastern coals were used. Smooth, stable, secondary combustion was observed. NOx emissions in the 250 ppmv range were recorded. Flyash carryover was quantified as to particulate size distribution, chemical composition, and morphology. The flyash was of a dominant spherical shape with 5% of the particulate above 10 miccons. Short term testing revealed highly friable deposits on the simulated convective pass tubes. No slag spillover effects from the combustor into the furnace volume were noticed.

This final technical report describes the combustors and combustion systems evaluated during the course of the contract. The System Studies analyses are summarized in this report, while the detailed analyses are contained in a separate report.

2.0 PROJECT DESCRIPTION

2.1 OVERALL APPROACH

The work statement for the Advanced Slagging Coal Combustion System Development Project (ASCCS) subdivided the work into two phases and eight tasks as shown below:

Phase I - Combustor Characterization and Scaling

Task 1 - System Studies

Task 2 - Characterization Tests, 10 MM Btu/hr

Task 3 - Scaling and Performance Verification Tests, 50 MM Btu/hr

Task 4 - System Integration Design

Task 8 - Program Management and Control

Phase II - Combustion System Interactions

Task 5 - Secondary Air Injector and Tube Bundle Fabrication

Task 6 - System Interaction Tests

Task 7 - Fuel Evaluation (Optional task, not performed)

Task 8 - Program Management and Control

The tests were performed at TRW's Capistrano Test Site (CTS). The Phase I testing was performed using TRW designed and fabricated combustion system "workhorse" combustors. Phase II testing included a boiler simulator supplied by TRW.

2.2 TASK DESCRIPTION AND STATEMENT OF WORK

2.2.1 (Task 1) System Studies

Combustion system integration studies were conducted by a team of engneers from TRW, SWEC (Stone and Webster Engineering Corporation), and FWEC (Foster Wheeler Energy Corporation). These studies considered the complete combustion system from coal preparation to stack exhaust. During Phase I, the system studies task concentrated on the technical and economic requirements for the conversion of utility boilers, industrial boilers, process heaters and furnaces, including identification of their technical and economic sensitivities.

The major technical issues included, but were not limited to:

- o Compatibility of furnace designs and sizes with proposed coal combustion systems and modifications, as required to implement the conversion to coal.

- o Compatibility of existing convective pass design characteristics with proposed combustion system, and modifications, as required, to implement the conversion to coal.
- o Fan and air preheat requirements and modifications.
- o Integration of combustion system cooling.
- o Mechanical interfacing problems.
- o Coal storage, preparation, and feed system requirements.
- o Slag removal system requirements.
- o Emission control and requirements: NOx, SOx, and particulates.
- o Derating requirements.

The system economic studies addressed:

Capital costs required to perform the conversion to coal.

Operating costs including the effects of fuel costs, down times, system efficiency and derating, and maintenance costs.

At the end of Phase I, a combustion system was defined for each of four application areas. The following application areas and approximate single combustor size were selected as the starting point for the system design studies:

- o Utility boiler, 85 and 150 MM Btu/hr
- o Industrial boiler, 50 MM Btu/hr
- o Process heater, 50 MM Btu/hr
- o Furnace, 20 MM Btu/hr

2.2.2 <u>(Task 2) Characterization Tests, 10 MM Btu/hr</u>

The 10 MM Btu/hr characterization tests were conducted with existing TRW supplied combustion system test hardware. The goals of the characerization tests were to establish baseline data over a range of operating conditions relevant to industrial and utility applications for system performance and scaling verification. The data included, but was not limited to:

- o System pressure drop and cooling requirements.
- o Slag retention, spill-over, and carry-over.
- o Complete system NOx characterization.
- o Secondary burner performance including flame characterization and excess air requirements.
- o Effects of coal type on overall system performance.
- o Coal/water slurry and dry coal transport techniques.
- o Carbon conversion efficiency.
- o Compatibility at the heat utilization equipment interface.

All tests were conducted near atmospheric pressure and at a nominal coal throughout of 0.5 ton per hour, using the existing coal combustion system. Particular attention was paid to the emissions reduction characterization data for system environmental acceptability.

2.2.3 <u>(Task 3) Scaling and Performance Verification Tests, 50 MM Btu/hr Combustor</u>

The baseline precombustor, combustor, and facility were supplied by TRW. (The same air preheater system used in Task 2 was also used). A complete combustor system checkout test phase was performed with TRW funding prior to the beginning of the verification test series. Preheat temperatures were varied over the range expected, where possible, for industrial and utility applications. Stability of operation, slag surface conditions, and slag flow patterns were the criteria for evaluation and acceptance.

Once satisfactory precombustor operation was obtained, the slagging stage was operated to obtain verification of:

- o Acceptable slag flow patterns and slag recovery.
- o Heat transferred to cooling water.
- o Combustion air temperature requirement.
- o Carbon conversion.
- o Product gas composition.
- o System pressure drop.

The combustor was then operated over the range of turndown anticipated for future applictions. The scaling and performance verification tests were designed to provide basic scaling data and to investigate the NOx, SOx, and particulate emissions reduction capability. The data included, but was not limited to:

- o Fuel type effects (class, moisture, mineral matter, coal particle size and distribution).
- o Carbon conversion efficiency.
- o Slag retention, spill-over, and carry-over characterization.
- o NOx reduction characterization.
- o SOx reduction characterization.
- o Combustor pressure drop.
- o Cooling load requirements.

Test durations were approximately two hours of duration, which were sufficient to reach pseudo-equilibrium or equilibrium conditions. The actual test durations were determined by the operating conditions. Most tests were at a nominal firing rate of 50 MM Btu/hr, with excursions to determine peak load.

2.2.4 (Task 4) System Integration Design

This task provided for the design of major hardware items. These items were the secondary air injector assembly, the tube bundle assembly for the boiler simulator convective pass section and miscellaneous integration hardware. A preliminary design was generated based upon the available designs and prior test results obtained from the 10 MM Btu/hr combustion system, where appropriate.

2.2.5 (Task 5) Secondary Air Injector and Tube Bundle Fabrication and Assembly

This task involved the fabrication and assembly of the secondary air injector and convective pass tube tundle assembly. After completion of the fabrication, the subassemblies were inspected and integrated into the 50 MM Btu/hr combustor/boiler simulator system.

2.2.6 (Task 6) System Interaction Tests

This task was concerned with the influence of secondary combustion on NOx, SOx, and particulate emission levels and the interactions between the secondary flame, combustion products, boiler firebox, and convective pass sections, thus characterizing the combustor/radiant furnace integration and the effects of the resultant flue gases on the convective sections of the boiler. Typical measurements included:

- Gas composition
- Temperatures
- Pressures
- Slag capture, spill-over, carry-over
- Particle size distribution of ash entering the convective section
- Carry-over and deposits (slag/ash physical properties/composition)
- Heat transfer Characteristics

3.0 PROJECT RESULTS

3.1 SYSTEM STUDIES (Task 1)

A separate Systems Studies report prepared by Foster Wheeler Energy Corporation, Stone and Webster Engineering Corporation, and TRW describes the retrofit case studies in detail. A brief summary is presented in this section.

From its inception, the TRW slagging combustion system has been developed to serve four basic applications:

- o Industrial retrofit
- o Industrial expansion/replacement
- o Utility retrofit
- o Utility expansion/replacement

From an overall system design standpoint, the most critical of these applications involve retrofitting of gas/oil fired equipment to use coal. Typical performance characteristics/goals used in the retrofit analyses are shown in Table 3.1. Significant enhancement factors, Table 3.2, are offered which include compactness of design, refractory free construction, highly efficient combustion, and high ash removal. These characteristics, combined with low NOx operation, small size particulate carry-over and high turndown ratio, allow operational flexibility combined with low maintenance and high reliability. The characteristics/goals for sulfur capture are conspictuously absent from this table as the method of implementation, and thereby cost estimates, are currently undecided.

The combination of simplicity and compactness make the device ideal for retrofitting existing oil- and gas- fired kilns, furnaces, and boilers, even where limited space is available. For example, a combustor 3.5 feet in diameter by 6 feet long produces 50 MM Btu/hr and when scaled by a factor of five to 250 MM Btu/hr grows to only 7 feet in diameter by 11.5 feet long.

The slagging coal combustor system is integrated from standard components in a manner optimal for each individual application. For example, where required, the control console and the coal supply tank containing pulverized coal or CWM may be remotely positioned. In applications where space near the heat utilization equipment is at a premium, the design of the connecting duct may be customized so as to utilize available space.

Combustion air temperatures available with resonably priced waste heat recovery systems vary over a wide range. Air preheat temperatures of 80-350°F are common in some chemical and industrial applications, whereas, 400-650°F is typical for large industrial and utility plants. By using the steam heat exchanger, air preheat temperatures up to 350°F can be achieved. Alternately, this heat may be used as additional heat

Table 3.1 Performance Characteristics

Operating pressure (atms)	1.05 - 1.1
Air preheat temperature* (°F)	100 - 500
Equivalence ratio range (first stage)	0.7 - 0.9, 1.2 excursions
Heat release rate	1 Million Btu/ft^3
Maximum slag capture (%)	94
Carbon burnout (%)	> 99.5
NO_x (ppm)	230 - 450
Outlet temperature (°F)	280 - 3600
Precombustor discharge temperature (°F)	100 - 1800
Main combustor axis inclination	15°
Turn down	3 to 1
Coal size	70% thru 200 mesh
Coal to precombustor	15% - 25%
Coal characteristics tested ash%	6.0 - 25%
moisture	2.0 - 31.5%**
HHv Btu/lb	8,000 - 13,000

* At entrance to precombustor
** Coal water mixture

Table 3.2 Application Criteria

Criteria	Solution
Fit existing space	• Compact size due to high heat release • Flexible design accommodates diverse applications
Facilitate waste disposal	• Remove majority (up to 90%) of ash as low leaching slag
Minimize support systems	• Shell heat can be recovered in - Air preheating - In-plant, low-pressure steam - Feedwater train
Minimize site redesign	• Provide for feed options such as - On site pulverization and feed - Remote pulverization and dense phase feed - Coal slurries
Provide maximum fuel flexibility	• Vary operating parameters to accommodate a wide range of coals, without equipment redesign
Reduce furnace erosion	• Lower fly ash loading with smaller ash size and less abrasive fly ash particles
Minimize maintenance	• Use simple water cooled cylinder design • Avoid use of refractory
Maximize efficiency	• Use high heat release rate and turbulent mixing
Reduce NO_x emissions	• Provide two stage combustion
Control SO_2 emissions	• Burn low sulfur coal • Add sorbents to combustor

Table 3.3 Retrofit Application Cases

Case	Type Unit	Original Fuel	New Fuel	Unit Rating	Combustor Size MMBtu/hr	No.
1	Kiln	Gas or oil	CWM	———	70	1
2	Industrial package, D-type	#2, #6 Oil	CWM	40,000 lb/hr sat. steam	50	1
3	Industrial field erected boiler	#2, #6 Oil or Gas	PC	275,000 lb/hr superheated	100	4
4	Utility boiler	Gas or Oil	PC	410 MW_e	250	16

to the plant, in some cases, resulting in an overall increase in capacity.

Slag handling is accomplished in a variety of ways depending upon the particular application. For example, a submerged drag chain may be directly coupled to the combustor slag tap or a water filled slag tank with integral crusher may be used with a solids handling pump.

A number of industrial and utility plant studies have been conducted to assess the most economical way to use the TRW slagging combustor system. All the studies revealed substantial savings in initial capital costs and operating costs compared to other approaches, including replacement of heat utilization equipment, pulverized coal burner installation and retrofit with less advanced combustors.

Four specific retrofit application cases are outlined in Table 3.3. These evaluations have resulted in complete system designs from the physical boiler modifications to balance of plant requirements. Each case study includes the site specific conceptual engineering, conversion capital cost estimates, operating and maintenance cost estimates, and a pay-back assessment.

A single combustor retrofit (Case 2) is shown in Figure 3.1. The original firing configuration is preserved. This single combustor retrofit is typical of small face-fired industrial furnaces, boilers, and process heaters.

An example of a multiple combustor retrofit is shown in Figure 3.2. The original 275,000 lb/hr steam (300,000 MCR capable when retrofitted with 4 - 100 MM Btu/hr combustors), industrial field erected boiler is retrofitted with four slagging coombustors in an opposed wall firing configuration. Dual fuel capability is preserved by retaining the original burner firing positions.

Pay-back assessments of the four cases are presented in Figure 3.3 as the simple-pay back period in years as a function of fuel cost differential in $/MM Btu. The economic recovery periods, as reflected in Table 3.3, become attractive as the fuel price differential increases to a point where the recovery period is less than 3 to 4 years. The effect of retrofit size upon the recovery period is clearly noticed for the larger Case 3 and Case 4 studies. For Case 3, the fuel price differential of $3/MM Btu was derived from the assumption that the FOB (freight on board) cost of coal was $60/ton and the FOB cost of No. 2 fuel oil was $32.48/US barrel.

The economic recovery periods will naturally fluctuate with the analysis assumptions. However, we believe that the assumptions made in this study to arrive at overall capital installed costs, and operational and maintenance costs, are well within standard E & C estimating guides, as provided by Stone and Webster.

The detailed analysis is contained in Volume 2 of this final report, entitled "System Studies."

Figure 3.1

Case 3 – Industrial Field Erected Boiler

275,000 #/Hr Superheated Steam at 265 psia

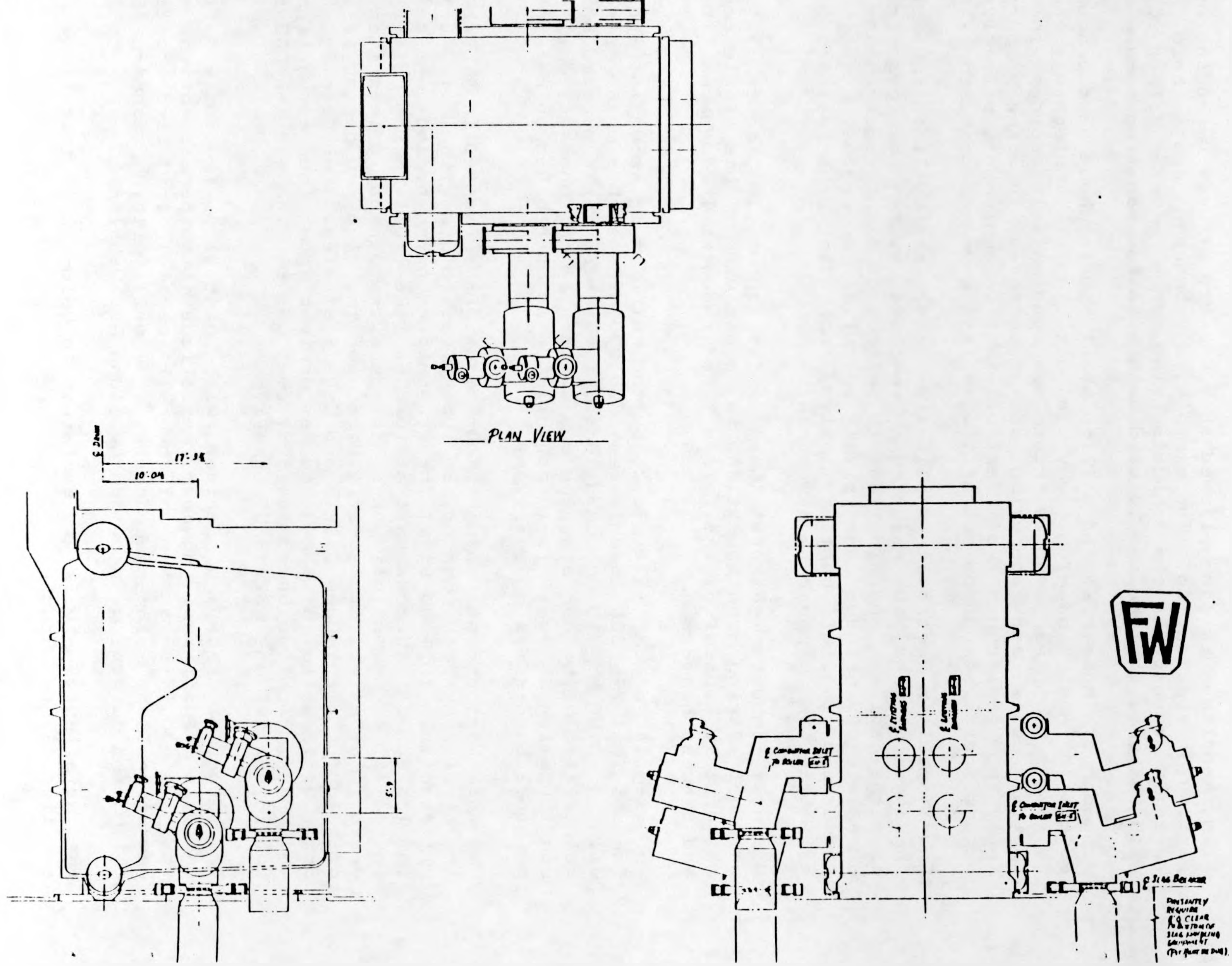
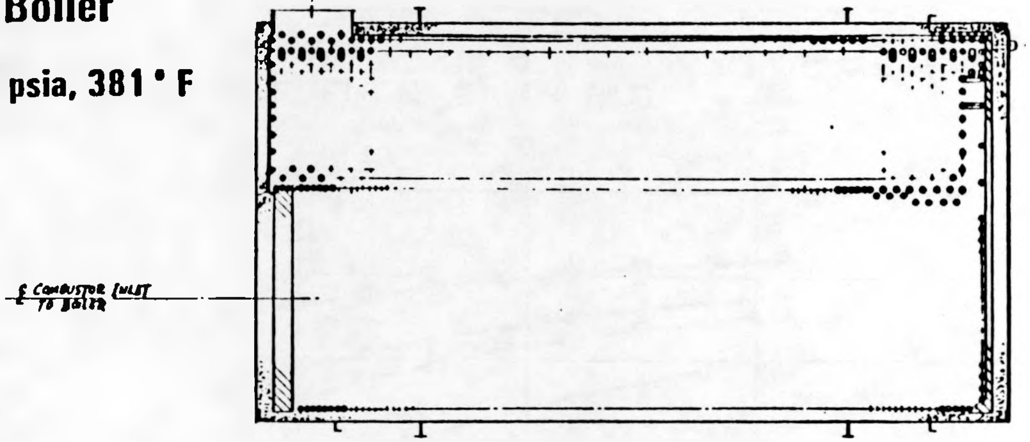


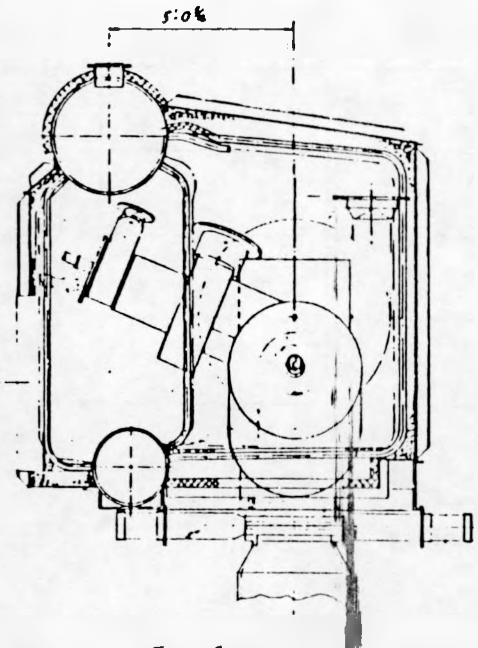
Figure 3.2

Case 2 – Industrial Package Boiler

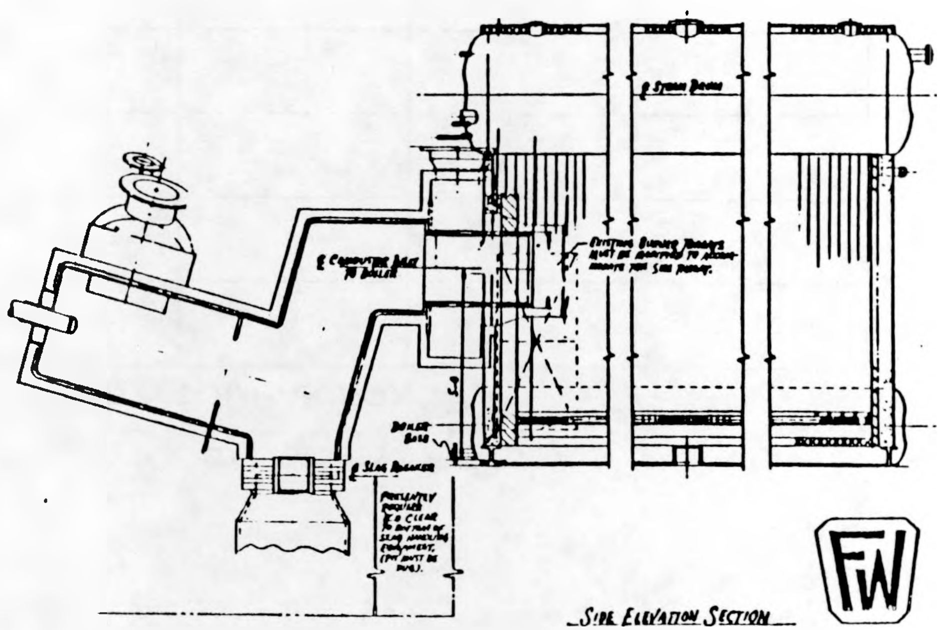
40,000 #/Hr Saturated Steam at 198 psia, 381 ° F



PLAN SECTION



FRONT SECTION

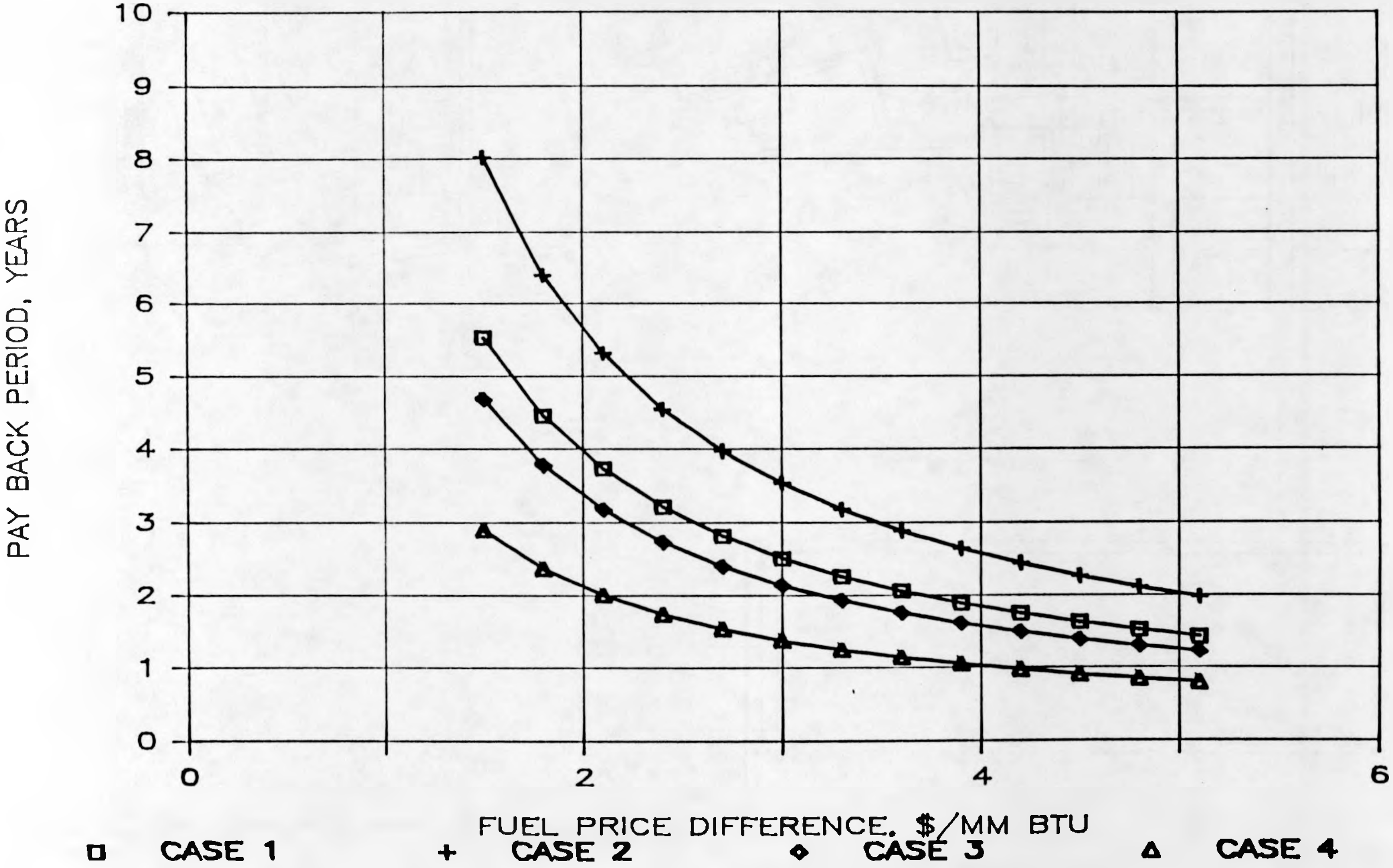


SIDE ELEVATION SECTION

Figure 3.3

ECONOMIC RECOVERY

CASE STUDY COMPARISONS



3.2 CHARACTERIZATION TESTS, 10 MM BTU/HR COMBUSTOR (TASK 2)

The general objective for the tests conducted under this task was to establish a data base using the existing TRW 10 MM Btu/hr combustion system. The range of operaing conditions was relevant to industrial and utility applications, with emphasis on system performance. Although the size of the unit is significantly smaller than that contemplated for most future retrofit appplications, the combustion system is nevertheless a useful tool for development testing and can provide a valuable data base for scaling verification.

A general description of the system is followed by the principles of operation. A discussion of the instrumentation and diagnostics is followed by the test results.

3.2.1 Combustion System Description

An overall schematic of the 10 MM Btu/hr combustion system is shown in Figure 3.4. A more detailed schematic has been presented in the Executive Summary as Figure ES-1. It consists of a precombustor or vitiator, a first or slagging stage , a transition or connecting duct, a secondary burner, and a boiler simulator followed by a water quench section, an exhaust scrubber and a stack. The system was installed in Cell 1 of the Fossil Energy Test Site (FETS) as shown in Figure 3.5. Hot combustion air is supplied by an indirectly fired air preheater from a forced draft fan system. Air heated to tempeatures up to 650 F is available for both the first and second stage of the combustion system. This same draft fan system also supplies the combustion air to Cell 3 which contains the 50 MM Btu/hr combustor.

The sulfur emission control tests utilized a "stinger injector" to introduce sorbent on the combustor centerline axis pointed directly at the head end of the combustor from the slag recovery section. The injector was positioned in the center of the baffle.

3.2.2 Principles of Operation

The precombustor consists of two separate stages, designated as Stage 01 and Stage 02. Heated air from the indirectly fired preheater enters a combustion can tangentially. Approximately 15% to 25% of the total coal flow is introduced axially. The stoichiometry within this combustion can is maintained from 0.9 to 1.0 to promote rapid combustion within a very short length. The precombustor is operated in a non-slagging mode. The remaining combustion air is mixed with the hot combustion gases to act as a diluent which reduces the bulk temperature in the range of 1800 F. This hot air is introduced tangentially into the main, or slagging stage (Stage 1). At this point in the combustion process, the NOx levels are in excess of 1000 ppmv. The balance of the coal is introduced axially in the head end via the patented TRW coal injector in a hollow cone pattern. This slagging stage is a 17 - inch diameter water cooled cylinder. A baffle at the exit creates a strong confined vortex for intense mixing and combustion. Under the action of the swirling flow and high combustion

TRW

Figure 3.1

10 MMBTU/HR COAL COMBUSTION SYSTEM

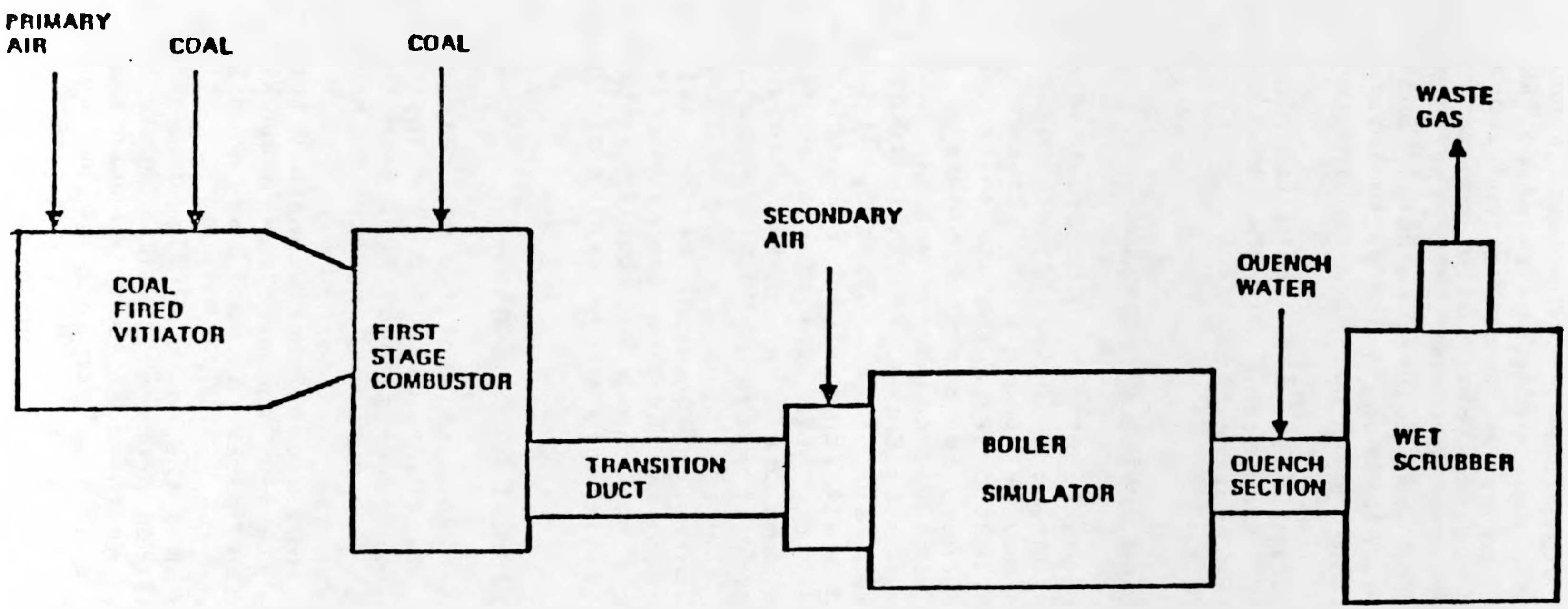
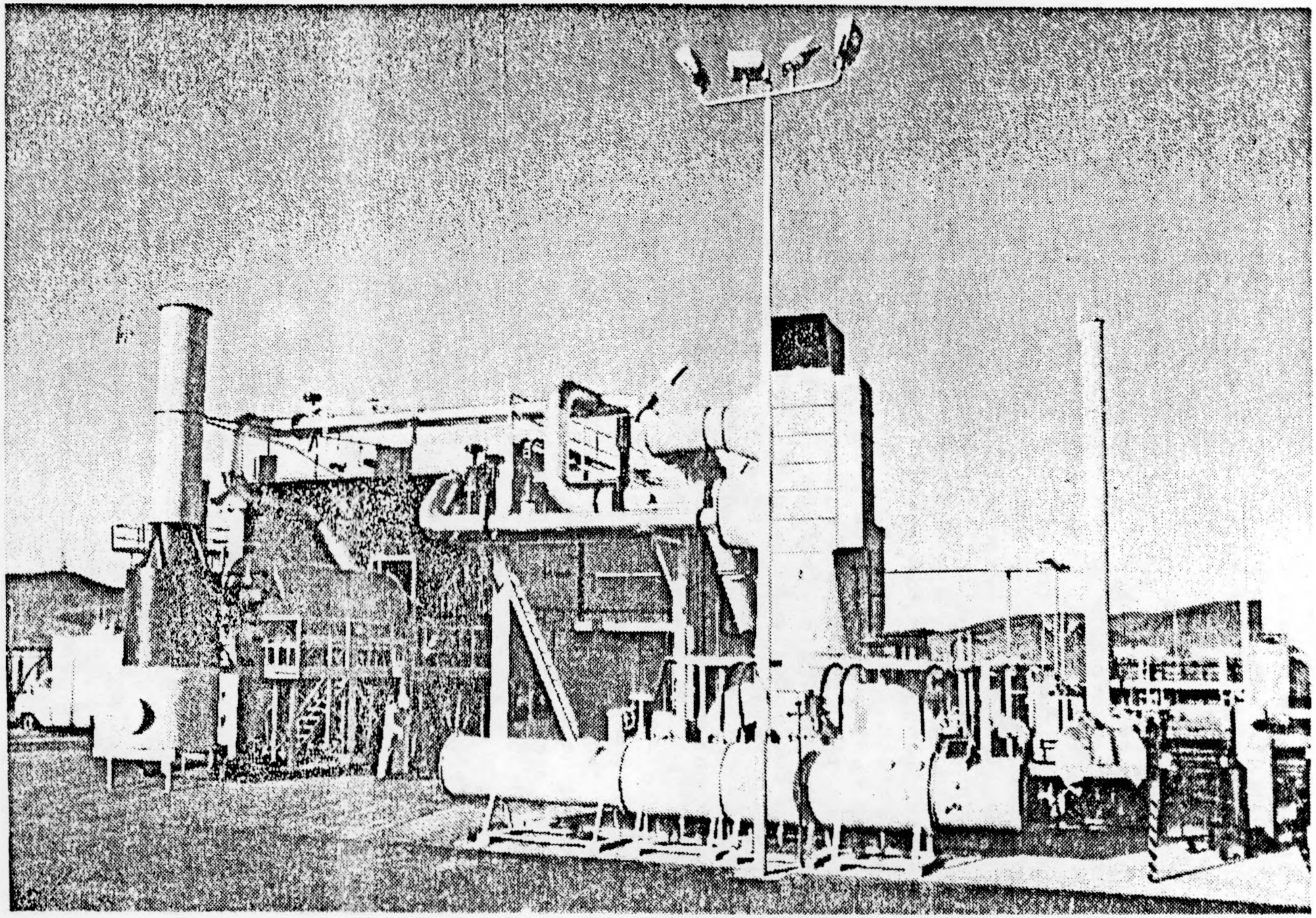


Figure 3.5

Cell No. 1 - 10 MMBtu/hr Combustion System Installation



intensity, coal ash particles are melted in flight and centrifuged to the walls of the combustor. These particles consolidate into a molten slag layer covering a frozen slag layer next to the water cooled walls. It is this composite slag layer that provides thermal and chemical protection of the metallic combustor walls. The molten slag layer flows out of the system under the influence of gravity and shear forces. The flow of slag out of the system is facilitated by inclining the combustor 30 degrees to the horizontal as shown in Figure 3.6.

The slagging stage is operated under fuel rich conditions at stoichiometries of between 0.7 and 0.9. This condition lowers the combustion temperature which, in turn, lowers the cooling load to be integrated with the heat utilization equipment and provides an NO reburning environment for primary NOx control. The hot gases, rich in CO and hydrogen exit the slagging stage through a key-holed baffle. A slag tank (refer to Figure ES-1), located downstream of the baffle, collects the slag from the slagging stage. In the slag recovery section, the gases make a 90 degree turn towards the secondary burner. A 60 - inch long, 12 - inch diameter connecting duct connects the slagging stage to the secondary burner. In field applications, the connecting duct would need only be long enough to join the first stage to the heat utilization equipment as geometry and space dictate. A second slag tank (refer to Figure ES-1), installed at the exit of the transition duct, collects slag sheared slong the walls of the system by the high velocity flow. Designs, such as the 34 - inch, 50 MM Btu/hr unit, have a modified slag recovery section which reduces slag spill-over and omits this second slag tank.

At the end of the connecting duct, the combustible gases enter a secondary combustion chamber which simulates the heat utilization equipment. The chamber (5 feet diameter, 15 feet long) is large enough to contain the secondary flame (5 feet diameter, 15 feet long). At the end of the simulator, the gases are water quenched, cleaned by a cyclonic scrubber and exhausted to the atmosphere.

Typical test durations were on the order of one to two hours which was long enough to establish steady-state conditions.

3.2.3 Instrumentation and Diagnostics

All flow reactants, i.e., fuel, air, sorbent (when used), were continuously monitored by recording the weight change of the respective feed hoppers in the case of pulverized coal and sorbent, and by the RPM of a precalibrated Moyno pump in the case of CWM. All water flows were also continuously monitored to obtain the necessary cooling load data. Pressures are measured at selected locations so that the contributions from the various components to the total system pressure drop can be determined. These are located at the precombustor inlet, precombustor outlet, slag tank, secondary air inlet, boiler simulator, and scrubber. Provisions for gas sampling are at the precombustor outlet, slag recovery section, slag tank, boiler simulator inlet, three places along the boiler simulator, the boiler simulator exit, and the stack exhaust. A continuous emission monitoring system provides data on the CO, CO2, NO, CHn, and SO2 content in the gases. All determinations are on a dry

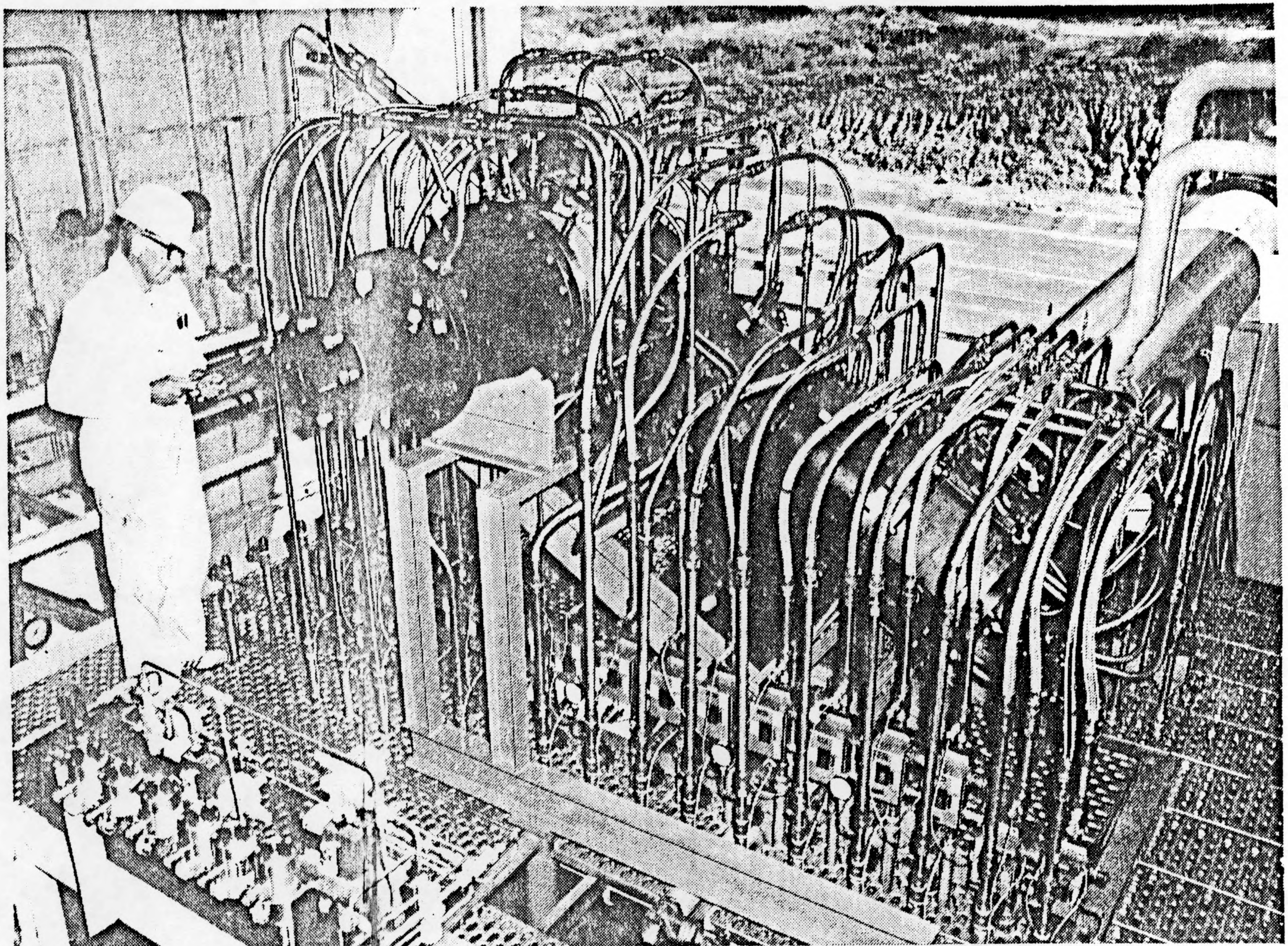


Figure 3.6. 10 MM BTu/hr Coal Combustion System Being Tested at TRW

basis except for SO_2, which is on a wet basis. The SO_2 measurement system uses heat traced lines maintained at 250 °F to avoid condensation. Optical diagnostics also available with the system include: a two color pyrometer for secondary flame temperature measurements located on a port in the boiler simulator; video pin-hole cameras located such to have view angles of the precombustor flame, the slagging stage flame, and the secondary combustion flame.

At the conclusion of each test, the test hardware is opened for visual inspection of the inner surfaces and photographic records are taken of the state of the surface in the slagging stage. The slag (and possibly sorbent, when used) collected during the test are weighed to determine slagging performance. Samples of the slag are saved for subsequent compositional analyses for comparision with the virgin coal ash.

3.2.4 Characterization Testing

The coals utilized in all three test tasks were carefully selected after an analysis of the known coal reserve base in the United States. The coals utilized had to be representative of the fuels that could be used for retrofitted systems, be within a proximity to the retrofit sites, have a large reserve base, and not be a specialty coal such as mineralogical coal. The coals also were to be run-of-mine coals not subjected to preprocessing, such as washing, or drying. A sub task of the Task 1 System Studies, described in Volume 2 of the final report, examined the coal data base from which the coal selections were made. One Western, subbituminous coal was selected, as were two Eastern bituminous coals; one of which was tested in pulverized form and in coal water mixture form. Appendix A contains properties of all the coals utilized in the test tasks.

The Western coal was Wyoming Rosebud; the two Eastern coals were a Pittsburgh No. 8 and a Blacksville No. 2. The CWM was processed from the Blacksville No. 2 by the Atlantic Research Corporation. The pulverized coals were ground to a nominal 70% through 200 mesh.

A test plan was prepared which covered the test effort activities and refurbishing of some of the sections of the slagging stage. This test plan is contained in Appendix B.

Cold flow functional checks were performed to verify the operational status of the overall system prior to the first hot fire tests. These included check-out of:

- Air supply system
- Cooling water supply system
- Fuel supply
- Coal transport system
- Coal water mixture transport system

- Sorbent transport system
- Nitrogen system

A total of 28 tests were completed with a cumulative run time of over 62 hours. Approximately 24 tons of pulverized coal annd eight tons of CWM were consumed during these tests. A summary of these tests is presented in Table 3.4. In it are listed the test number, the coal type, the coal load in MM Btu/hr, the precombustor preheat boost, and the first stage stoichiometry. A short comment also indicates the nature of the test. For most of these tests, the air preheat temperature was 600 F. The precombustor was fired with the same fuel as the slagging stage except for the last six tests where the effect on sulfur capture was investigated and, for the CWM tests as only one slurry injector was available (slagging stage) and the small size of the precombustor would have made CWM combustion difficult to implement.

Combustion Characteristics

Combustion was, in general, good under most combustor conditions when operated with pulverized coal. This is illustrated in Figure 3.7 where the first stage stoichiometry as determined by gas analysis is plotted against the first stage stoichiometry as determined by reactant flow rates. The value computed from gas analysis relies on the excess oxygen measured at the system exit (before the water quench). When these two stoichiometries are equal, this indicates essentially 100% carbon conversion. When the stoichiometry determined by gas analysis exceeds that determined by flow rates, the carbon conversion is less than 100%. The carbon conversion is expressed as

$$\text{conversion, \%} = \frac{\text{Phi by flow}}{\text{Phi by } O_2} \times 100$$

Although there is some data scatter, it is apparent that for stoichiometries greater than 0.75 with pulverized coal, within the precision of the measurements, the carbon conversion is very close to 100%. The combustion efficiency drops below 100% at low stoichiometries for pulverized coal and also in the case of the coal water slurry where atomization difficulties were encountered.

In general, secondary combustion was also quite good with CO levels of the order of 100 to 200 ppmv at the stack for excess oxygen levels of 3% or less. For the slurry tests, and as a result of the high slurry viscosity, atomization was incomplete. Good combustion was achieved only on the last slurry test after some adjustments were made and the system was opeated at a first stage stoichiometry close to 1.

Slagging Performance

The slagging performance of the combustor was good with a relatively uniform and complete coverage of the walls of the first stage. This is

Figure 3.7. Fuel Conversion Efficiency Plot

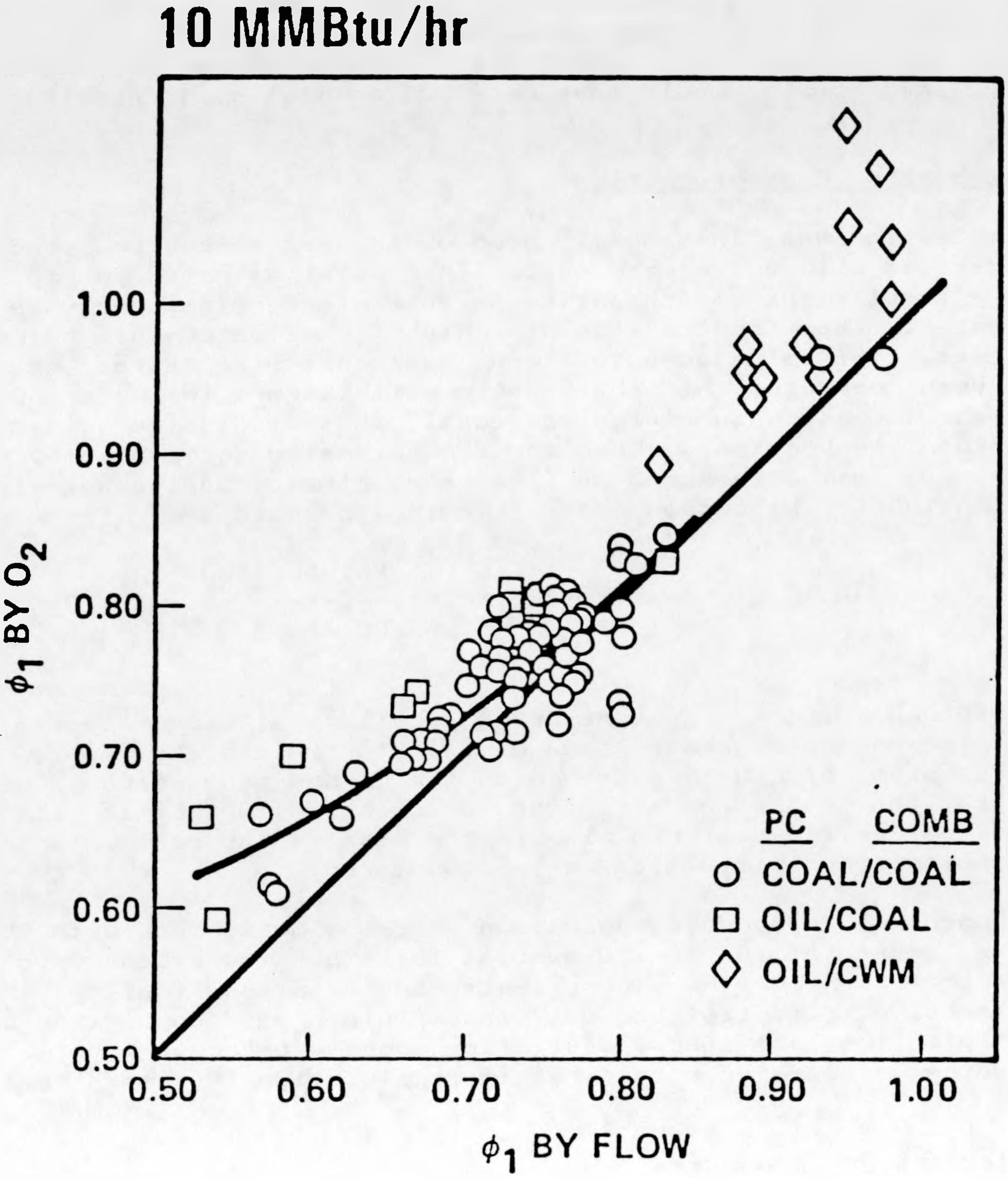


Table 3.4 10 MM Btu/hr Characterization Tests. Summary Table

Test #	Coal Type	Coal Load MM Btu/hr	Precombustor Exit Temp. °F	First Stage ϕ_1	Test Description
338	Wyoming	--	--	--	Pre-Combustor Checkout
339	Wyoming	12.8	1770	.81	Hot-fire checkout, slagging stage
340	Wyoming	12.3-13.5	1800-1900	.6-.8	ϕ_1 sweep
341	Wyoming	13.0	1700-1800	.67,.71	2ϕ_1's, NO_x data
342	Wyoming	13.3	1970	.78	Steady stage slagging run
343	Wyoming	13.2	2060	.68	Steady stage slagging run
344	Wyoming	7.6	1630-1790	.83-.97	Low load, vary ϕ_1
345	Wyoming	10.2	1830-1705	.68,.83	Low load, vary ϕ_1
46	Blacksville #2	12.8-13.6	1730-1850	.60-.83	ϕ_1 sweep, switching slag coverage
347	Blacksville #2	13.5	1940	.76	Steady state run
348	Blacksville #2	12.7	1870	.78	Steady state with vicron injection at 2 Ca/S
349	Blacksville #2	12.7	1870	.77	Steady state with vicron injection at 2 Ca/S
350	Blacksville #2	11.8-12.3	2000-2100	.72-.76	One Ca/S, ϕ_1 varied, problems with precombustor coal flow
351	Blacksville #2	12.7	2000	.76	Steady state, Dolomite injection

Test #	Coal Type	Coal Load MM Btu/hr	Precombustor Exit Temp. °F	First Stage $\emptyset_1$	Test Description
352	Pittsburgh #8	13.7	1900	.62-.76	Baseline, slag switchover
353	Pittsburgh #8	12.8-13.4	1900	.76-.80	Slagging run
354	Pittsburgh #8	12.6-13.8	1780-1850	.73-.79	Larger diameter baffle (8-1/4") - Vicron injection
355	Pittsburgh #8	12.7-13.6	1650-2000	.68	Vary preheat-Vicron injection - Larger diameter baffle
356	Pittsburgh #8	10.7-11.8	1620-1950	.71-.76	Baffle lock to 6-3/4"-2 preheats - vicron injection
357	Pittsburgh #8	11.2-11.8	1500	.75	1 Ca/S with vicron-Moved sorbent injection
358	Pittsburgh #8	11.5-12.3	1900-2050	.72-.77	Repeat #357
359	Pittsburgh #8	12.0-12.5	2000-2200	.58-.80	Particulate test - lower $\emptyset$ and effect on SO_x
360	Pittsburgh #8	12.4-13.0*	1500	.59-.73	Oil fired precombustor - effect on SO_x
361	Pittsburgh #8	12.2-13.0*	1380-1500	.53-.83	$\emptyset_1$ effect on SO_x with oil fired precombustor
362	Blacksville #2 Slurry	14.5-15.0*	1430-1630	.64-.74	Slurry operation check-out - oil precombustor

Test #	Coal Type	Coal Load MM Btu/hr	Precombustor Exit Temp.°F	First Stage $\emptyset_1$	Test Description
363	Blacksville #2 Slurry	10.3*	1540	.97-1.0	Change slurry injection positions, atomizing air, etc.
364	Blacksville #2 Slurry	12.2-13.0*	1750-1900	.85-.92	Repeat #364 at higher preheat
365	Blacksville #2 Slurry	12.0*	1800	.93	Steady state run

* Includes oil load from precombustor.

illustrated in the photograph of Figure 3.8 taken at the conclusion of a pulverized Blacksville No. 2 test. The uniform coverage of all the surfaces is readily apparent. Good coverage and the absence of char or slag accumulation is also shown in Figure 3.9 taken at the conclusion of test number 305 where a Blacksville No. 2 coal water mixture was used with good results.

A second measure of slagging performance is provided by the slag recovery computed as the ratio of the weight of slag recovered from the system to to total recoverable ash injected with the coal. As only a few steady state slagging runs were completed, the data is relatively scarce. From past experience, slag recovery is known to be sensitive to the first stage equivalence ratio. This is illustrated in Figure 3.10 for a Wyoming Rosebud pulverized coal. Slag recoveries in the 80% to 90% range were achieved at stoichiometries at or above 0.78. The slag recovery dropped to 60% at a stoichiometry of 0.68. Figure 3.10 illustrates the effect of load on slag recovery. A decrease in slag recovery at reduced load occurred despite increases in the first stage stoichiometry. A comparison of the slag recoveries for the Blacksville No. 2 pulverized coal and coal water mixture is contained in Figure 3.11. Recoveries between 75% and 90% were obtained. Notice, however, that the stoichiometry for the CWM is considerably higher than that for the pulverized coal test.

No significant differences were found in the slagging behavior of the Eastern and Western coals.

Cooling Loads

The tests also yielded detailed data on the system cooling loads. Figure 3.12 is a plot of fractional cooling load as a function of combustor load. The fractional cooling load increases sharply as the load decrease. This is to be expected under conditions where radiative losses are dominant. The Blacksville No. 2 coal exhibits higher cooling loads than the Wyoming coal. This may be due to the higher heating value of the Blacksville No. 2 coal. The cooling load at 13 MM Btu/hr is 20%. The cooling load consists of contributions from the precombustor, slagging stage, slag recovery section, and the connecting duct. The fractional cooling load as a function of precombustor boost appears in Figure 3.13. The cooling load is insensitive to preheat boost in the outlet temperature range of 1650 F to 2050 F.

System Pressure Drop

The system pressure drop was measured at 40 inches of water when the combustor was operated at its nominal load of 10 MM Btu/hr. This pressure drop is compatible with typical combustion air fans operating in plants which have retrofit application potential.

Nitrogen Oxide(s) Emission Control

NOx emissions are shown in Figure 3.14 through Figure 3.16. The data

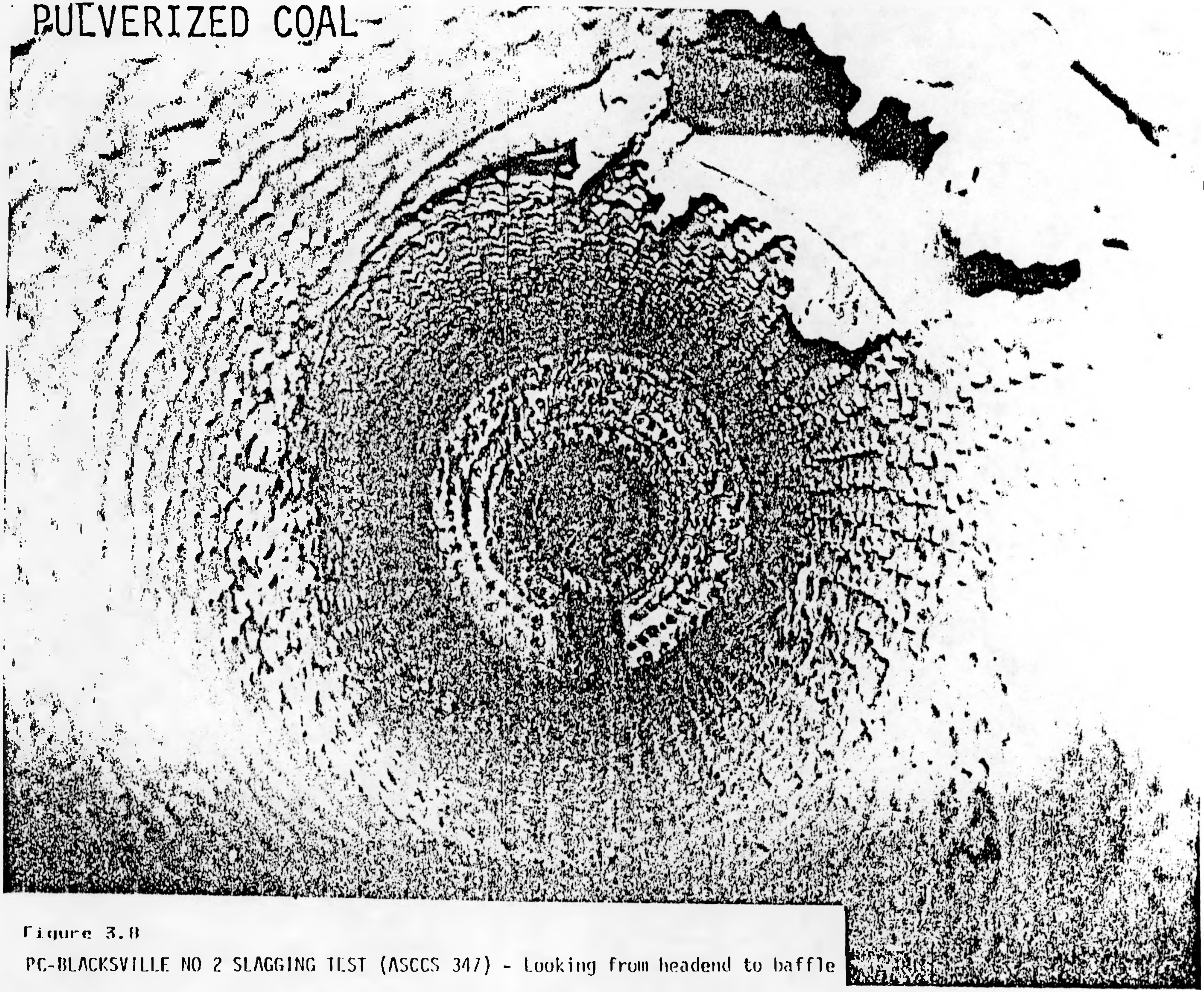


Figure 3.8

PC-BLACKSVILLE NO 2 SLAGGING TEST (ASCCS 347) - Looking from headend to baffle

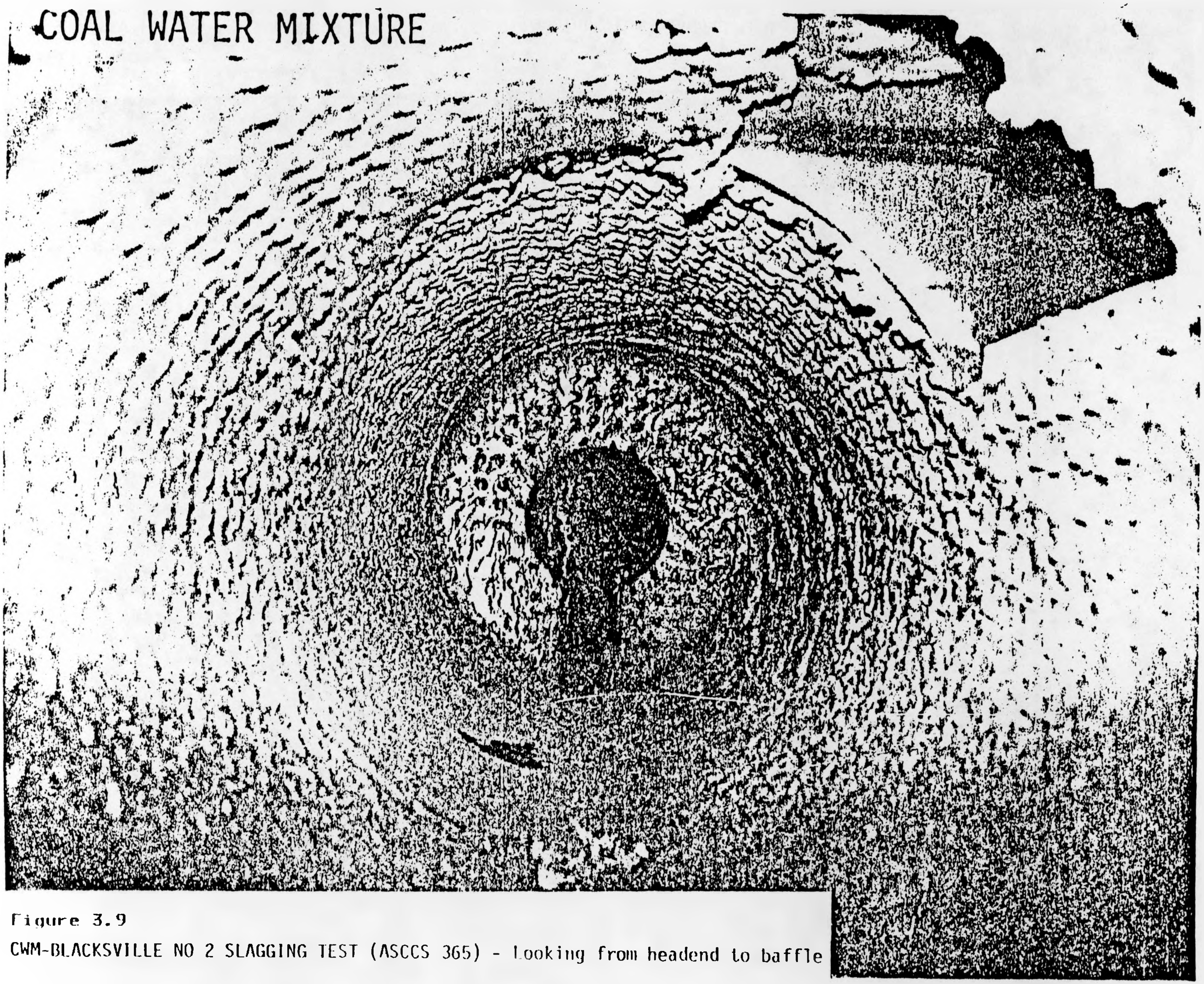
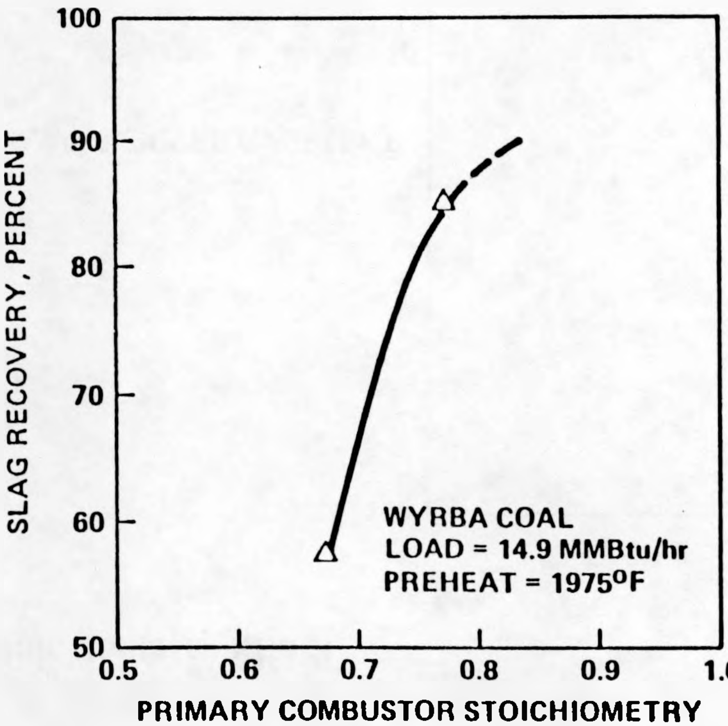


Figure 3.9
CWM-BLACKSVILLE NO 2 SLAGGING TEST (ASCCS 365) - Looking from headend to baffle

Figure 3.10

Slag Recovery - 10 MMBtu/hr Combustor

Load Effect
Stoichiometry Effect



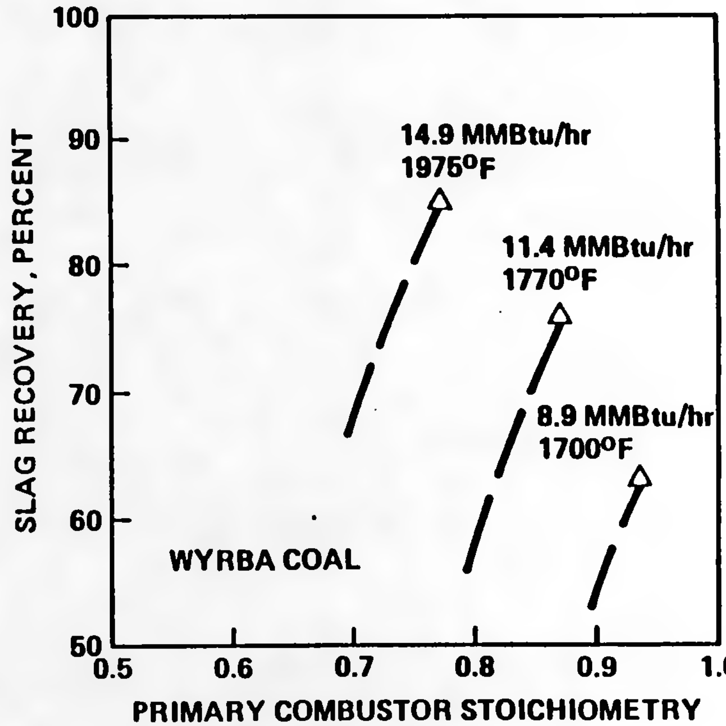


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Figure 3.11

TRW

Slag Recovery - 10 MMBtu/hr Combustor
Fuel Effect
Stoichiometry Effect

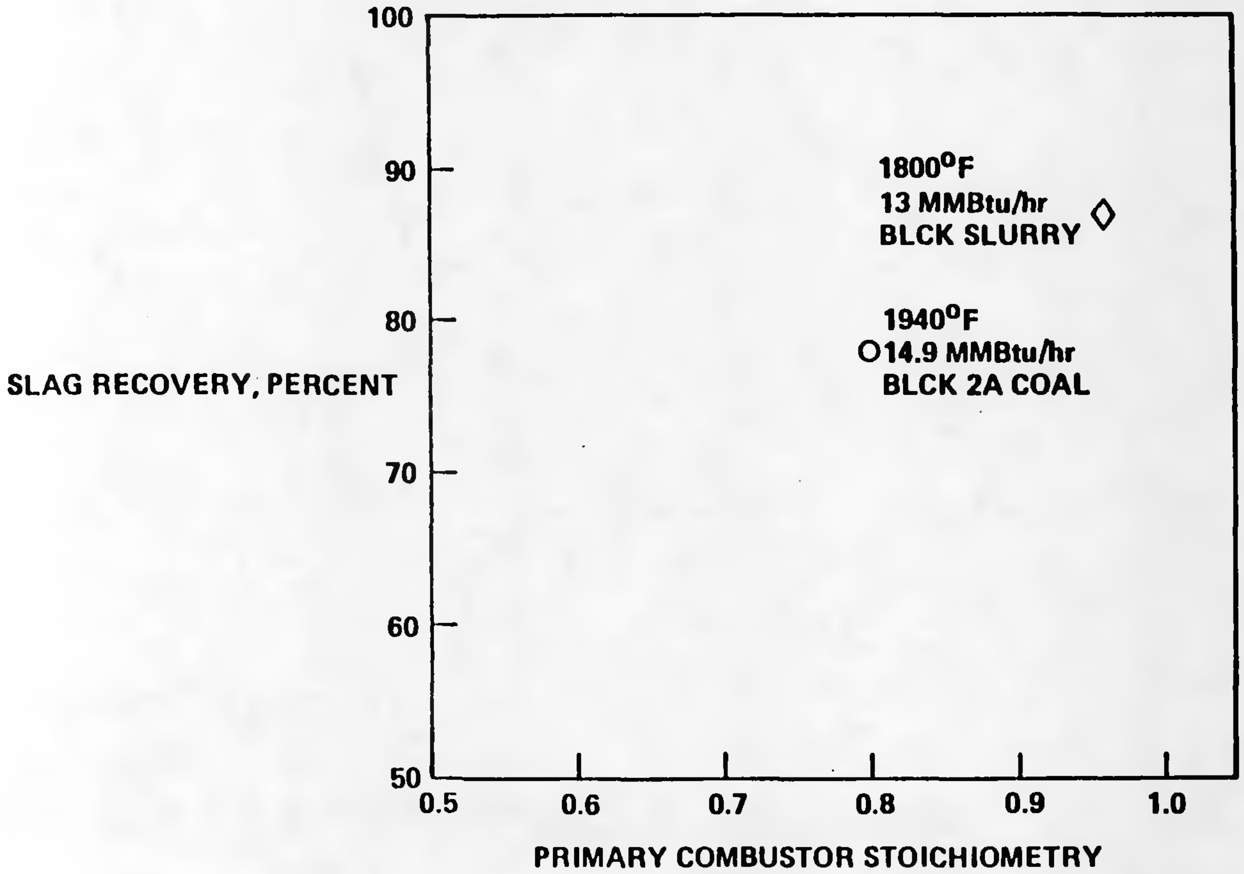

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Figure 3.12

Cooling Load - 10 MMBtu/hr Combustor

Load Effect
Fuel Effect

TRW

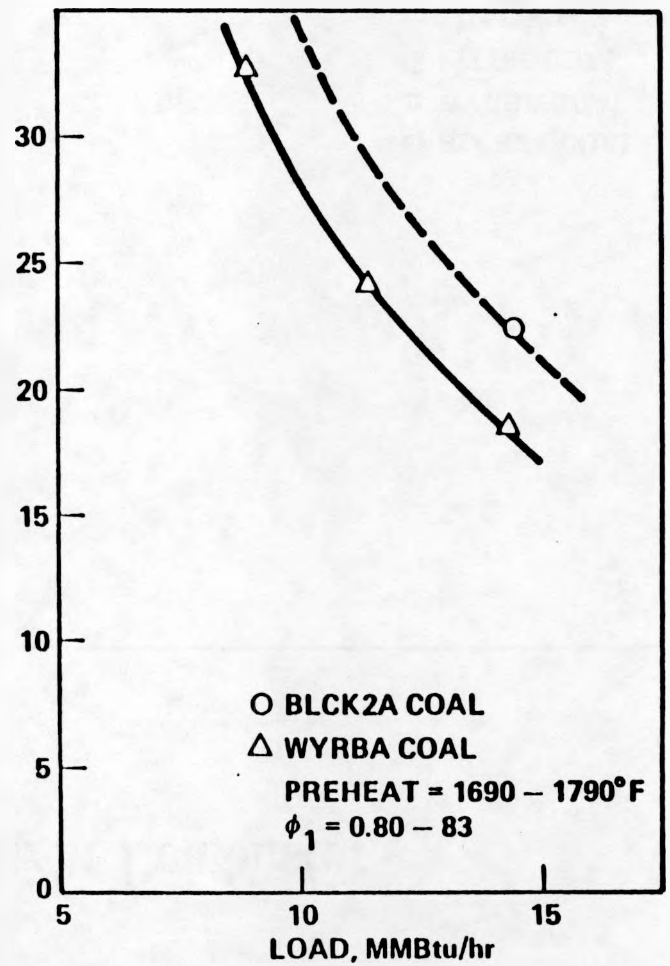

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Figure 3.13

Cooling Load - 10 MMBtu/hr Combustor

Preheat Effect
Fuel Effect

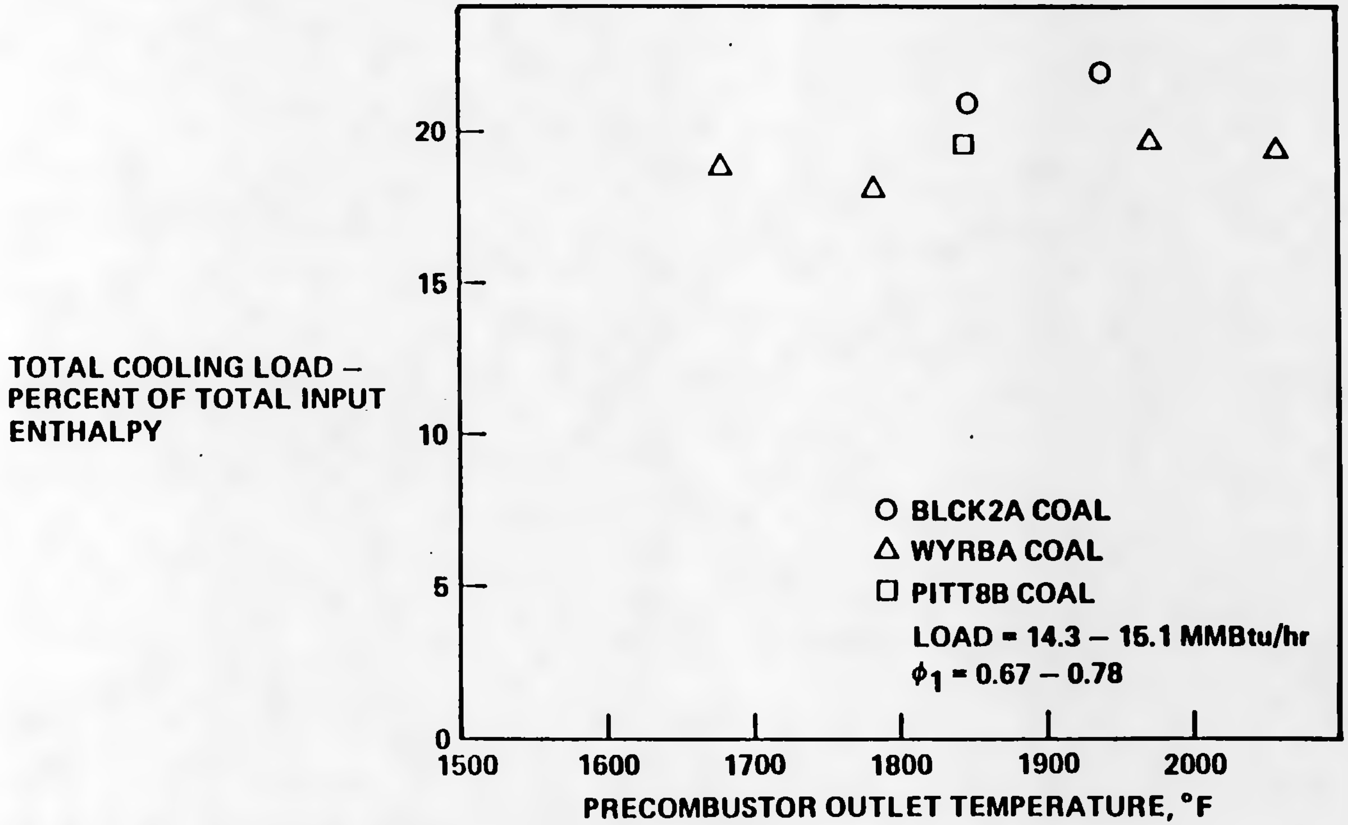

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Figure 3.14

NO_X Variation with Stoichiometry
Fuel Effect
Scaling Effect

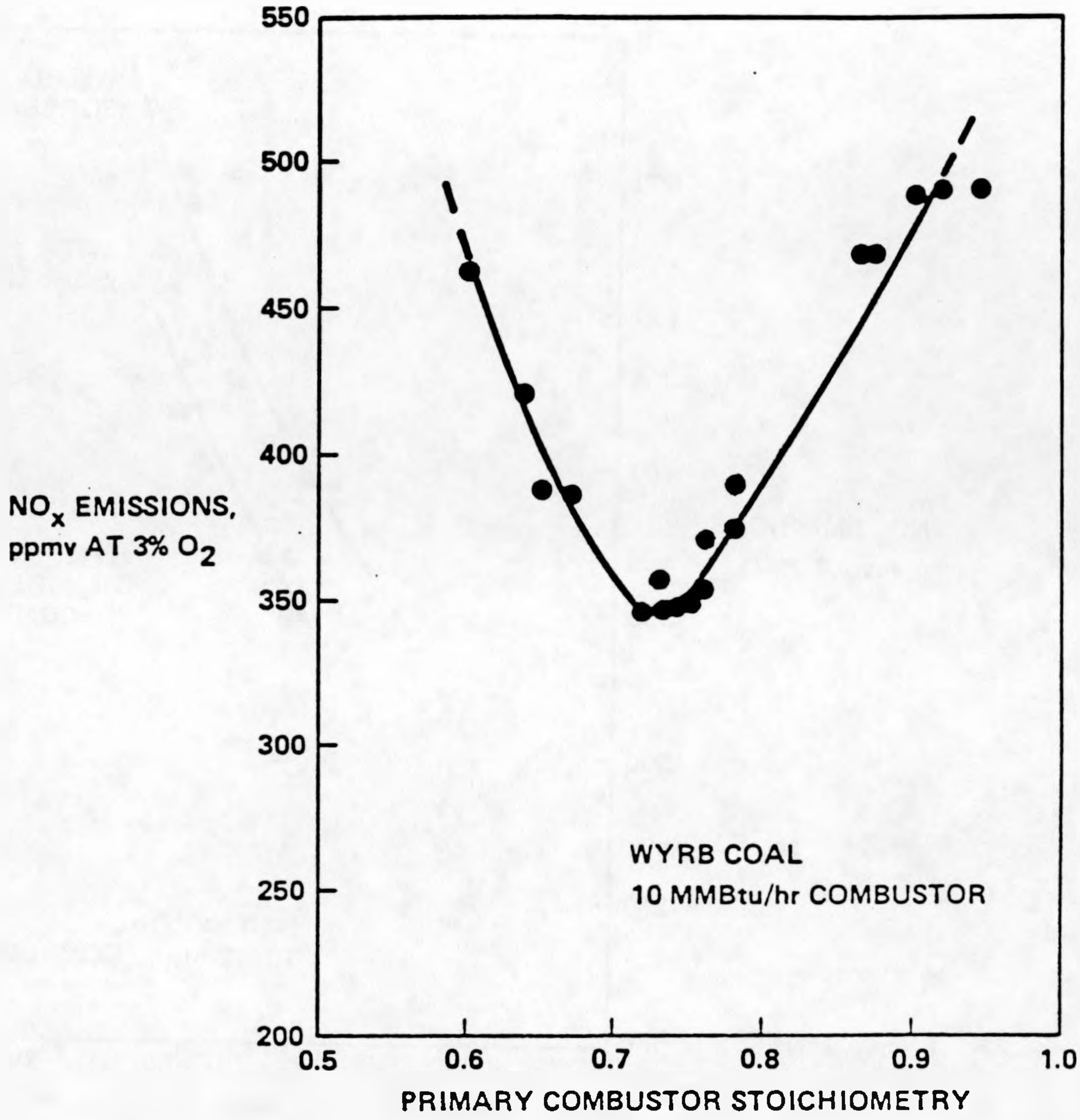

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Figure 3.15

NO_x Variation with Stoichiometry
Fuel Effect
Sorbent Effect

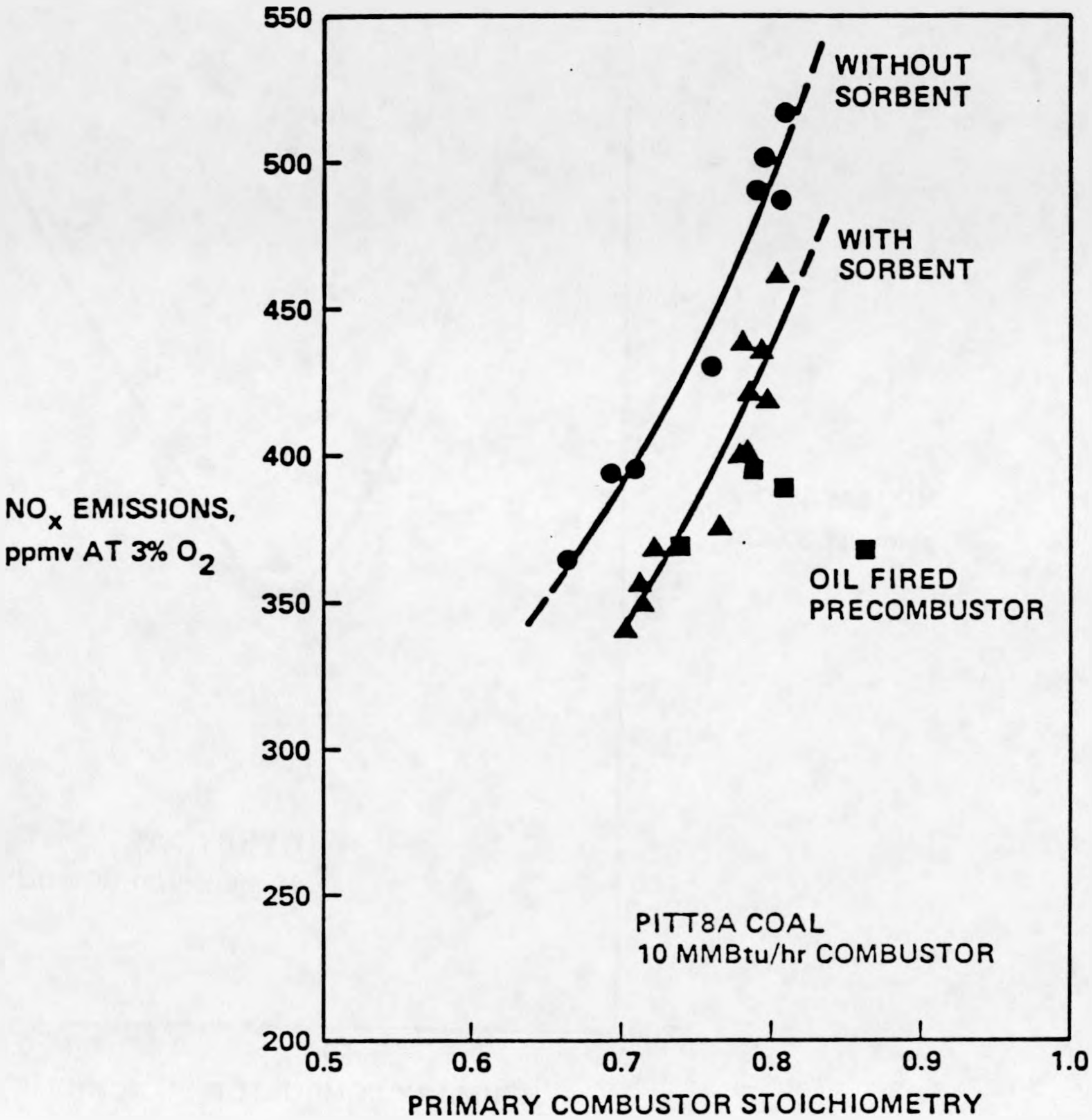

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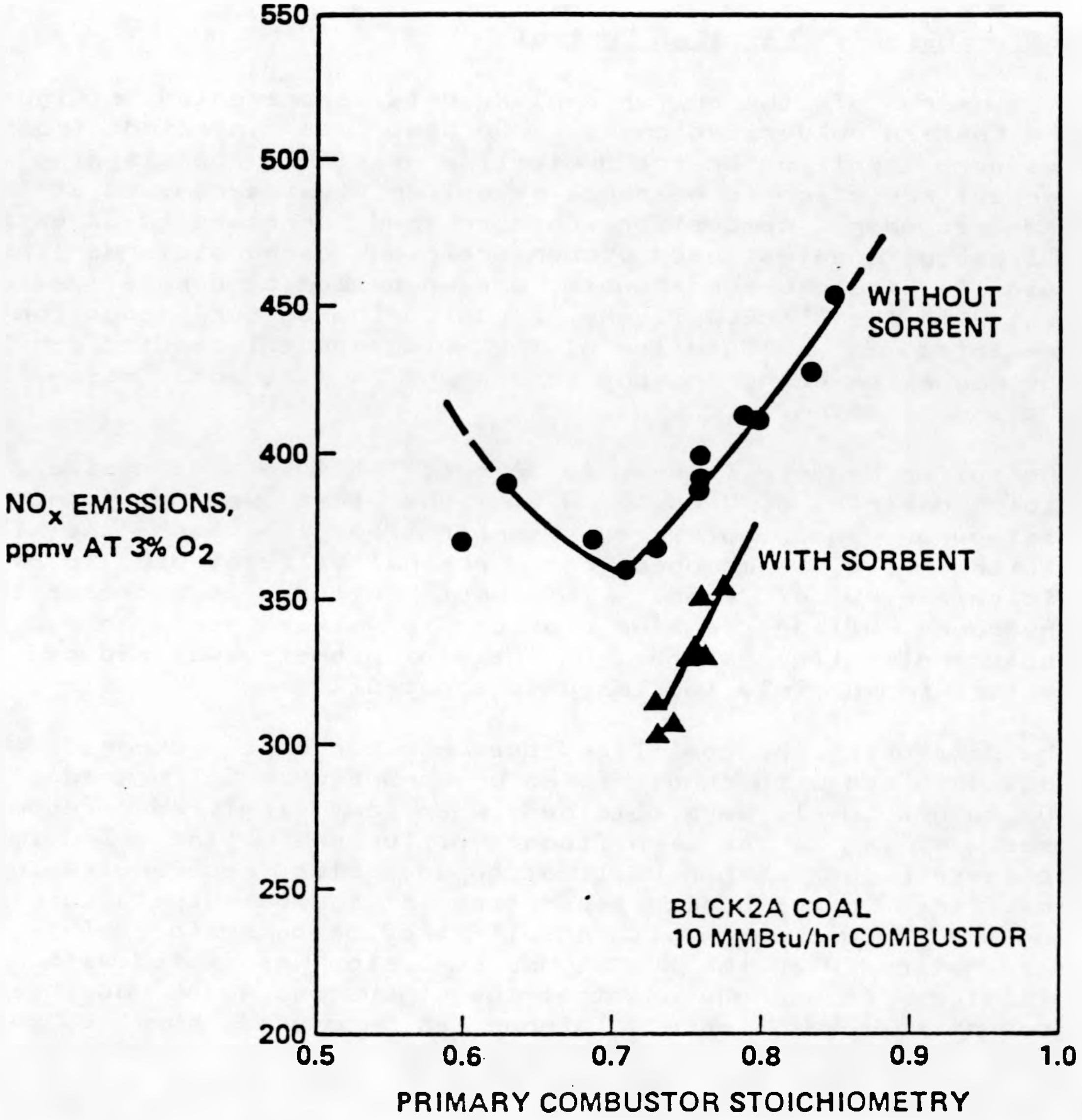
Figure 3.16

NO_X Variation with Stoichiometry

Fuel Effect

Sorbent Effect



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were measured at the exit of the secondary combustion chamber and have been corrected to 3% excess oxygen. There is a strong dependence of NOx level on the first stage stoichiometry. In the case of two of the coals, a minimum stack NOx level of the order of 350 ppmv is noticed at a first stage stoichiometry of about 0.7. In the case of the Pittsburgh No. 8 coal and of the Blacksville No. 2 coal, a decrease of 50 ppmv was noticed when sorbent was injected into the slagging stage. This is more than likely a thermal effect (lowered combustion temperatures).

Sulfur Oxide(s) Emission Control

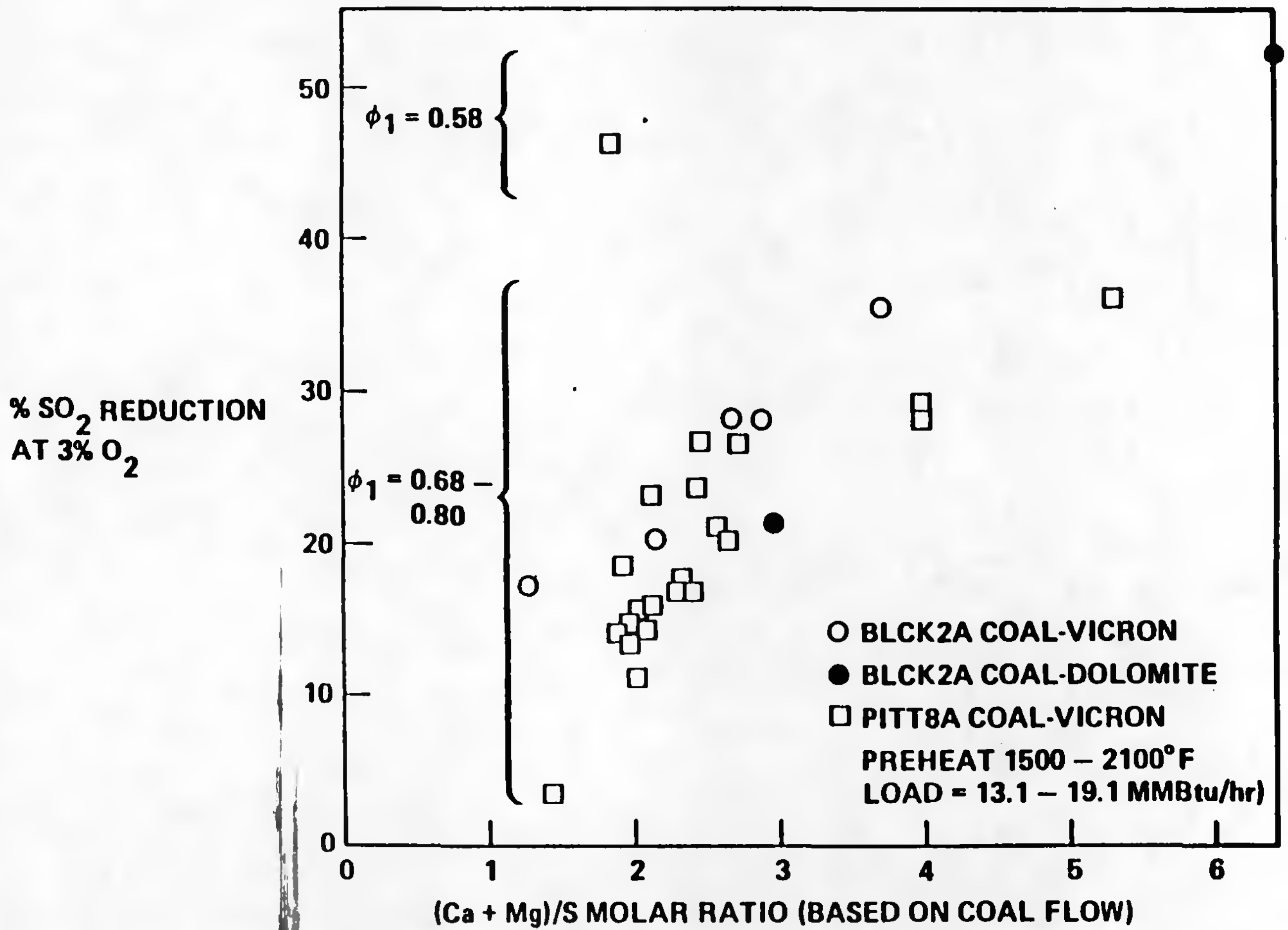
A summary of the sulfur capture data is presented in Figure 3.17 for the Eastern pulverized coals. Sorbent was injected from the slag recovery section on the centerline axis into the slagging stage. The percent reduction is measured as sulfur dioxide removed at the exit of the secondary combustion chamber and corrected to 3% excess oxygen. All except one test used Vicron (calcium carbonate) as the sorbent. Dolomite (calcium carbonate and magnesium carbonate) was used in one test with the Blacksville No. 2 coal. The sulfur reduction data are presented as a function of the molar sorbent loading as (Ca + Mg)/S, the magnesium being present to account for the added mass loading for the use of dolomite.

The sulfur capture is seen to be only 15% to 30% at nominal first stage stoichiometries of 0.68 to 0.8. One test was performed with the Pittsburgh No. 8/vicron combination in which the first stage stoichiometry was changed from a nominal value of 0.8 to a very low stoichiometry of 0.58. This was intended to increase the ratio of (hydrogen sulfide)/(sulfur dioxide) to values more conducive to the capture of sulfur as CaS. As the stoichiometry was reduced, the sulfur capture immediately increased to about 47%.

The data using the coal-fired precombustor were compared to previous data obtained with an oil-fired precombustor. Sulfur reductions in the 50% to 60% levels were obtained when an oil-fired precombustor was used. This is a significant difference. The slagging combustor achieves higher carbon utilization and slag recovery values with a coal-fired precombustor operating at equivalent stoichiometries when compared to operation with an oil-fired precombustor. This effect was also noticed when the 20 MWt MHD combustor was fitted with a coal-fired vitiator. It was obvious that the combustion mode had been altered. Combustion was more intense as measured by the cooling load distribution and levels in the headend. The only significant difference in the precombustor exhaust was the presence of hot slag particles. Analysis indicated that the particles made up a radiating "cloud" which provided additional heat transfer to the head end. The amount of heat transferred was sufficient to "lock" combustion into the headend. Essentially, a thermokinetic barrier was created. The higher headend combustion temperatures reduced the amount of sulfur in the form of hydrogen sulfide which could be captured.

Figure 3.17

SO_2 Reduction with Vicron Injection - 10 MMBtu/hr Combustor



35

3.2.5 Test Task Conclusions

The sub-scale 17 - inch combustor test results revealed overall combustion system operating trends and indicated that the concept was applicable to both bituminous and subbituminous pulverized coals. The concept appeared to be feasible for operation with coal water mixtures, once an injector with adequate atomization could be developed. The carbon utilization and slagging performance were compatible for retrofit applications. The NOx emissions were acceptable for most industrial applications, but additional reductions may be required for utility applications. Similarly, the cooling loads taken out by the water were at a low enough level so as to pose no problems with integration in the retrofit plant.

It became very clear at this stage of combustor development that the simultaneous control of NOx, SOx, and particulates would not be possible within the slagging stage. NOx and particulate control had been achieved, but sulfur emission control was elusive. The combustor operating conditions for modest sulfur control resulted in very poor carbon conversion, very poor slag recovery, and high NOx levels.

These tests also indicated that proper precombustor operation was vital for overall high system performance. The Task 3 testing initially concentrated on precombustor peformance prior to combined stage operation. Sulfur control attempts with the 50 MM Btu/hr combustor were to be limited; testing would be confined to verification of the bleak data obtained with the small combustor.

3.3 SCALING AND PERFORMANCE VERIFICATION TESTS 50 MM BTU/HR COMBUSTOR (TASK 3)

The general objective for the tests conducted under this task was to obtain scaling and performance verification data on the 50 MM Btu/hr workhorse combustor and compare that data to that obtained from the nominal 10 MM Btu/hr combustor tested in Task 2. The workhorse combustor had been scaled primarily on constant velocity principles. A factor of two increase in the diameter would result in a factor of four in load rating. The nominal 17- inch combustor, at its design conception, was targeted to operate at a thermal rating of 10 MM Btu/hr. The scaled 34 - inch combustor would then have a predicted thermal rating of 40 MM Btu/hr. However, extensive testing of the 17 - inch combustor revealed that its thermal rating was more in the 12 to 13 MM Btu/hr range. The thermal rating of the 34 - inch combustor would therefore be 50 MM Btu/hr nominal.

The performance and verification data were also to be used to compare operation with bituminous and subbituminious pulverized coals, and a coal water mixture manufactured from a bituminous coal.

A general description of the system, with differences from the 17 - inch combustor noted, is followed by the test results.

3.2.1 Combustion System Description

An overall schematic of the 50 MM Btu/hr combustor system is shown in Figure 3.18. It consists of a precombustor or viitiator, a first or slagging stage, a slag recovery section, an "afterburner" for secondary combustion, a quench chamber, an exhaust scrubber and a stack. The system was installed in a new test position, Cell 3, at the Fossil Energy Test Site (FETS). The test cell and combustor system was constructed with TRW funds. The installation is shown in Figure 3.19 and the "virgin" slagging stage is shown in Figure 3.20. Hot combustion air is supplied by the same indirectly fired air preheater used for the Task 2 tests.

The coal water mixture supply sytem contains provisions for two CWM injectors: precombustor and slagging stage. A schematic of the supply system is shown in Figure 3.21. The CWM was transported to the test site in 5,000 gallon tankers and positioned adjacent to the test cell. A nitrogen purge was maintained on the tanker. Recycle provisions were also incorporated to prevent the possibility of CWM settling and or compacting. A CWM tanker is shown next to the test cell in Figure 3.22. The two CWM pumps are to the right of the tanker at ground level.

This combustor incorporates a different slag recovery section than does the 17 - inch combustor. A "stovepipe" recovery section with a vertical exit is employed to prevent slag from "creeping" along the walls and spilling over into the heat utilization equipment. This design eliminated the need for a second slag tank. A continuous slag removal system is also incorporated. The combustor is inclined at a 15 degree angle to the horizontal rather than the 30 degree inclination

Figure 3.18

50 MMBtu/hr Combustor System

TRW

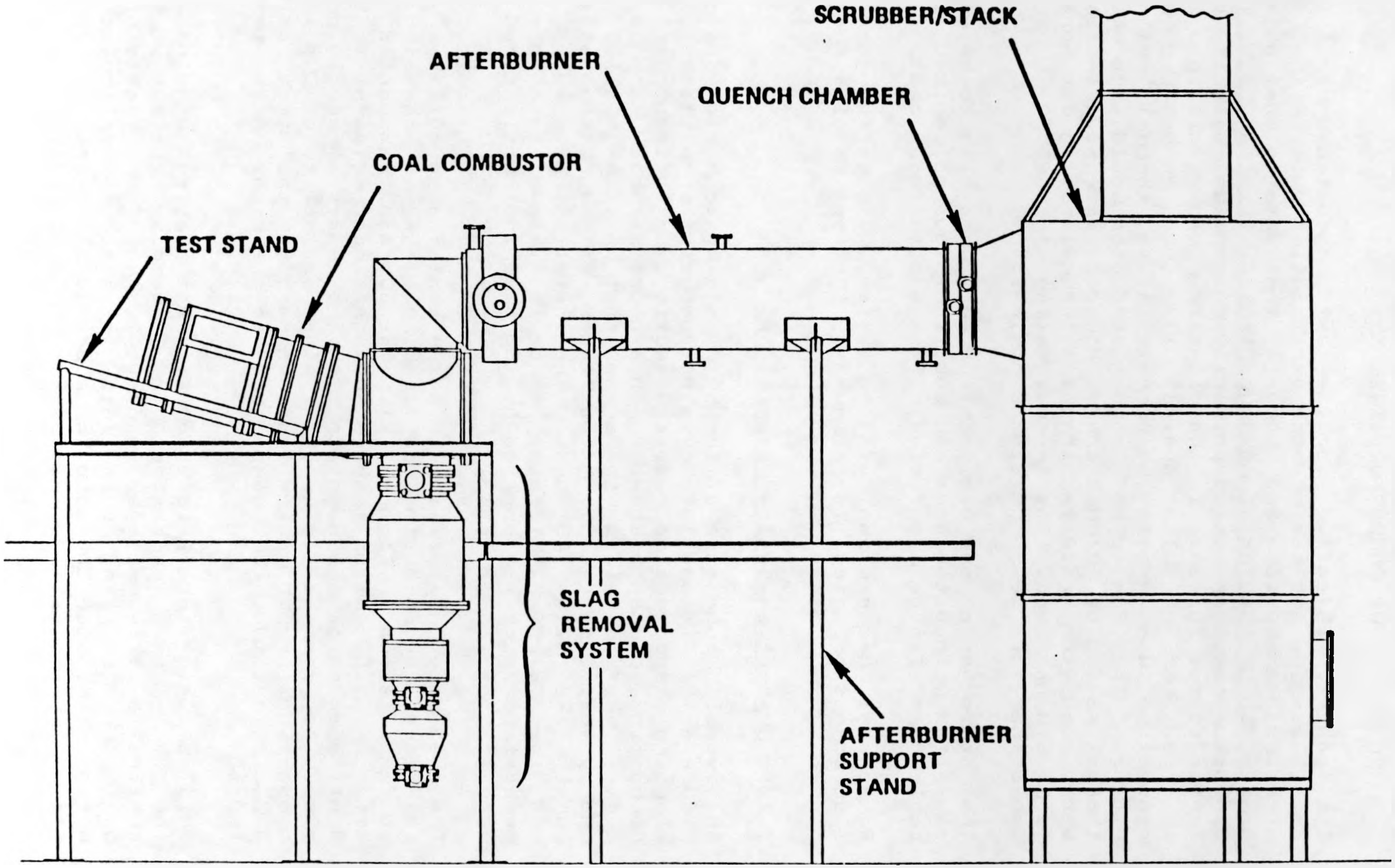


Figure 3.19

Cell No. 3 - 50 MMBtu/hr Combustor Installation

TRW

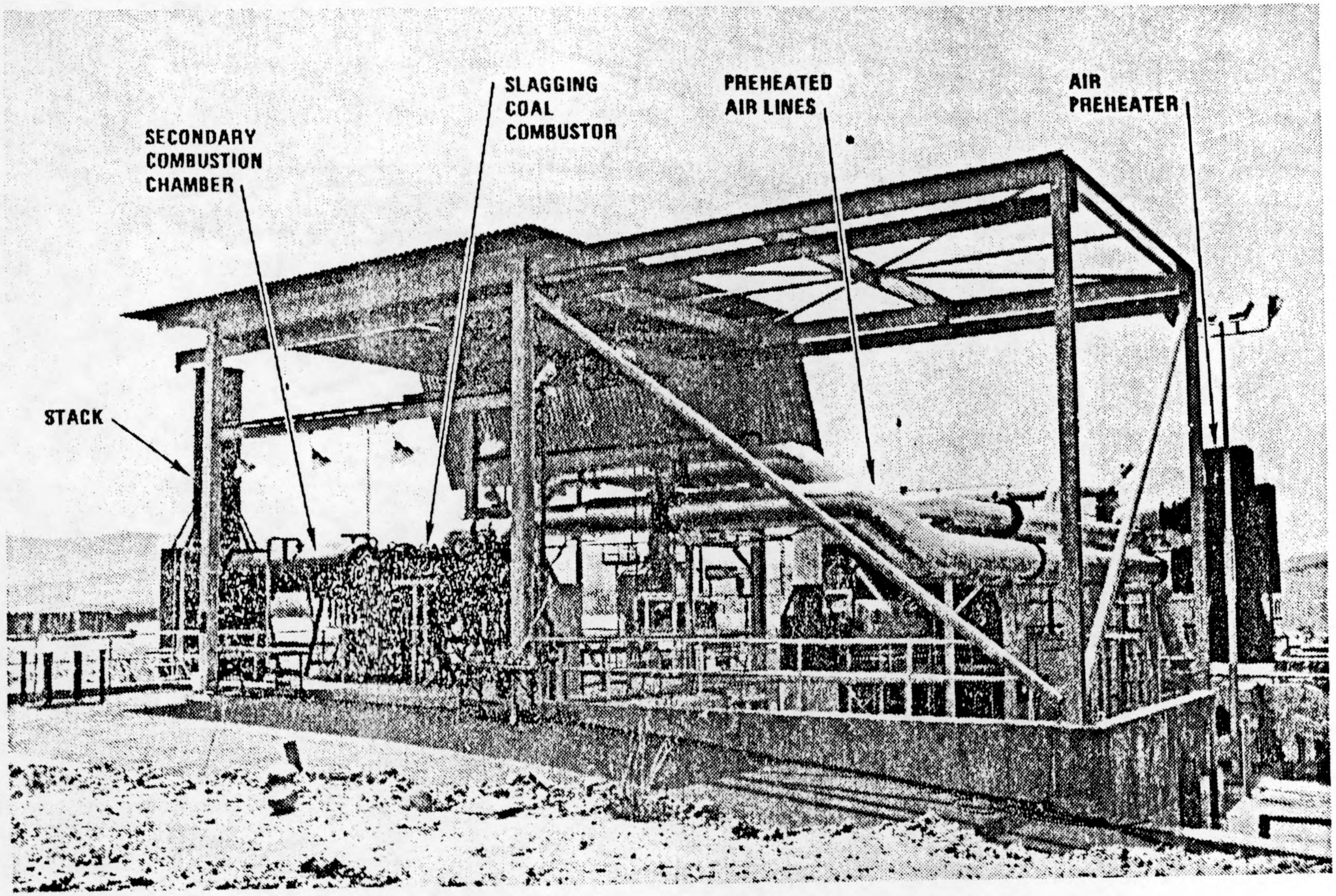


Figure 3.20

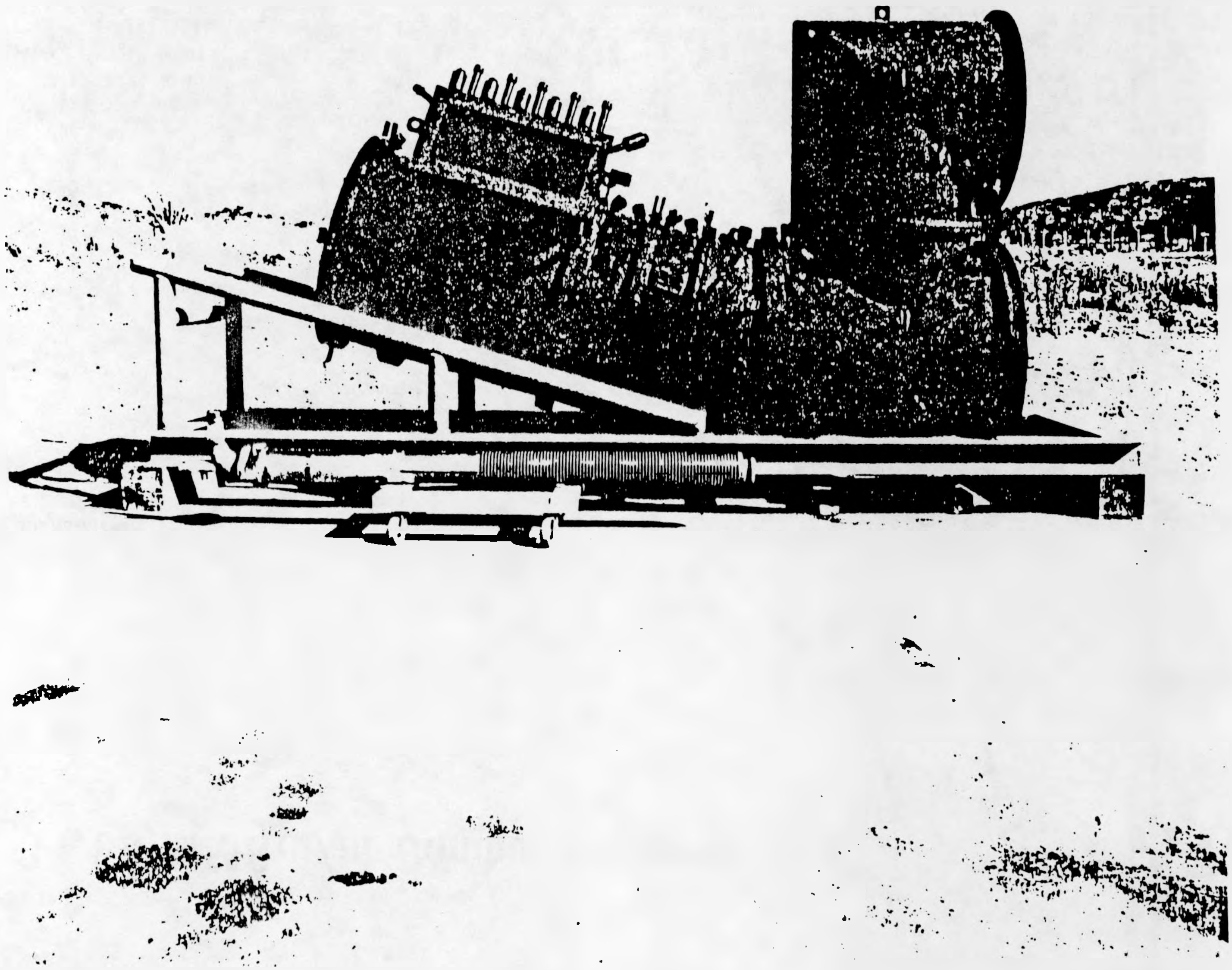


Figure 3.21

CWM SUPPLY SYSTEM

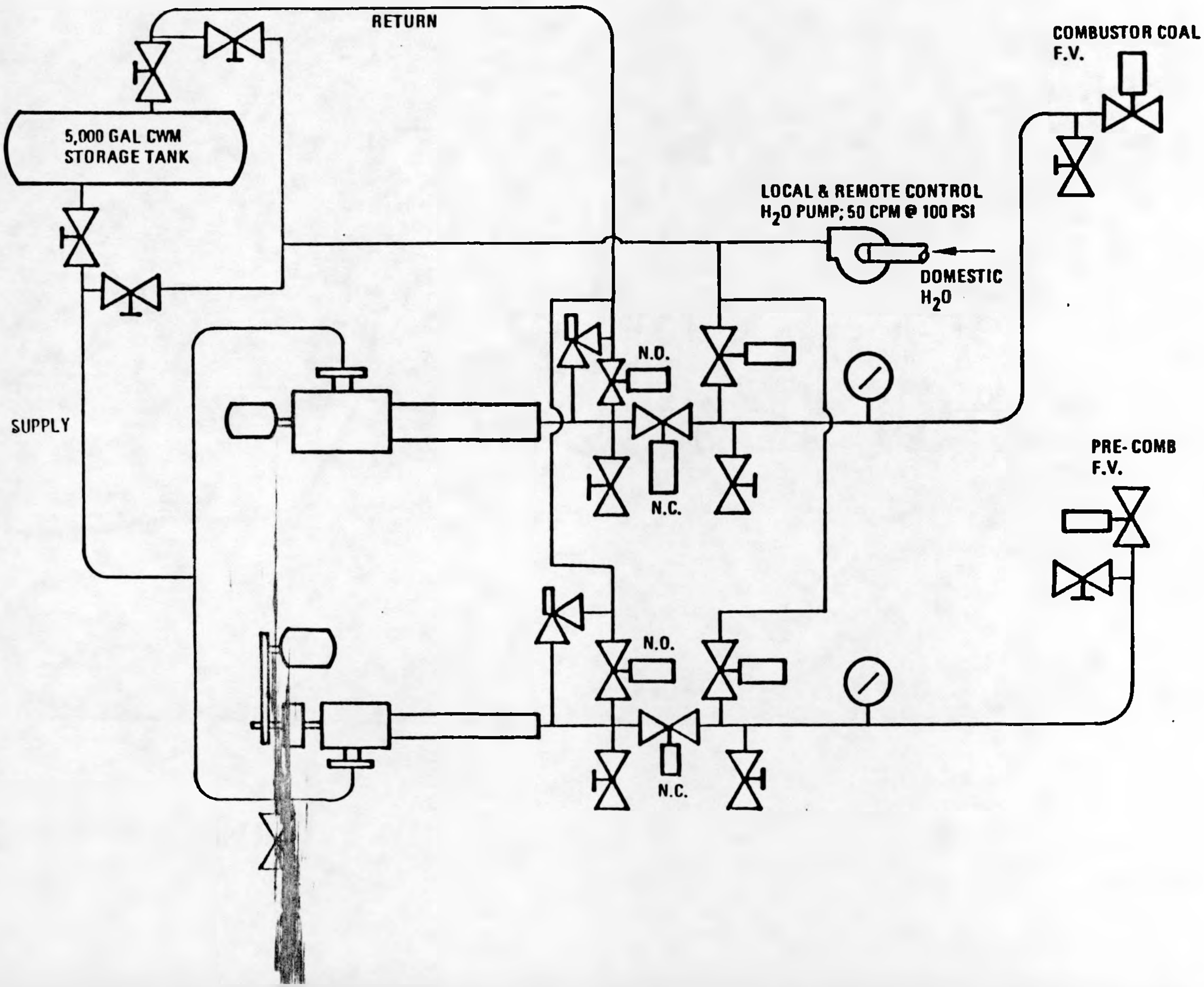
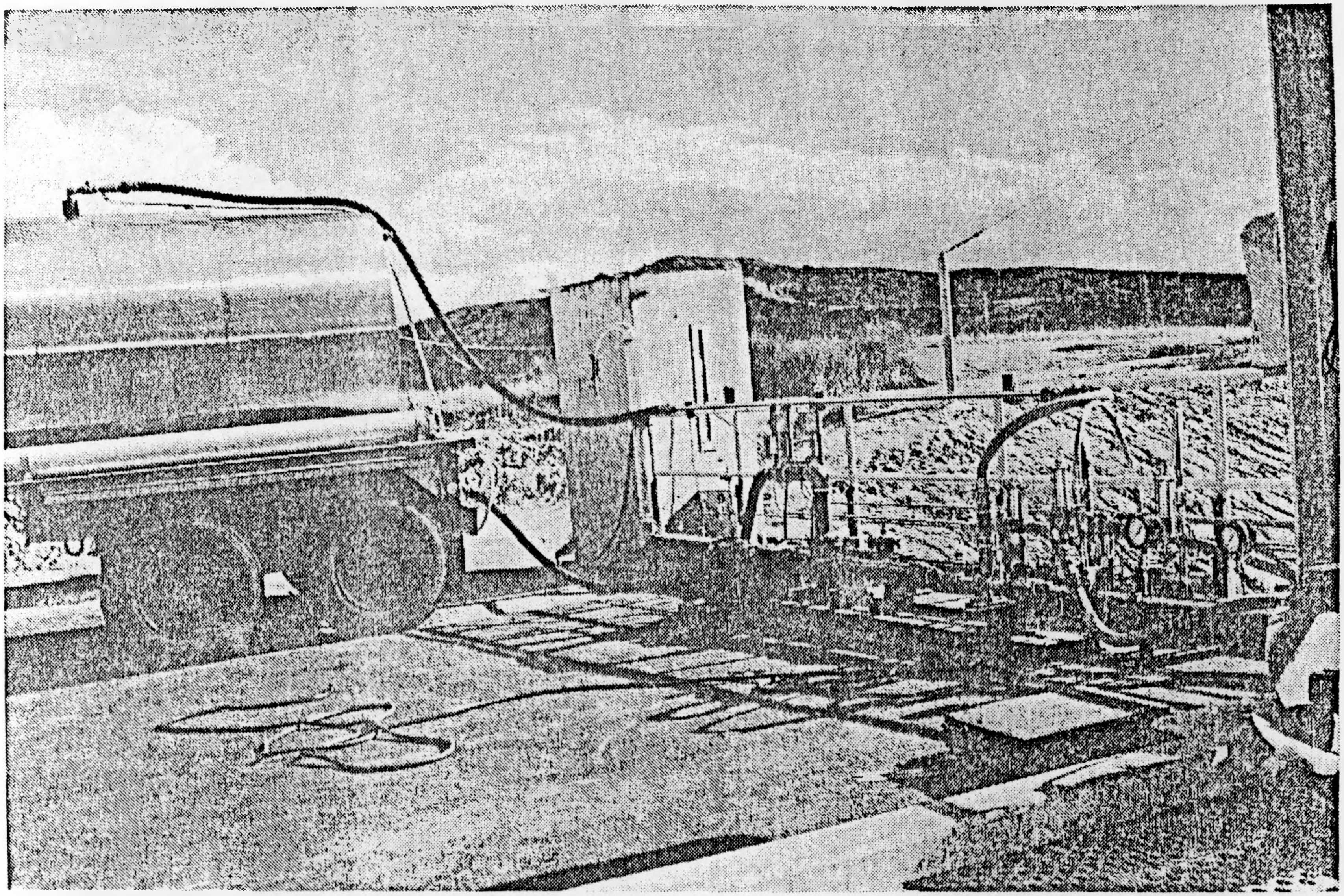


Figure 3.22

CWM Feed System



DE-AC22-84PC60422

for the 17 - inch combustor.

Sorbent injection for the sulfur emission reduction tests employed the same type of "stinger" injector as did that for the Task 2 tests.

3.3.2 Principles of Operation

The principles of operation are basically identical to the 17 - inch combustor which have been described in section 3.2.2. The equipment used in this test task did not contain a boiler simulator, which was installed in Task 6. Instead, an afterburner was employed wherein air is rapidly mixed with the combustion gases and then quenched. It shouldbe noted that this type of arrangement notoriously produces higher NOx values than does operation with a boiler or boiler simulator.

3.3.3 Instrumentation and Diagnostics

With the exception of instrumentation for the boiler simulator, the instrumentation and diagnostics were virtually identical to those used on the 17 - inch combustor for the Task 2 tests (section 3.2.3).

The final gas composition measurements were made at the end of the afterburner prior to the water quench section.

3.3.4 Performance and Verification Testing

The coals used for this test task were similar to those used in the Task 2 testing. The coal property values are contained in Appendix A. The coals tested were:

- o Ohio No. 6, used for check-out testing
- o Wyoming Rosebud pulverized coal
- o Pittsburgh No. 8 pulverized coal
- o Upper Freeport pulverized coal
- o Upper Freeport coal water mixture

A test plan was prepared which covered the test effort activities. This test plan is contained in Appendix C.

Cold flow functional checks were performed to verify the operational status of the overall system prior to the first hot fire tests. These included check-out of:

- o Air supply system
- o Cooling water system

- o Fuel system
- o Coal transport system
- o Coal water mixture transport system
- o Sorbent transport system
- o Nitrogen system

A total of 52 tests were completed with a cumulative run time of 75 hours. Approximately 86 tons of pulverized coal and 17 tons of coal water mixture were consumed during this effort. A summary of these tests is presented in Table 3.5.

<u>Combustion Characteristics</u>

The combustion characteristics were judged as excellent when the system was fired with pulverized coal, and marginal to poor when fired with the coal water mixture. This is illustrated in Figure 3.23, where the first stage stoichiometry as determined by gas analysis is compared to the first stage stoichiometry as determined by the reactant flowrates. The carbon conversion is 100% when both stoichiometries are equal, and less than 100% when the stoichiometry by gas measurements is greater than the stoichiometry by flow. The carbon conversion is basically 100% at stoichiometries greater than 0.72 for pulverized coal. The carbon conversion is about 85% to 90% for testing with the CWM. The pulverized coal carbon conversion is significantly better with the larger combustor than with the smaller combustor.

Another indicator of good combustion was the level of CO at the stack which remained at 50 ppmv or below at excess oxygen levels on the order of 3%.

The poor performance with the CWM had its roots within the precombustor. The switchover from pulverized coal to CWM was accomplished by changing only the injectors. No internal geometry changes to the precombustor were made. The large amount of water (30%) present changed the devolatilization kinetics. Insufficient residence time prevented complete combustion within the precombustor. As a result, combustion in the slagging stage headend was not intense enough to allow complete combustion there either. Attempts were not made to begin a CWM combustion development task. The precombustor was subsequently operated on oil, which by itself does not provide the correct precombustor exit thermal environment. Additional work is required with CWM combustion.

Tests conducted on pulverized coal were also aimed at finding the minimum air preheat temperature at which the system could be operated without requiring an ignitor for precombustor flame stabilization. The system was brought up on line and allowed to reach steady stage conditions. The air preheat temperature at this point was nominally 450 F. Fuel oil to the indirectly fired air preheater was then shut off and the air preheat temperature was allowed to decay. The flame in

Table 3.5. ASCCS Test Summary

Test No.	Type of Test	Comments	Coal	Burn Time, Min. Precomb.	Burn Time, Min. Comb.	Total (1) Load MMBtu/hr	Precomb. Exit Temp., °F	Average ϕ_1 by flow
20	Precombustor (PC) checkout	Unstable combustion. High CO; dirty stack. Ignitor required for PC to stay lit.	Ohio 6B	21	---	~10	---	---
21A	PC characterization with injector in different position.	High CO; dirty stack. PC remained lit without ignitor.	Ohio 6B	29	---	10	1750	---
21B	PC characterization with PC air inlet velocity (swirl) increased.	High CO; dirty stack. No change with increased swirl.	Ohio 6B	36	---	10	1750	---
22AB	PC characterization with different injector position. Vary carrier flow and PC air inlet velocity.	Appeared lower carrier flow promotes better mixing. Air flow stability problems at low air flows. Stack plume and CO level improved slightly.	Ohio 6B	68	---	8.5	varied 1500-2000	---
23	PC characterization. Vary ϕ_{01}, preheat, load independently.	Very high preheat initially with clean stack low CO, ϕ_{01} .8. CO fluctuated w/coal flow, ϕ_{01}. Increasing load, thus higher air inlet velocities, appeared to increase stack opacity.	Ohio 6B	123	---	9 -12	varied 1850-2400	---
24	PC characterization at higher load. Stage PC combustion by reducing ϕ_{01}.	Not as stable combustion at higher load. PC flame oscillating. Stack intermittently hazy. Lower CO and clear stack occured at preheat ~2000-2100, ϕ_{01} ~.8-.9. Problem	Ohio 6B	84	---	15.4	2000	---

(1) Includes all fuel (oil, propane, coal or CWM) and air.

ASCCS Test Summary

Test No.	Type of Test	Comments	Coal	Burn Time, Min. Precomb.	Comb.	Total (1) Load MMBtu/hr	Precomb. Exit Temp., °F	Average $\emptyset_1$ by flow
24		with control of air flows. Shut down due to loss of PC air P transducer.						
25	PC characterization at higher load w/PC air inlet damper removed. Stage PC combustion by reducing $\emptyset_{01}$.	Good test. Results of test 24 confirmed. PC appears sensitive to PC air flow. Ignitor required a few times to maintain PC flame stability.	Ohio 6B	101	---	15.9	2050	---
26	PC at test 25 conditions. Checkout main combustor operation.	PC air flow fluctuating probably causing PC flame oscillations. Operating PC carrier at ~21:1. Successful combustor operation. Uniform slag coverage.	Upper Freeport "A"	132	67	52.0	2050	.78
27	Evaluate PC operation w/ increased swirl baffle diameter. Obtain information on smoke limit.	Unstable combustion in PC. Ignitor on periodically to stabilize PC flame. PC flame pulsated in semi detached position. Combustor can run at $\emptyset_2 \sim$ 1.13 with no smoking. Aborted w/high combustion air inlet ring temperature. Post test combustor appearance was good.	Upper Freeport "A"	62	38	50.8	2100	.78
28ABC	Evaluate PC operation w/new baffle configuration and injector position.	A: Aborted w/high combustion air inlet ring temperature.	Upper Free-	94	0	13.3-15.7	2000-2350	---

(1) Includes all fuel (oil, propane, coal or CWM) and air.

ASCCS Test Summary

Test No.	Type of Test	Comments	Coal	Burn Time, Min. Precomb.	Burn Time, Min. Comb.	Total (1) Load MMBtu/hr	Precomb. Exit Temp., °F	Average $Ø_1$ by flow
28ABC		B: Unstable combustion in PC. Ignitor required to stabilize PC flame. Lost 1 lb/s in combustion air (WAMU)-shut down. C: Ran lower load so reduced PC air inlet velocity. Stack clear, CO low at high preheat (2300); at lower preheat, ignitor required for stabilization. Post test discovered PC coal injector gap inside oil ring. Combustor looked stripped. Appeared preheat temps. too high.						
29ABC	Evaluate PC operation with injector gap free.	Unstable combustion in PC, ignitor required. Problem w/combustion air valve (WAMU). High ΔT on deswirl plug - shut down.	Upper Freeport "A"	81	11	14-16.6	2000	---
30A	Combined stage, steady state operation.	Stack hazy w/PC lightoff, cleared up with combustor lightoff. Shut down to check out smoke coming from PC area. Found disconnected hose.	Upper Freeport "A"	22	21	53.6	2000	.75

(1) Includes all fuel (oil, propane, coal or CWM) and air.

ASCCS Test Summary

Test No.	Type of Test	Comments	Coal	Burn Time, Min. Precomb.	Burn Time, Min. Comb.	Total (1) Load MMBtu/hr	Precomb. Exit Temp., °F	Average $\emptyset_1$ by flow
30B	Combined stage, steady state.	Good test. Ran 40 min. without ignitor. Steady combustion. Post test showed fairly good slag coverage.	Upper Free-port "A"	51	51	46.2	1950	.72
31	Combined stage, steady state.	Good test. PC operation fairly stable. Good slag coverage, smooth, semi-shiney.	Upper Free-port "A"	54	54	~46	2000	.72
32	$\emptyset_1$ sweep at constant preheat, letting load vary.	PC flame instabilities after first 25 min. of running; ignitor required a few times. Momentary drop in combustor flow during middle of test. Problem adjusting second stage "make air".*	Upper Free port "A"	83	83	45.3-52.5	2000	.69-.81
33	Evaluate PC operation w/reduced baffle diameter. Combined stage operation-vary preheat at constant $\emptyset_1$ and load. Varied PC carrier flow.	No significant change w/change in PC carrier. Flucuations in PC coal and PC air flow possibly contributing to PC flame oscillations. Periodically indicated high CO levels. At lower preheat, (~1700) thus lower PC air flows PC flame appeared more stable. Slag coverage same as previous test.	Upper Free-port "A"	126	83	50.0	1600-2000	.78

(1) Includes all fuel (oil, propane, coal or CWM) and air.

*("Make air" is O_2 and N_2 mixed together with 30-40% O_2). Slag coverage about same as last test.

ASCCS Test Summary

Test No.	Type of Test	Comments	Coal	Burn Time, Min. Precomb.	Burn Time, Min. Comb.	Total (1) Load MMBtu/hr	Precomb. Exit Temp., °F	Average ϕ_1 by flow
34	Evaluate PC operation w/ new injector position.	PC flame stability appeared sensitive to PC air flow fluctuations, PC air velocity and PC coal flow fluctuations.	Upper Freeport "A"	59	6	15.1	2000	---
35	Steady state combined stage operation.	PC flame appeared to operate on "edge" of stability;would de tach and reattach to PC w/o ignitor. Combustor ran fine. Slag coverage fairly uniform; colder looking in head end/air inlet.	Upper Freeport "A"	110	109	51.0	2050	.71
36	Evaluate PC operation w/increased baffle length	When PC flame detach-head rumbling in comb. PC appears more stable w/WAPC <~2.4 lb/s. Appears increased baffle length improved PC operation, Ignitor required a few times to stabilize PC flame. PC flame still sensitive to system fluctuations.	Wyoming Rosebud "B"	140	99	52.0	1550-1950	.74
37	Steady state combined stage operation.	Good test. Some ocsillation in PC flame, ignitor required. Appeared to have switched slag coverage except in test section. Slag coverage uniform, thinner than w/UPFRA coal.	Wyoming Rosebud "B"	91	88	51.0	1825	.75

← (1) Includes all fuel (oil, propane, coal or CWM) and air.

ASCCS Test Summary

Test No.	Type of Test	Comments	Coal	Burn Time, Min. Precomb.	Burn Time, Min. Comb.	Total (1) Load MMBtu/hr	Precomb. Exit Temp., °F	Average Ø1 by flow
37		Post test discovered leak in coal injector sleeve.						
38	Steady state combined stage operation at lower preheat.	Good test. Momentary PC flame detachments. Still very sensitive to change in air flow pressure, coal flow. Slag coverage maintained from previous test.	Wyoming Rosebud "B"	88	87	51.0	1670	.725
39	Steady state combined stage operation at lower preheat.	Good, smooth test. No detachment of PC flame. Noticed increased fluctuations in PST, PDPCST. Discovered plugging w/ slag rejection system. Post test-uniform slag coverage."Growthy" region in Cl. Buildup in after burner around 2nd stage air nozzles.	Wyoming Rosebud "B"	83	80	50.5	1560	.73
40	Steady state combined stage combined stage operation at high load.	Fluctuations in PC flame w/and w/o ignitor. Limits in air flows due to back pressure would not allow coal load >~53.5 mm.	Wyoming Rosebud "B"	85	84	57.1	1570	.73
41	Steady state combined stage operation at high load.	Initial problem with combustion air flow (WAMU). Shut down	Wyoming Rosebud "B"	46	43	56-58	1800	.73

(1) Includes all fuel (oil, propane, coal or CWM) and air.

ASCCS Test Summary

Test No.	Type of Test	Comments	Coal	Burn Time, Min. Precomb.	Burn Time, Min. Comb.	Total (1) Load MMBtu/hr	Precomb. Exit Temp., °F	Average $\emptyset_1$ by flow
41		due to problem w/slag rejection system. Never obtained steady state condition.						
42	Steady state combined stage operation at high load.	Fairly steady test. Problem w/SO_2 analyzer. Small coal flow fluctuations. Post test-scrubber full of water; overall combustor appearance looked dry, like different coal.	Wyoming Rosebud "B"	75	75	57.5	1760	.73
43	Combined stage operation. Vary $\emptyset_1$ at two preheats.	Problem w/PC flame detaching. Appeared to be caused by PC coal flow "glitches" and/or air flow fluctuations. Problem with "make air" N_2 freezing-running 50% O_2 enrichment in 2nd stage. Post test had fairly uniform slag coverage.	Wyoming Rosebud "A"	165	164	51.9	1760,1580	.69-.82
44	Combined stage operation. Vary $\emptyset_1$. Slag switchover.	Rumbling heard coming from elbow section when PC flame detached. Ran last 15 min. of test w/ignitor at low flow; PC flame unstable. Problems stabilizing air flows.	PC: Wyoming Rosebud "A" Comb: Upper Freeport "B"	97	95	52.7	1815	.68-.72

(1) Includes all fuel (oil, propane, coal or CWM) and air.

ASCCS Test Summary

Test No.	Type of Test	Comments	Coal	Burn Time, Min. Precomb.	Burn Time, Min. Comb.	Total (1) Load MMBtu/hr	Precomb. Exit Temp., °F	Average $\emptyset_1$ by flow
44		Post test, combustor looks colder overall						
45	Combined stage, steady state operation at higher velocity.	PC required ignitor to remain attached. Ran with ignitor at low flow. PC coal dropped off momentarily during test. Combustor appeared colder from previous test. Slag buildup in after burner is substantial.	Upper Freeport "B"	84	83	51.8	1850	.75
46	PC evaluation varying preheat, $\emptyset_1$, load, air flows.	No change made any significant difference in PC operation; PC flame still very unstable. Post test-combustor slag coverage stripped in areas. Slag appearance is char-like, with pity surface.	Upper Freeport "B"	140	---	13.0	1900-2360	---
47	PC evaluation of change in baffle diameter. Determined required air inlet temp. to maintain combustion in PC.	Overall, PC improved w/baffle diameter change. However, PC operation is still not that stable. It appears that most significant factor affecting PC flame stability is PC air flow-too high of	Upper Freeport	198	---	11.2-15.4	1550-2050	---

(1) Includes all fuel (oil, propane, coal or CWM) and air.

ASCCS Test Summary

Test No.	Type of Test	Comments	Coal	Burn Time, Min. Precomb.	Comb.	Total (1) Load MMBtu/hr	Precomb. Exit Temp., °F	Average ϕ_1 by flow
47		air flows results in flame instabilities. PC appears to perform better w/carrier flow at ~10 to 1. Reduced air inlet temp. to <300°F successfully. Post test-combustor more stripped than previous test.						
48	Combined stage steady state operation.	Good test. Fairly stable combustion. Ignitor turned on an instant only ~5 times; slag coverage improved from test 47 but is still thin, dull, non-uniform.	Upper Freeport "B"	95	80	50.1	1900	.76
49	Combined stage steady state operation.	Fairly good test except last 10 min PC required ignitor; PC flame continued oscillating. Refractory installed in bare spots post test 48 slagged over fairly well. Overall, combustor coverage remained nonuniform.	Upper Freeport "B"	70	69	49.8	1830	.82

(1) Includes all fuel (oil, propane, coal or CWM) and air.

ASCCS Test Summary

Test No.	Type of Test	Comments	Coal	Burn Time, Min. Precomb.	Burn Time, Min. Comb.	Total (1) Load MMBtu/hr	Precomb. Exit Temp., °F	Average Ø1 by flow
50	Combined stage steady state operation.	Heard loud "pop" when combustor turned on. Fluctuations in PC coal flow and PC injection pressure affecting PC flame stability. Lost PC coal flow 20 min. after start. Last 60 min. of test was fairly steady; ignitor turned on for instant ~4 times. Post test slag coverage same as post test 49. Slagged over newly installed refractory, afterburner leak increased after having repaired post test.	Upper Freeport "B"	96	95	51.2	1915	.81
51	Combined stage steady state operation at higher load.	First 40 min. of test required ignitor on every 1-2 min. Appeared problem related to PC injection pressure; PC coal flow dropped off once. Slag coverage remained constant from Test 50. Afterburner full of material-mixture slag/scrubber type.	Upper Freeport "B"	70	69	59.6	1815	.75
52	Combined stage steady operation first part of test, vary Ø1 second part.	Fairly steady test. Ignitor turned on for an instant only 2 times.	Upper Freeport "B"	95	94	51.3	1900	.76, .70

(1) Includes all fuel (oil, propane, coal or CWM) and air.

ASCCS Test Summary

Test No.	Type of Test	Comments	Coal	Burn Time, Min. Precomb.	Burn Time, Min. Comb.	Total (1) Load MMBtu/hr	Precomb. Exit Temp., °F	Average $\emptyset_1$ by flow
52		Post test slag coverage changed slightly-refractory came off in some areas; average slag thickness maintained afterburner leak increased.						
53	Combined stage steady state. ~1 hr. Sorbent injection rest of test.	PC coal flow stopped ~20 min. into test. Shut down due to plugging of emission analyzers. Had sorbent on for 1 hr. at fairly steady flow. Post test combustor full of sorbent; slag coverage overall same as post test 52 min. Material in afterburner; partial plugging of 2nd stage air inlet ports.	Upper Freeport "B"	89	88	51.8	1880	.75
54	Combined stage operation. $\emptyset_1$ sweep at constant preheat. Flowed some sorbent.	35 min. into test comb. coal flow dropped off. Problem flowing sorbent Ignitor turned on for an instant ~12 times. 2nd lightoff, comb. lit off with "boom". Slag coverage appears dull; main change from post test 53 is 2 in. spacer is now 80% bare. Leak in afterburner increased substantially.	Upper Freeport "B"	69	68	50.9-52.8	1950	.63-.77

(1) Includes all fuel (oil, propane, coal or CWM) and air.

ASCCS Test Summary

Test No.	Type of Test	Comments	Coal	Burn Time, Min. Precomb.	Burn Time, Min. Comb.	Total (1) Load MMBtu/hr	Precomb. Exit Temp., °F	Average ϕ_1 by flow
55	Combined stage steady state flowing sorbent at 3 Ca/s ratios.	Ignitor turned on for an instant ~16 times. PC operating different PC flame running in halfway detached position part of test. No significant change in slag coverage from post test 54. Slag not as dull looking. Large amount of material cleaned from afterburner.	Upper Freeport "B"	110	100	51.4	1900	.76
56	Combined stage operation. ϕ_1 sweep. Slag switchover.	Ignitor turned on periodically to stabilize PC flame. PC flame seemed to operate between attached and detached position. Combustor appearance deteriorated slightly from post test 55-2 in. spacer only 5% covered; Air inlet and test section slightly thinner large amount of material cleaned from afterburner.	Pittsburgh 8 "B"	92	90	51.6-53.9	1850-2000	.66-.78

(1) Includes all fuel (oil, propane, coal or CWM) and air.

ASCCS Test Summary

Test No.	Type of Test	Comments	Coal	Burn Time, Min. Precomb.	Burn Time, Min. Comb.	Total (1) Load MMBtu/hr	Precomb. Exit Temp., °F	Average ϕ_1 by flow
57	Combined stage steady state operation.	Ignitor on for an instant ~12 times. PC injection pressure fluctuating. Towards end of test, PC coal flow cycling-would drop off then come back to normal. No significant change in slag coverage from previous test; however test section appears slightly thinner. Afterburner leak increased.	Pittsburgh 8 "B"	80	77	51.1	1920	.82
58	Combined stage steady state operation. Inject sorbent at 3 ca/s ratios.	Sorbent on 54 min. Ignitor on for an instant ~21 times. PC injection pressure fluctuating. 35 min. into test combustor flow stopped. PC coal flow dropped off ~4 times. Combustor has sorbent sprinkled inside. Looked like slag and scrubber material had more unburned coal than usual.	Pittsburgh 8 "B"	100	99	51.3	1870	.75

(1) Includes all fuel (oil, propane, coal or CWM) and air.

ASCCS Test Summary

Test No.	Type of Test	Comments	Coal	Burn Time, Min. Precomb.	Burn Time, Min. Comb.	Total (1) Load MMBtu/hr	Precomb. Exit Temp., °F	Average $\emptyset_1$ by flow
59	Combined stage steady state operation. Inject sorbent at constant flow-rate. Inject water.	Sorbent on 57 min. First 70 min., PC ran steady. Remaining test-PC coal flow very unstable-hopper wt. may have been too low. Sorbent flow did not stay constant. No significant change in combustor slag coverage.	Pittsburgh 8 "B"	97	96	50.4	1885	.77
63	PC checkout for slurry operation. No slurry burned.	Ignitor required oxy-gen enriched air to reach necessary ignition temp. Oil flame sensitive to PC air flow; problem w/ignition at high air flow. Appears oil velocity too high-oil burning on walls.	Upper Freeport slurry	0	0	---	---	---
64	PC checkout for slurry operation.	Oil flame stability required high ignitor temp. (~1800 F), and oil flow > 55 mlb. Slurry burned w/gun position 2 in. from baffle trailing edge; would not burn w/gun 1/2 in. from baffle trailing edge. Slurry appears to start better with "no water lead" start.	Upper Freeport slurry	14	0	14.8	---	---

(1) Includes all fuel (oil, propane, coal or CWM) and air.

ASCCS Test Summary

Test No.	Type of Test	Comments	Coal	Burn Time, Min. Precomb.	Burn Time, Min. Comb.	Total (1) Load MMBtu/hr	Precomb. Exit Temp., °F	Average ϕ_1 by flow
65AB	PC checkout for slurry operation. No slurry burned.	Oil flame not stable at high swirl. Slurry lightoff very sensitive to stable oil flame. Limited operating range w/ignitor, oil and slurry to maintain combustion. Lost one fan before test 65B.	Upper Freeport Slurry	0	0	---	---	---
66	PC and comb. checkout for slurry operation. Oil boost in both PC and comb.	Obtained fairly stable flame in PC. oil ignition in main stage checked out. Established slurry flame in comb. w/o oil on. No apparent change in comb. flame w/or w/o oil.	Upper Freeport Slurry	27	5	16.4	---	---
67	Combined stage slurry operation w/oil boost in PC.	Getting buildup in PC w/char; pieces would blow away causing black/grey puff out stack. Comb. appeared to run fairly well combustor slag coverage is "flakey" in some sections, flakes off when touching it. Overall, comb. has char like appearance. No visual post test build up in PC. However buildup may have blown away after shutdown.	Upper Freeport Slurry	51	37	44.2	2000	.87

(1) Includes all fuel (oil, propane, coal or CWM) and air.

ASCCS Test Summary

Test No.	Type of Test	Comments	Coal	Burn Time, Min. Precomb.	Burn Time, Min. Comb.	Total (1) Load MMBtu/hr	Precomb. Exit Temp., °F	Average ϕ_1 by flow
68	Combined stage slurry operation w/oil boost in PC; varied slurry flowrate.	Appeared to got char buildup on oil ring in PC. Oil ring did not improve PC operation, still getting char buildup in PC. Increase in slurry flowrate lowered O_2 by approx. same %. Could not keep oil flame lit when tried running only oil in PC; appeared air flows were too high. Post test comb. appearance is improved overall from last test. Appeared to have burned hotter.	Upper Freeport	37	25	44.8	2050	.89
69A	Combined stage operation w/oil boost in PC.	Still getting char buildup in PC which affects overall operation. Went to oil fired PC to concentrate on combustor performance w/slurry.	Upper Freeport Slurry	35	30	44.8	2030	.90
69B	Combined stage operation w/oil fired PC.	Potential problem w/ N_2 enriched air going to PC from "make air" system. Increased comb. slurry flow rate to reduce O_2-backed off when got smoke out of stack.	Upper Freeport Slurry	99	84	46.3	1890	.80

(1) Includes all fuel (oil, propane, coal or CWM) and air.

ASCCS Test Summary

Test No.	Type of Test	Comments	Coal	Burn Time, Min. Precomb.	Burn Time, Min. Comb.	Total (1) Load MMBtu/hr	Precomb. Exit Temp., °F	Average $Ø_1$ by flow
69B		Intermittently had black puffs out stack during last 30 min. of test. Post test, test section, baffle, HEC looks pretty good; air inlet section looks cold, but not "flakey". Had char ridge at C1/A1 interface.						
70	Combined stage steady state operation w/oil fired PC. checkout of new slurry injector gap settings.	Fairly good, steady test. Slurry appears to have burned OK. Fewer "black puffs" than previous test. Post test comb. appearance overall is slightly thicker coverage than previous test. Char ridge increased in size slightly. Few "flakey" areas visible.	Upper Freeport Slurry	102	96	43.7	1870	.85
71	Combined stage steady state operation w/oil fired PC. checkout of new slurry injector gap settings.	Lowered slurry flowrate and "black puffs" were reduced, ΔT's increased. Head end and air inlet temp. gradually	Upper Freeport Slurry	167	163	41.5	1840	.88

(1) Includes all fuel (oil, propane, coal or CWM) and air.

ASCCS Test Summary

Test No.	Type of Test	Comments	Coal	Burn Time, Min. Precomb.	Comb.	Total (1) Load MMBtu/hr	Precomb. Exit Temp., °F	Average ϕ_1 by flow
71	-	decreased. Overall, appeared to run fairly well for such a long test.						
72	Combined stage steady state operation w/oil fired PC at higher pre-heat.	More "black puffs" than previous test. Potential plugging of slurry injector indicated by increased injection pressure. Shut down when comb. flame started looking dim; problem was w/ slag tank water level too high causing steam to cool down flame.	Upper Freeport Slurry	59	50	41.7	2000	.86
73	System problems w/respect to slurry flowrate invalidated any data.	Discovered slurry drain was open during test so only small percentage of slurry was actually being burned.	Upper Freeport Slurry	---	---	---	---	---

(1) Includes all fuel (oil, propane, coal or CWM) and air.

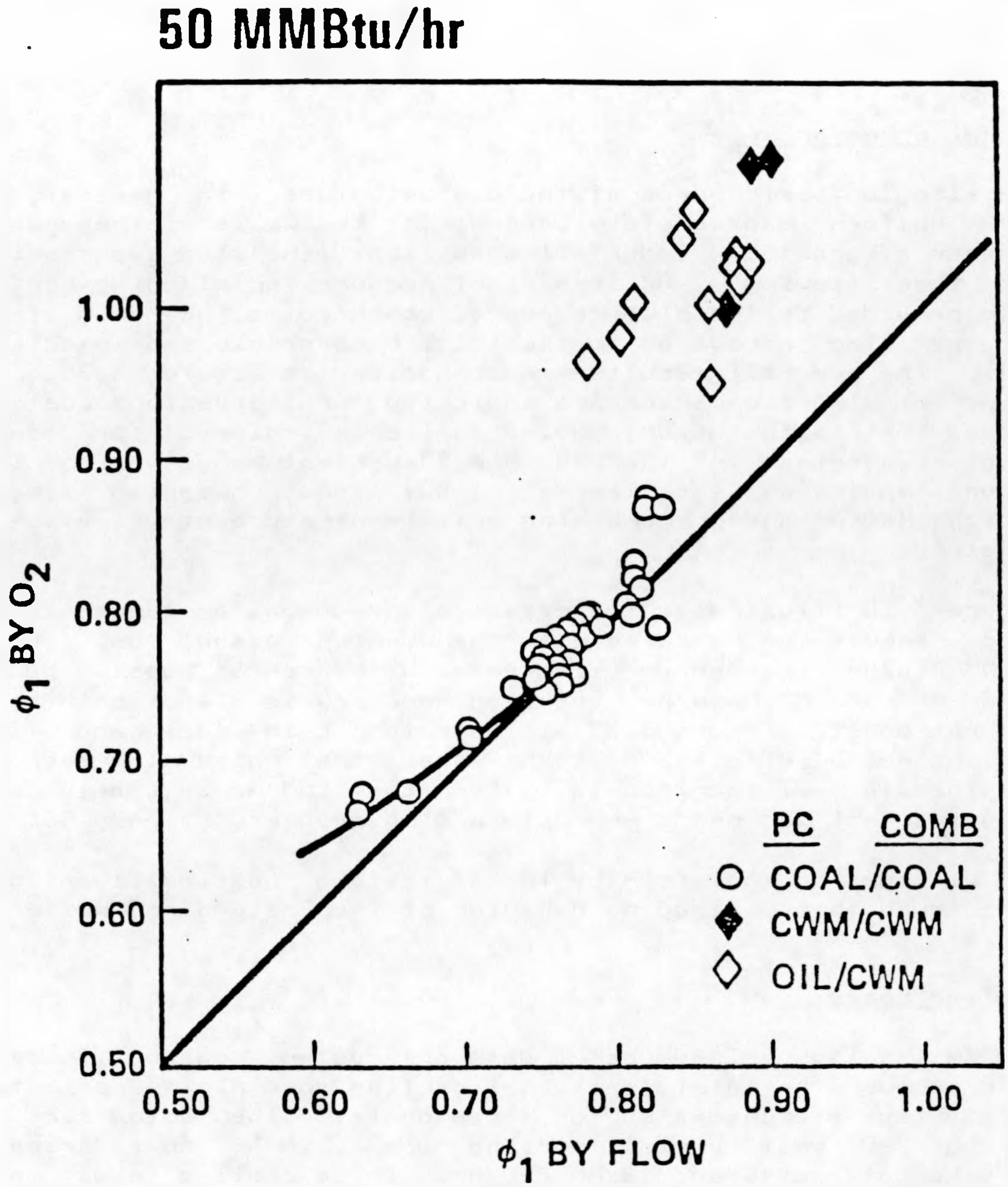


Figure 3.23. Combustor Performance

the precombustor was carefully observed for any signs of flame destabilization. The air preheat temperature as a function of the decay time after turning off the preheater is shown in Figure 3.24. Beginning at 275 F, the precombustor ignitor was required for flame stabilization. The minimum air preheat temperature required for operation without a neat fuel boost can be taken to be nominally 300 F. This was an important result, as the system study analyses indicated that 300 F was well within the capability of the smaller industrial plant systems.

Slagging Performance

The slagging performance of the combustor was, in general, excellent with uniform and complete coverage of the walls of the system and the absence of growths. Under all conditions, the slag tap remained clear and free flowing. An important measure for slagging performance is also provided by the slag recovery, computed as the ratio of the weight of the slag recovered to the total recoverable ash injected with the coal. The overrall results are summarized in Figure 3.25, where the range of slag recoveries are indicated for the various coals. The TRW funded tests with the Ohio No. 6 coal are indluded for completeness. Slag recoveries in the 80 and 90 percent range were achieved. The figure indicates the thermal input load, slagging stage average stoichiometry, and precombustor exit temperature at which the data were obtained.

Figure 3.26 illustrates the effect of precombustor temperature boost on slag recovery as measured with the Wyoming Rosebud coal. At a load of 51 MM Btu/hr, the recovery increases with preheat boost. However, at a load of 57 MM Btu/hr, the slag recovery is 95% at both high and low preheat boost. Figure 3.27 illustrates both fuel and first stage stoichiometry effects. It is seen that high slag recoveries were obtained for all four coals. For the CWM case, only one steady slagging test was performed with a slag recovery of only 56%.

As was the findings fromthe Task 2 testing, no significant differences were found in the slagging behavior of the Eastern and Western coals.

Cooling Loads

The tests also yielded useful data on system cooling loads. Figure 3.28 shows the total fractional cooling load plotted as a function of first stage stoichiometry for three coals. The data for the Upper Freeport A coal yields cooling loads in 14% to 17% range at loads varying between 45 and 49 MM Btu/hr. These cooling loads include the precombustor, slagging stage, slag recovery section and connection to the afterburner. The slagging stage cooling load alone was only of the order of 6% to 7% of the total input enthalpy. The figure shows a trend towards decreased cooling loads as the stoichiometric ratio in the slagging stage is reduced. Cooling loads for the Pittsburgh No. 8 coal and the Upper Freeport B coal appear to be systematically 2 percentage points higher than that for the Upper Freeport A coal. This is attributed, in part, to the loss of a substantial number of slag

Figure 3.24

Minimum Air Temperature Requirements - No Ignitor

TRW

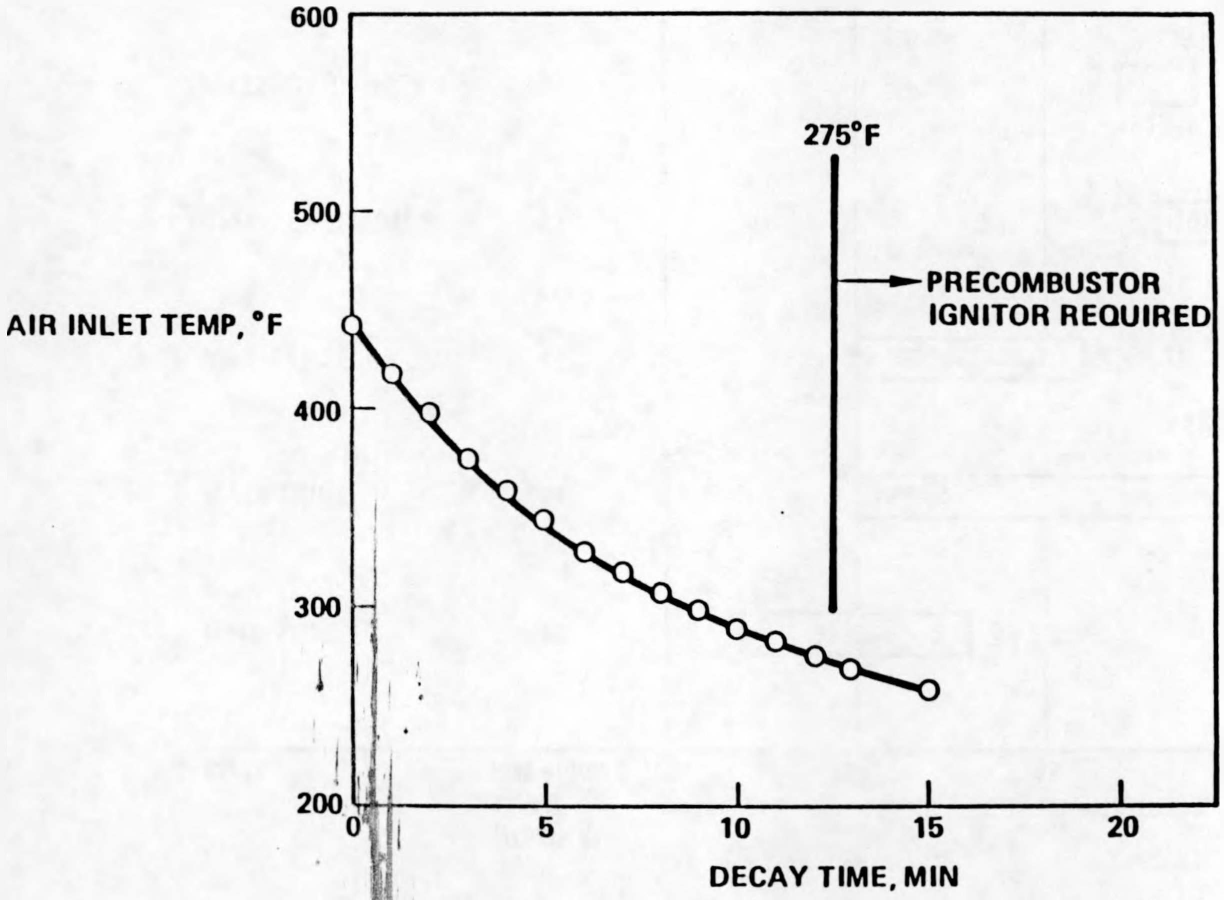


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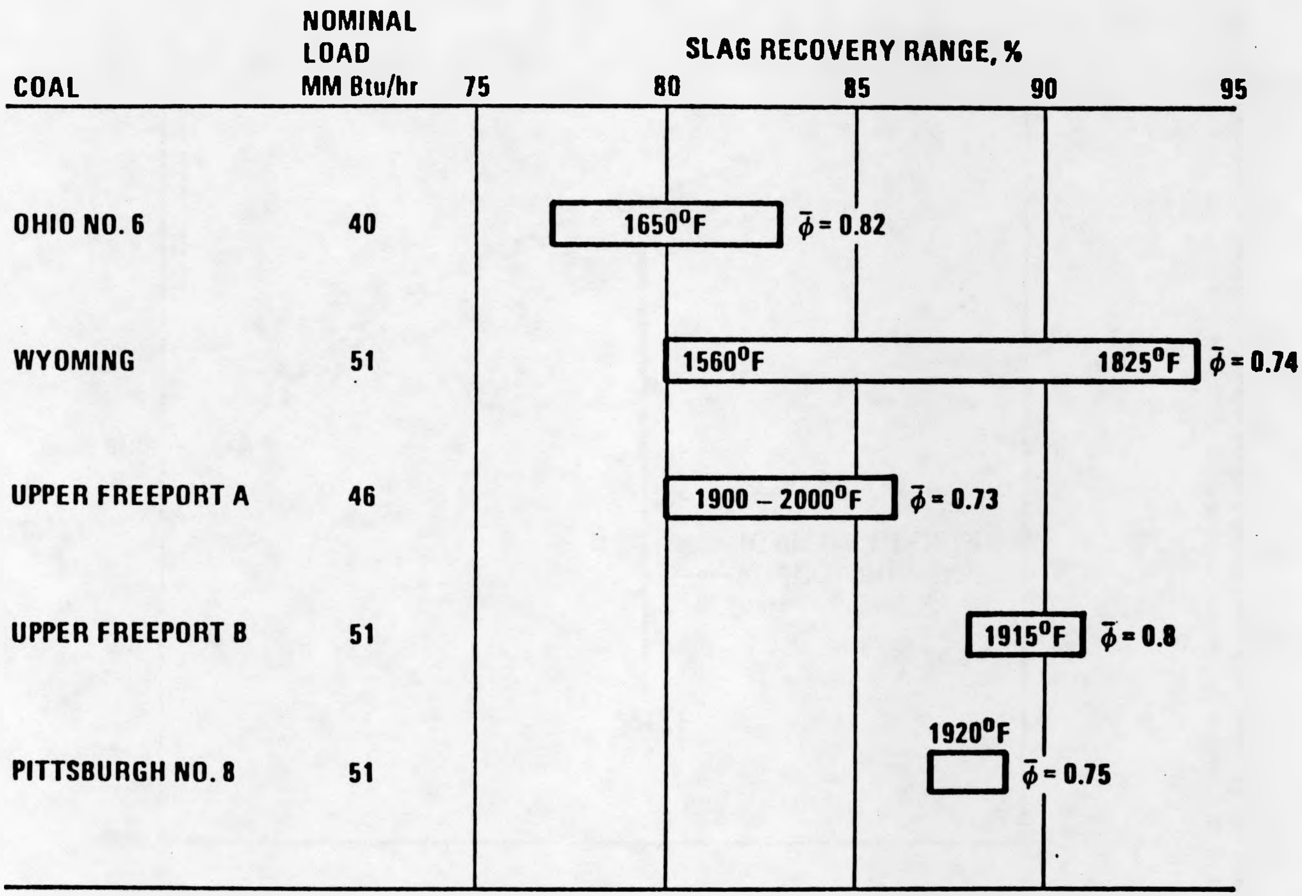
Figure 3.25

Slag Recovery Data



TEMPERATURES REFER TO PRECOMBUSTOR EXIT TEMPERATURES
$\bar{\phi}$ IS THE AVERAGE PRIMARY COMBUSTOR STOICHIOMETRY

Slag Recovery - 50 MMBtu/hr Combustor

Preheat Effect
Load Effect

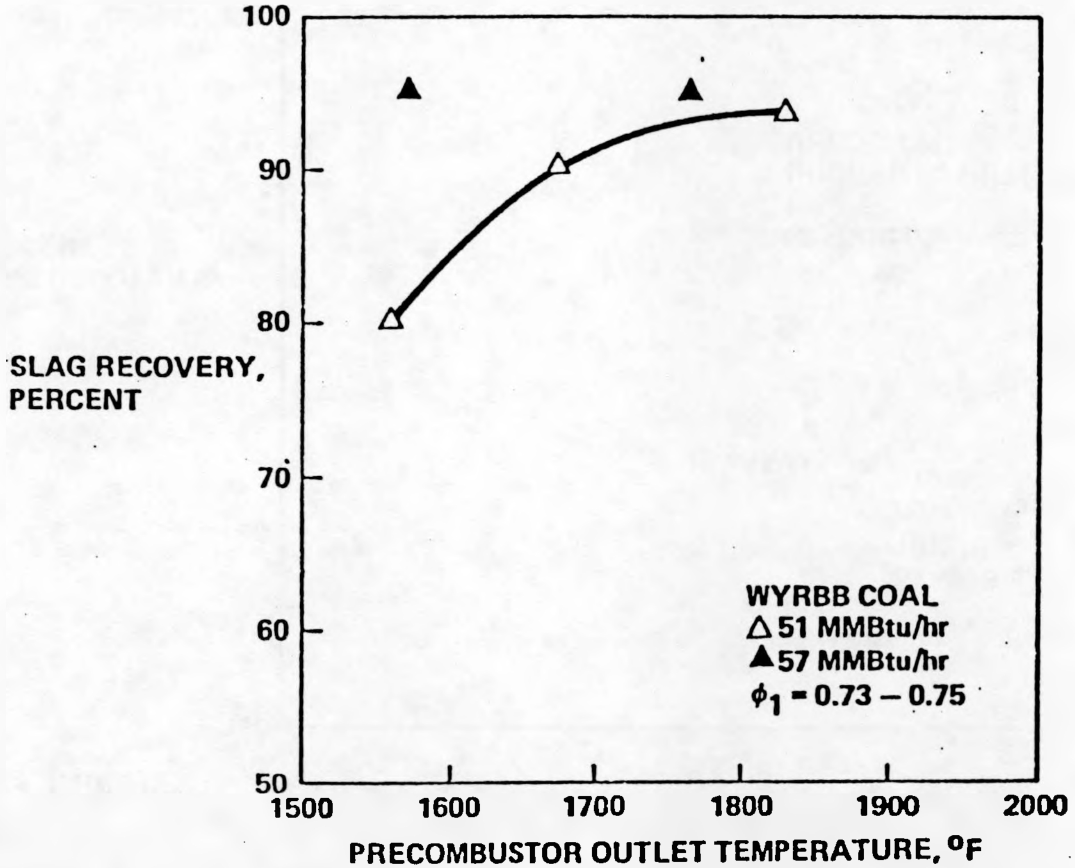


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Figure 3.27

Slag Recovery - 50 MMBtu/hr Combustor

Fuel Effects
Stoichiometry Effects

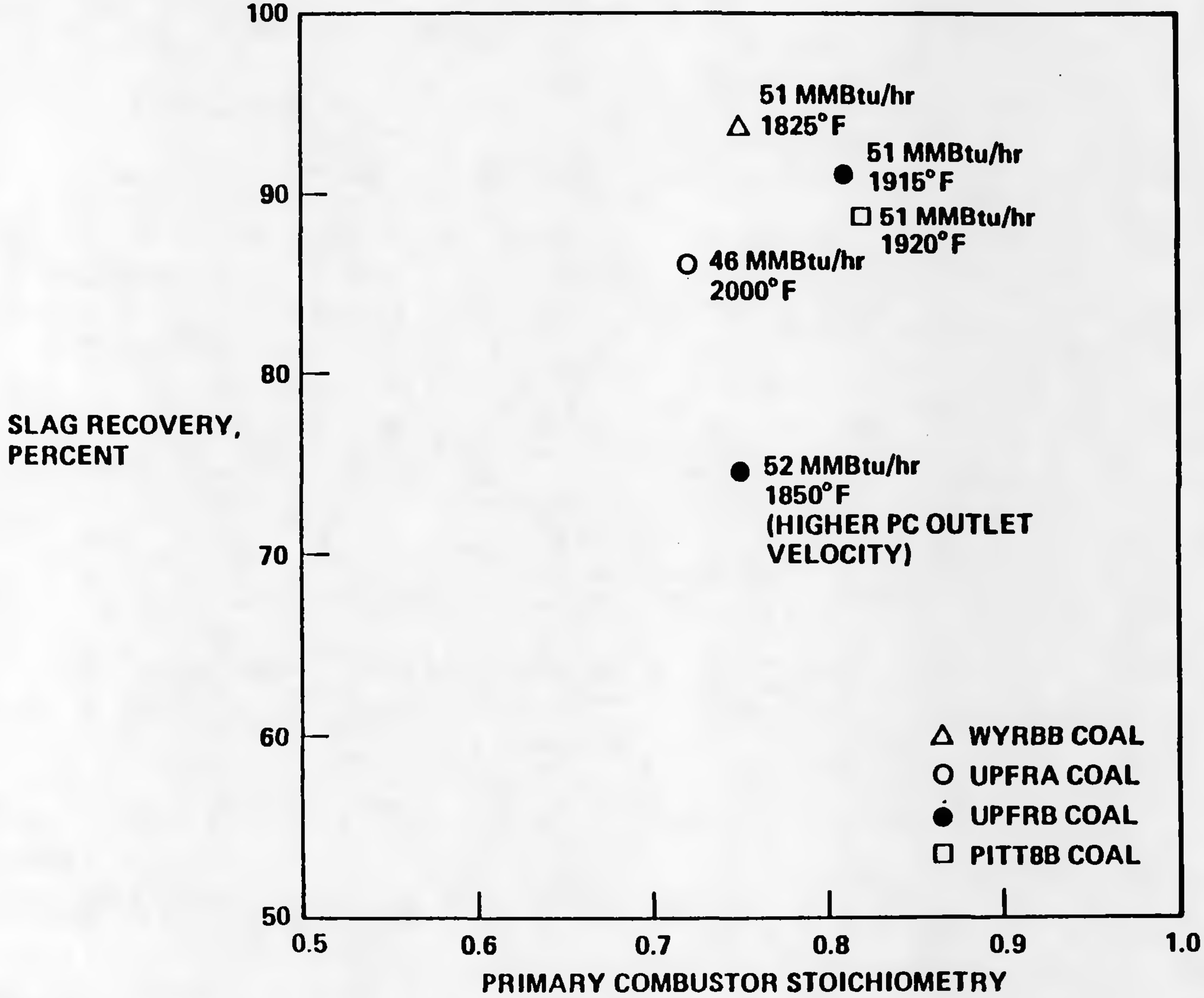

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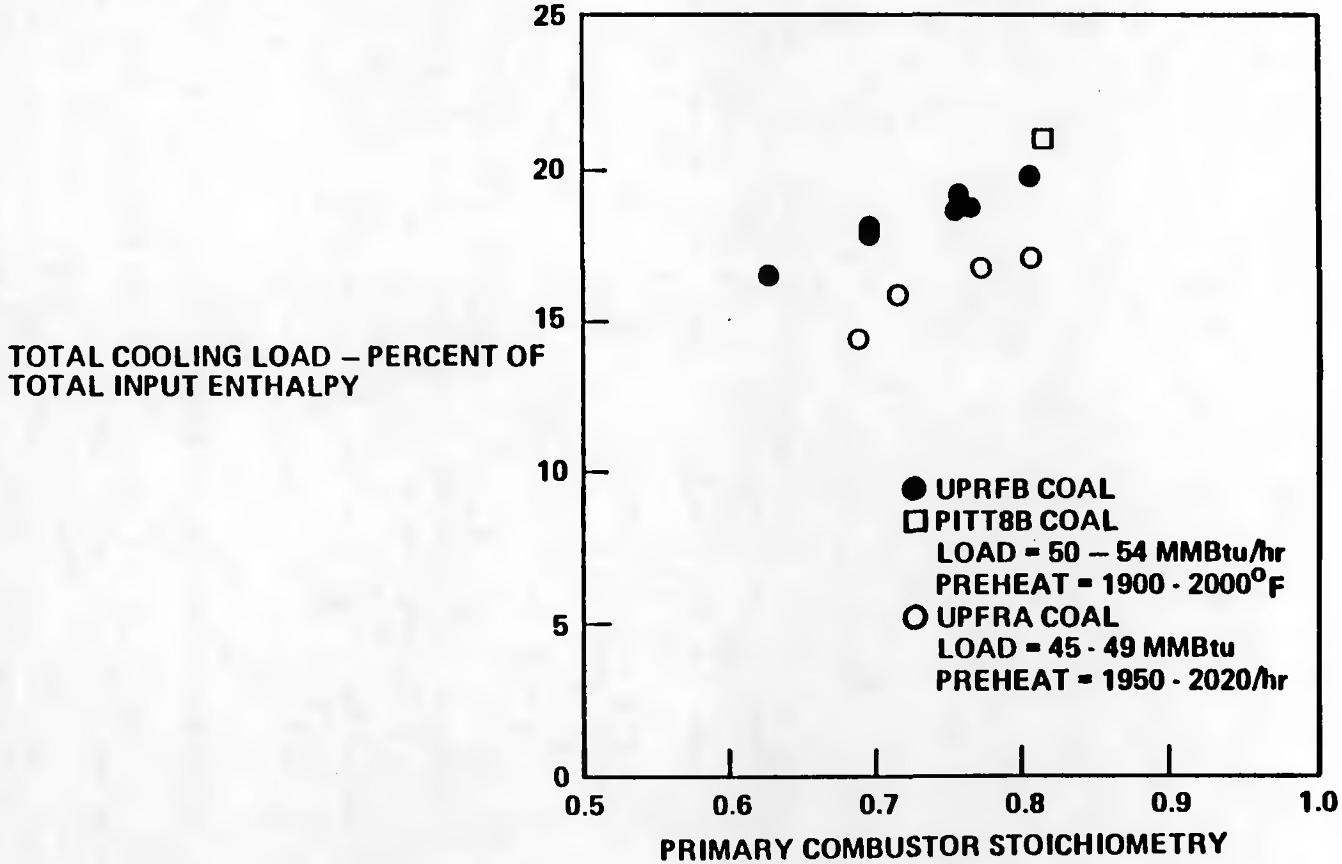
Figure 3.28

Cooling Load - 50 MMBtu/hr Combustor
Stoichiometry Effect
Fuel Effect



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retaining pins from the combustor inner walls which resulted in only partial coverage of the combustor walls for the latter tests. Figure 3.29 shows a similar dependence of cooling load on slagging stage stoichiometry in the case of the coal water mixture. Figure 3.30 illustrates the effect of load. In the 50 to 60 MM Btu/hr range, the relative cooling load appears to decrease as the fuel input is increased. Finally, Figure 3.31 shows the effect of precombustor outlet temperature on cooling load. There is not a strong effect of preheat boost on the cooling load in the range of 1500 F to 2100 F outlet temperature.

System Pressure Drop

Pressure drop data were also collected during the tests and some of the results are summarized in Figure 3.32. The pressure drop, in inches of water, has been plotted as a function of load in MM Btu/hr. All other things equal, a parabolic increase of pressure drop with load is expected. The pressure drop is near 40 inches of water at the nominal load of 50 MM Btu/hr as was anticipated.

Nitrogen Oxide(s) Emission Control

NOx emission results are shown in Figures 3.33 and 3.34. The NOx level measured after secondary combustion is corrected to 3% excess oxygen and plotted as a function of the first stage stoichiometry. A minimum NOx slightly below 350 ppmv occurs at a first stage stoichiometry near 0.75 for the Wyoming coal. The minimum level is appsoximately the same as previously measured on the 10 MM Btu/hr system, but the sensitivity to stoichiometry is higher. Figure 3.34 shows a similar plot for the Pittsburgh No. 8 coal. In general, the NOx level is affected by several factors, including coal type. The effect of fuel is illustrated in Figure 3.35, where the NOx level measured for a reference slagging stage stoichiometry of 0.8 for various coals and for the 10 and 50 MM Btu/hr combustors has been plotted as a function of the dry, ash free (DAF) nitrogen content of the fuel. Note that the NOx level appears to be nearly proportional to the coal nitrogen content. It should be pointed out that the first stage stoichiometry of 0.8 selected here for the porpose of comparison, does not correspond to the minimum system NOx.

Sulfur Oxide(s) Emission Control

The sulfur capture data for the Pittsburgh No. 8 coal and the Upper Freeport Coal are shown in Figure 3.36. Vicron (calcium carbonate) was injected into the slagging stage axially towards the headend from the slag recovery section by a "stinger" injector. As was the case with the 10 MM Btu/hr, when operated with a coal fired precombustor and at comparable stoichiometries, low sulfur captures were measured. These expected results verified the earlier predictions that sorbent injection into the slagging stage was not a viable method of sulfur emission control.

Figure 3.29

Cooling Load - 50 MMBtu/hr Combustor
Stoichiometry Effect

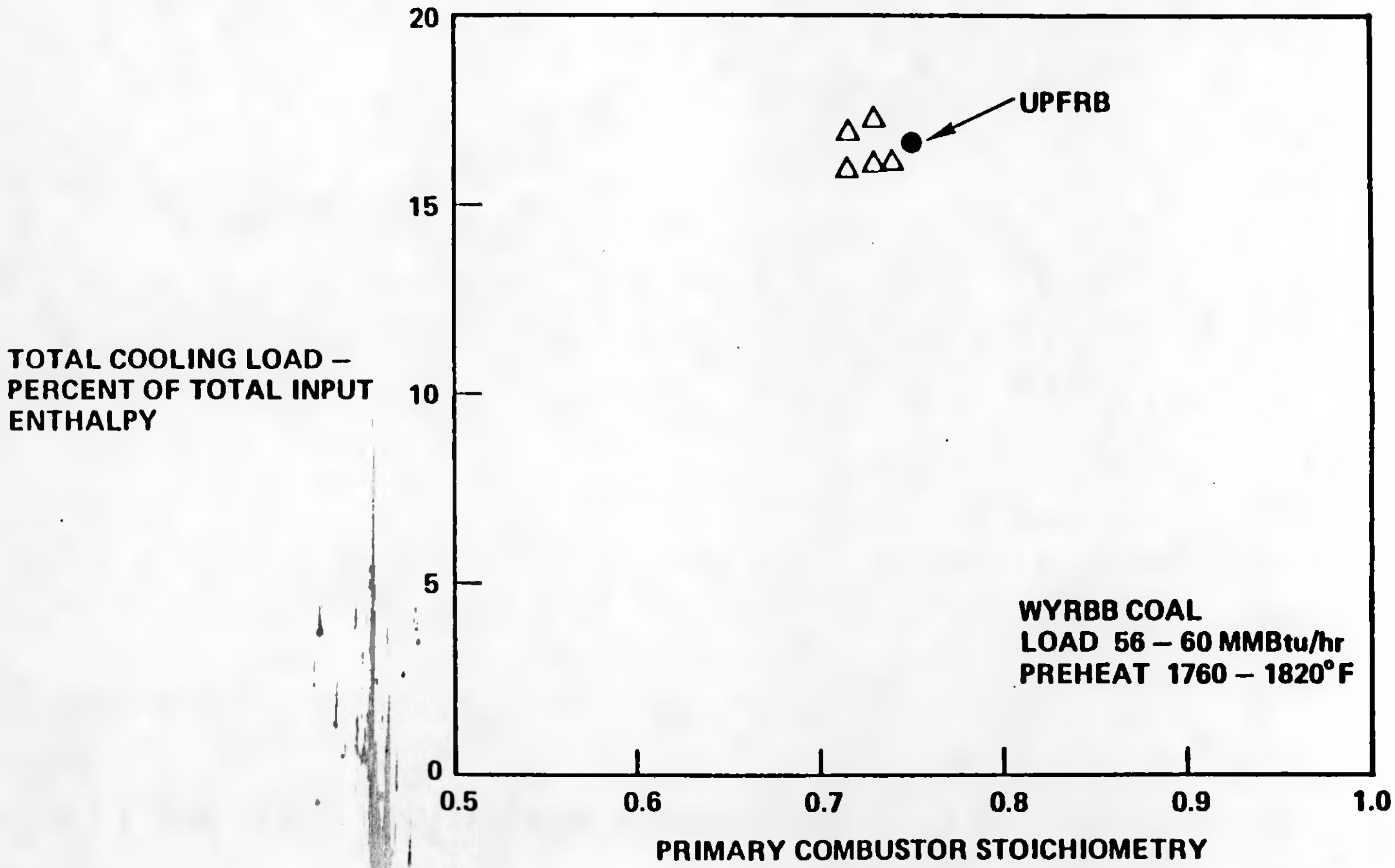

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Figure 3.30

Cooling Load - 50 MMBtu/hr Combustor

Fuel Effect
Load Effect

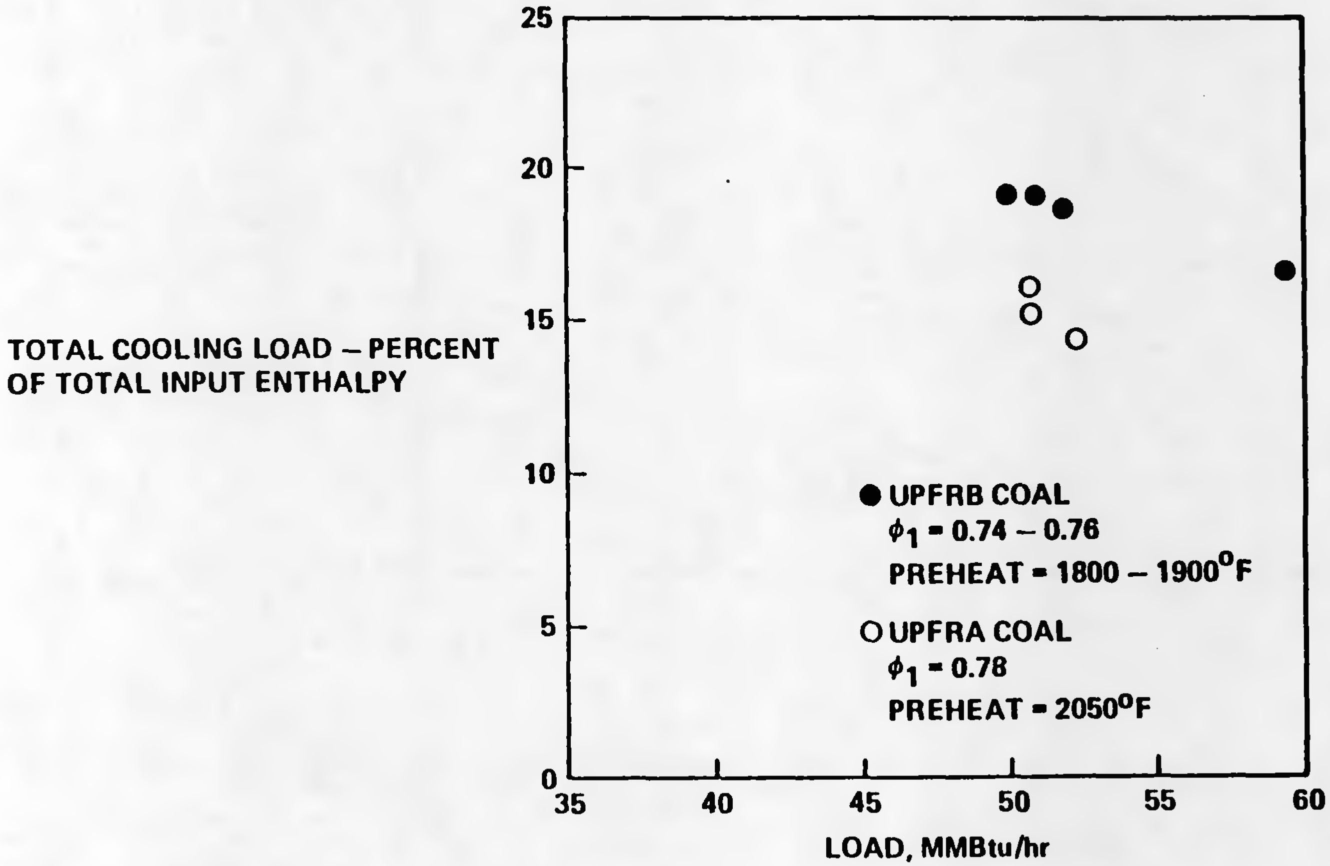

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Figure 3.31

Cooling Load - 50 MMBtu/hr Combustor

Preheat Effect

TRW

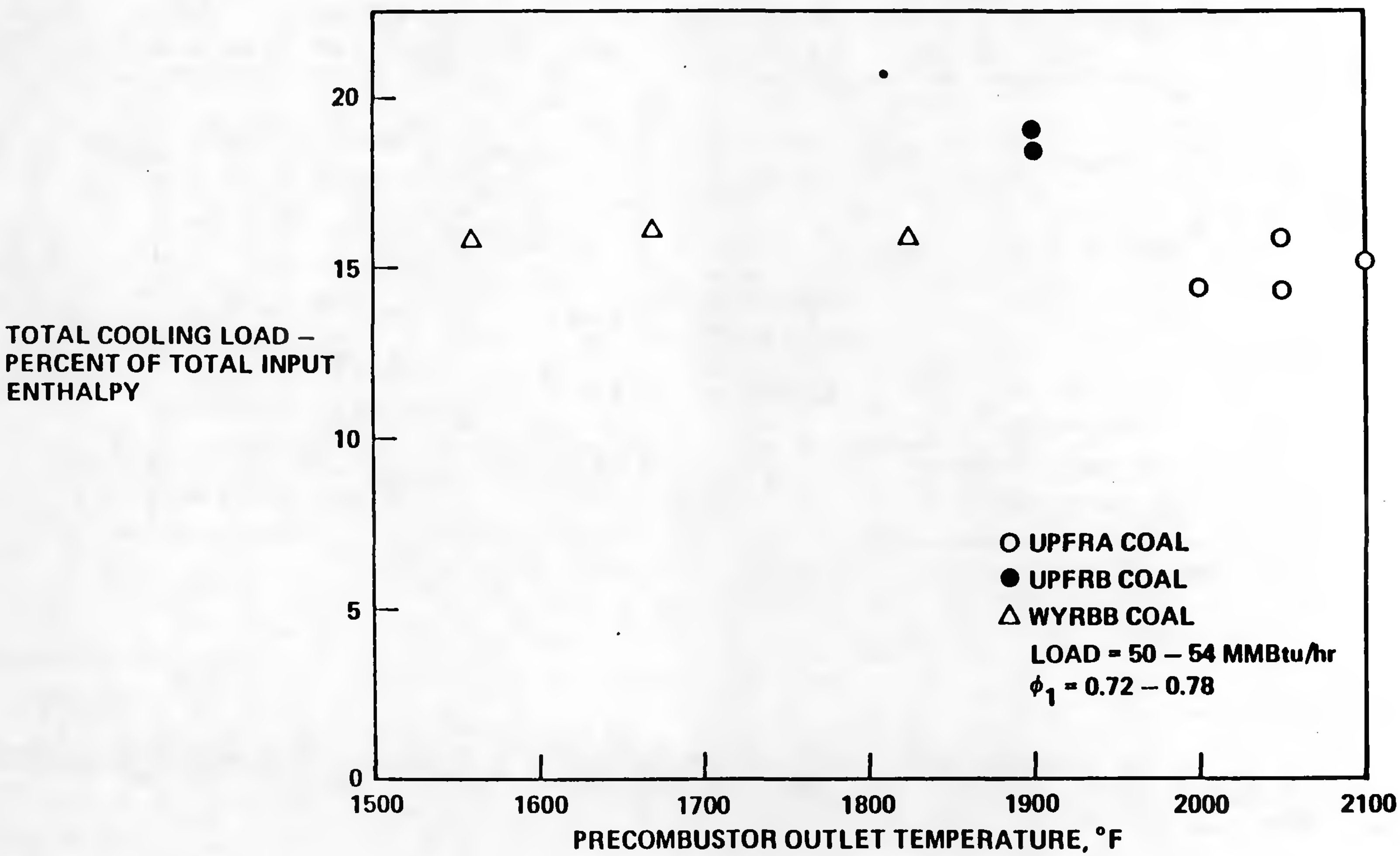

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Figure 3.32

System Operating Pressure - 50 MMBtu/hr Combustor

Load Effect

Configuration Effect

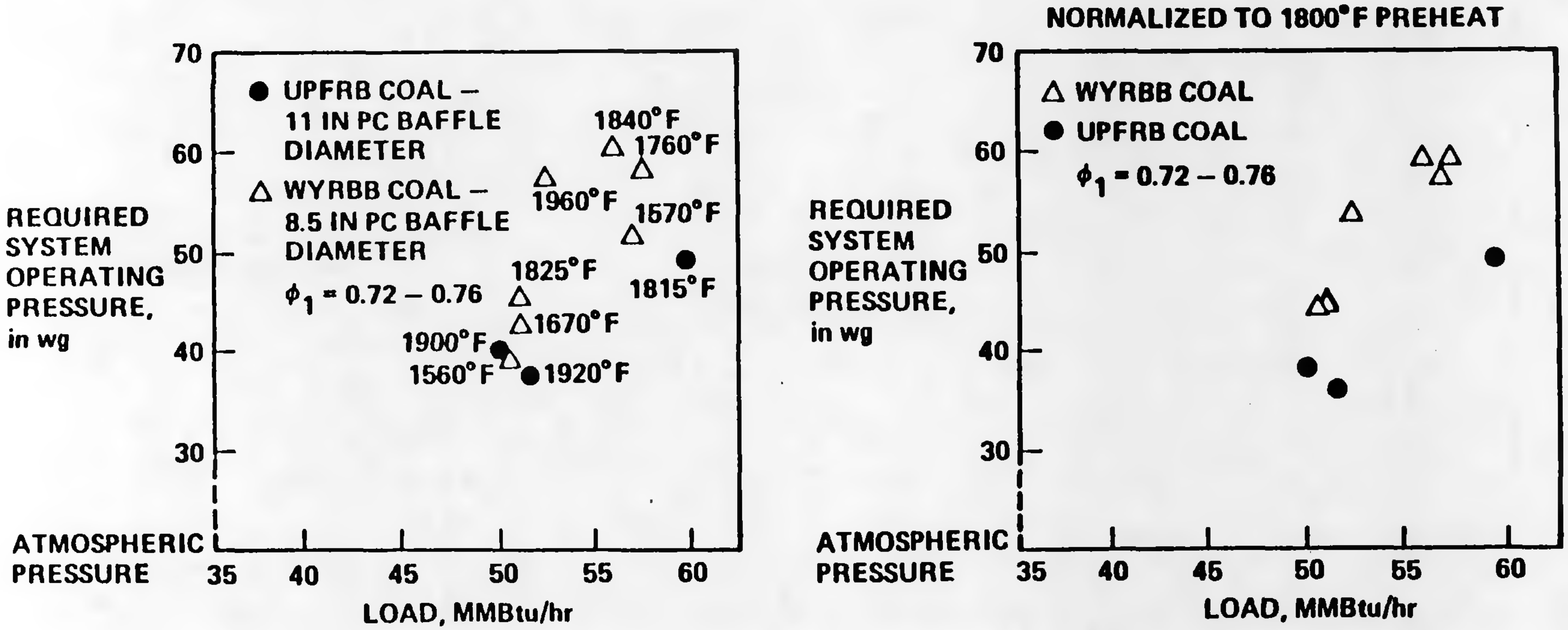

Figure 3.33

NO_X Variation with Stoichiometry
Fuel Effect
Scaling Effect

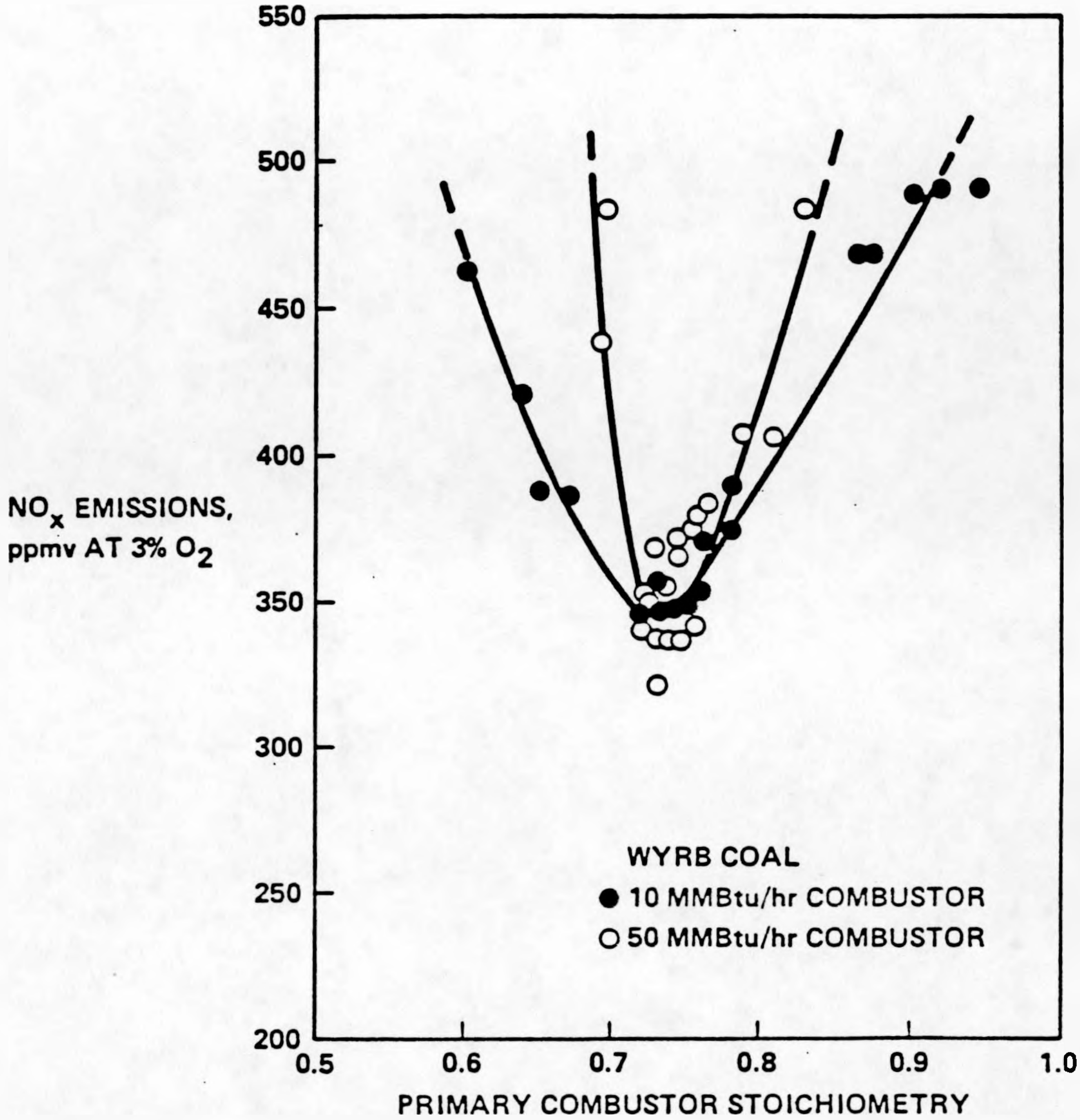

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Figure 3.34

NOx Variation With Stoichiometry
Fuel Effect
Sorbent Effect

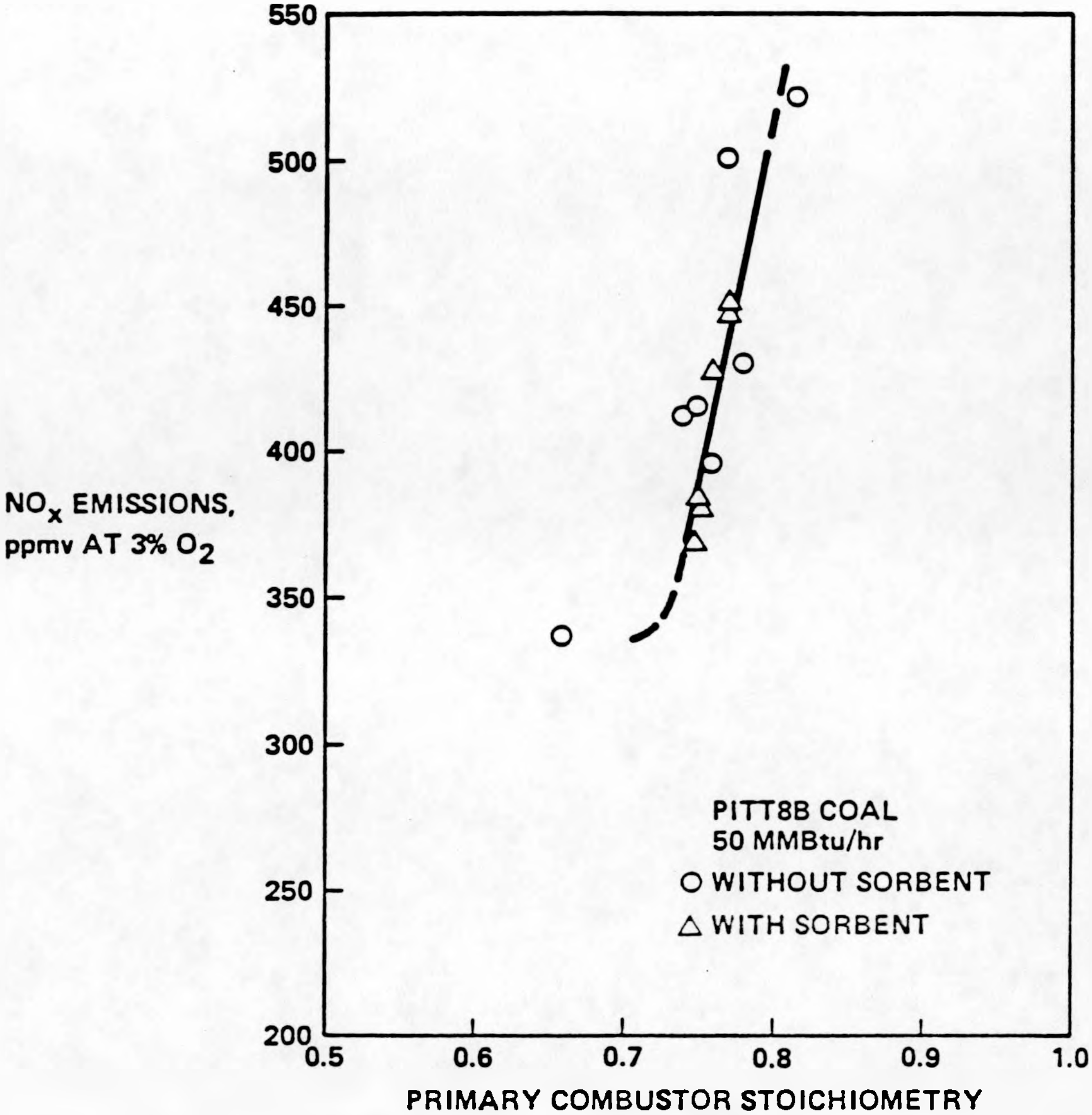

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Figure 3.35

Measured NO_x Variation with Fuel Nitrogen

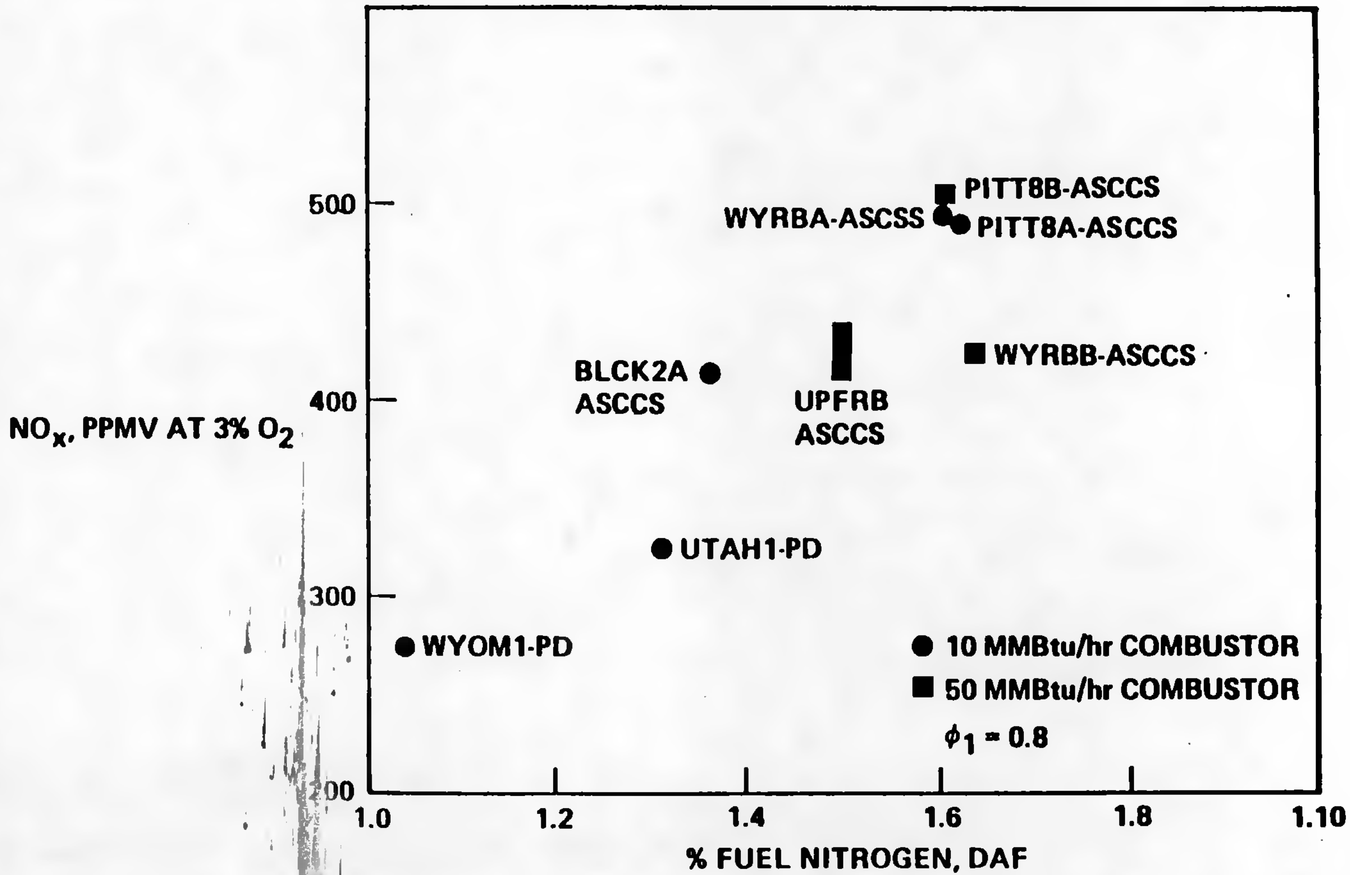

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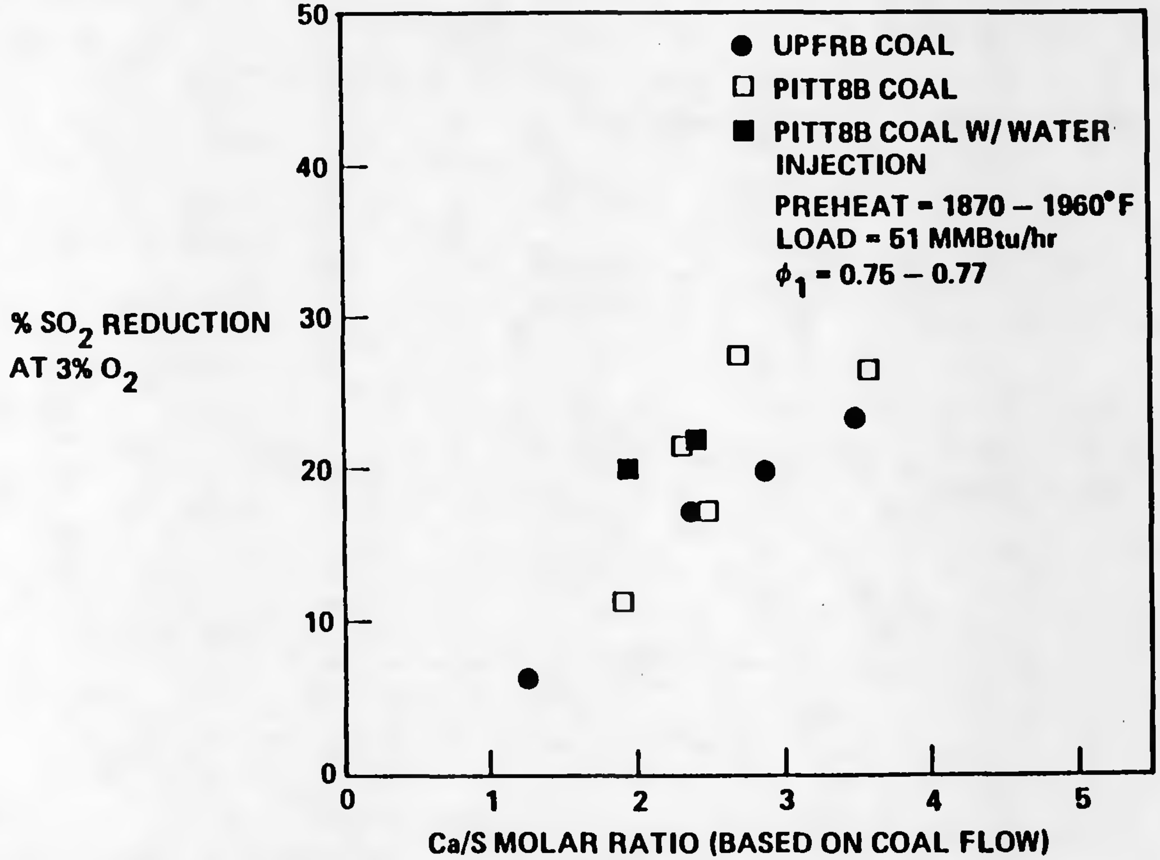
Figure 3.36

SO_2 Reduction with Vicron Injection - 50 MMBtu/hr Combustor



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3.3.5 Test Task Conclusions

Scaling has been verified in going from a nominal 10 MM Btu/hr slagging combustor to a nominal 50 MM Btu/hr combustor. A significant effect of scale was noticed on the performance of the 50 MM Btu/hr combustor. The combustion and slagging characteristics were much better than the 10 MM Btu/hr combustor. Carbon utililization was esentially 100% at stoichiometries giving slag recoveries in the 80% and 90% ranges AND yielding the minimum system NOx. However, the simultaneous control of all three emissions, i.e., NOx, SOx, and particulates, cannot be achieved within the slagging stage.

The precombustor performance drives the entire system performance. A malfunctioning precombustor will result in poor system performance. This aspect was responsible for the poor performance with the coal water mixture. Clearly, more development work is required with the CWM.

3.4 SYSTEM INTEGRATION DESIGN (Task 4)

This task provided for the design of the secondary air injector (SAI), convective tube pass bundle and hardware rquired to integrate the slagging stage of the combustor to the TRW provided boiler simulator. A schematic of the combustor system, as it appeared at the end of the Task 3 testing, is shown in Figure 3.37. A conceptual schematic of the boiler simulator is shown in Figure 3.38. An artist's conception of the installation in Cell 3 is shown in Figure 3.39. The simulator consists of modular units making up a furnace section, and a convective pass section for tube deposition studies.

The design characteristics of the boiler simulator are listed below:

- o Multi-purpose, modular design for maximum flexibility
- o Furnace section provides for nominal 2000 F exit temperature (FEGT)
- o Provisions for interaction test parameters
  - secondary combustion flame transport properties
  - NOx and SOx influence parameters
  - ash caryover and slag spill over quantification
  - indications of tube fouling
- o Alternate fuels characterization.

The boiler simulator furnace entrance module allows for an optional slagging stage firing configuration. These two configurations are illustrated in Figure 3.40. Position A is the configuration at the end of the Task 3 testing. Position B allows for removal of the slag recovery elbow section. Position A was chosen for the Task 6 testing so as to have a one-to-one correlation with the configuration tested at the Cleveland Demonstration Site. Position B was not tested.

It was decided early-on to have as much hardware similarity as possible to the Cleveland combustor system. To this end, the same secondary air windbox and injection assembly was used. This was a commercial Peabody Engineering design. The general arrangement in relation to the combustor is shown in Figure 3.41. A variable vane air register was incorporated into the unit to investigate flame shaping capability. The vanes were equiped with a remote hydraulic actuator. The hot gas transition duct and SAI are moveable to the Position B firing configuration.

A transition duct length of five feet maximum was selected based on the Task 3 afterburner cooling load analyses and furnace inlet temperature requirements. These data are shown in Figures 3.42 through 3.44. The nominal 3000 F, post secondary combustion temperature can be met in either firing configuration. However, the final duct length was

Figure 3.37

50 MMBtu/hr Combustor System

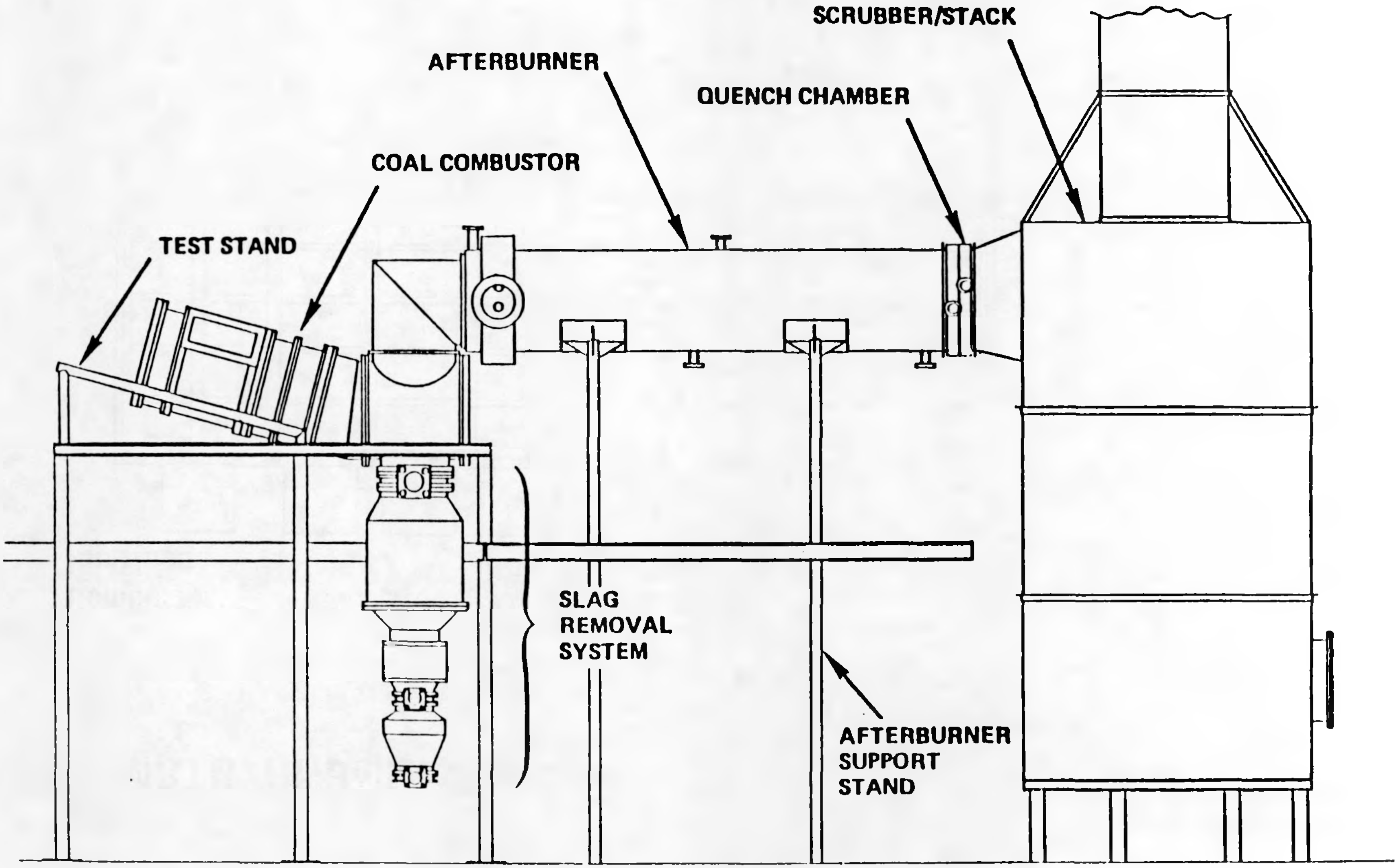

Figure 3.30

50 MMBTU/Hr Boiler Simulator

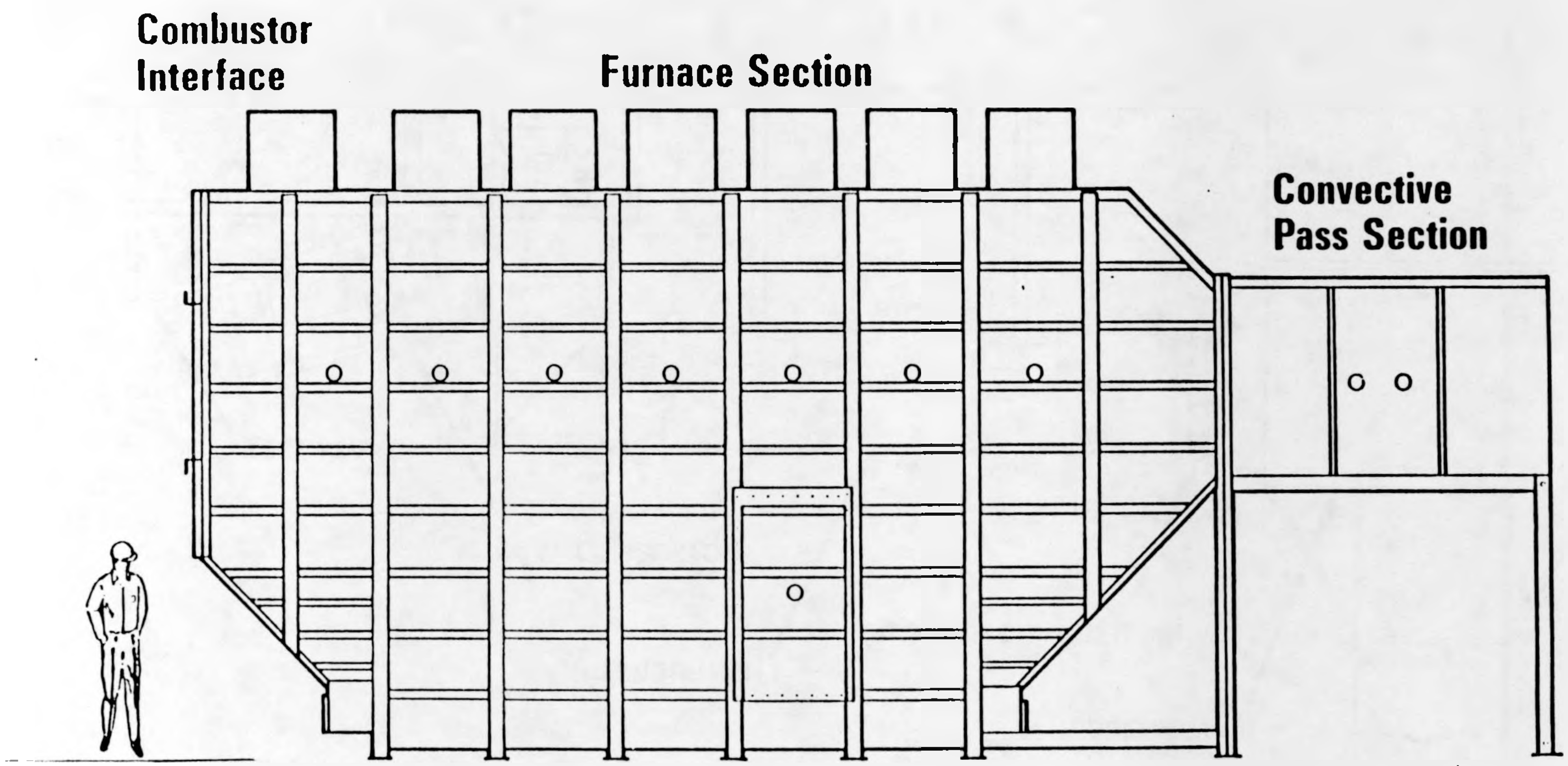

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Figure 3.39

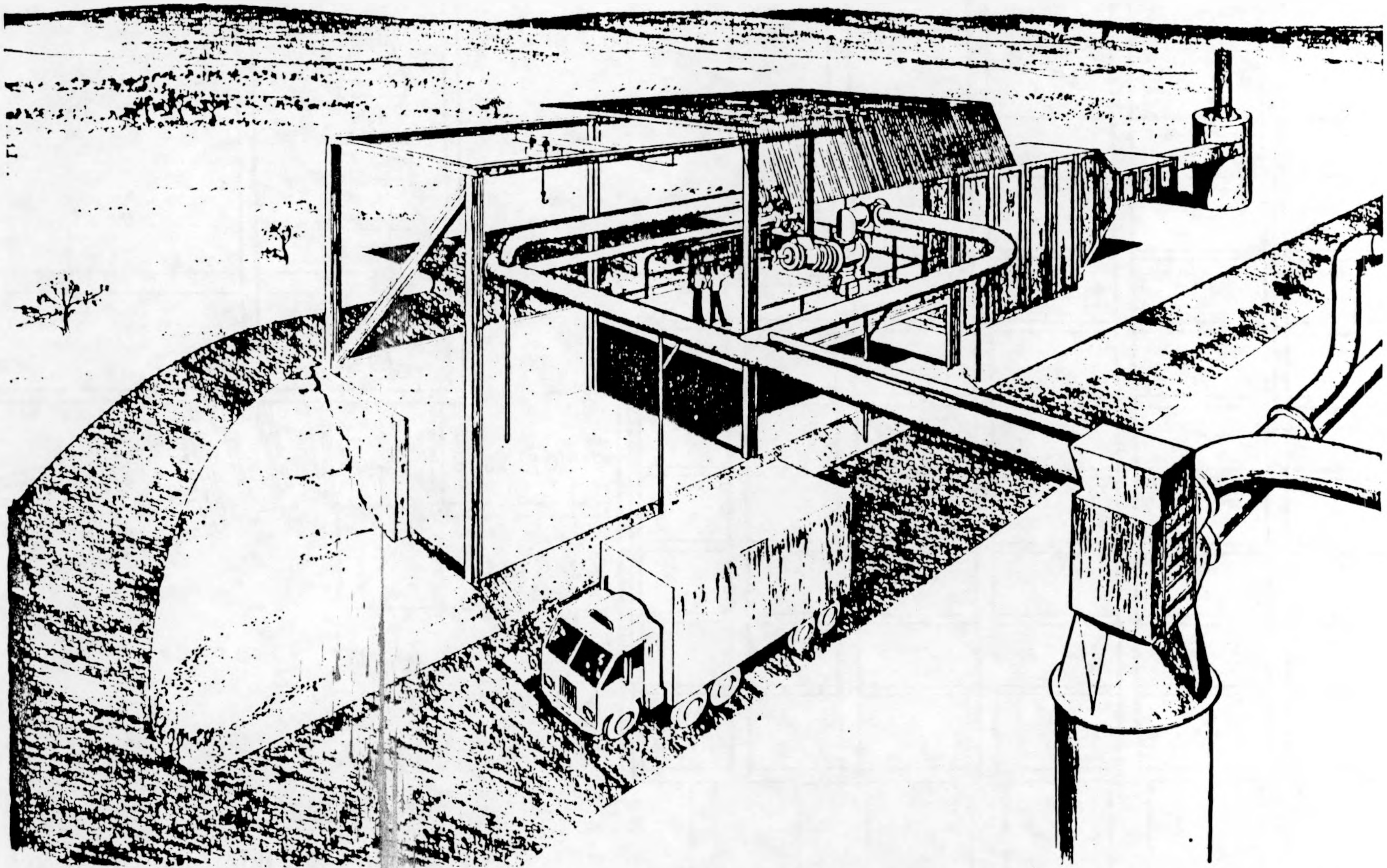
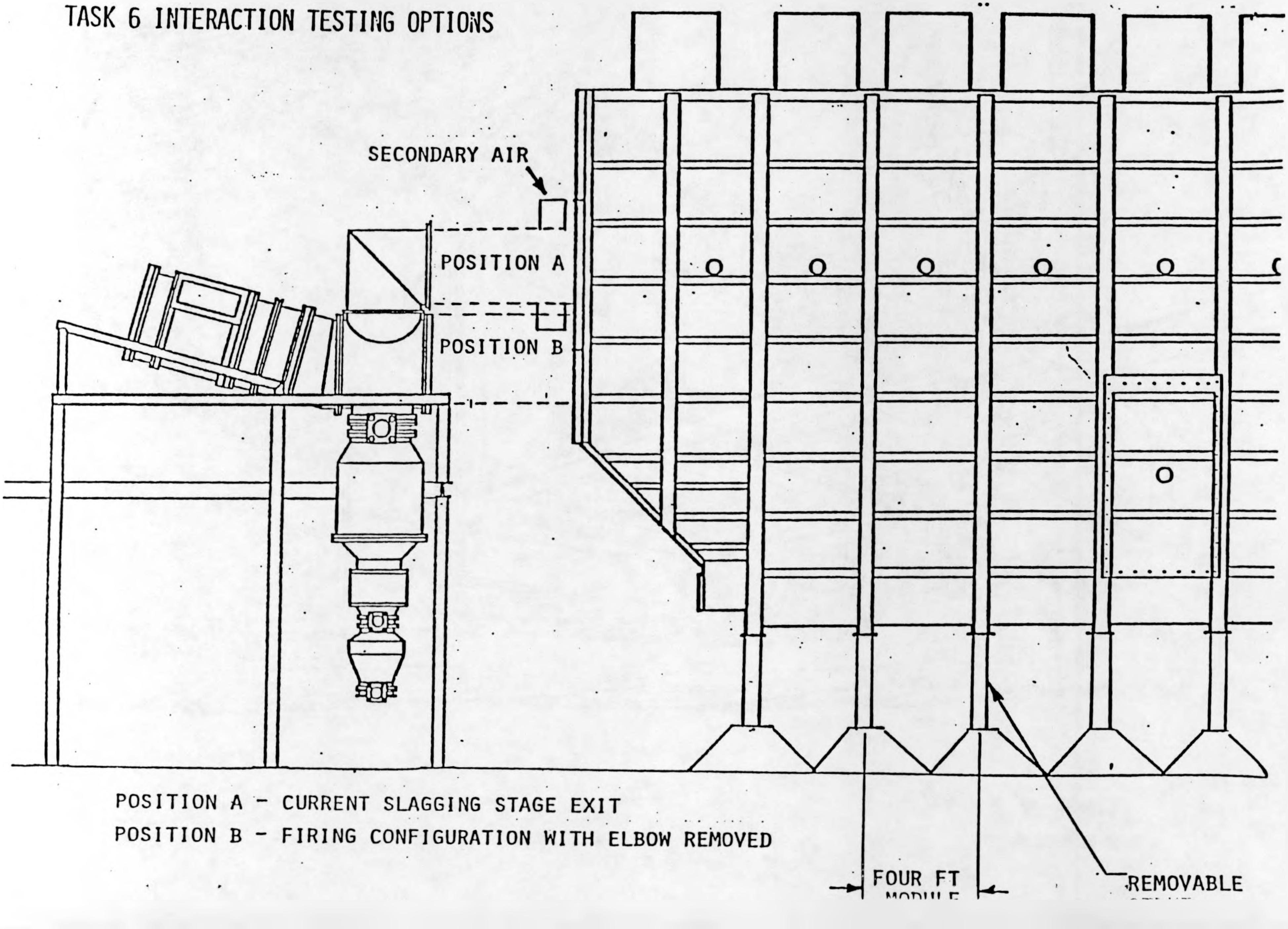


Figure 3.40

TASK 6 INTERACTION TESTING OPTIONS

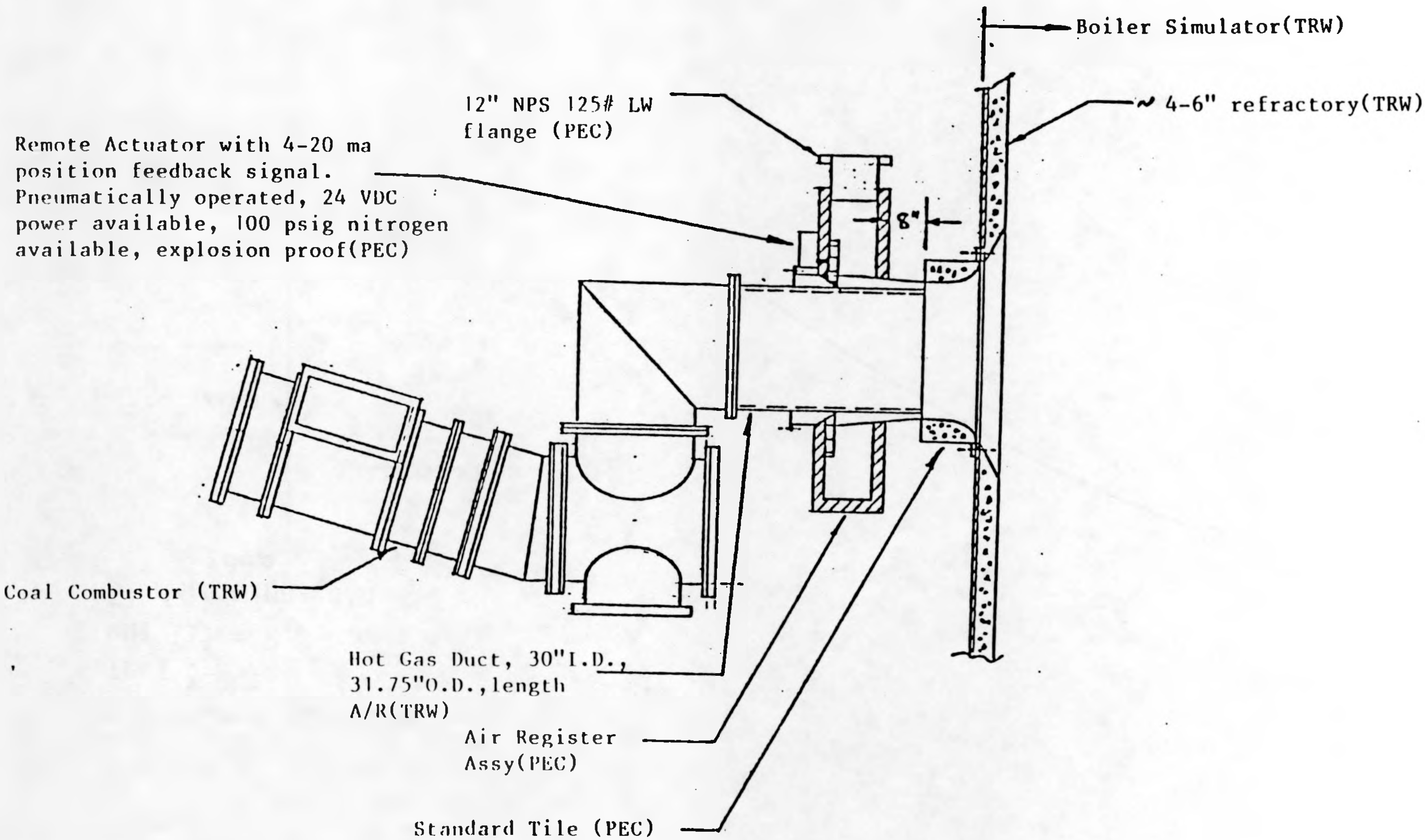


POSITION A - CURRENT SLAGGING STAGE EXIT

POSITION B - FIRING CONFIGURATION WITH ELBOW REMOVED

Figure 3.41

SECONDARY AIR INJECTOR ARRANGEMENT (position A)



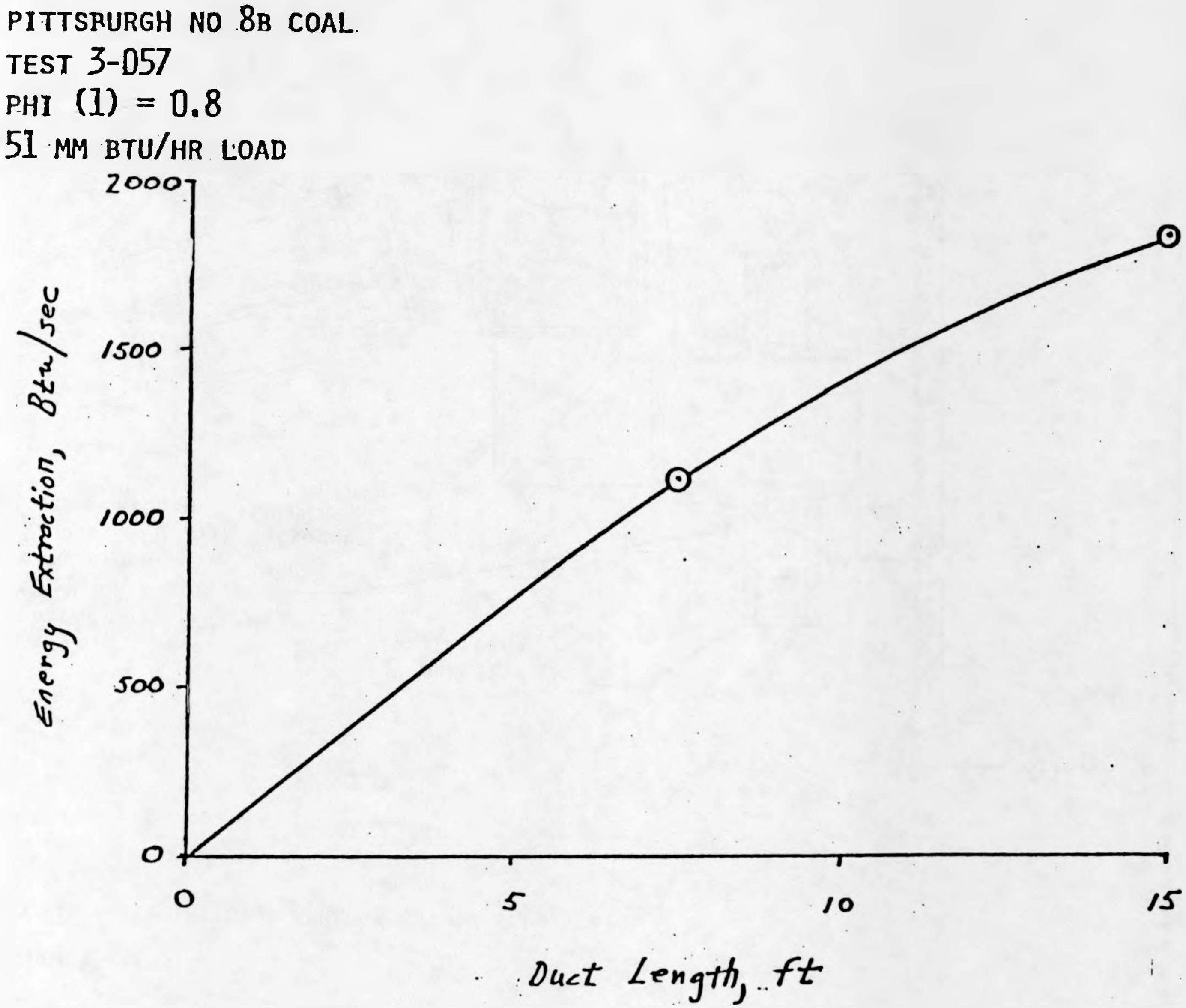


Figure 3.12 . Afterburner Cooling Load

TEST 3-057

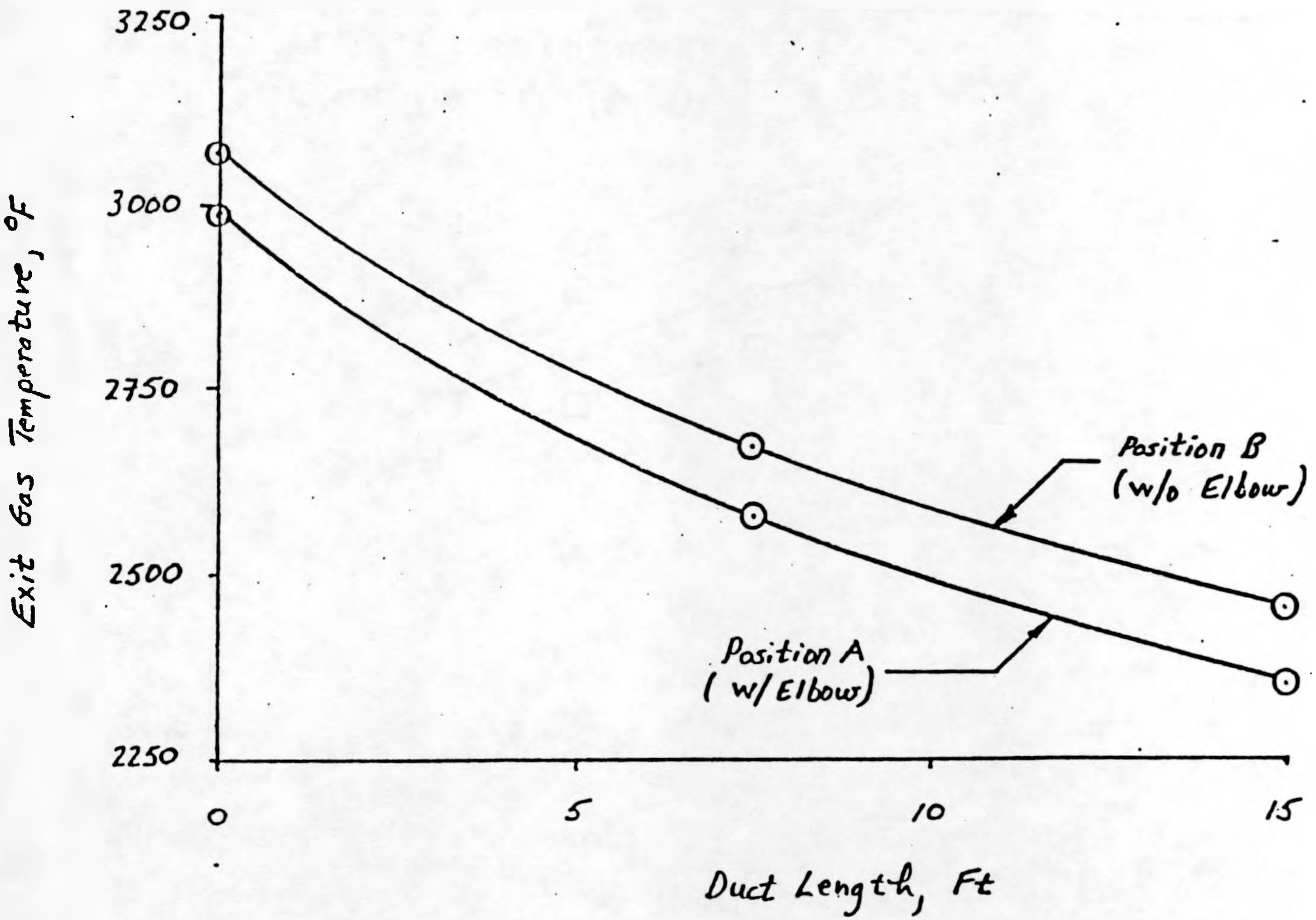


Figure 3.43. Transition Duct Gas Temperature

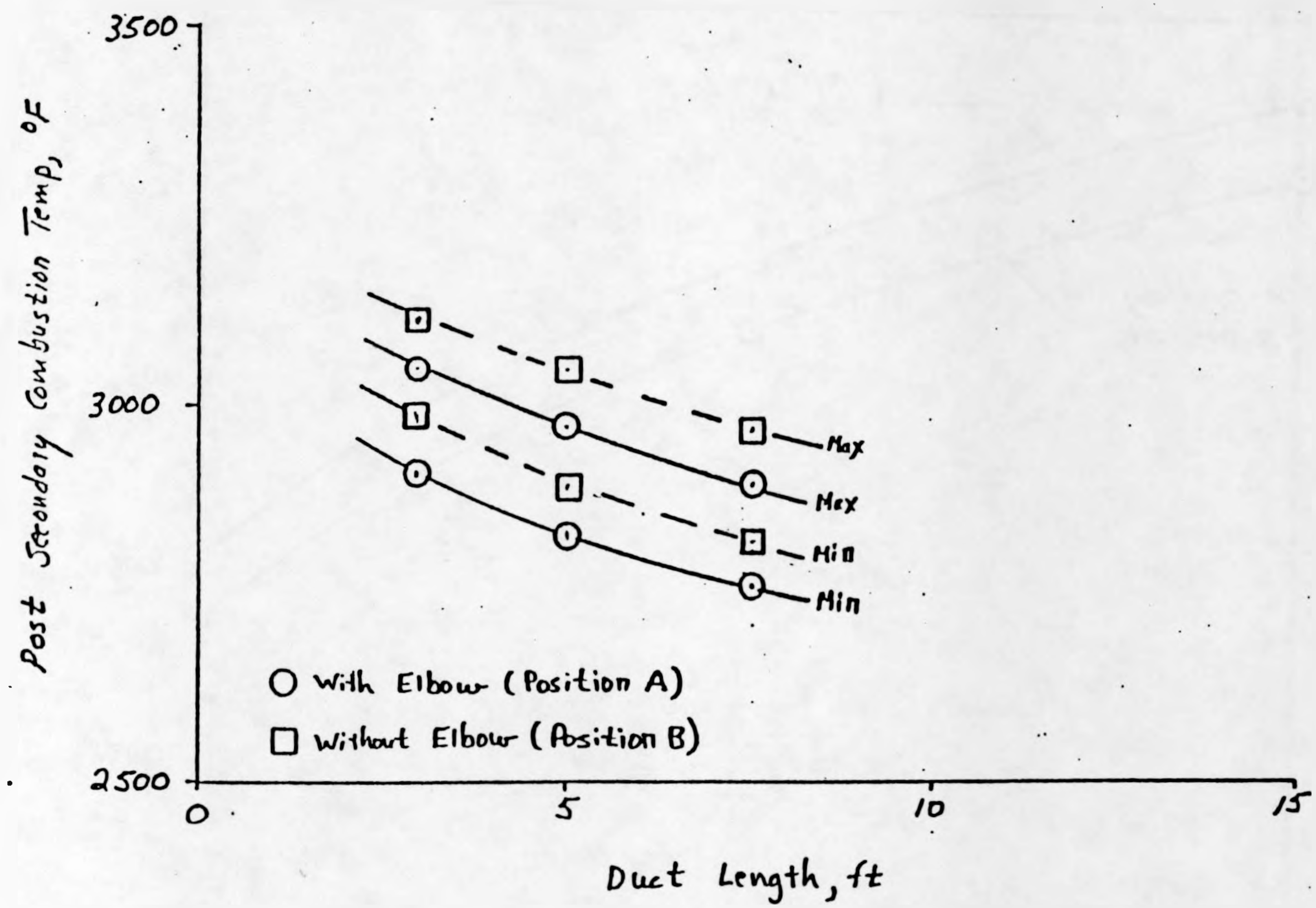


Figure 3.11. Furnace Inlet Temperatures

contingent on the necessity for the workhorse configuration working room.

A complete system heat balance was performed based on a Pittsburgh No. 8 reference coal used in Task 3, and nominal operating conditions established during the Task 3 testing. The heat balance schematic appears in Figure 3.45 and the corresponging process enthalpy flow is presented in Figure 3.46.

The layout of the convective pass tube bundle assembly is shown in Figure 3.47. The central, air cooled tubes form the "fouling" test section, while the other tubes provide the correct dynamic environment to maintain velocities. The ten test tubes are top supported by an assembly jig with a gasket press fit on each end to allow movement during thermal cycling. The assembly was designed to allow either modular insertion of all ten tubes as a unit or as individual tubes.

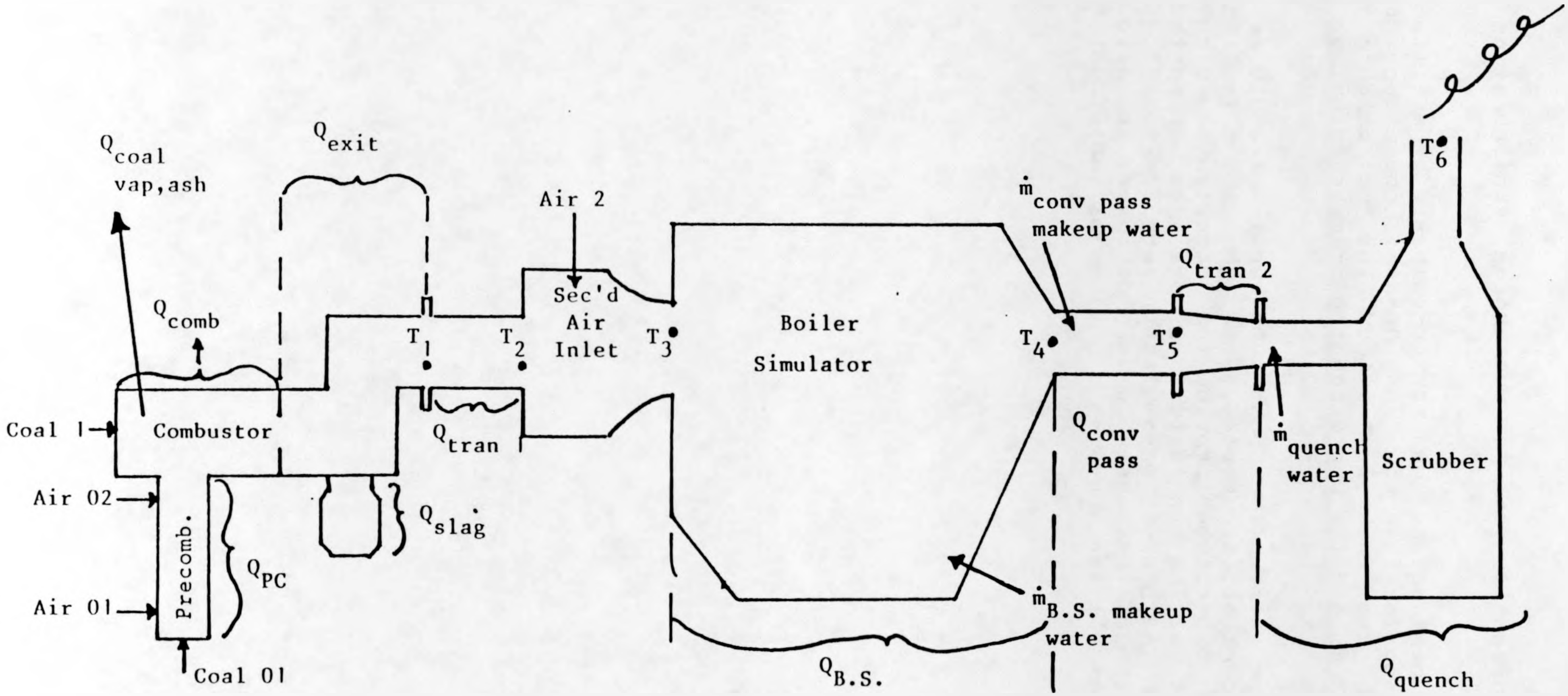


Figure 3.45. Heat Balance Schematic

Inputs (Btu/s)

Coal 01 - 3451
Coal 1 - 10432

@ $450^{\circ}F$ { Air 01 - 240, Air 02 - 527, Air 2 - 358 }

TOTAL = 15008

Q out (Btu/s)

Q_{pc}	- 70
Q_{comb}	-1050
Q_{exit}	-1358
Q_{slag}	- 70
$Q_{coal\ vap,ash}$	- 556
$Q_{tran\ 1}$	- 884
$Q_{B.S.}$	-3827
$Q_{conv\ pass}$	- 614
$Q_{tran\ 2}$ + Q_{quench}	-5970

TOTAL = 14399

Temp., $^{\circ}F$

T_1 = 2866
T_2 = 2578
T_3 = 2905
T_4 = 2000
T_5 = 1850
T_6 = 275

Water Flows

$\dot{m}_{B.S.\ makeup\ flow}$ = 24.6gpm
$\dot{m}_{conv.\ pass\ makeup\ flow}$ = 4.0gpm
$\dot{m}_{quench\ flow}$ = 34gpm

Emissions

NO_x = 0.45 lbs/MM Btu (~ 475 ppmv)
SO_2 = 3.9 lbs/MM Btu (~ 1869 ppmv; no SO_2 reduction techniques)

OVERALL HEAT BALANCE ⇒

$$(\Sigma \dot{m}_i h_i)_{in} = Q_{total\ out} + (\Sigma \dot{m}_o h_o)_{out}$$

15008 = 14399 + (enthalpy of flue gas leaving stack at $275^{\circ}F$ = 609)

15008 = 15008 ⇒ BALANCES

Figure 3.46. Process Enthalpy Flow

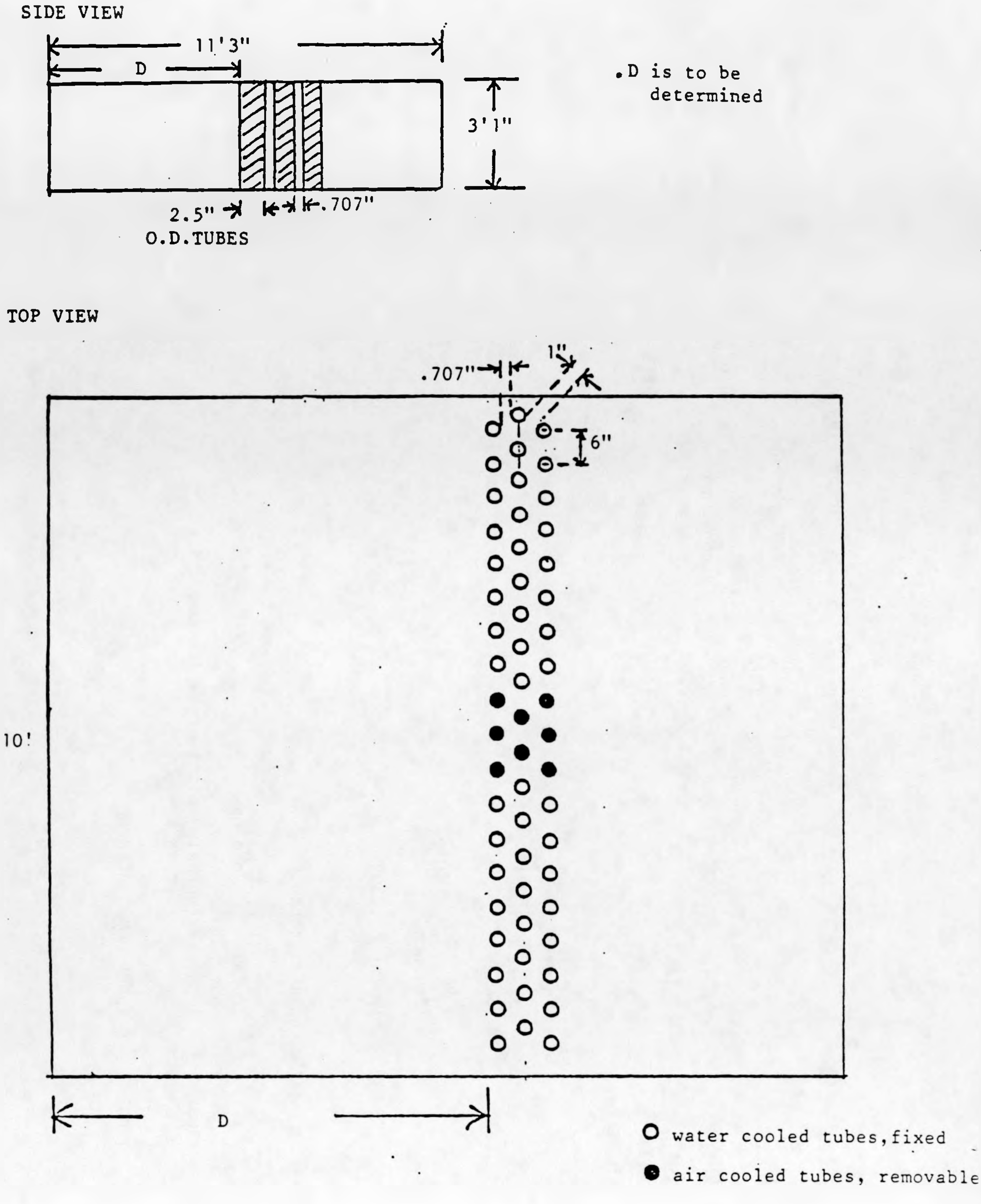


Figure 3.47. Convective Pass Section Design

3.5 SECONDARY AIR INJECTOR AND TUBE BUNDLE FABRICATION AND ASSEMBLY (Task 5)

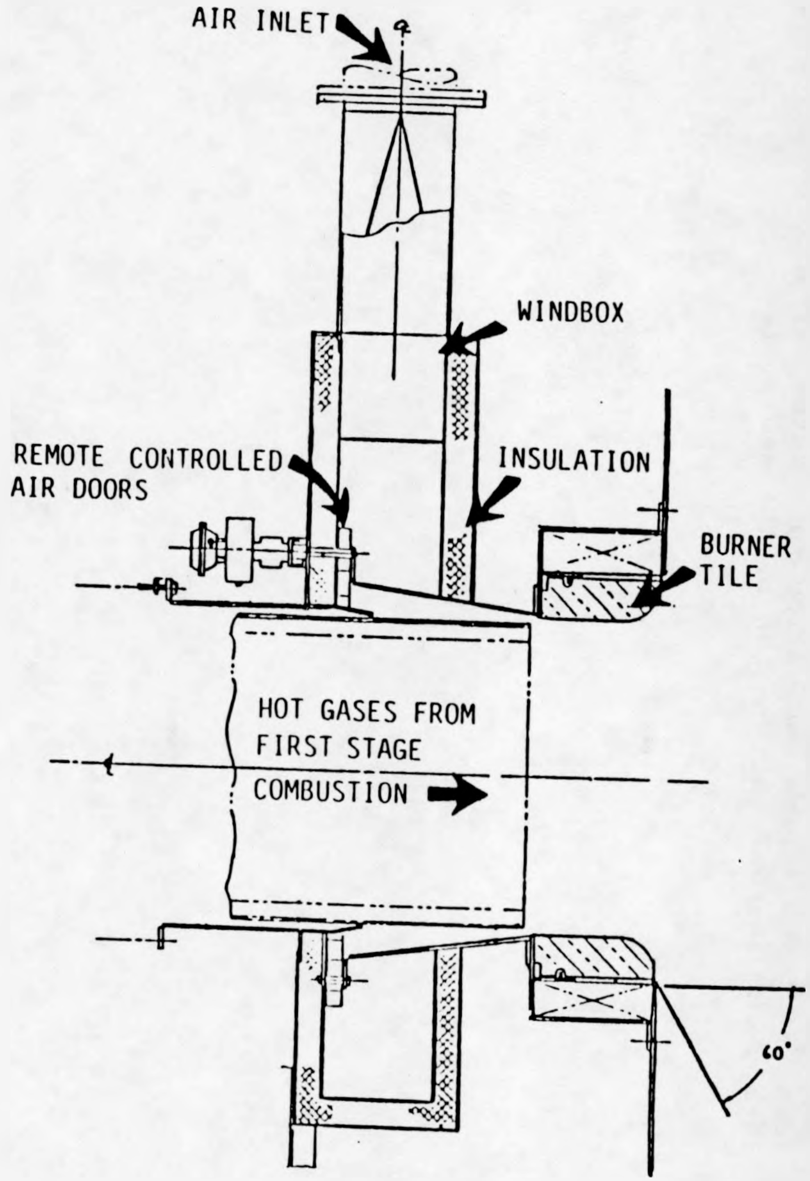
The secondary air injector and windbox assembly were purchased as an integral assembly from Peabody Engineering. The design is identical to the unit installed for a commercial demon- stration test in Cleveland, Ohio. The unit selected for the Task 6, System Interaction Test, has a pneumatic air vane actuator for remote adjustment of the secondary air swirl. A schematic of the unit appears in Figure 3.48.

The complete secondary air unit is shown assembled and mated to the first furnace module of the boiler simulator in Figure 3.49. Only three of the four furnace modules were installed at this point in time.

The tube bundle piece parts were fabricated as part of this task, but were not assembled and installed into the convective pass test section. Testing of the tube bundle was not scheduled to occur until late in the Task 6 test series to allow for system refractory curing, checkout firing and thermal calibration of the new system.

Figure 3.48

Secondary Burner Assembly



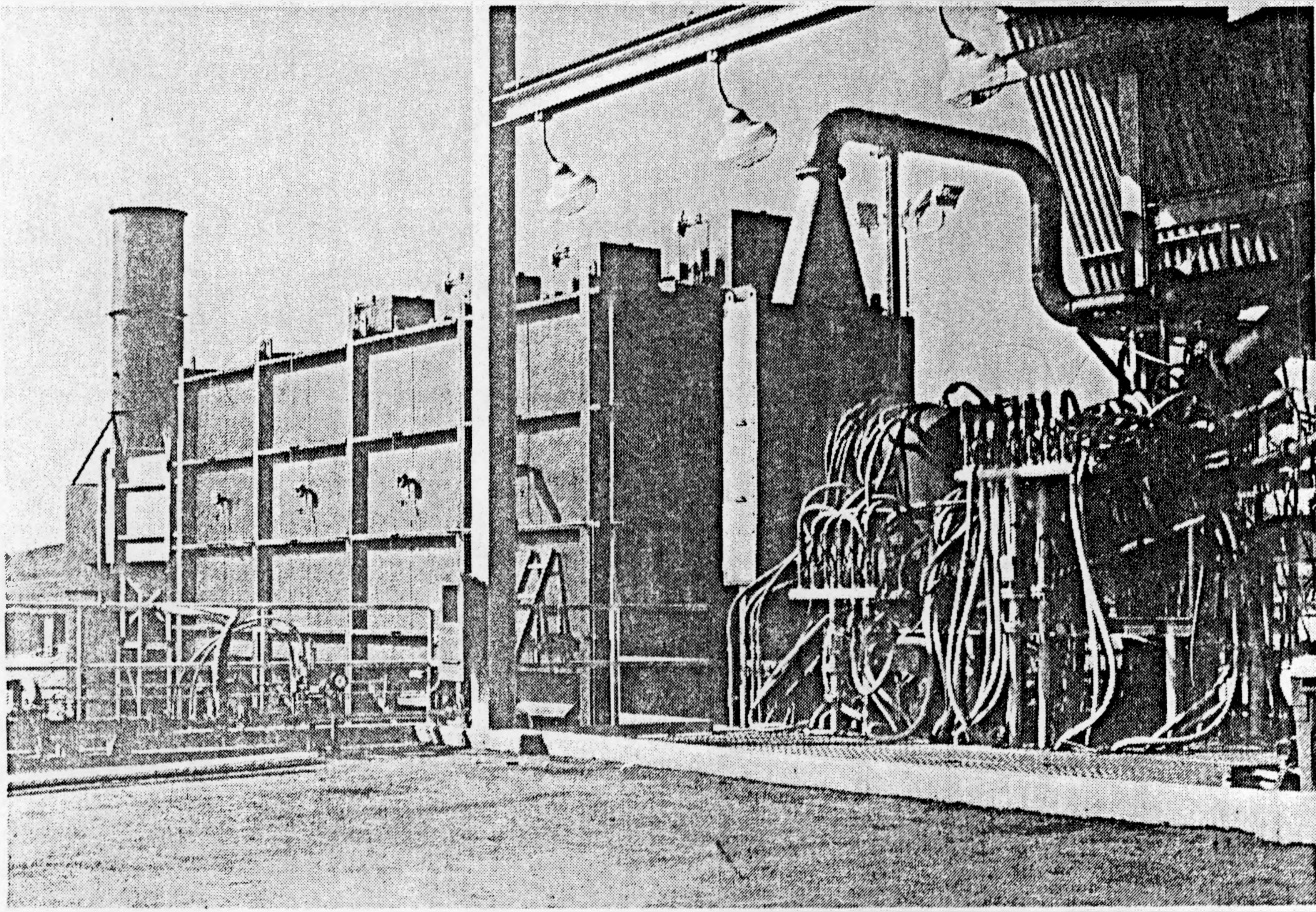


Figure 3.49. Combustor/Secondary Air Register/Simulator Interface

3.6 SYSTEM INTERACTION TESTS (Task 6)

This task consisted of several major subtasks required to render the system operable. They are listed below:

- o Boiler simulator installation
- o Secondary air injector assembly installation
- o Convective pass section installation
- o Quench duct installation
- o Scrubber relocation
- o Plumbing and instrumentation hookups
- o Boiler simulator refractory cure cycle
- o Hot fire integration acceptance
- o Interaction tests

3.6.1 Fabrication and Installation

In-process fabrication photographs of the boiler simulator are shown in Figures 3.50 through 3.52. The method of anchoring the castable refractory to the furnace modules is shown in Figure 3.50. One of the two center section modules is shown in Figure 3.51, prior to having the refractory cast in the V-bottom. The as cast V-bottom refractory is shown in Figure 3.52.

The boiler simulator refractory was installed in the fabricator's shop, but was cured at the test site. A cure cycle of approximately 48 hours was recommended to obtain optimum mechanical and thermal properties. The general cure cycle requirements are illustrated in Figure 3.53. This cycle consists of controlled heatups, soaks, and cooldown trransients. The method by which the heatup cycle was effected is two fold: 1) the indirectly fired air preheater was used to cure the refractory up to approximately 500 F; and 2) for the transient requirements above 500 F and soaks at 700 F and 1000 F, an oil vitiation boost was provided within the precombustor.

Overviews of the completed boiler simulator installation are shown in Figures 3.54 through 3.56, respectively. The secondary air register/boiler simulator interface is presented in Figure 3.57. This view is from the rear of the furnace looking towards the transition duct interface. The first module is insulated by an all castable refrac- tory. The second and third modules have castable reractory in the V-bottom, and a checker board network of panels which may be added or removed to vary the heat extraction profile, and hence the furnace exit gas temperature. A close up of the interface is shown in Figure 3.58. This view, however, does not show the burner tiles installed.

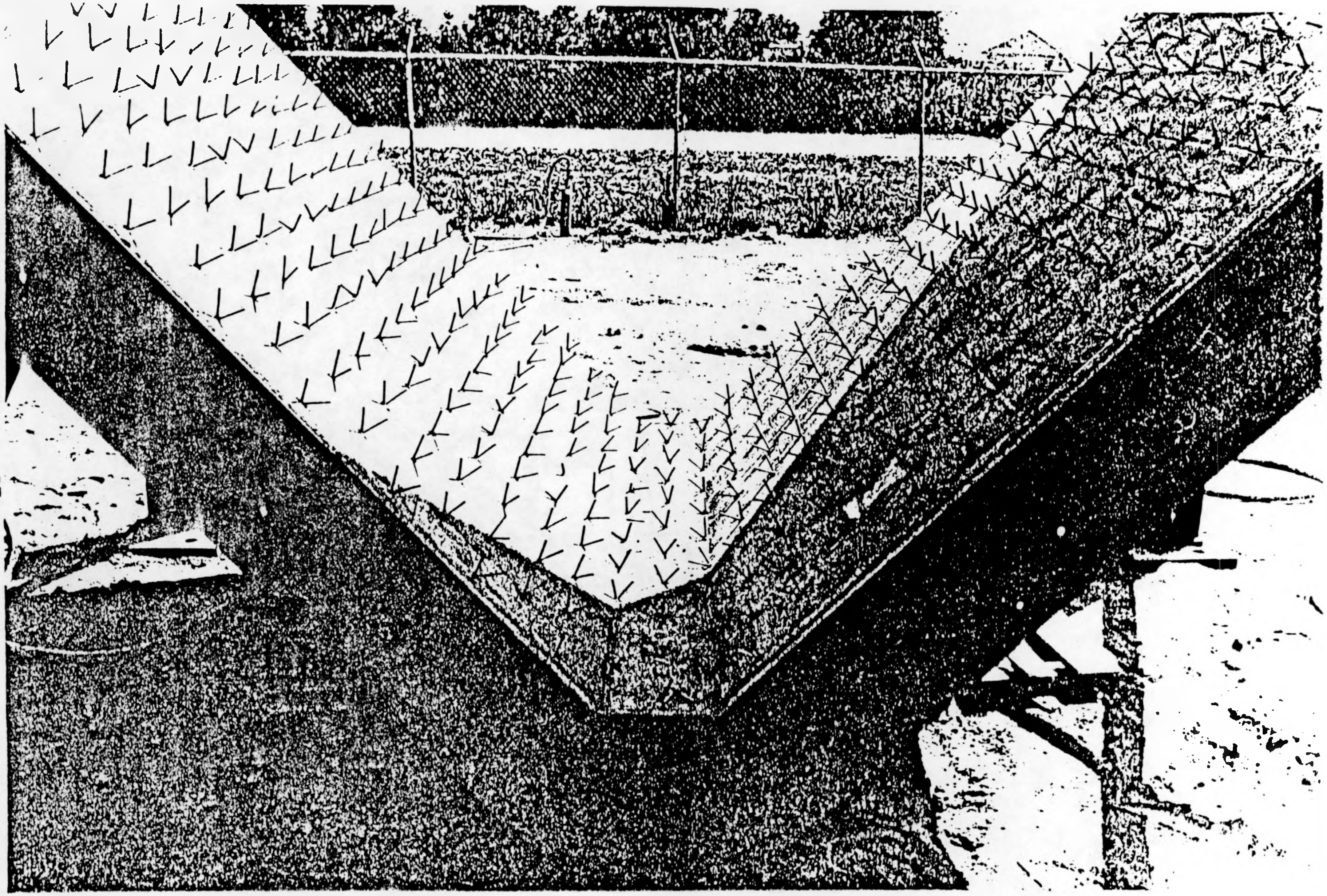


Figure 3.50. Installation of Refractory Anchors

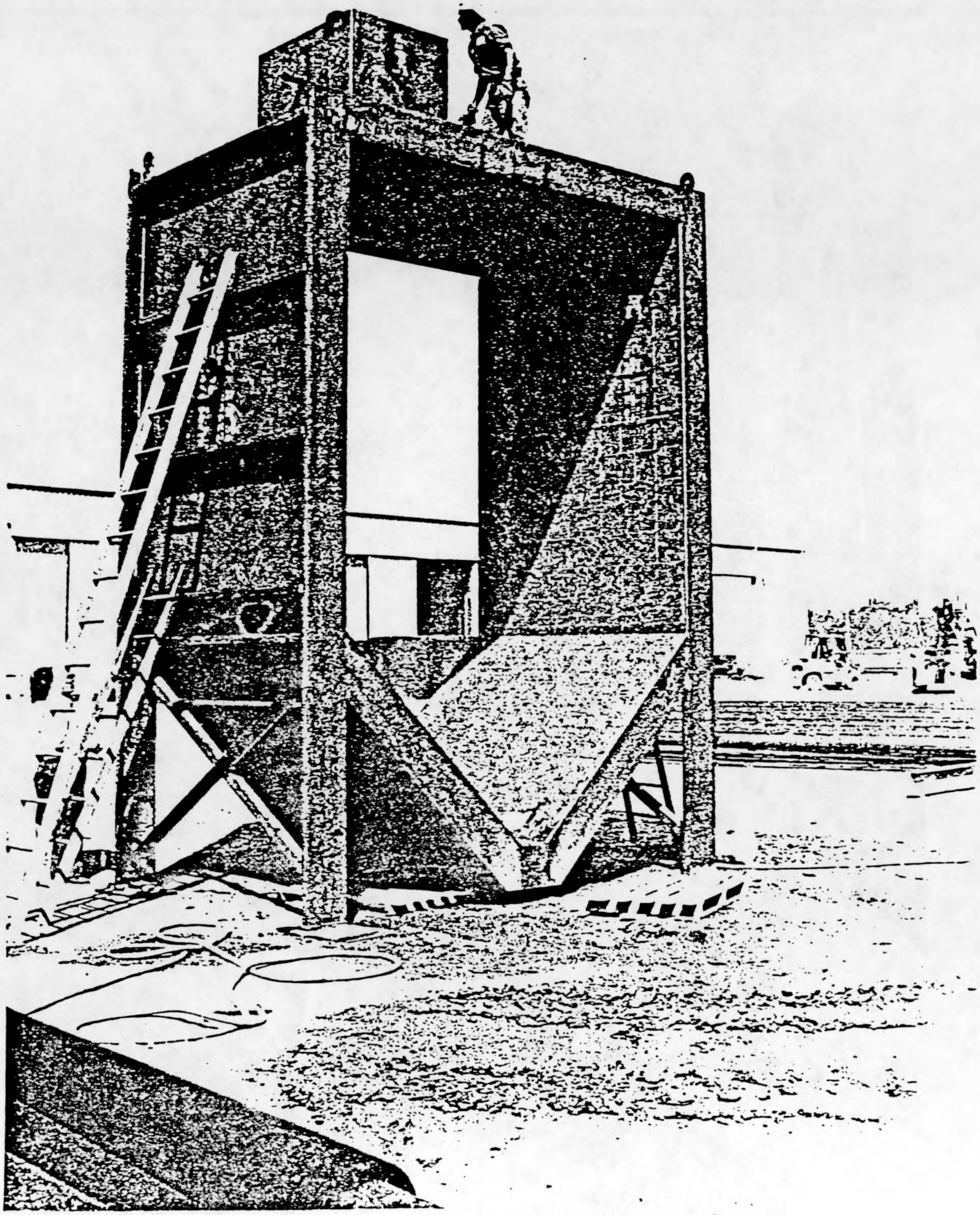


Figure 3.51. Center Section Module

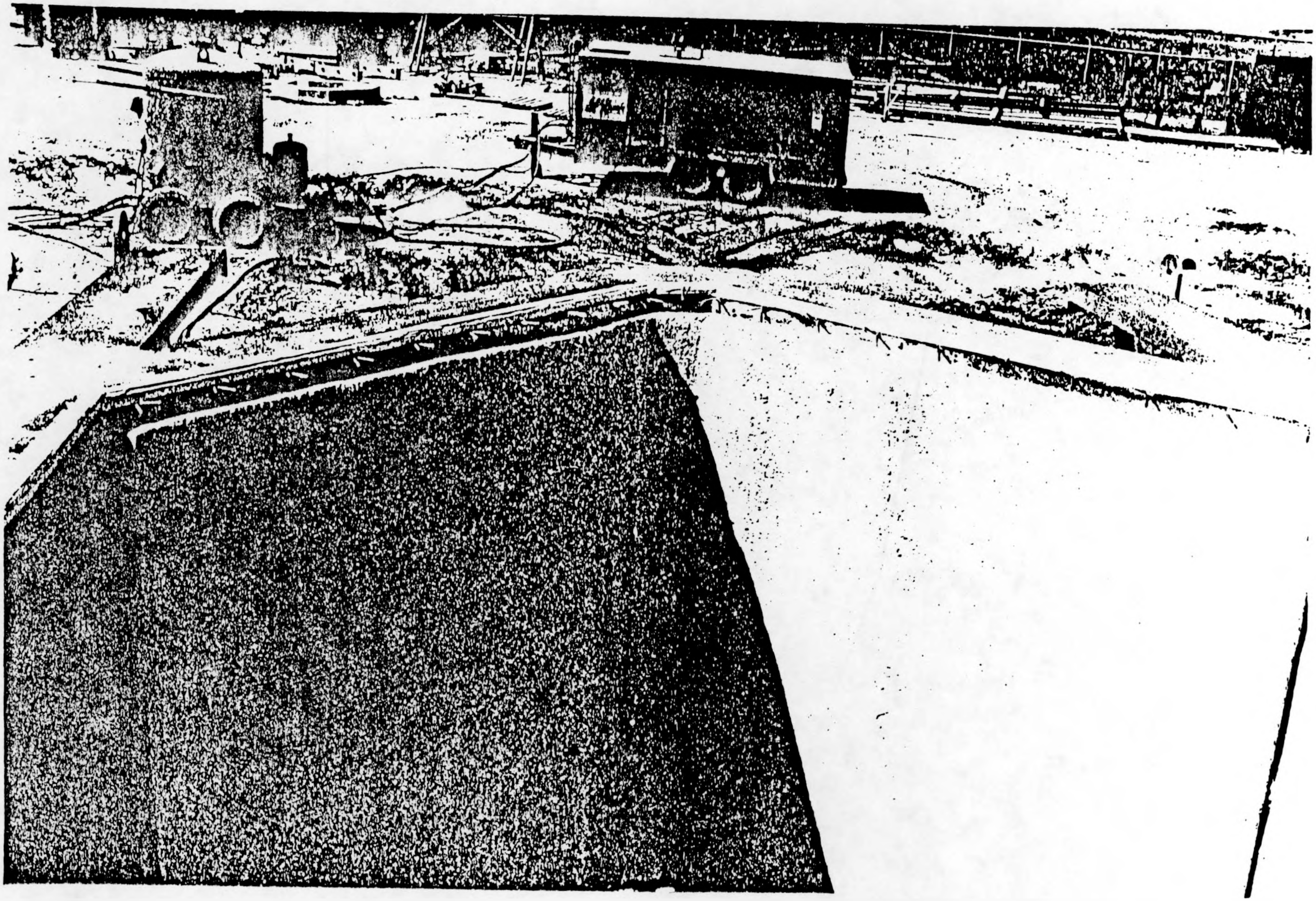


Figure 3.52. Castable Refractory Installed in Furnace Module

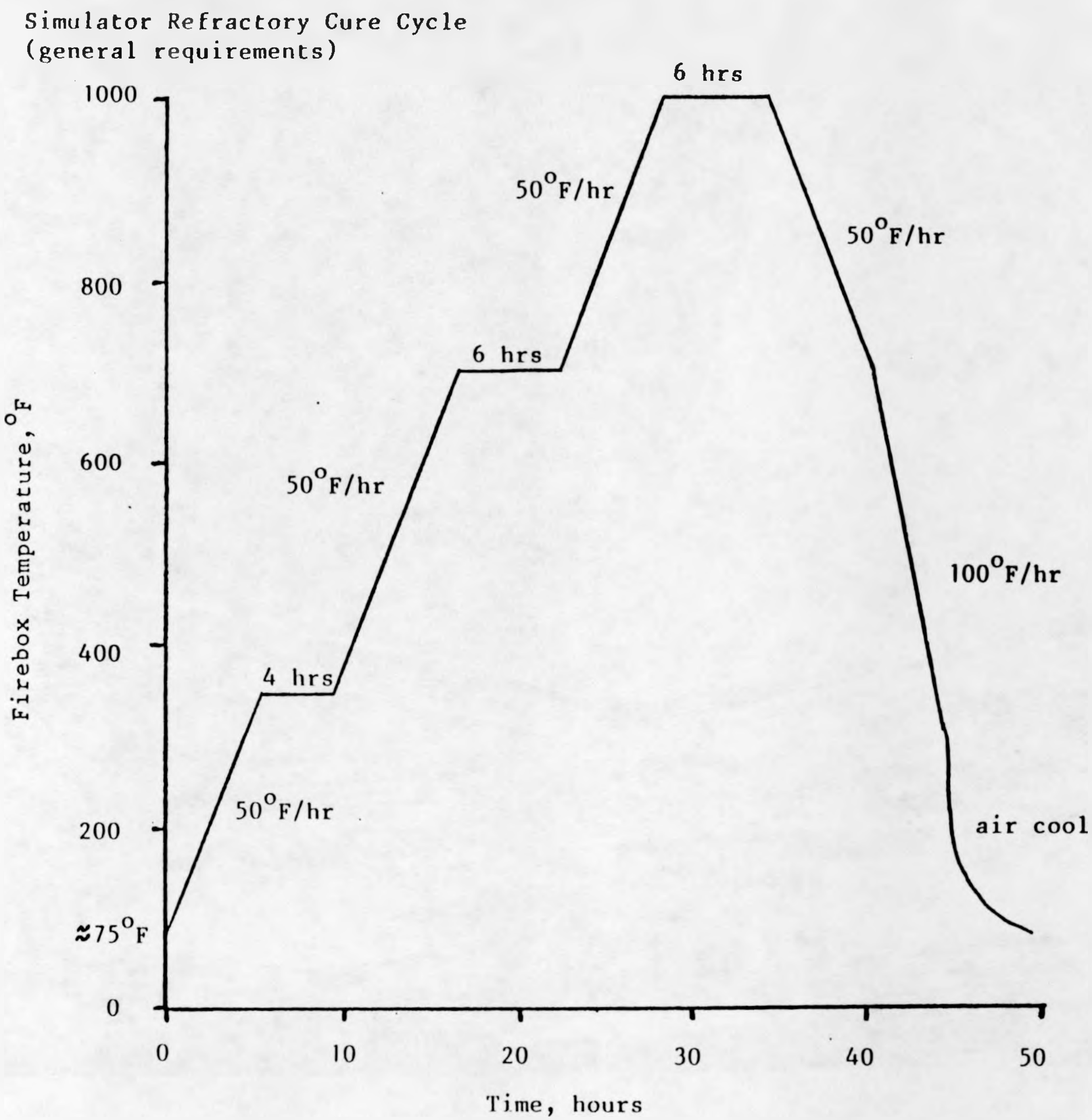


Figure 3.53. Refractory Cure Cycle

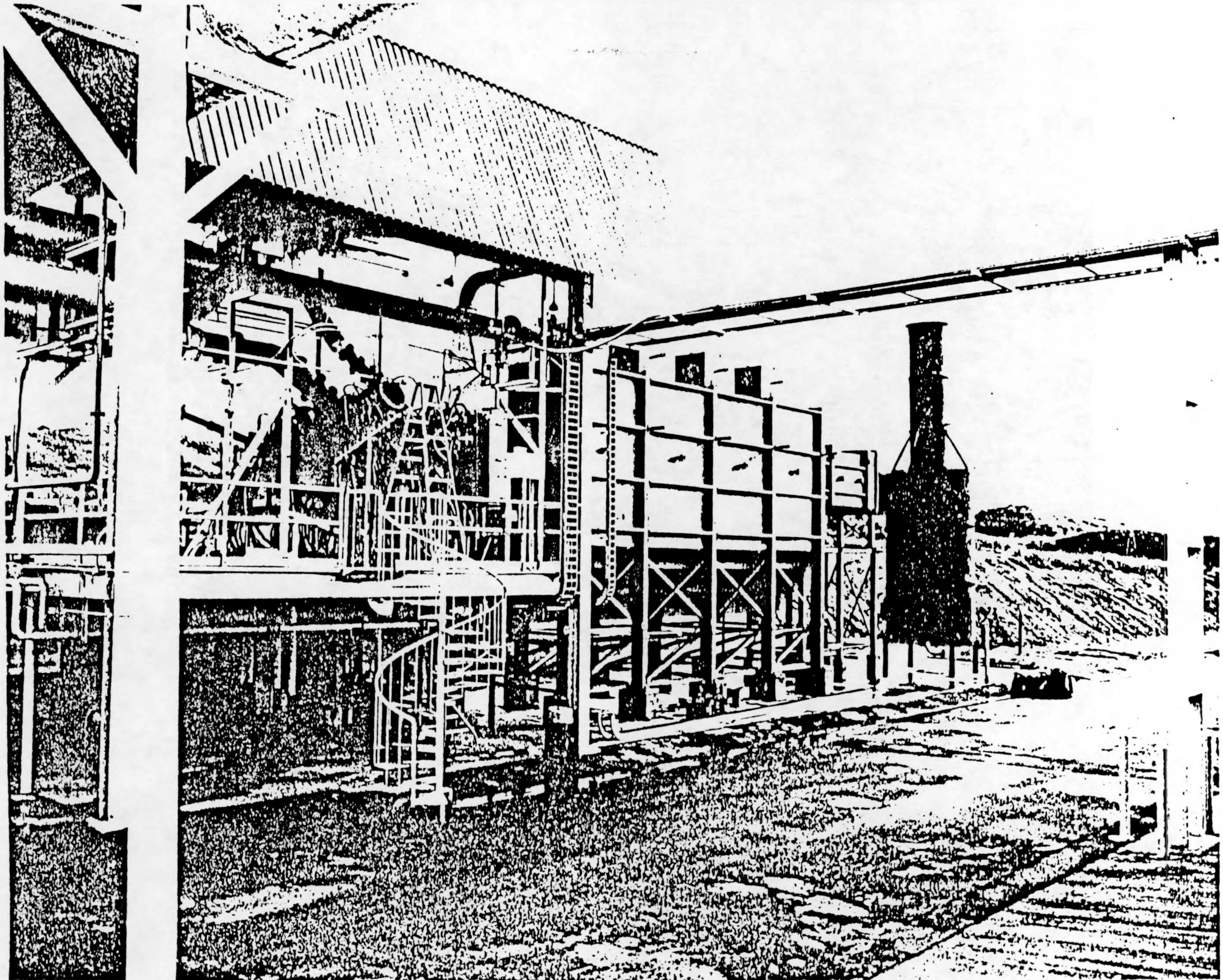


Figure 3.54. Boiler Simulator Installation, South-East View

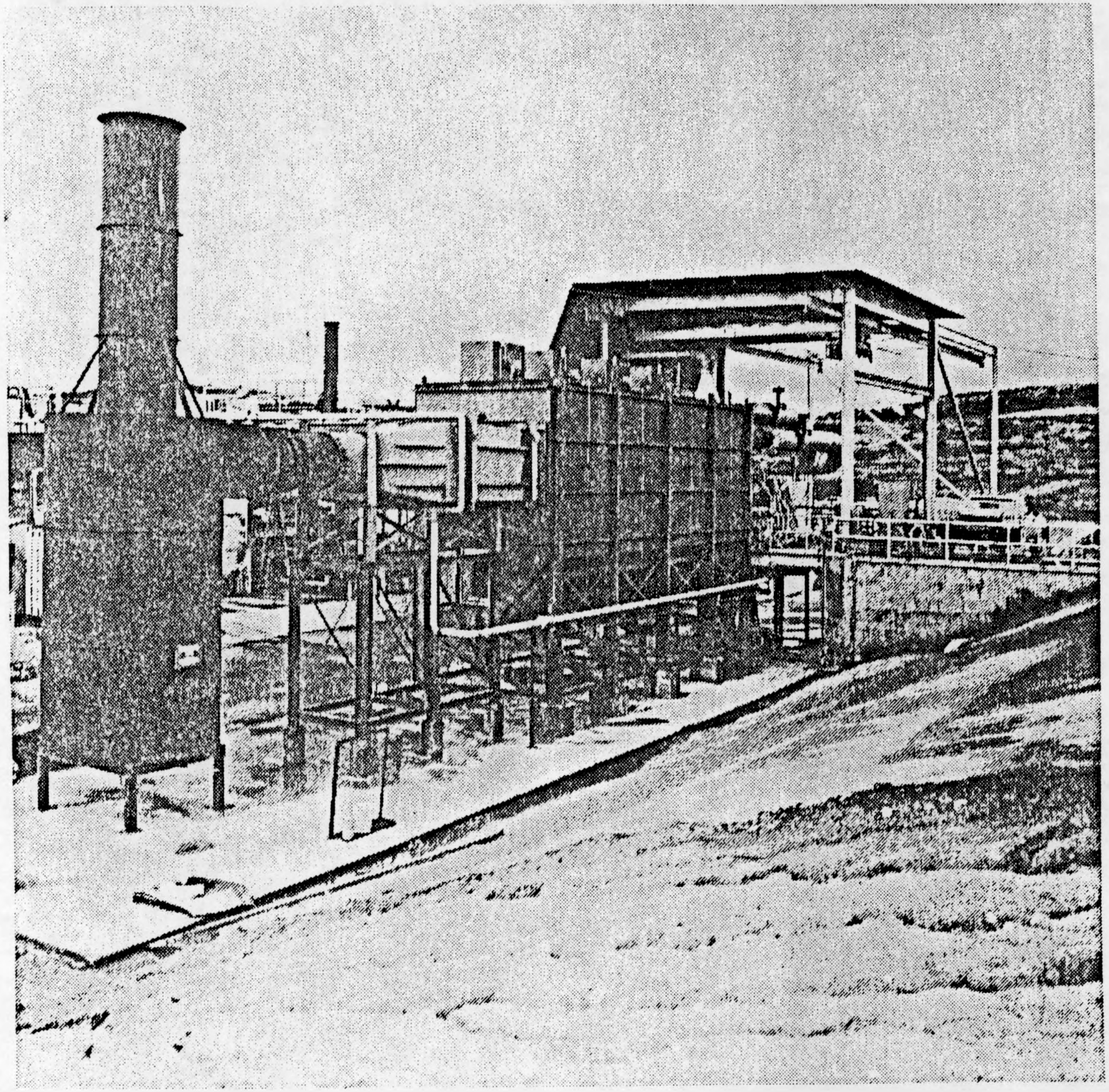


Figure 3.55. Boiler Simulator Installation, North-West View

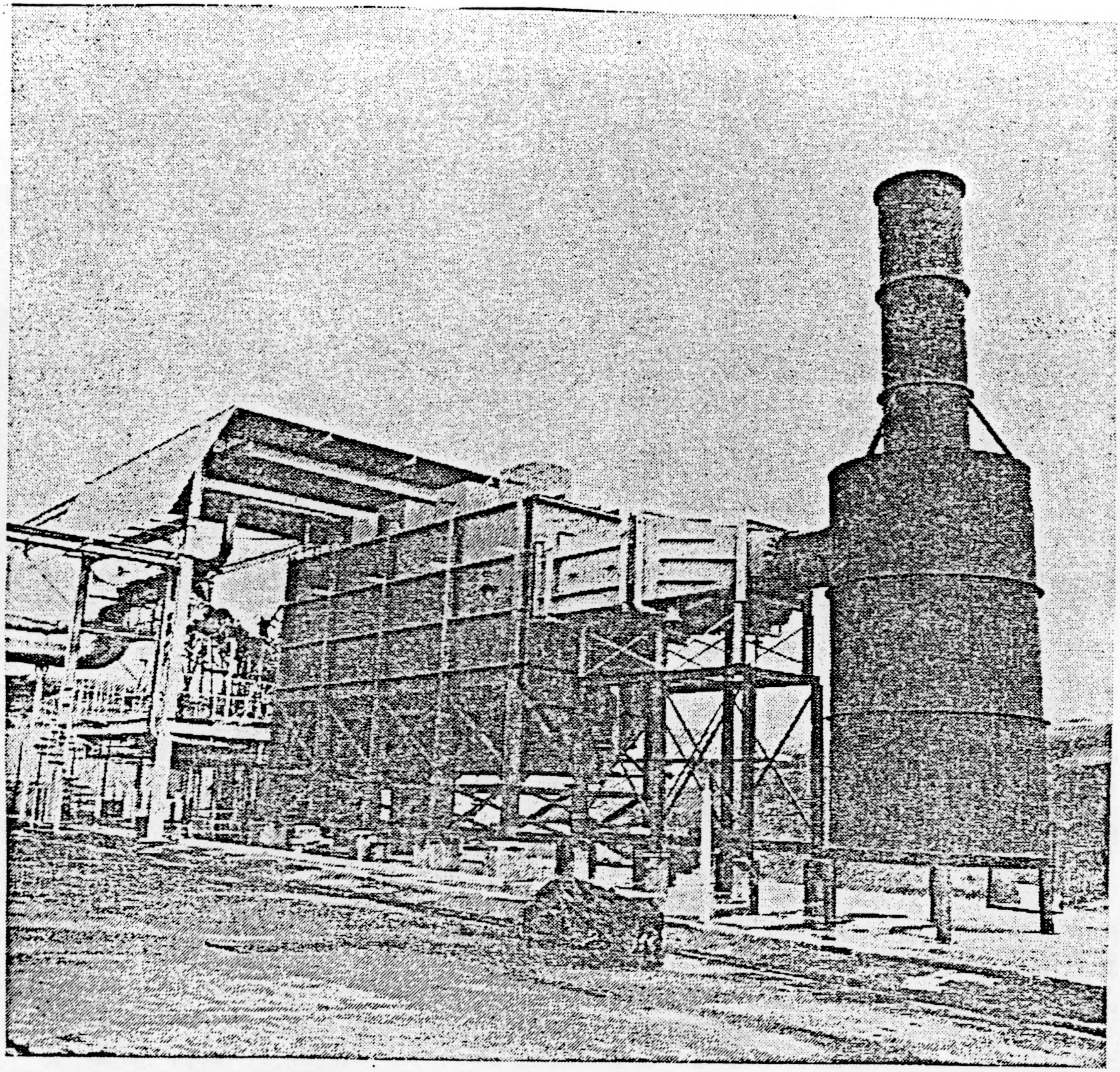
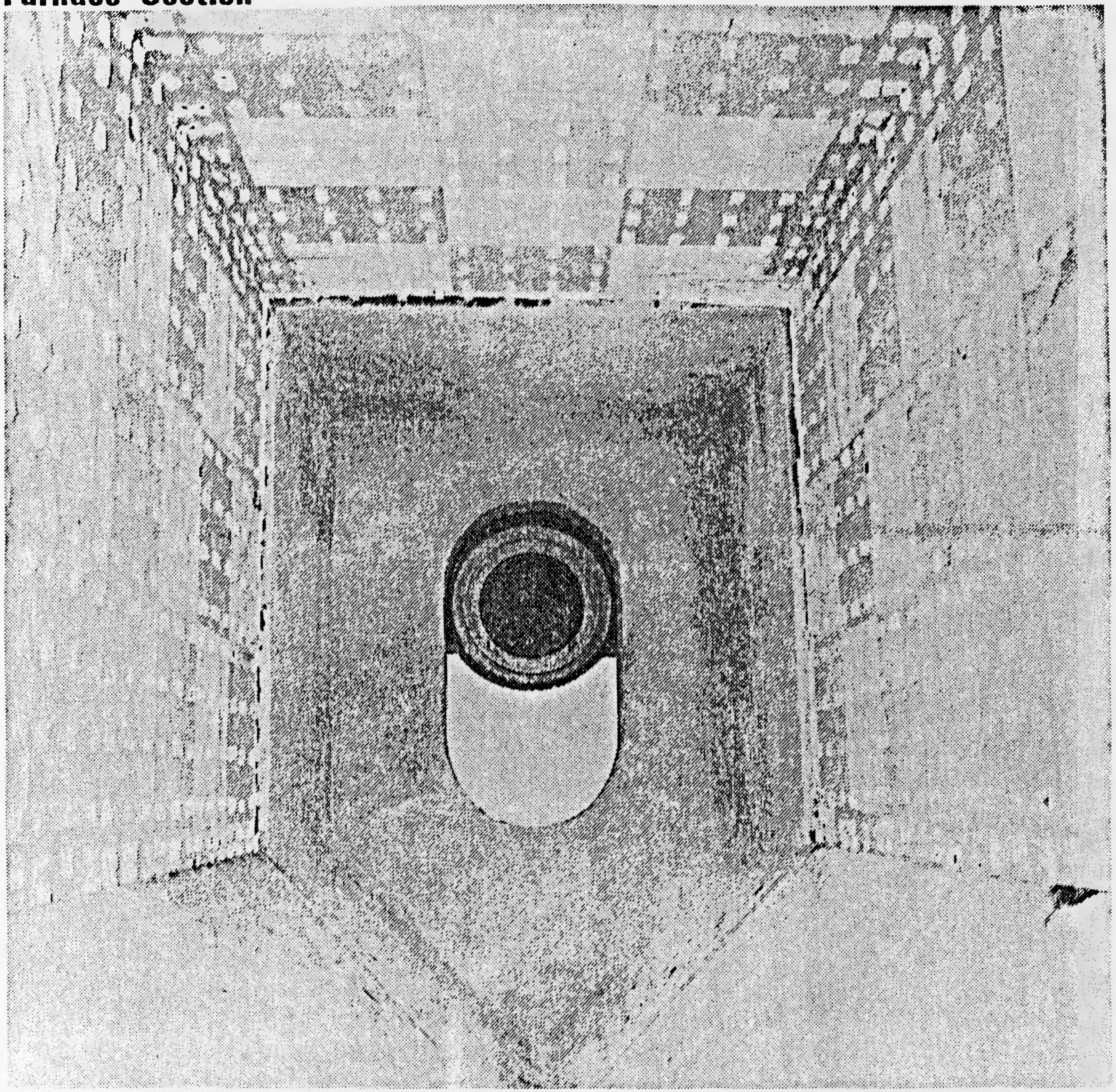


Figure 3.56. Boiler Simulator Installation, North-East View

Figure 3.57

Furnace Section



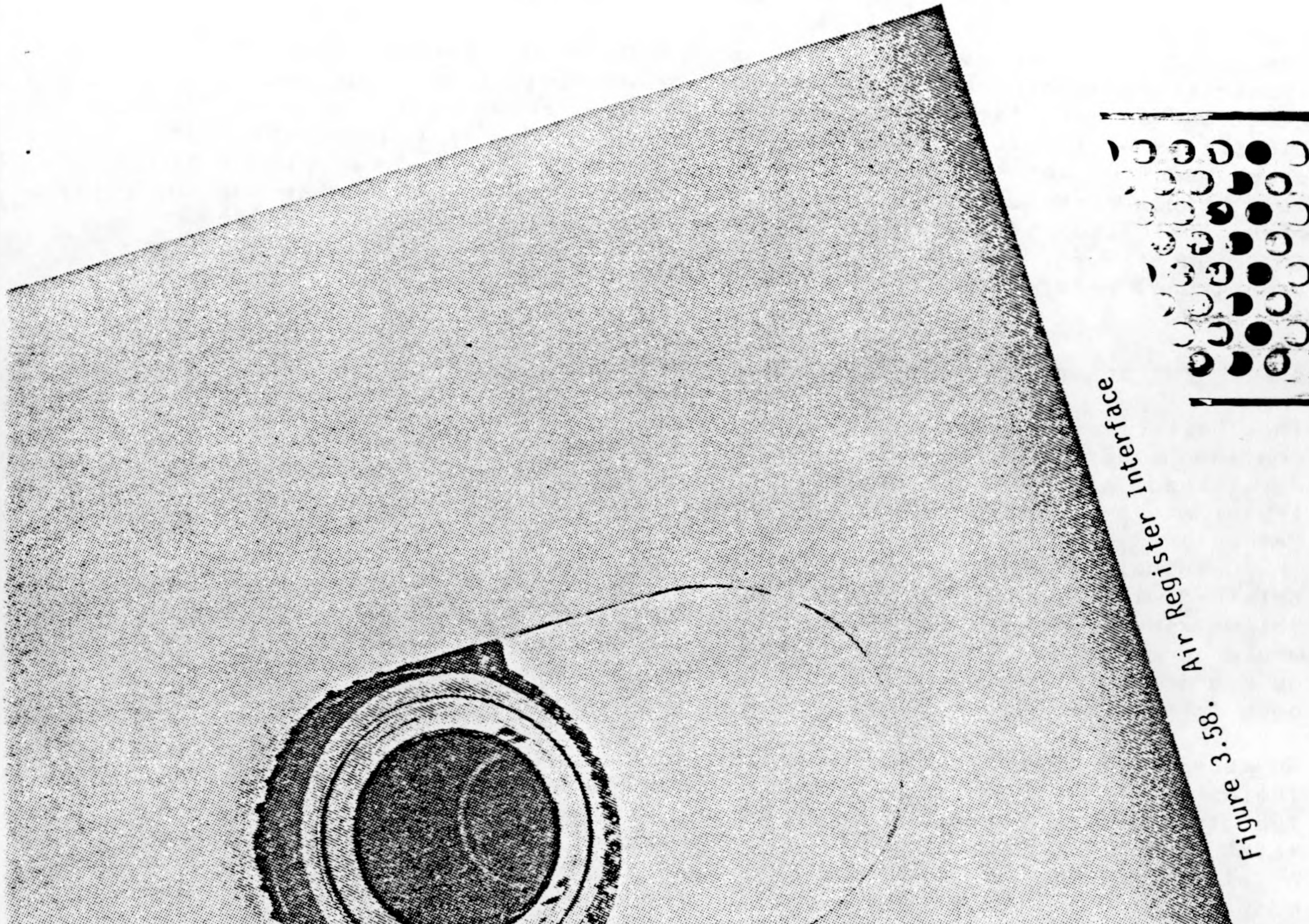


Figure 3.58. Air Register Interface

A view to the rear of the boiler simulator appears in Figure 3.59. Module 4, the last furnace module, is also insulated by the castable refractory. The central convective pass test tube bundle is not installed. An access port is provided at the rear of module 4 for inspection and maintenance purposes. The convective pass entrance and relationship of the stationary tubes are shown in Figure 3.60. Dimensions of the furnace module stack-up are shown in Figure 3.61 The cross section of modules 1 and 4 is shown in Figure 3.62. The test tube bundle arrangement is shown in Figure 3.63, and its relationship when installed in the convective pass to the furnace section is shown in Figure 3.64. The overall combustion system schematic, with dimentional references, is shown in Figure 3.65.

3.6.2 Refractory Cure Cycle and Acceptance Test

The boiler simulartor refractory cure cycle was conducted over a continuous 33.5 hour period. The precombustor exit temperature was maintained at 1850 F nominal for the last 24 hours after an initial transient ramp-up to operating temperature. The boiler simulator refractory was maintained at a nominal 600 F during the 24 hour soak. The original desired maximum temperature of 1000 F could not be obtained without over stressing the precombustor. Discussions with the boiler simulator fabricator indicated that a 24 hour soak at 600 F would produce the desired end result. A post cure inspection revealed no degradation of abnormalities. The precombustor was then switched back to coal firing.

An acceptance test was the first full-up coal firing of the new system. The air preheat from the indirectly fired heater was 450 F nominal. The total coal load was 50 MM Btu/hr, and with the air enthalpy, the total system load was 54 MM Btu/hr. The slagging stage was operated at a stoichiometry of 0.8 and the overall system stoichiometry was adjusted to 1.16 (3% excess oxygen). The convective pass tube bundle was absent for the initial tests.

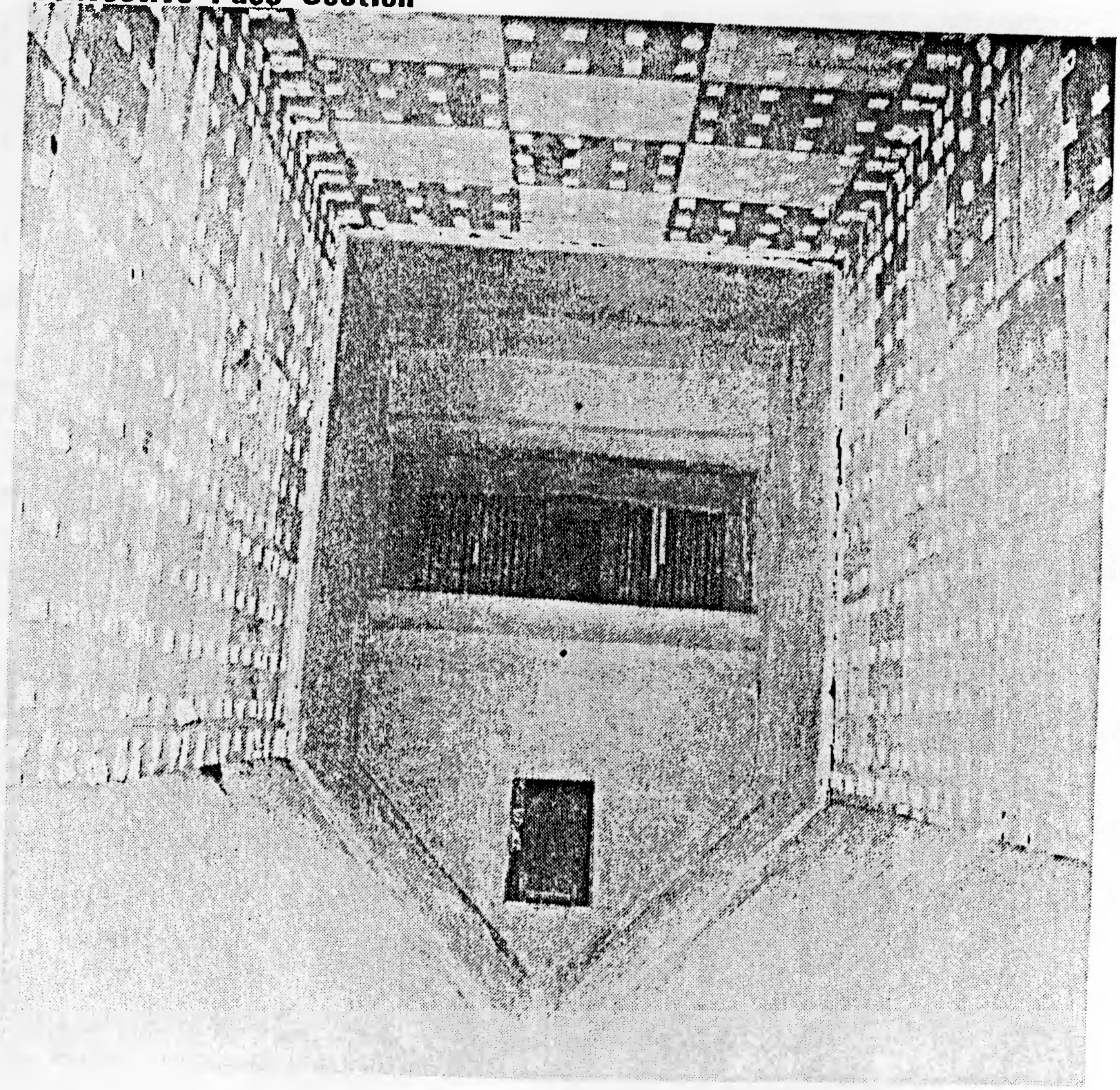
The criteria for a successful acceptance test was the mechanical and structural integrity of the hardware, the absence of any water leaks, the ability to measure process flow parameters, and a comparison of the design parameters against the measured test results.

Only minor problems were noticed with the water level float controls on modules 3 and 4. No combustor or simulator degradation or any other problems were encountered.

3.6.3 Interaction Test Results

The interaction test series (Appendix D contains the test plan) was begun on an Upper Freeport coal. Several tests were required to allow an equilibrium slag layer to form and replace, in-situ, the sacrificial refractory pounded into the air inlet section of the combustor. A total of ten tests were performed using Upper Freeport coal. Partial slagging within the precombustor was noticed on some tests, and, as a result, slag recovery performance was not as high as had been during

Figure 3.59
Convective Pass Section



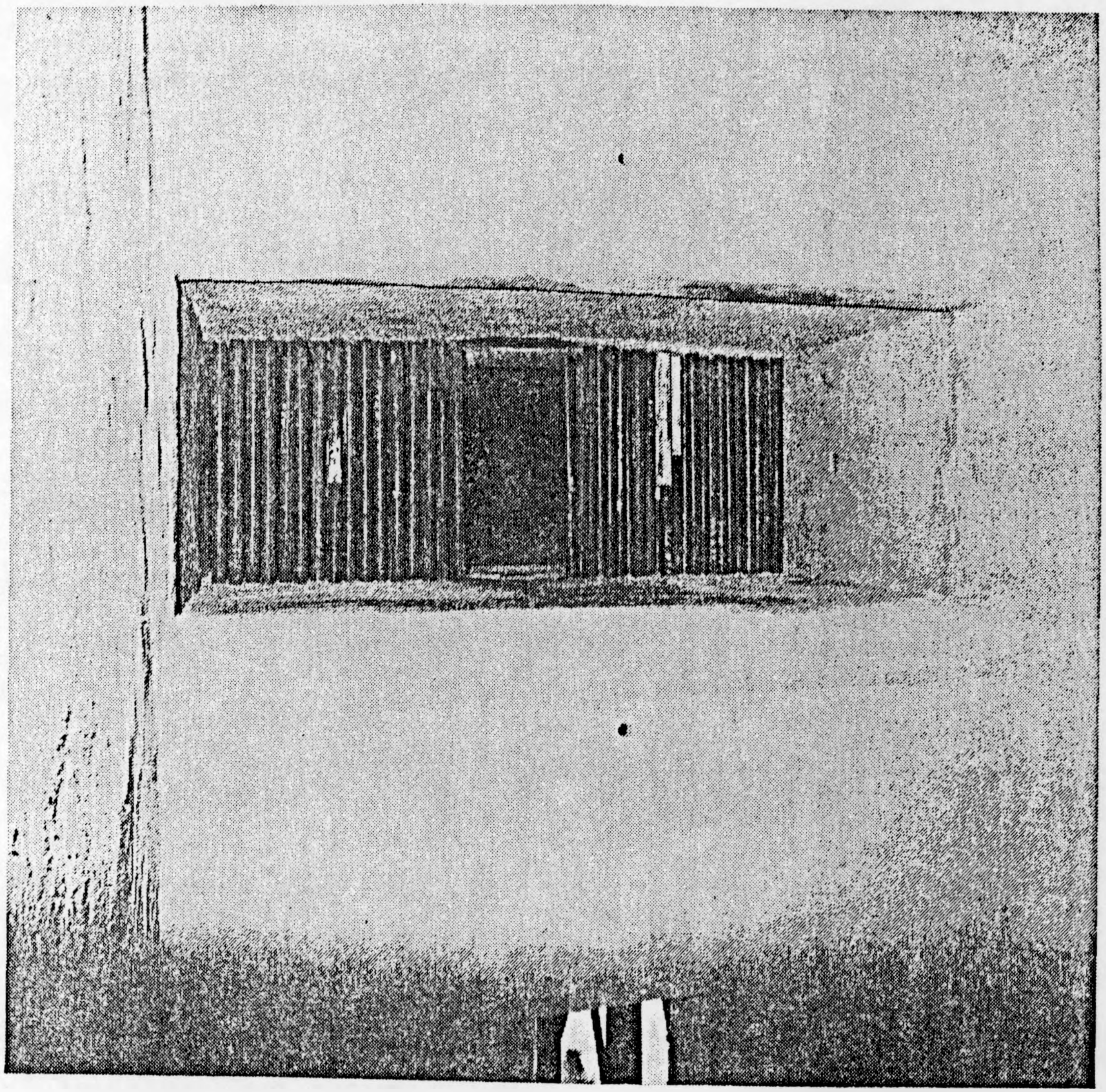


Figure 3.60. Convective Pass Entrance

FURNACE MODULES

DIMENSIONS IN FEET

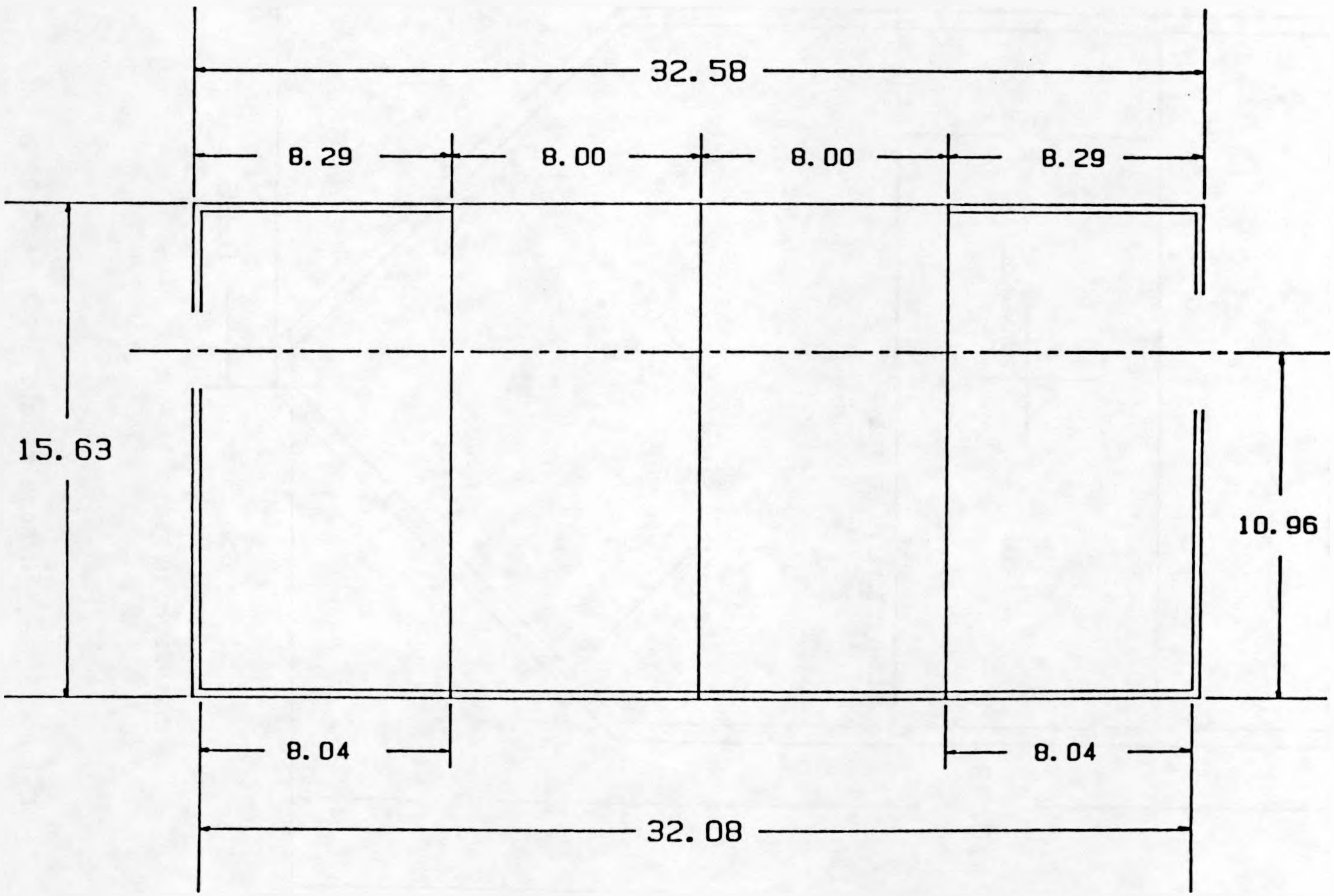


Figure 3.61 . Boiler Simulator Furnace Section

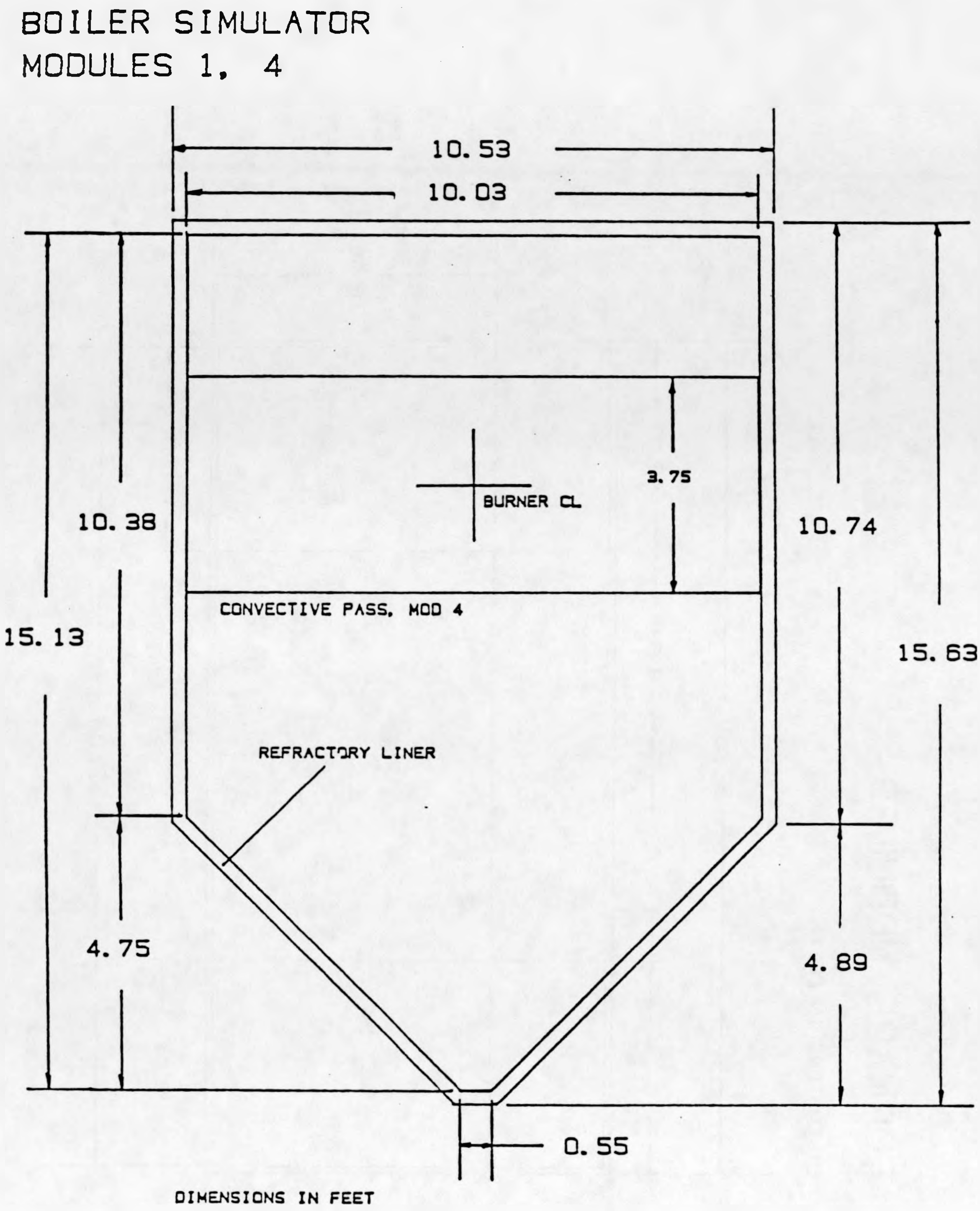
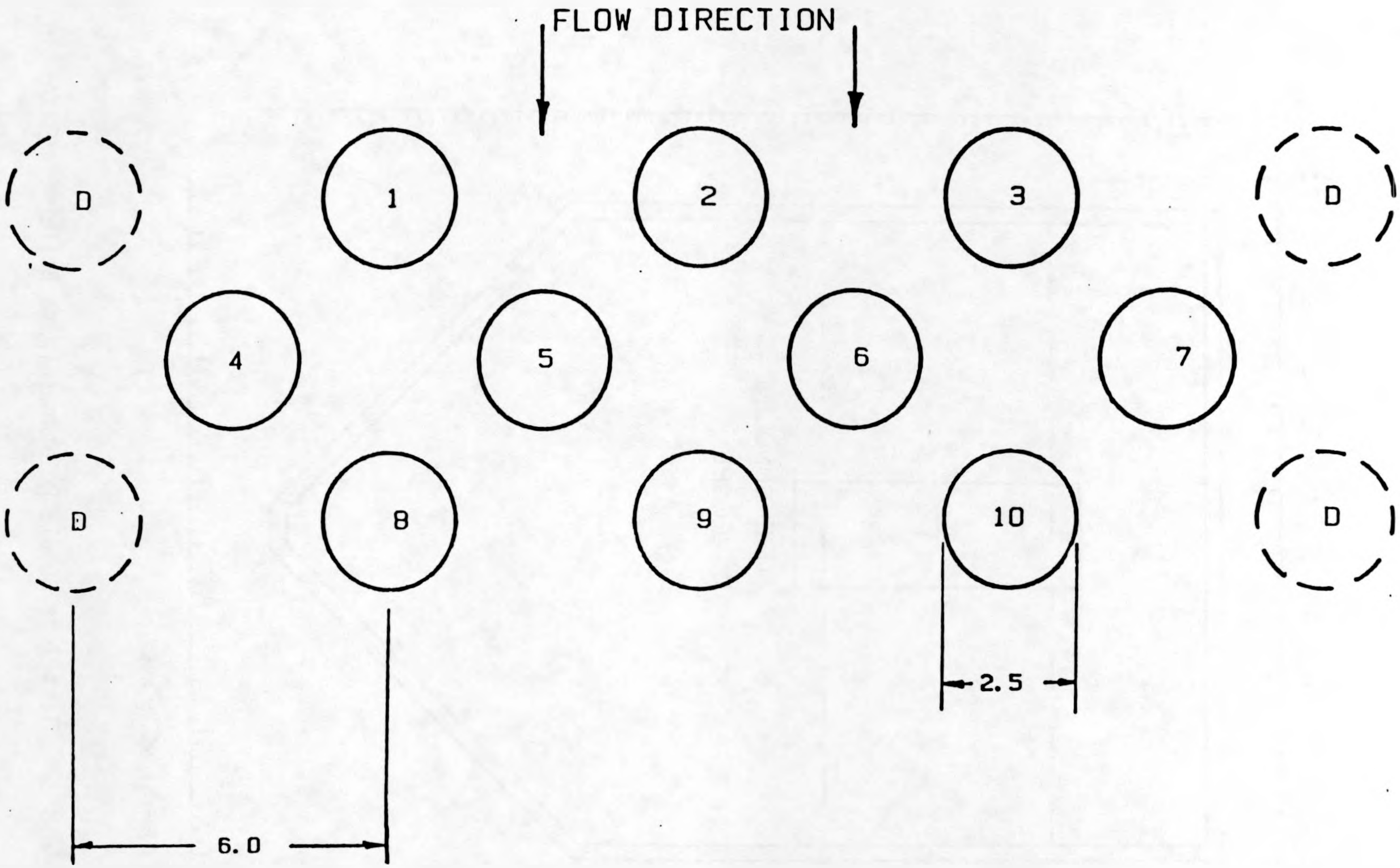


Figure 3.62. Furnace Module Cross Section

TUBE BUNDLE



DIMENSIONS IN INCHES   TEST TUBES: 1-10, D - DUMMY TUBES

Figure 3.63 . Test Tube Bundle Arrangement

MODULES 1, 4

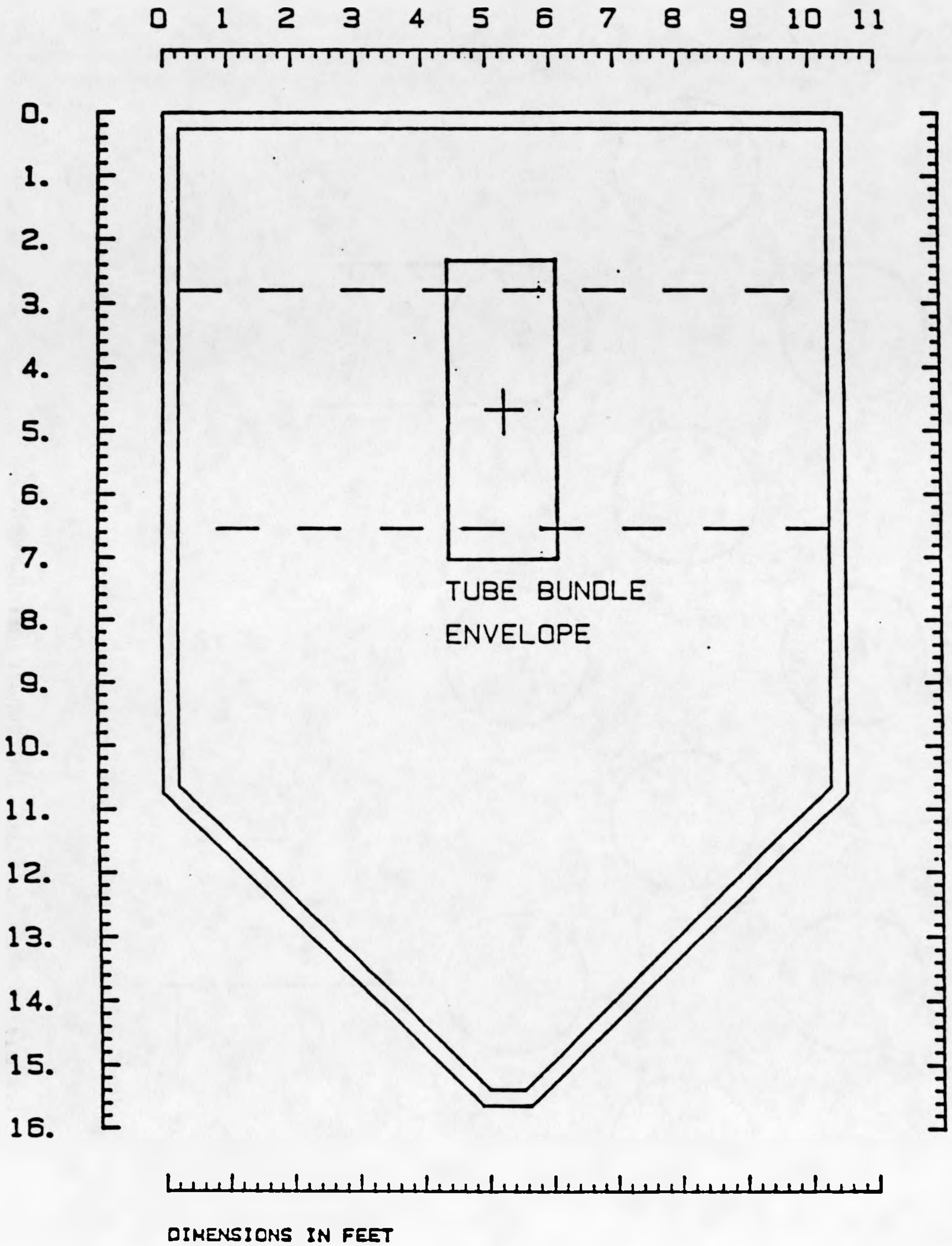


Figure 3.64 . Test Tube Bundle Relationship to Boiler Simulator

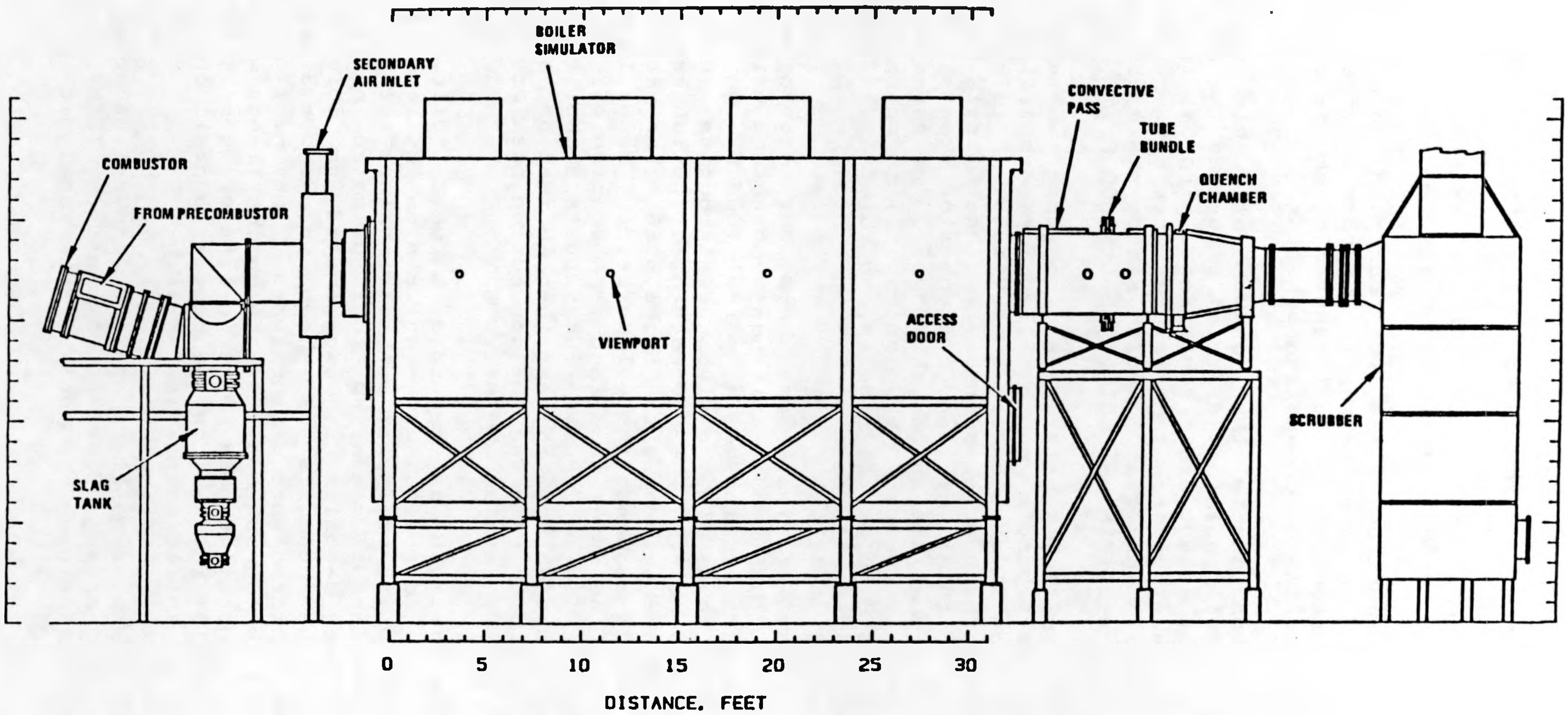


Figure 3.65. Advanced Slagging Coal Combustion System

the Task 3 test series. No combustor degrdation or boiler simulator degradation was noticed during these tests. Secondary combustion was smooth with the overall carbon conversion in excess of 98% as measured by the oxygen level in the convective pass.

The secondary combustion flame, as observed on video cameras, was stable and appeared to be quite short. Changes in the secondary air swirl from full clockwise to full counter clockwise did not appear to make any difference in the combustion behavior.

Test time limitations due to the maximum allowable stack emissions imposed by the local regulatory district prevented the boiler simulator from achieving full steady state conditions. Typical test times were 1.5 hours. Furnace exit gas temperatures were between 1800 F and 1900 F by the end of the test. Full steady-state boiler simulator conditions would result in an FEGT of about 2000 F.

Following the initial tests with the Upper Freeport coal, the convective tube pass bundle was installed for deposition studies. A Pittsburgh No. 8 coal was used for these tests. A total of eight tests were performed on the bundle assembly. These tests were of short duration with a total of ten precombustor starts, eight combustor starts, and eight complete system shutdowns. The operating time on the precombustor was 9 hours, 46 minutes. The operating time on the slagging stage was 8 hours, 34 minutes. A total of 14.2 tons of coal was burned during these tests.

The upstream face of the pass tubes was maintained at 1000 F by nitrogen cooling. The furnace exit gas temperature prior to entry into the convective pass section was a nominal 1800 F. An on-line particle analyzer was used to sample the flyash distribution just upstream of the test tube bundle. The average distribution results from three successive tests are presented in Figure 3.66. The mean particle size is just less than 3 microns; the volume percent above 10 microns is 5%. This distribution indicates that long term erosion of convective pass tubes should not be a problem for industrial boiler retrofits with convective pass tube velocities less than 60 feet per second. The mass loading of the flyash entering the convective pass was between 0.9 and 1.0 pounds of particulate per MM Btu.

The tube bundle assembly was removed as a unit following the tests. Extremely friable deposits were noticed on the leading faces of the tubes. These deposits could not be kept in place even during careful handling. The deposit geometry is illustrated in Figure 3.67. The magnitude of the deposits is exaggerated on this schematic. A photograph of the deposits is shown in Figure 3.68. The view is looking at the upstream face of the tubes. The manifold assembly at the top of the photograph contains the mating flange which attaches to the top of the convective pass. A thin line of deposit can be noticed in Figure 3.68. Of interest is the heavier deposit on the middle row, indicative of the accelerating flow field.

Samples ofthe flyash deposited on the convective pass tubes were examined in a Scanning Electron Microscope (SEM) equipped with a dispersive energy analyzer. A bulk scan analysis of the deposit

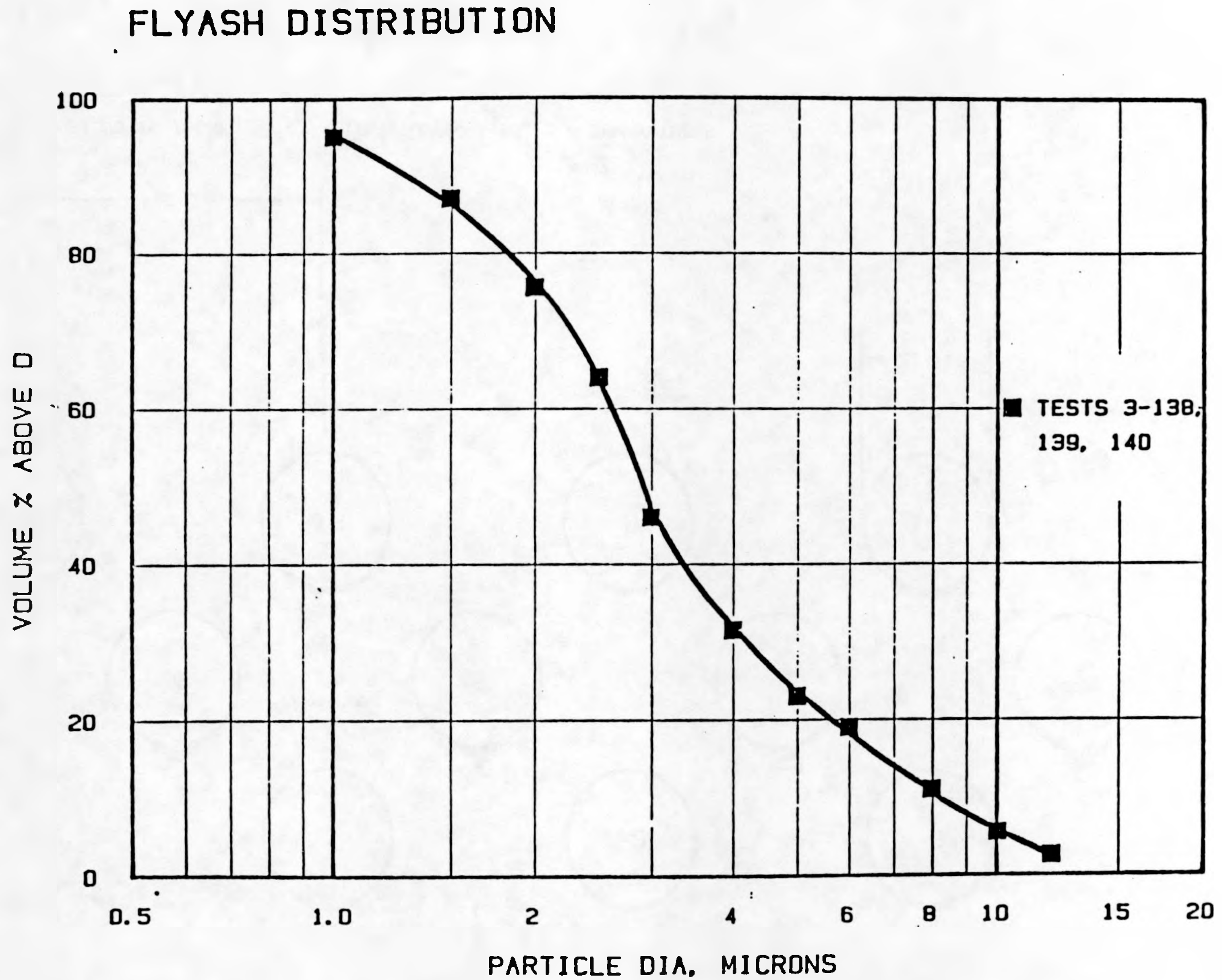


Figure 3.66. Convective Pass Flyash Distribution

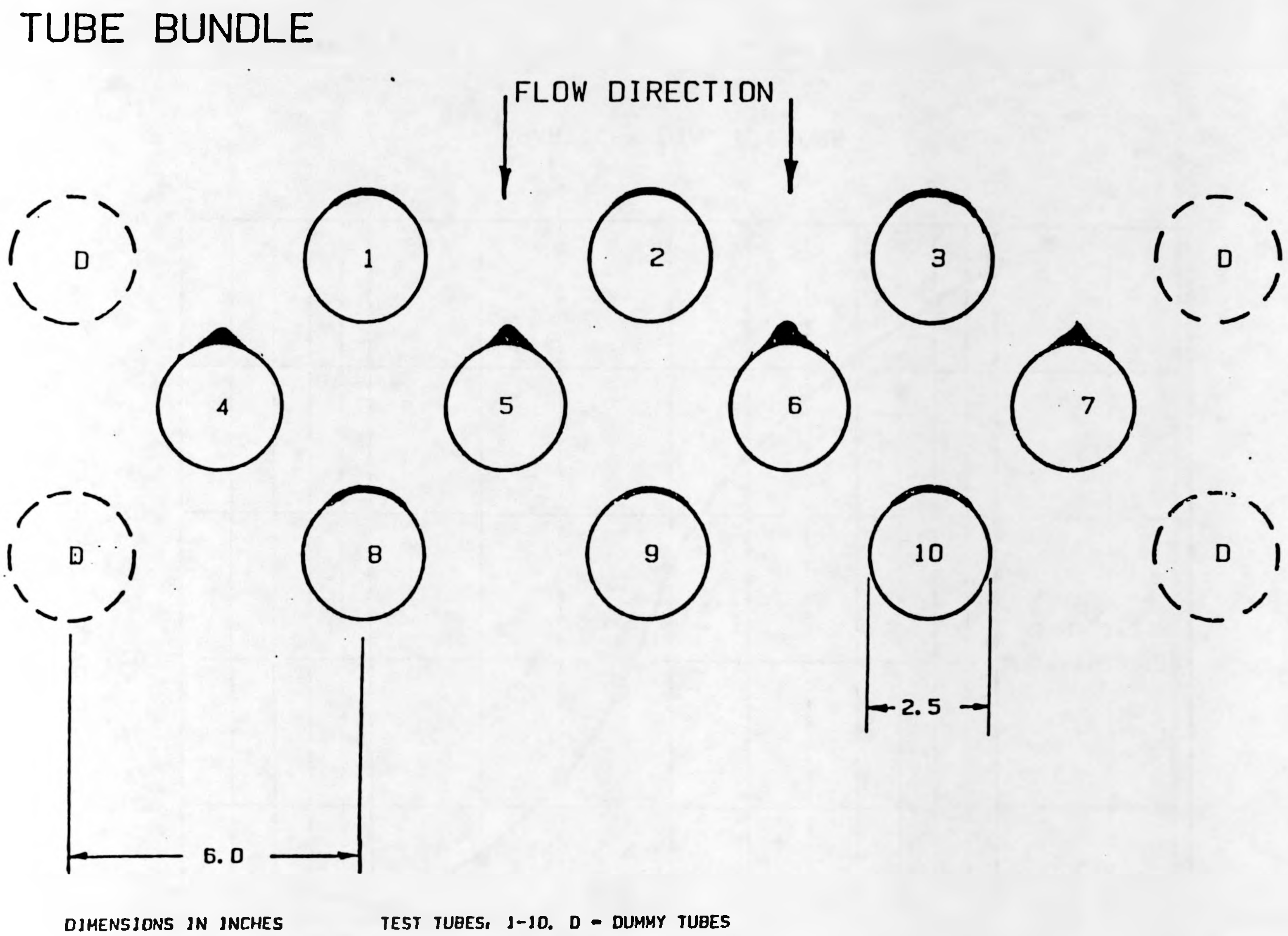


Figure 3.67. Tube Bundle Deposit Geometry

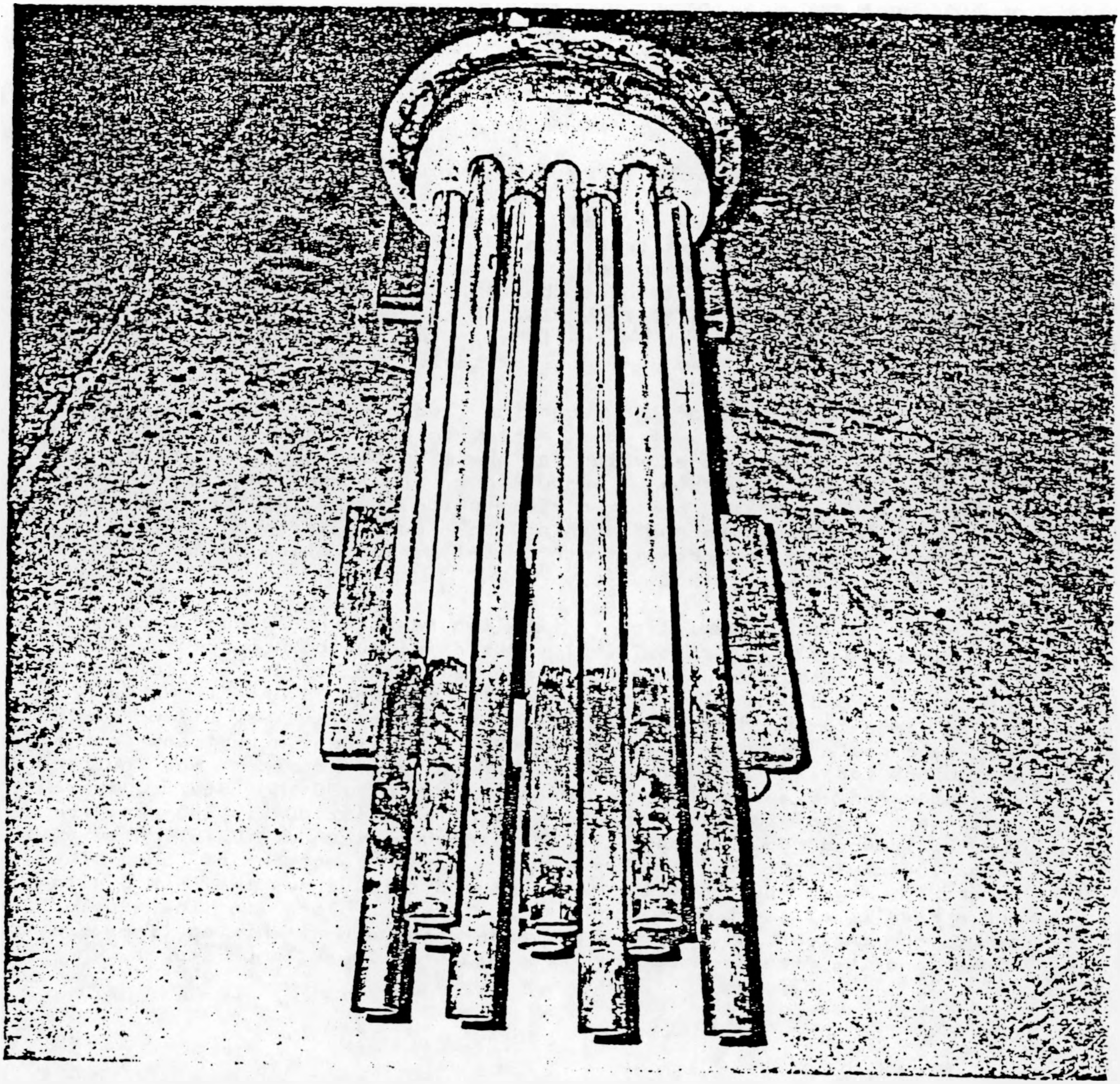


Figure 3.68 . Post Test Tube Bundle Appearance

material agreed reasonably well with the bulk ash analysis performed by Commercial Testing. Table 3.6 contains the analysis comparisons. It should be noted that the dispersive energy analyzer does not yield a compound analysis, but rather an elemental analysis. The values have been converted to an assumed oxide form, the same as the results obtained from a standard ash analysis. Several individual particles were analyzed, and depending upon the accelerating voltage, i.e., effective depth of penetration, and particle size, the composition appeared to have quite a range of values.

The tube deposit particle size distribution data is compared to the flyash distribution data in Figure 3.69. The tube deposit was taken from the upstream side of test tube No. 2. The tube deposit distribution indicates that less than 10% of the particulate is less than 20 microns. The potential for long tern erosion is not apparent judging from the particulate distribution. Also of interest is the wide belief that small particles, i.e., 2 to 3 microns, will follow the streamlines and not deposit on the tubes. This is clearly refuted as 25% of the tube deposit is 3 microns or less.

The physical morphology of the deposited flyash appears in Figure 3.70. The overwhelming majority of the particulate is composed of solid spheres. This is to be expected for the TRW slagging combustor's mode of intense, high temperature combustion. The ash particles which become flyash are in a molten state prior to leaving the combustor. The solidification process within the furnace section following secondary combustion promotes spherical shapes which should be more benign in erosive potential.

The system NOx characteristics for the two Eastern Coals are presented in Figure 3.71 and Figure 3.72. The NOx data have been corrected to 3% oxygen. The combustor was operated at a slagging stage stoichiometry between 0.7 and 0.9. The load was varied between 38 and 51 MM Btu/hr. The data are compared to that obtained during the Task 3 effort with the same coal. Both sets of data reveal significant reductions in the NOx values for tests with the secondary air register and boiler simulator in place. At a nominal load of 50 MM Btu/hr, these reductions are of the order of 100 ppmv. The total NOx is 250 ppmv for the Pittsburgh No. 8 coal at a stoichiometry of 0.75. Also of significance is the NOx level reduction as a function of load The generally lower NOx levels of the Task 6 data versus the Task 3 data are a result of secondary combustion taking place in the boiler simulator instead of the straight pipe afterburner. Mixing times are slower and the final combustion takes place at lower temperatures.

Table 3.5. Ash Analysis Comparisons

Component	Coal Ash	Slag	Tube Deposit	SEM Analysis Tube Deposit
SiO_2	46.64	48.42	52.39	48.98
Al_2O_3	22.06	19.56	25.49	28.28
TiO_2	0.92	0.70	1.16	3.32
Fe_2O_3	23.22	23.71	13.24	7.49
CaO	1.16	1.35	2.13	3.30
MgO	0.82	0.86	1.04	----
K_2O	2.11	2.50	2.10	3.43
Na_2O	0.25	0.47	0.37	----
SO_3	0.71	0.31	1.10	5.20
P_2O_5	0.20	0.20	0.31	----
SrO	0.14	----	0.07	----
BaO	0.05	----	0.10	----
Mn_3O_4	0.05	----	0.01	----
Undetermined	1.67	2.14	0.49	----
T_{250}, ^{o}F	2415	2355	2646	----

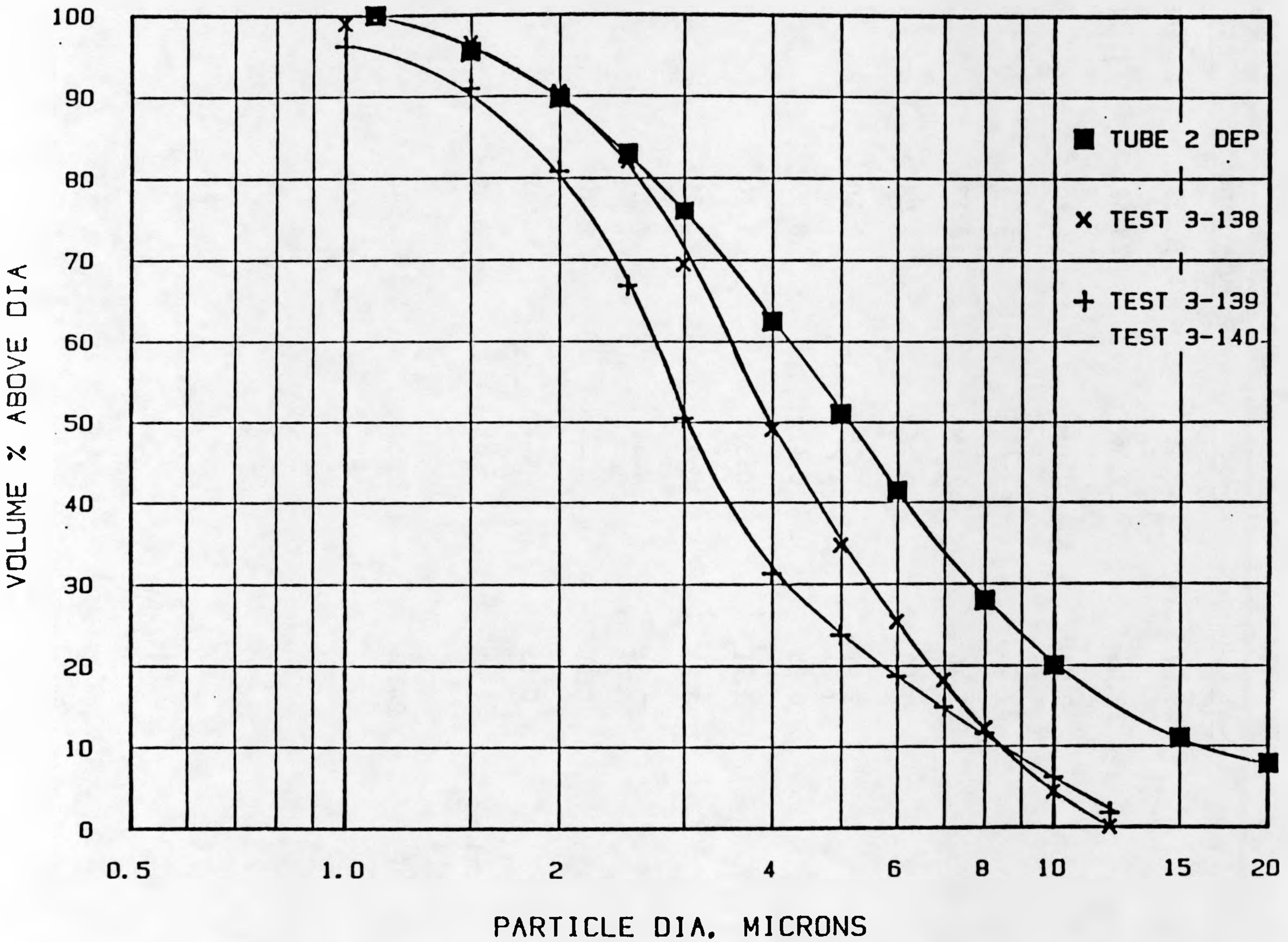
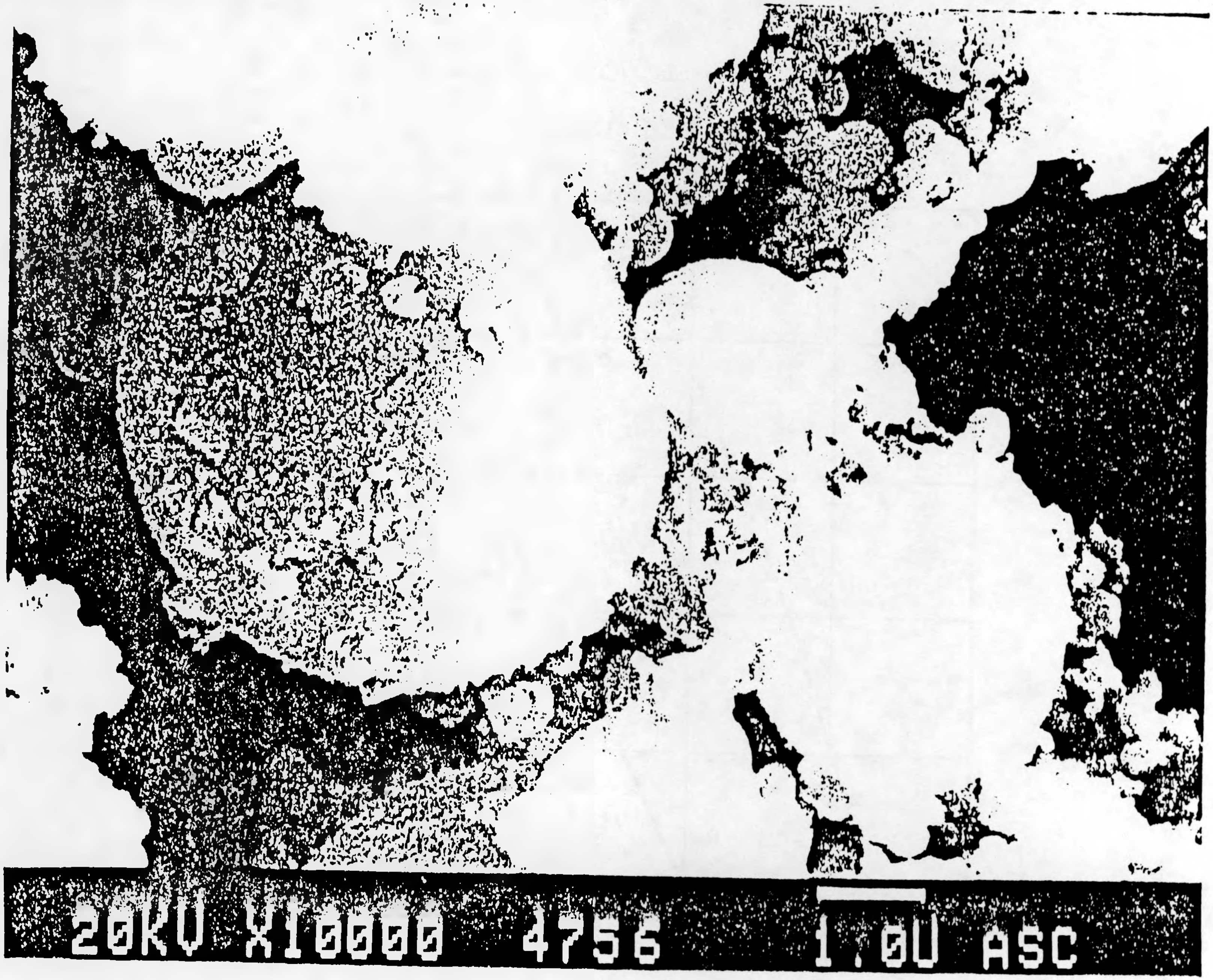


Figure 3.69. Flyash Distribution


20KV X10000 4756 1.0U ASC

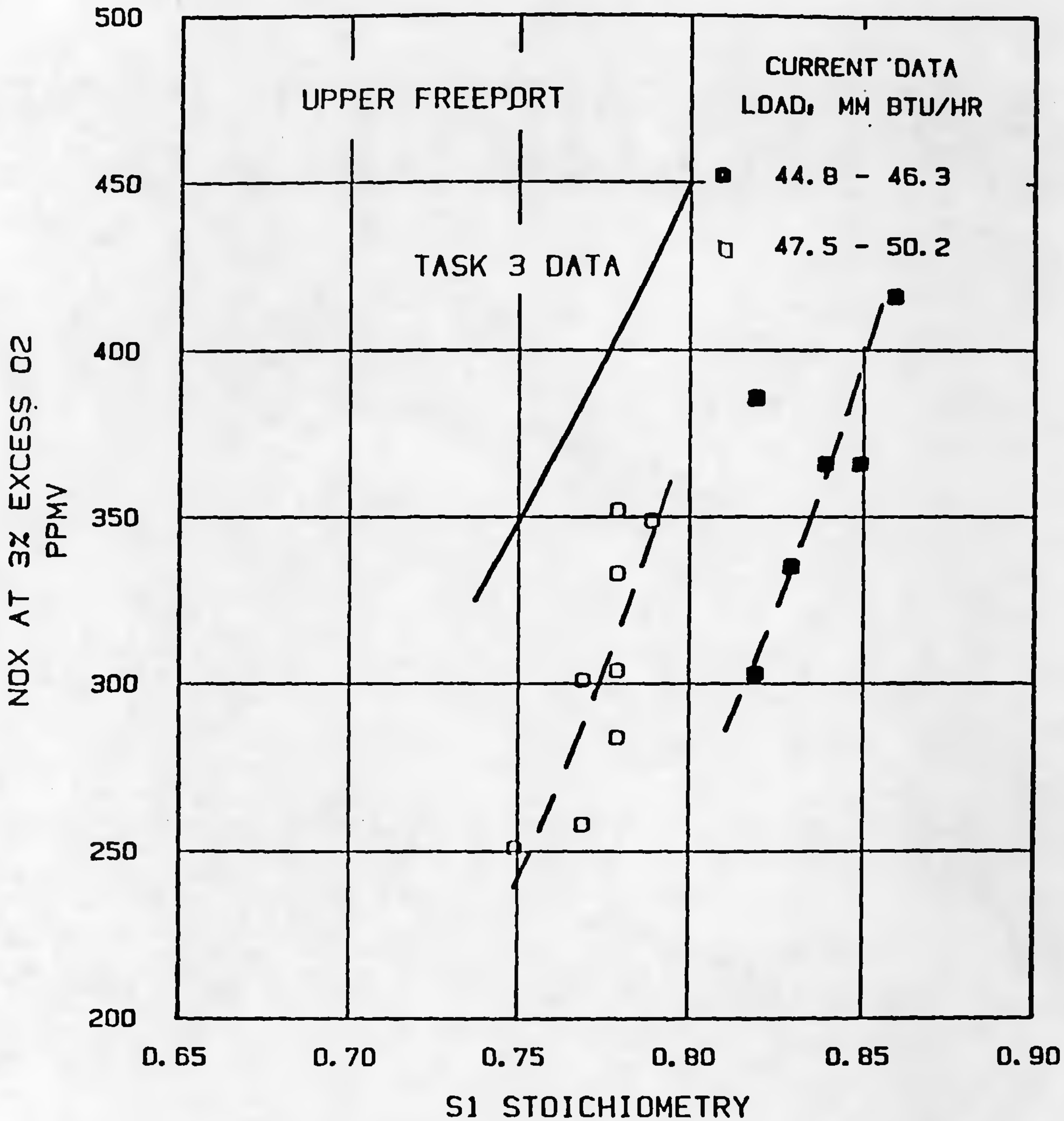


Figure 3.71. NO_x Data for Upper Freeport Coal

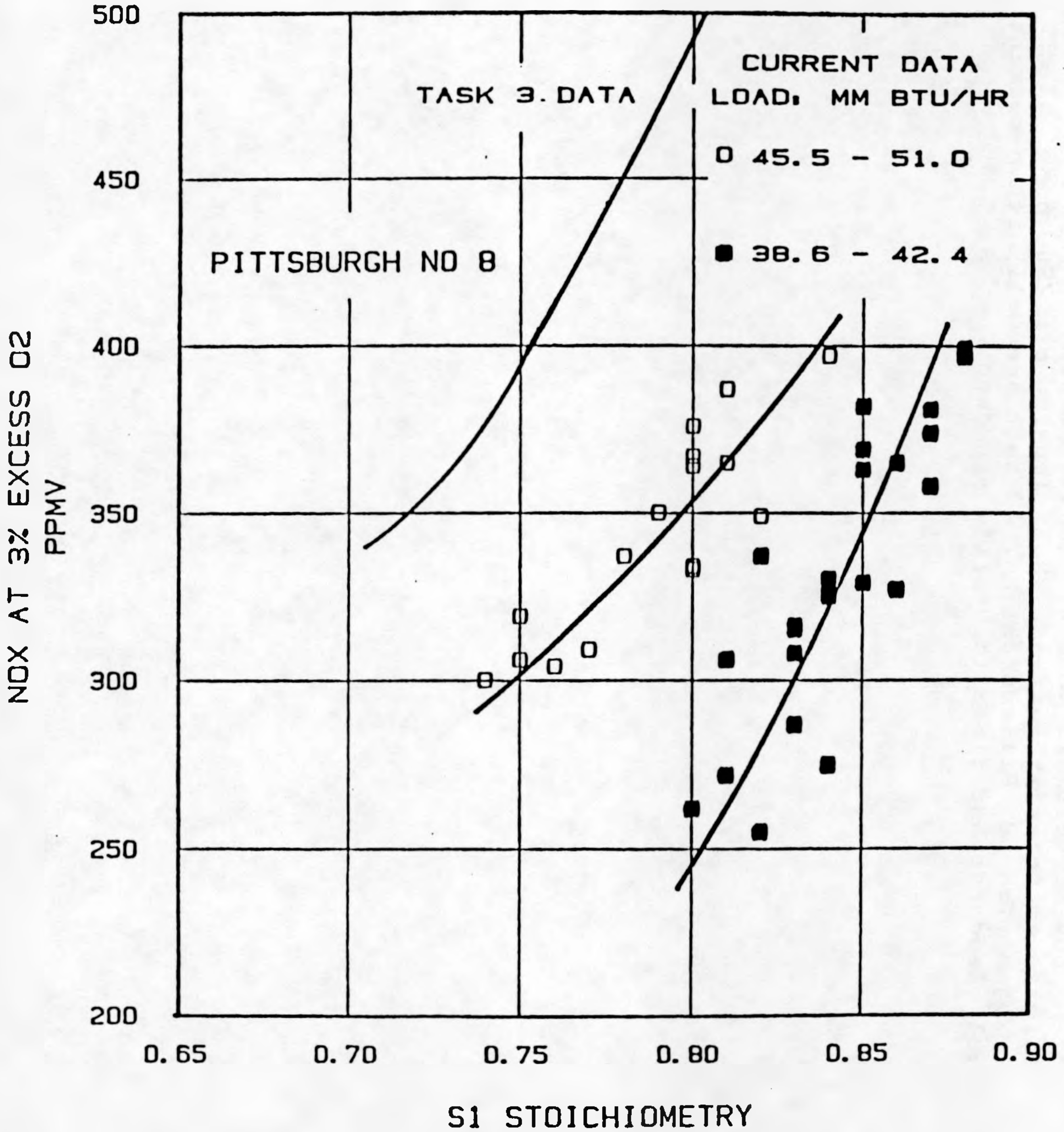


Figure 3.72. NO_x Data for Pittsburgh No. 8 Coal

3.6.4 Test Conclusions

The system interaction tests, although of very short time by industry standards, gave every indication that the particulate effluent from the TRW slagging combustor would not pose problems to heat utilization equipment from the aspects of convective pass tube erosion or from deposits that would foul heat transfer equipment. The deposits noticed on the simulated convective pass tubes should be highly amenable to soot blowing.

The system NOx levels in this test phase revealed the importance of matching intended retrofit systems. NOx levels of 250 ppmv at 3% excess oxygen for a Pittsburgh No. 8 coal are well within current industrial standards and close to utility standards.

4.0 CONCLUSIONS

The Advanced Slagging Coal Combustion System Development Project has been successful in establishing a broad engineering data base for the advancement of coal as the fuel of choice for furnaces, boilers, and other heat utilization equipment.

The partially developed, slagging combustor at the 10 MM Btu/hr scale was characterized to the maximum extent possible for scaling information to the larger 50 MM Btu/hr size. Test data from both combustors verified that the scaling criteria developed were accurate.

A performace enhancement was noticed with the full scale, 50 MM Btu/hr combustor. Slag recoveries in the 90 percentile range are achievable when proper attention is addressed to operation of the precombustor. A significant contribution to the data base has been made in characterizing the particulate effluent from the combustor. Concern had been expressed about the convective pass tube fouling potential and subsequent boiler derating aspects. The particulate matter exiting the combustor has a mean diameter of between three and four microns with only 5% above 10 microns. The nature of material deposited on representative convective pass tubes appears to be benign, is readily amenable to soot blowing, and is of dominant spherical geometry.

Low NOx operation, i.e., values around 250 ppmv, is achieved by fuel and oxidizer staging. The slag removal for a Pittsburgh No. 8 coal at this condition is 88%. Efforts at obtaining the simultaneous reduction of deleterious emissions, especially sulfur containing species, was met with partial success. The direct injection of calcium based sorbents into the high temperature slagging stage is not warranted as a primary means of controlling sulfur emissions.

The combustor has been shown to be inherently tolerant of coals with a wide range in property values. Operation with coal water mixtures appears to be feasible, but additional work is necessary.

The data generated from this project will assist the private sector in making decisions on the technical, economic, and environmental feasibility of using slagging coal combustion systems.

5.0 RECOMMENDATIONS

The combustion system's ability to simultaneously control emis- sions is mandatory for industrial and utility user acceptance. The Advanced Slagging Coal Combustion System Development Project has been successful in the simultaneous control of two of these emissions. particulates and oxides of nitrogen. The control of sulfur emissions could not be achieved to environmentally acceptable standards, i.e., within the 70% to 90% reduction range without compromising control of particulates and NOx. Additional research and development is necessary to realize the full potential of TRW's slagging coal combustor as an emission control device.

Major emphasis was placed on using pulverized coal during the project. A limited amount of coal water mixture work was performed with no combustor configuration changes other than an injector change. As such, only a partial understanding of CWM/slagging combustor operation was achieved. New injection concepts need to be developed for CWM combustion in the compact slagging combustor. Configurational variables require investigation before the full feasibility of CWM operation can be ascertained.

APPENDIX A

TEST TASK COAL PROPERTIES

ADVANCED SLAGGING COAL COMBUSTION SYSTEM
COAL PROPERTIES

TASK 2 COALS: PROXIMATE ANALYSIS

ABBRV	COAL DESIGNATION	FORM	PROXIMATE ANALYSIS, %				
			VOLAT	FIX C	MOIST	ASH	HHV
WYRBA	WYMOING ROSEBUD A	PC	38.33	45.49	9.17	7.01	11484
PITT8A	PITTSBURGH NO 8	PC	36.49	49.52	2.66	11.33	12777
BLCK2A	BLACKSVILLE NO 2	PC	34.21	48.37	5.35	12.07	12458
BLK2SB	BLACKSVILLE NO 2	CWM	21.7	40.46	29.17	8.67	9297

The higher heating value is expressed in BTU/lb

ADVANCED SLAGGING COAL COMBUSTION SYSTEM
COAL PROPERTIES

TASK 2 COALS: C, H, O, S, N

ABBRV	COAL DESIGNATION	FORM	ULTIMATE ANALYSIS, %				
			CARBON	HYDROG	OXYGEN	SULFUR	NITROGEN
WYRBA	WYOMING ROSEBUD A	PC	64.86	4.81	12.16	0.61	1.34
PITT8A	PITTSBURGH NO 8	PC	71.24	4.67	6.22	2.39	1.39
BLCK2A	BLACKSVILLE NO 2	PC	67.62	4.89	5.77	3.05	1.12
BLK2SB	BLACKSVILLE NO 2	CWM	52.35	3.39	3.31	1.93	0.93

ADVANCED SLAGGING COAL COMBUSTION SYSTEM
COAL PROPERTIES

TASK 2 COALS: ASH COMPOSITION

ABBRV	COAL DESIGNATION	FORM	ASH ANALYSIS, %									T250 DEG F
			SiO2	Al2O3	TiO2	Fe2O3	CaO	MgO	K2O	Na2O	SO3	
WYRBA	WYOMING ROSEBUD A	PC	34.12	16.18	0.71	9.24	18.97	4.77	0.99	0.57	12.6	2118
PITT8A	PITTSBURGH NO 8	PC	50.53	23.25	0.91	19.67	1.15	0.76	2.3	0.57	0.14	2510
BLCK2A	BLACKSVILLE NO 2	PC	42.4	18.56	1.01	20.18	6.9	0.99	1.65	0.72	6.88	2320
BLK2SB	BLACKSVILLE NO 2	CWM	46.14	23.05	0.98	15.04	4.74	1.1	1.79	0.91	5.45	2495

ADVANCED SLAGGING COAL COMBUSTION SYSTEM
COAL PROPERTIES

TASK 3 COALS: PROXIMATE ANALYSIS

ABBRV	COAL DESIGNATION	FORM	PROXIMATE ANALYSIS, %				
			VOLAT	FIX C	MOIST	ASH	HHV
WYRBB	WYMOING ROSEBUD B	PC	40.1	45.49	7.77	6.64	11736
PITT8B	PITTSBURGH NO 8	PC	37.66	49.9	2.34	10.1	12975
OHIO6B	OHIO NO 6	PC	37.75	50.96	2.76	8.53	12932
UPFRA	UPPER FREEPORT A	PC	32.94	51.88	3.19	11.99	12948
UPFRB	UPPER FREEPORT B	PC	33.37	53.68	2.71	10.24	13157
UPFRSA	UPPER FREEPORT A	CWM	22.07	40.05	31.45	6.43	9319

The higher heating value is expressed in BTU/lb

ADVANCED SLAGGING COAL COMBUSTION SYSTEM
COAL PROPERTIES

TASK 3 COALS: C, H, O, S, N

ABBRV	COAL DESIGNATION	FORM	ULTIMATE ANALYSIS, %				
			CARBON	HYDROG	OXYGEN	SULFUR	NITROGEN
WYRBB	WYOMING ROSEBUD B	PC	66.41	4.77	12.27	0.71	1.4
PITT8B	PITTSBURGH NO 8	PC	71.68	4.92	6.91	2.57	1.41
OHIO6B	OHIO NO 6	PC	72.68	4.82	7.75	1.85	1.48
UPFRA	UPPER FREEPORT A	PC	72.19	4.67	4.78	1.75	1.31
UPFRB	UPPER FREEPORT B	PC	73.25	4.77	5.68	1.89	1.3
UPFRSA	UPPER FREEPORT A	CWM	52.67	3.21	3.89	1.1	1.13

ADVANCED SLAGGING COAL COMBUSTION SYSTEM
COAL PROPERTIES

TASK 3 COALS: ASH COMPOSITION

ABBRV	COAL DESIGNATION	FORM	SiO2	Al2O3	TiO2	Fe2O3	CaO	MgO	K2O	Na2O	SO3	T250 DEG F
			ASH ANALYSIS, %									
WYRB8	WYOMING ROSEBUD 8	PC	39.25	18.96	1	9.03	14.72	6.07	1.09	0.37	8.53	2284
PITT88	PITTSBURGH NO 8	PC	48.25	23.56	0.8	22.2	0.72	0.69	1.72	0.32	0.07	2475
OHIO68	OHIO NO 6	PC	48.39	27.28	1.1	17.4	1.02	0.72	2.4	0.42	0.07	2547
UPFRA	UPPER FREEPORT A	PC	53.4	21.81	1.1	16.14	1.74	0.99	2.73	0.42	1.11	2565
UPFRB	UPPER FREEPORT B	PC	48.42	24.28	1.01	19.42	1.84	0.74	2.4	0.37	0.92	2490
UPFRSA	UPPER FREEPORT A	CWM	49.97	24.01	1.2	16.69	2.09	0.86	2.4	0.32	0.96	2550

ADVANCED SLAGGING COAL COMBUSTION SYSTEM
COAL PROPERTIES

TASK 6 COALS: PROXIMATE ANALYSIS

ABBRV	COAL DESIGNATION	FORM	PROXIMATE ANALYSIS, %				
			VOLAT	FIX C	MOIST	ASH	HHV
PIT881	PITTSBURGH NO 8	PC	37.58	48.87	2.33	11.22	12813
UPFR81	UPPER FREEPORT	PC	32.31	54.49	3.03	10.17	13062

The higher heating value is expressed in BTU/lb

ADVANCED SLAGGING COAL COMBUSTION SYSTEM
COAL PROPERTIES

TASK 6 COALS: C, H, O, S, N

ABBRV	COAL DESIGNATION	FORM	ULTIMATE ANALYSIS, %				
			CARBON	HYDROG	OXYGEN	SULFUR	NITROGEN
PIT881	PITTSBURGH NO 8	PC	71.09	4.66	6.62	2.53	1.46
UPFR81	UPPER FREEPORT	PC	73.33	4.53	5.66	1.78	1.34

ADVANCED SLAGGING COAL COMBUSTION SYSTEM
COAL PROPERTIES

TASK 6 COALS: ASH COMPOSITION

ABBRV	COAL DESIGNATION	FORM	ASH ANALYSIS, %									
			SiO2	Al2O3	TiO2	Fe2O3	CaO	MgO	K2O	Na2O	SO3	T250 DEG F
PIT881	PITTSBURGH NO 8	PC	46.64	22.06	0.92	23.22	1.16	0.82	2.11	0.25	0.71	2415
UPFR81	UPPER FREEPORT	PC	46.67	23.14	1.08	19.55	2.15	1.15	2.82	0.21	1.48	2510

APPENDIX B

TASK 2 TEST PLAN

TRW Inc.
Electronics &
Defense Sector

One Space Park
Redondo Beach, CA 90278

FSCM NO. 11982

TITLE

ASCCS Program
Phase I, Task 2
Test Plan

DATE 16 April 1984

NO. ASCCS-I-84-007
REV.

SUPERSEDING: ____________

PREPARED BY: A. L. F. Egense
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1. INTRODUCTION

The DOE sponsored Advanced Slagging Coal Combustion System (ASCCS) Research and Development Program is planned as one of a number of research projects leading to the establishment of a broad, commercially acceptable, engineering data base for the advancement of coal as the fuel of choice for boilers, furnaces and heaters.

This test plan describes Phase I, Task 2 testing to be conducted on the 10 MM Btu/hr combustor at TRW's test facility in San Clemente, CA.

2. OBJECTIVES

The primary objective of these tests is to supplement existing baseline data over a range of operating conditions relevant to industrial and utility applications with emphasis on system performance, scaling verification, and emission control technology development.

3.0 APPROACH

To meet the objectives, testing will consist of both parametric and steady state tests utilizing two coals in a pulverized (PC) form and one coal in both a pulverized form and in a coal-water-mixture. For two coals and the CWM, sorbent will be injected into the combustor at one injector location. A coal fired precombustor will be used unless the coal-water-mixture is being run; then an oil-fired precombustor would be employed.

4.0 TESTING

4.1 Cold Flow Functional Tests

Cold flow testing will be conducted to verify the operational status of overall systems prior to the first hot fire test. These tests shall be performed, with the combustor and facility system completely assembled and operational, on the following:

- o Air supply system
- o Cooling water supply system
- o Fuel supply
- o Propane supply
- o Coal transport system
- o Coal water mixture transport system
- o Sorbent transport system
- o GN_2 system

All systems shall be tested over the flow rates specified in Table 1.

Table 1. Coal Combustor Flow Requirements

SYSTEM	IDENTIFICATION	REQUIRED FLOW MIN (LB/SEC)	REQUIRED FLOW MAX (LB/SEC)	PRESSURE AT COMBUSTOR INLET (PSIG)	TEMPERATURE AT COMBUSTOR INLET (°F)
GN_2	Coal Fluidizing	0.02	0.13	0-150	Ambient
	Carrier Gas	0.02	.06	0-150	Ambient
	Coal Hopper Ullage	0.10	1.00	0-150	Ambient
	Sorbent Hopper Ullage	0.05	1.00	0-150	Ambient
Air	Precombustor Make-Up Air	0.5	1.00	5	650°F(Max)
	Precombustor Primary Air	0.5	1.50	5	650°F(Max)
	Secondary Comb.Air	0.5	1.50	5	650°F(Max)
Oil	#1 Heater Oil	0.005	0.055	0-250	Ambient
	#2 Heater Oil	0.005	0.055	0-250	Ambient
	#1 Ignitor GO_x	0.0006	0.001	0-200	Ambient
	#2 Ignitor GO_x	0.0006	0.001	0-200	Ambient
Propane	#1 Ignitor Propane	0.0008	0.0012	0-540	Ambient
	#2 Ignitor Propane	0.0008	0.0012	0-540	Ambient
Coal	Coal (Combustor)	0.10*	0.3*	20-35	Ambient
Coal	Coal (Precombustor)	0.02*	0.10*	20-35	Ambient
Sorbent	Sorbent	0.02	0.08	20-35	Ambient

*Dry Flow Rate

4.2 Program Tests

Table 2 summarizes the Phase I, Task 2 test program. A description of each Test Parameter listed in Table 2 follows.

4.2.1 Baseline Testing

Baseline tests shall be performed on all fuels for multiple first stage stoichiometries to establish emission trends and overall combustor performance for a given coal. Baseline data will be repeated at selected conditions during subsequent tests.

4.2.2 Slag Recovery

Steady state tests at selected conditions shall be performed on all fuels to obtain slag recovery data. Emphasis will be on selecting conditions which maximize slag recovery and minimize slag carryover. Slag data will be collected both with and without sorbent injection and at more than one load condition. During these steady state slagging runs, the first part of the test will be used to repeat selected conditions with and without sorbent.

4.2.3 Turndown Capability

It is felt that turndown capability is not strongly dependent on fuel type and thus combustor turndown will be examined for only one of the eastern coals and the coal-water-mixture. This approach allows more available time to concentrate on parameters that are fuel dependent such as slag recovery and emissions. These tests are planned to first run the combustor at nominal conditions, repeating a previous data point if possible, the run at a selected, lower load condition at steady state.

4.2.4 Sorbent Injection

Sorbent will be injected during tests utilizing the eastern coals and the coal-water-mixture. Sorbent flowrate and combuster stoichiometry will vary during these tests so that information on SO_2 reduction can be obtained. In addition, it is planned to run at least one steady state test with sorbent injection for slagging data. Both Vicron and Dolomite are anticipated as the sorbent types but final selection is subject to program manager approval.

4.2.5 Secondary Burner Performance

Secondary burner performance shall be evaluated throughout the tests with performance optimization emphasized on one of the eastern coals and the coal-water-mixture. As with turndown, secondary burner operation is not that fuel dependent. It is felt that more information can be obtained concentrating on two fuels rather than trying to evaluate secondary burner operation on all fuels. Evaluation will consist of emissions monitoring,

Table 2. Phase 1, Task 2 Overall Test Matrix

FUEL

TEST PARAMETER	Wyoming Rosebud	Pittsburgh #8 seam		Upper Freeport	CWM (Eastern coal)
Baseline for Multiple Stoichiometries	X	X		X	X
Slag Recovery	X	X		X	X
Turndown Capability		X	OR	X	X
Sorbent Injection		X		X	X
Secondary Burner Performance		X	OR	X	X
Steady State Testing	X	X		X	X

4.2.5 Secondary Burner Performance (Con'td)

flame characterization, and slag carryover determination along with examining compatibility with heat utilization equipment. During selected tests, second stage stoichiometry and/or our inlet velocity may vary.

4.3 Detailed Test Matrix

A tentative test plan is presented in Table 3. The specific test conditions will be distributed to the test conductor prior to the start of testing each morning. Figure 1 shows the format used to supply this information.

4.4 Test Schedule

Testing will begin the third week of April and extend for a minimum of one month. The planned test schedule is presented in Figure 2.

Table 3. Detailed Test Plan - ASCCS Phase 1, Task 2

Test #	Duration	Fuel	Description of Test	Information Aquired*
1	4 hours	Wyoming Rosebud	·2 hr. to cure refractory (no coal) ·precombustor coal injector checkout ·steady state test at constant $Ø_1$ to put slag coverage on combustor.	·overall combustor operation ·slagging combustor since started with bare combustor. ·obtain baseline emissions data
2	2 - 3 hours	Wyoming Rosebud	·$Ø_1$ sweep at full load ·run at selected $Ø_1$, low load	·emissions variation with $Ø_1$ ·overall combustor performance at low load.
3 - 4	2 hours each	Wyoming Rosebud	·repeat $Ø_1$ data point in test 2 ·run steady state at selected $Ø_1$	·repeatability of data ·slagging data for selected $Ø_1$ ·scaling verification data (ie ΔP, cooling load)
5	2 - 3 hours	Pittsburgh #8 seam	·repeat test 2 for new coal	·see above
6 - 8	2 hours each	Pittsburgh #8 seam	·same as tests 3, 4 for new coal	·see above
9	2 hours	Pittsburgh #8 seam	·repeat $Ø_1$ from test 5 at low load (1 data point) ·run steady state at selected $Ø_1$ for low load	·repeatability of data at low load ·slagging data for selected $Ø_1$ at low load ·overall system performance at low load.
10 - 11	2 - 3 hours	Pittsburgh #8 seam	·sorbent injection, 3 (Ca+Mg)/S ratios at selected $Ø_1$ for each of 2 sorbents. ·repeat baseline	·SO_2 reduction variation with $\frac{Ca+Mg}{S}$ ·sorbent effect on combustor performance ·Baseline repeatability
12	1 1/2 - 2 hrs	Pittsburgh #8 seam	·sorbent injection for one sorbent at selected (Ca+Mg)/S, and $Ø_1$	·repeatability of sorbent injection data ·slagging data with sorbent injection ·overall system performance with sorbent injection.
13	2 - 3 hours	Upper Freeport Seam	·repeat test 2 for new coal	·see above
14 - 15	2 - 3 hours each	Upper Freeport Seam	·repeat tests 10, 11 for new coal	·see above
16	1 1/2 - 2 hrs	Upper Freeport Seam	·repeat test 12 for new coal	·see above
17 - 20	refer to above	CWM with either Pittsburgh #8 or Upper Free-Port	·repeat tests 13 -16 for coal water mixture	·see above

*For ALL tests, the following are measured: temperatures, pressures, cooling water flowrates, airflows, coal flows, sorbent flows (if applicable), and emissions (O_2, CO, H/C, CO_2, SO_2, NO_x) and observations are made during testing on both combustor and secondary burner performance.

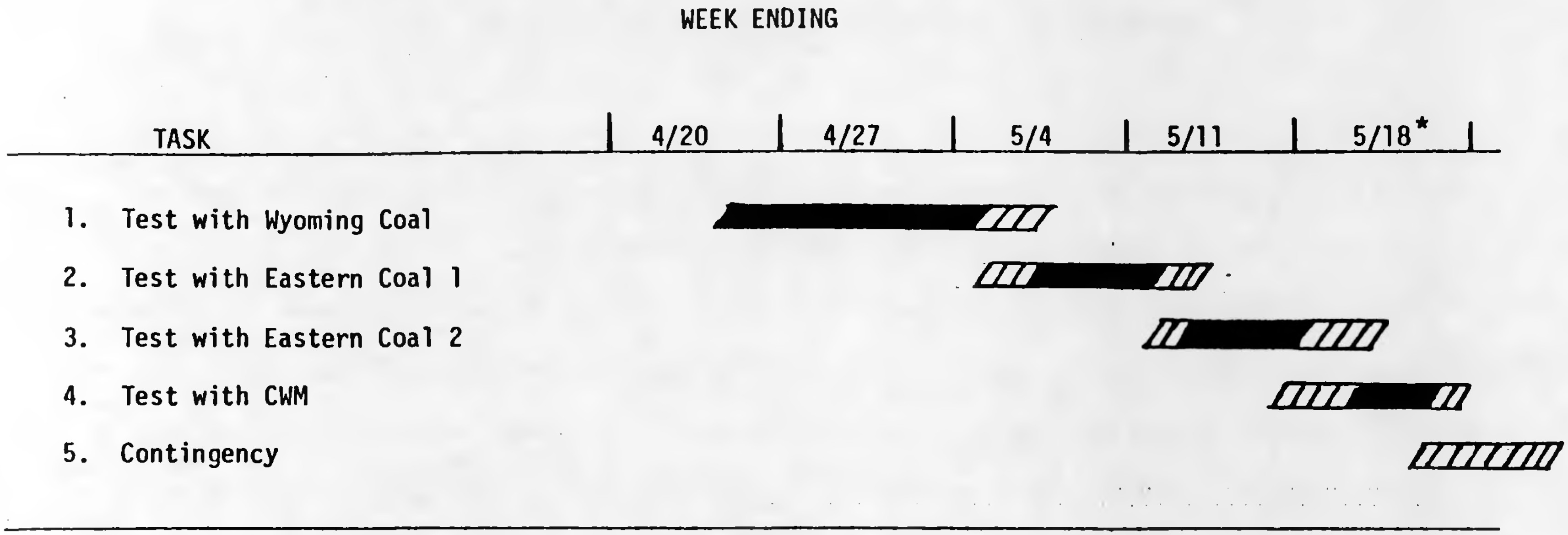
ATMOSPHERIC COAL COMBUSTION DEVELOPMENT TEST BRIEF

Test # ______________ Test Date ____________________ Coal Type: Combustor ____________________________

Test Purpose ____ Precombustor ____________________________

Conditions								
Parameter								
WAPC, mlb/sec								
WAMU, mlb/sec								
WA2S, mlb/sec								
WOIL, mlb/sec								
WC COAL, lb/sec								
WCCAR RATIO								
WPC COAL, lb/sec								
WPCCAR RATIO								
ϕ_1								
ϕ_2								
COAL LOAD, MM Btu/hr								
Preheat Boost, °F								

Figure 1. Test Conditions Summary for Test Conductor



* Schedule may conflict with MHD testing; will be resolved at a later date.

Figure 2. Test schedule for cell 1 ASCCS Testing

5.0 TEST FACILITY AND REQUIREMENTS

5.1 Test Hardware

5.1.1 Combustion System

The 10 MM Btu/hr combustion system shall be used for all tests. A coal precombustor shall be employed except when running the coal-water-mixture. An oil fired precombustor is necessary for this fuel. The configuration shall be as given in Figure 3.

5.1.2 Sorbent Injector

The injector shall be the one used during previous TRW tests with sorbent injection.

5.1.3 CWM Injector

The TRW Proprietary CWM injector shall be inspected, refurbished as necessary, and supplied for use on the DOE program.

5.2 Facility Requirements

The combustor flow and cooling water requirements as well as the corresponding facility/combustor instrumentation list are identical to those listed in the most recent test plan, 10 MM Btu/hr Coal Combustor System Evaluation Test Plan No. T650.82.3S-065.

5.3 Consumables

Consumables required for this program are based on approximately 20 tests over a 1 month period. Estimated quantities are given in Table 4. The program anticipates four fuels and two sorbents. The three selected coals are Wyoming Rosebud, Pittsburgh #8 and Upper Freeport from West Virginia all in a pulverized form. The forth fuel will be a coal-water-mixture from either the Pittsburgh #8 or Upper Freeport coal. If neither of these coals is slurriable, a Blacksville #2 slurry will most probably be used.

The two selected sorbents are:

- Dolomite, $CaCO_3 \cdot MgCO_3$. Estimated mean particle size: 13 um.
- Limestone (Vicron 45-3), $CaCO_3$. Estimated mean particle size: 8.9 um.

5.4 Special Test Equipment

The following special test equipment, provided by the project office, shall be used in addition to the list given in Test Plan No. T650.82.3S-065:

1) SO_2 analyzer, ultraviolet spectrophotometer type, Teledyne Model 611D.
2) Two-color pyrometer, Capintec Ratioscope-8.

This equipment requires the following interfaces:

1) SO_2 analyzer (Teledyne): Heated sample line from probe installed in boiler simulator to analyzer. 110 VAC unregulated. 0-5 VDC output to data logger. Figure 6 shows the sampling system flow diagram.

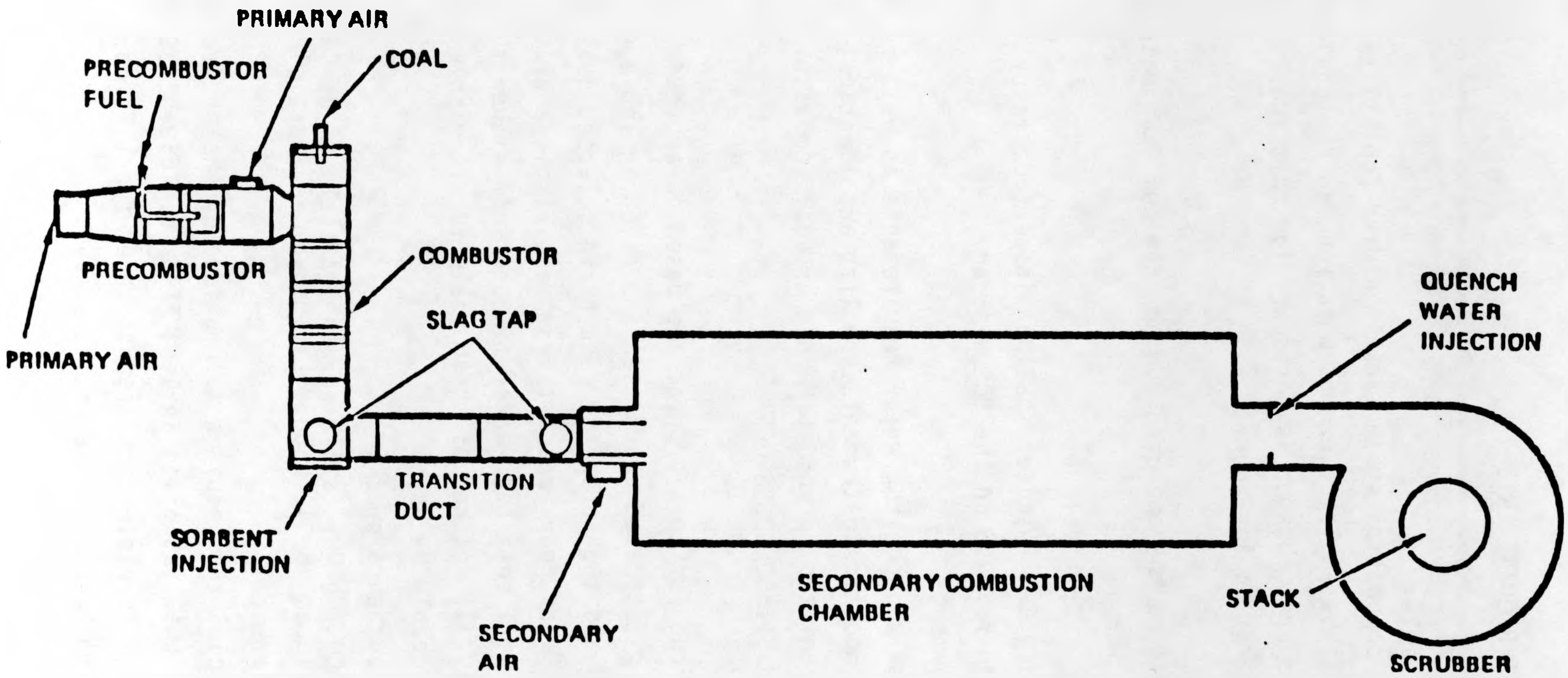


Figure 3. The 17-Inch Atmospheric Slagging Combustor System.

Table 4. Consumables

ITEM	GRADE/SPECIFICATION	MAXIMUM QUANTITY
GN_2	Commercial	2,000,000 ft^3
Oil	#2 Diesel Fuel	17,000 gal*
Propane	Commercial	200 gal
GO_x	Bottled Gas	for igniter only
Coal	Wyoming Rosebud	16,000 lbs.
Coal	Pittsburgh #8	22,000
Coal	Upper Freeport	22,000
Coal	CWM	11,000
Sorbent	Vicron 45-3	2,200
Sorbent	Dolomite	2,200

*Indirect fired air heater (2.5 gpm) and oil fired precombustor for CWM (0.25 gpm)

5.4 Special Test Equipment (Con'td)

2) Two-color pyrometer (Capintec): Installed on boiler simulator side wall. 115 VAC. 0-1 VDC output to recording channel of the main computer and display on the control panel.

In addition to these items, output of the O_2, SO_2 and NO_x analyzers shall be displayed on the control panel and recorded on a channel of the main computer.

5.5 Operational Requirements

The operating limits, procedural and safety requirements, and shutdown procedures for this test series are identical to those described in Test Plan No. T650.82.3S-065.

5.6 Test Procedure

The most recent test procedure prepared by the test conductor for the 10 MM Btu/hr coal combustor, FR-14P-03, shall be adhered to in this test series.

6.0 DATA REQUIREMENTS

Data requirements for testing are listed her briefly.

6.1 Pre-test Inputs

Variables and data reduction formulas required to perform on-line data reduction include coal and oil properties, calculated air preheat temperature and air inlet dimensions. These must be input prior to testing. Figure 4 presents the format employed for these inputs.

6.2 On-line Data Output

The main computer scans transducer output every 800 msec and prints the data every minute. These data include pressures, temperatures, flow rates, and reduced data.

6.3 Emissions Data

Emissions data shall be monitored and recorded at least once for each test condition and several times during steady state tests. Data shall be sampled mainly in the boiler simulator but may also be sampled in the combustor. Also, a vent line is installed between the combustor slag tank and scrubber providing for emissions sampling near the slag tank. The vent line allows investigation of regeneration of SO_2 from CaS interaction with water in the slag tank.

The following emissions shall be monitored:

- SO_2
- NO_x/NO
- O_2
- CO_2
- CO
- HC

List of Variables to be Input Prior to Every Test

Cell__________________

Test #__________________Date_______________

Combustor Fuel_________________Precombustor Fuel_______________

HHVCC	=	Higher Heating Value of Combustor Coal, WWA	________
H_2OCC	=	Fraction of Water in Combustor Coal	________
OCC	=	Fraction of Oxygen In Combustor Coal, DWA	________
OFCC	=	Stoichiometric Oxygen to Fuel Ratio	________
		Combustor, DWA	________
HHPCO	=	Higher Heating Value of Oil	________
GAPOPC	=	Gap Out of Precombustor	________
GAPSS	=	Gap Into Second Stage	________
TPREH	=	Air Inlet Temperature (^oR)	________
HHVPCC	=	Higher Heating Value of Precombustor Coal,WWA	________
H_2OPCC	=	Fraction of Water in Precombustor Coal	________
OPCC	=	Fraction of Oxygen in Precombustor Coal,DWA	________
OFPCC	=	Stoichiometric Oxygen to Fuel Ratio,DWA	________

Figure 4. Format for Pre-Test Inputs to Computer

6.4 Post-test Data

Following each test, slag captured in the slag tanks will be weighed for slag recovery data. The head-end closure shall be removed for inspection of combustor slag coverage. The deswirl closure shall be removed as requested by the project office. Slag samples will be collected from each tank and the scrubber and, as requested by the project office, from the combustor walls and the secondary combustion chamber.

Still photographs shall be taken after each test; additional photos as requested by the project office.

6.5 Data Analysis

Raw data will be assembled into a test results package at the conclusion of each test and distributed to the Program Manager. Preliminary test results shall be distributed to project personnel and discussed at scheduled data review meetings. At the conclusion of Phase I, Task 2 testing, data will be compiled and reduced to include in a report to the customer.

6.6 Coal Analysis

Complete analyses of each coal type shall be performed by an outside lab prior to testing with the coal. A composite sample comprised of coal from each tote bin will be used for the analyses. The following will be performed:

- Ultimate analysis
- Proximate analysis
- Mineral analysis of ash
- Sulfur forms
- Water soluble alkalies
- Fusion temperature of ash
- Free swelling index

In addition, a sieve analysis for mesh size distribution and approximate analysis of the composite sample plus samples from each tote bin shall be performed in the TRW lab as required by the project office.

6.7 Sorbent Analysis

An analysis for particle size distribution has been performed on both Vicron and Dolomite. If any additional sorbents are used, a particle size distribution analysis will be performed.

6.8 Slag Analysis

Ash and chemical analyses of selected slag samples shall be conducted as requested by the project office.

APPENDIX C

TASK 3 TEST PLAN

TRW Inc.
Electronics &
Defense Sector

One Space Park
Redondo Beach, CA 90278

FSCM NO. 11982

TITLE

Test Plan, Task 3
Scaling and Performance Verification
ASCCS - Advanced Slagging Coal Combustion
System Development

DATE 2 August 1984

NO. ASCCS-I-84-053
REV.

SUPERSEDING: ____________

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ASCCS Project

SYSTEMS 1391 REV. 7-83

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1.0 INTRODUCTION

The DOE sponsored Advanced Slagging Coal Combustion System (ASCCS) Research and Development Program is planned leading to the establishment of a broad, commercially acceptable engineering data base for the advancement of coal as the fuel of choice for boilers, furnaces and heaters.

This test plan describes Phase I, Task 3 testing to be conducted on the 34-inch combustor at TRW's test facility in San Clemente, CA.

2.0 OBJECTIVES

The primary objective of these tests is to provide baseline data over a range of operating conditions relevant to industrial and utility applications.

Specific objectives include:

- Characterization of the precombustor and combustor for determination of operating windows (i.e. temperature, load, pressures, stoichiometry).
- Scaling verification between the nominal 17-inch and 34-inch combustor systems.
- Combustor operation with both western and eastern coals and an eastern coal water mixture.
- Slag recovery optimization.
- Continued investigation into SO_2 reduction using sorbent injection.

3.0 APPROACH

To meet the objectives, testing will consist of both parametric and steady state tests utilizing two coals in a pulverized (PC) form and one coal in pulverized form and as a coal-water-mixture. For two coals and the CWM, sorbent will be injected into the combustor system for SO_2 reduction information. A coal fired precombustor will be used for pulverized coal tests. With the coal-water-mixture tests, coal-water-mixture will also be fired in the precombustor.

4.0 TESTING

4.1 COLD FLOW FUNCTIONAL TESTS

Cold flow testing will be conducted to verify the operational status of overall systems prior to the first hot fire test. These tests shall be performed, with the combustor and facility system completely assembled and operational, on the following:

- Air supply system
- Cooling water supply system
- Fuel oil supply
- Propane supply
- Coal transport system
- Coal-water-mixture transport system
- Sorbent transport system
- GN_2 system
- GO_2 system

All systems shall be tested over the flow rates specified in Table 1.

4.2 PROGRAM TESTS

Table 2 summarizes the Phase 1, Task 3 test matrix. A description of each test parameter follows.

4.2.1 Baseline Testing

Baseline tests shall be performed on all fuels for multiple first stage stoichiometries to establish emission trends and overall combustor performance for a given coal. Baseline data will be repeated at selected conditions during subsequent tests.

4.2.2 Precombustor Characterization

Tests are planned which systematically evaluate precombustor operation. Stoichiometry and load will be varied to characterize the precombustor operating range. The minimum air inlet temperature required without ignitor operation will be determined. These tests will be conducted on both pulverized coals and the coal-water mixture.

Table 1. 34-Inch Coal Combustor Flow Requirements

System	Identification	Required Flow		Pressure at Combustor Inlet (psig)	Temperature at Combustor Inlet (F)
		Min Lb/sec	Max Lb/sec		
GN_2	Coal Fluidizing- Precombustor & Combustor Hoppers	0.02	0.13	0-150(1)	Ambient
	Coal Hopper Ullage- Precombustor& Combustor	0.10	1.00	0-150	Ambient
	Sorbent Hopper Ullage-	0.05	1.00	0-150	Ambient
	Carrier Gas-				
	Precombustor	0.015	0.20	0-150	Ambient
	Combustor	0.04	1.00	0-150	Ambient
	Sorbent	0.02	0.20	0-150	Ambient
	Atomizing Air				
	Precombustor			0-150	Ambient
	Combustor			0-150	Ambient
	Make Up Air-Peak Load Operation	0.05		0-150	Ambient
GO_2	Atomizing Air				
	Precombustor			0-150	Ambient
	Combustor			0-150	Ambient
	Make Up Air-Peak Load Operation			0-150	Ambient
Air	Precombustor Air	0.08	8.00	1-3(2)	250-600
	Precombustor Makeup Air	1.00	10.00	1-3	250-600
	Secondary Combustion Air	0.80	8.00	1-3	70-600
Oil	#1 Heater Oil	0.040	0.150	0-250	Ambient
Propane	#1 Ignitor	0.0008	0.0012	0-15	Ambient
Coal	Precombustor	0.1	0.4	12-20	Ambient
	Combustor	0.4	1.5	12-20	Ambient
Coal-Water-Mixture	Precombustor	0.1	0.4	12-20	Ambient
	Combustor	0.4	1.5	12-20	Ambient

(1) Available Pressure

(2) Required Pressure for Operation

Table 2. Phase 1, Task 3 Overall Test Matrix

FUEL

TEST PARAMETER	WYOMING ROSEBUD COAL	PITTSBURGH #8 COAL	UPPER FREEPORT COAL	UPPER FREEPORT COAL-WATER MIXTURE
Baseline	X	X	X	X
Precombustor Characterization	X	X	X	X
Combustor Characterization	X	X	X	X
Steady State Testing	X	X	X	X
Scaling Verification	X	X	X	X
Slagging Optimization		X	X	X
Turndown		X	X	X
Low Load		X		
Sorbent Injection		X	X	X
Peak Load	X			

4.2.3 Combustor Characterization

First stage combustor operation shall be examined for all fuels. These tests will evaluate the effect of preheat, air inlet velocity, and stoichiometry on combustor performance. Observation of combustor flame along with pressure, temperature and emissions data will serve as diagnostics for determing a combustor operating window.

4.2.4 Steady State Testing

The majority of the tests will be performed under steady state conditions where the system is maintained at constant conditions for the duration of the test. This mode of operation provides the best overall system performance data.

4.2.5 Scaling Verification

One goal for Task 3 testing is to verify scaling from the 17-inch size to the 34-inch size. This information is obtained throughout Task 3 Testing.

4.2.6 Slagging Optimization

Slagging data is obtained for all steady state tests. However, specific tests on both pulverized coal and coal-water-mixture will be performed which systematically evaluate the affect of selected parameters on slag recovery. Test conditions will be determined based on information from TRW's existing data base.

4.2.7 Turndown

Turndown will be investigated on pulverized coal operation. Tests are planned which cycle the system through load changes in addition to running the system at steady, lower load operation.

4.2.8 Low Load

Steady State tests at low load operation are planned to provide information on slag recovery and combustor performance. The minimum load for stable combustor operation will be determined.

4.2.9 Peak Load

The combustor system will be run at high load operation to simulate peak load firing. An upper load limit for combustor operation will be investigated depending on air flow limitations.

4.2.10 Sorbent Injection

Sorbent will be injected during tests utilizing the eastern coals and the coal-water-mixture. Sorbent flowrate will vary during these tests so that information on SO_2 reduction can be obtained. In addition, it is planned to run at least one steady state test with sorbent injection for slagging data. Vicron will be used as the sorbent.

4.3 DETAILED TEST MATRIX

A detailed matrix is presented in Table 3. All tests will be conducted at constant load unless indicated otherwise. The specific test conditions will be distributed to the test conductor prior to the start of testing each day. Figure 1 shows the format used to supply this information.

5.0 TEST FACILITY AND REQUIREMENTS

5.1 TEST HARDWARE

5.1.1 Combustor System

The 34-inch system, shown in Figure 2, shall be used for all tests. The System includes:

- Coal-fired precombustor with commercially available propane ignitor plus diesel boost
- Combustor with slag baffle and batch slag tank
- Exit elbow in vertical configuration
- Afterburner with quench chamber
- Scrubber with stack

Table 3. Detailed Test Matrix - Phase I, Task 3

Test #	Fuel	Description of Test	Information Acquired (1)
1	Upper Freeport	• hot fire checkout test-precombustor and combustor	• determination of operational difficulties
2 - 4	Upper Freeport	• precombustor characterization-vary temperature, stoichiometry, velocity • determine minimum temperature required with no ignitor • combustor at nominal operation	• operating window for precombustor • obtain baseline emissions data
5	Upper Freeport	• baseline at nominal conditions • ϕ_1 sweep at peak load	• systems response to increased load operation
6	Wyoming	• steady state at constant ϕ_1 to put new slag on combustor • precombustor at selected conditions	• precombustor operation comparison with new fuel • obtain baseline emissions data
7	Wyoming	• ϕ_1 sweep at peak load • steady state last half of test at constant ϕ_1	• ϕ_1 range at peak load • indication of slagging data at peak load
8 - 9	Wyoming	• steady state at selected conditions, peak load	• overall system performance at peak load • slagging data for peak load operation
10, 11, 12	Wyoming	• steady state at selected conditions, nominal load	• slagging data for nominal load operation
13	Upper Freeport	• ϕ_1 sweep at nominal load • steady state last part of test to put new slag on combustor	• obtain baseline emissions data • overall system performance
14 - 24	Upper Freeport	• steady state slagging runs systematically varying the following: -stoichiometry -preheat -air inlet velocity -baffle (optional)	• scaling verification data • effect of stoichiometry, temperatures and velocity on slag recovery and spillover • optimum slagging conditions (based on available data)
25	Upper Freeport	• sorbent injection, 3 Ca/S ratios at selected conditions	• obtain baseline data with sorbent
26	Upper Freeport	• steady state run at optimum slag recovery conditions for selected Ca/S ratio	• effect of sorbent on optimum slag recovery data • overall system performance with sorbent injection • repeat SO_2 reduction data
27	Upper Freeport	• steady state run at selected conditions for one Ca/S ratio	• slagging data with sorbent injection • overall system performance with sorbent injection • repeat SO_2 reduction data
28	Pitt #8	• repeat test 13 for new coal	• see above
29 - 34	Pitt #8	• steady state slagging runs as described in tests 14-24 for new coal	• see above
35 - 36	Pitt #8	• turndown evaluation • startup condition simulation	• combustor performance during startup simulation • limit on turndown for acceptable combustor operation
37 - 38	Pitt #8	• steady state at selected conditions, low load	• slagging data for low load operation • overall system performance at low load

Table 3. Detailed Test Matrix - Phase I, Task 3

Test #	Fuel	Description of Test	Information Acquired (1)
39 - 40	Pitt #8	• sorbent injection, 3 Ca/S ratios at selected conditions	• obtain baseline data with sorbent
41 - 42	Pitt #8	• steady state run at selected conditions for given Ca/S ratio	• slagging data with sorbent injection • repeat SO_2 reduction data • overall system performance with sorbent injection
43	Upper Freeport CWM	• CWM system-hot fire checkout tests • vary atomization air	• determination of operational difficulties • obtain atomization air operating range
44 - 46	Upper Freeport CWM	• repeat tests 2-4 with new fuel	• see above
47 - 51	Upper Freeport CWM	• combustor characterization vary stoichiometry, preheat temperatures, atomization air	• determine operating window with CWM
52 - 54	Upper Freeport CWM	• steady state run at selected conditions	• overall system performance at nominal load with CWM • slagging data for CWM • scaling verification data
55 - 56	Upper Freeport CWM	• sorbent, 3 Ca/S ratios at selected conditions	• obtain baseline data with sorbent • comparison of SO_2 reduction using PC coal & CWM • overall system performance with sorbent injection using CWM

(1) For ALL tests the following are measured:

- temperatures, pressures
- air flows
- fuel flows
- sorbent flows
- cooling loads
- emissions (O_2, CO, H/C, CO_2, SO_2, NO_x)

Additional information is obtained thru observation of system performance concurrent with testing.

ATMOSPHERIC COAL COMBUSTION DEVELOPMENT TEST BRIEF

Test # ______________ Test Date ______________ Coal Type: Combustor ______________

Test Purpose ______________________________ Precombustor ______________

Conditions								
Parameter								
WAPC, mlb/sec								
WAMU, mlb/sec								
WA2S, mlb/sec								
WOIL, mlb/sec								
WC COAL, lb/sec								
WCCAR RATIO								
WPC COAL, lb/sec								
WPCCAR RATIO								
Φ_1								
Φ_2								
COAL LOAD, MM Btu/hr								
Preheat Boost, °F								

Figure 1. Test Conditions Summary for Test Conductor

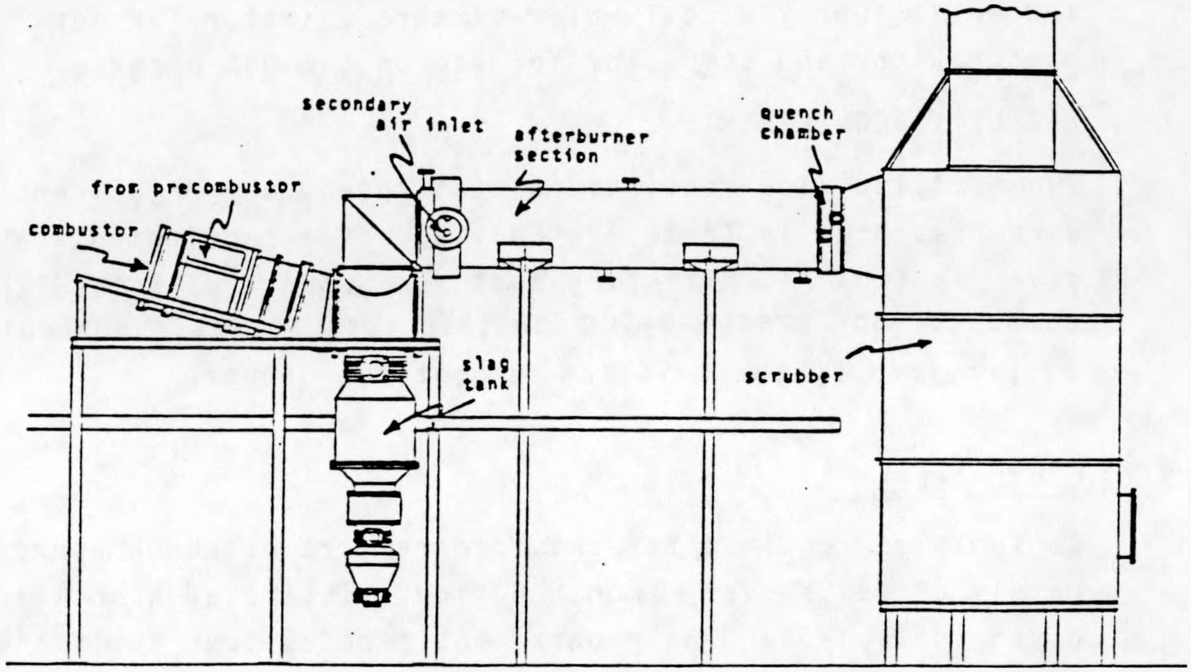

Figure 2. 34-Inch Combustor System

The system will be run with either pulverized coal in both the precombustor and combustor or coal-water-mixture in both sections.

5.1.2 Sorbent Injector

The injector design for the 17-inch combustor will be modified and a new injector fabricated for use in the 34-inch combustor.

5.1.3 CWM Injector

TRW shall supply a coal-water-mixture injector for both the precombustor and combustor for use on the DOE program.

5.2 FACILITY REQUIREMENTS

The facility flow requirements (nitrogen, oxygen air and fuel) were presented in Table 1. Cooling water requirements are given in Table 4. Existing coal run hoppers will feed the combustor and precombustor for this test series. Sorbent will be provided by the existing sorbent run hopper.

5.3 CONSUMABLES

Consumables required for this program are based on approximately 60 tests over a 3 month period. Estimated quantities are given in Table 5. The program anticipates four fuels and one sorbent. The three selected coals are Wyoming Rosebud (Wyoming), Pittsburgh #8 (W. Virginia), and Upper Freeport (Pennsylvania) all in a pulverized form. The fourth fuel will be a coal-water-mixture from Upper Freeport coal. The selected sorbent is Limestone (Vicron 45-3), $CaCO_3$ with an estimated mean particle size of 8.9 um.

Diesel oil is required for the indirect fired air heater; the amount of oil usage is dependent on the incoming system air temperature.

Propane supplies the commercial ignitor in the precombustor.

Table 4. 34-Inch Coal Combustor Water Requirements

Water Circuit	Minimum Flow Rate (GPM)	Minimum Outlet Manifold Pressure Psig	Max ΔT (°F)	Steady State ΔT (°F)
Combustor Coolant Water	2400	50	60	10 - 20
Afterburner	600	50	60	10 - 20
Quench Water/Scrubber	290	50	--	---

Table 5. Consumables (1)

Item	Grade/Specification	Maximum Quantity
GN_2	Commercial	6,638,000 $ft.^3$
GO_x	Commercial	216,000 $ft.^3$
Propane	Commercial	600 gal.
Oil	#2 Diesel Fuel Oil	16,500 gal.
Pulverized Coal	Wyoming Rosebud	162,000 lbs.
	Pittsburgh #8	138,000 lbs.
	Upper Freeport	180,000 lbs.
Coal-Water Mixture	Upper Freeport	160,000 lbs.
Sorbent	Vicron 45-3	8,000 lbs.

(1) Based on 12 weeks of testing.

Oxygen and Nitrogen provide the source of atomization air for coal-water-mixture operation and the required additional air for peak load operation. In addition, nitrogen is used as carrier gas for pulverized coal, as hopper ullage and fluidizing gas and as purge gas for various instrumentation and feed systems.

5.4 SPECIAL TEST EQUIPMENT

The following special test equipment, provided by the project office, shall be used for this test program:

a) Monitor Labs Data Logger Model 9350 with MX100 Printer

b) O_2 analyzer, Beckman, Model 7003

c) O_2 analyzer, Teledyne 9500-1

d) NOx analyzer, TECO Model 10AR (2)

e) CO analyzers, Beckman Infrared Model #864 and #865.

f) CO_2 analyzer, Beckman Infrared Model #864 (2)

g) HC analyzer, Beckman Model 400

h) SO_2 analyzer, Teledyne Model 611 D

i) Gas sampling probe

j) Pin hole TV camera

This equipment requires the following interface:

SO_2 analyzer (Teledyne): Heated sample line from probe installed in boiler simulator to analyzer. 110 VAC unregulated. 0-5 VDC output to data logger. In addition to these items, output of the O_2, SO_2, and NO_x analyzers shall be displayed on the control panel and recorded on a channel of the main computer.

5.5 TEST PROCEDURE

The most recent test procedure prepared by the test conductor for the 34-inch coal combustor, FR14P-04, shall be adhered to in this test series.

5.6 OPERATIONAL REQUIREMENTS

The operating limits, procedural and safety requirements for this test series are defined in Test Plan No. T650-.84.35-025. Shut down procedures are described in Test Procedure FR-14P-04, supplied by the test conductor.

6.0 DATA REQUIREMENTS

Data requirements for testing are listed here briefly.

6.1 PRE-TEST INPUTS

Variables and data reduction formulas required to perform on-line data reduction include coal CWM and oil properties, calculated air preheat temperature and air inlet dimensions. These must be input prior to testing. Figure 3 presents the format employed for these inputs.

In addition, for the 34-inch combustor, water flow rates are pre-set and pressures recorded. Prior to each test, pressures are checked and adjusted, if necessary, to maintain desired cooling water flow.

6.2 ON-LINE DATA OUTPUT

The main computer scans transducer output every 800 msec and prints the data every minute. These data include pressures, temperatures, flow rates, and reduced data. The output formats used for testing are given in Figures 4 and 5.

6.3 EMISSIONS DATA

Emissions data shall be monitored and recorded at lease one for each test condition and several times in the after-burner just upstream of the quench section and in the stack. In addition, there is provision for sampling in the exit elbow and slag tank. The following emissions shall be monitored:

List of Variables to be Input Prior to Every Test

Cell________________

Test #________________ Date______________

Combustor Fuel______________ Precombustor Fuel______________

HHVCC	=	Higher Heating Value of Combustor Coal, WWA	______
H_2OCC	=	Fraction of Water in Combustor Coal	______
OCC	=	Fraction of Oxygen In Combustor Coal, DWA	______
OFCC	=	Stoichiometric Oxygen to Fuel Ratio	______
		Combustor, DWA	______
HHPCO	=	Higher Heating Value of Oil	______
GAPOPC	=	Gap Out of Precombustor	______
GAPSS	=	Gap Into Second Stage	______
TPREH	=	Air Inlet Temperature (^{o}R)	______
HHVPCC	=	Higher Heating Value of Precombustor Coal,WWA	______
H_2OPCC	=	Fraction of Water in Precombustor Coal	______
OPCC	=	Fraction of Oxygen in Precombustor Coal,DWA	______
OFPCC	=	Stoichiometric Oxygen to Fuel Ratio,DWA	______

Figure 3. Format for Pre-Test Inputs to Computer

FETS – CELL3 ANALOG INPUT POINTS VALUES 08 38 00 04/13/84

WWHEC1	WWHEC2	WWINP	WWU	WWINS	WWCP	WWCINJ	WWC1	WWTAI	A010
30.00	30 00	25 00	3.00	28.00	20.00	20.00	30.00	401.50	0.00
WWAD1	WWAD2	WWSP21	WWC2	WWC3	WWC4	WWC5	WWBA	WWBB	WWBC
10.00	10.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00	30.00
WWW	WWSP22	WWEST	WWECP1	WWECP2	WWEEP	WWEP	WWST	WWEL	WWSNOP
148.80	30.00	310.20	30.00	30.00	25.00	20.00	60.50	317.66	25.00
WWPCC	WWPCIN	WWPCCP	WWPCAI	WWPCB	WWPCC1	WWPCC2	WWPCT1	WWPC12	WWPCU
20.00	10.00	10.00	108.27	30.00	30.00	30.00	30.00	30.00	3.00
WWAB1	WWAB2	A043	A044	A045	A046	WWO1	WWO2	A049	A050
314.23	320.94	0.00	·0.00	0.00	0.00	198.77	0.16	0.00	0.00
PST	PPC	A053	PDPCST	PDPCAT	A056	A057	A058	A059	A060
14.85	15.28	0.00	0.50	0.80	0.00	0.00	0.00	0.00	0.00
PWO	PWIT	A063	PPIOPC	PPHEIO	A066	A067	A068	A069	A070
51.18	106.28	0.00	25.16	0.00	0.00	0.00	0.00	0.00	0.00
POIL	POIL1	PCCAR	PCULL	PCFLU	PCMIX	PCINJ	PPCINJ	PPCCAR	PPCULL
17.75	21.09	88 73	33.30	150.87	15.19	14.78	16.00	102.70	56 40
PPCFLU	PSCAR	PSULL	PPCMIX	A085	A086	A087	A088	A089	PAPH
163.94	14.75	14.61	56.22	0.00	0.00	0.00	0.00	0.00	15.79
PAC	A092	PDPC	PDMU	PD25	PDOPC	PDOMU	PDO25	A099	A100
0.00	0.00	15.95	15.95	15.34	0.10	0.11	0.33	0.00	0.00
DTHEC1	DTHEC2	DTINP	DTU	DTINS	DTCP	DTCINJ	DTC1	DTTAI	A110
0.54	1.31	0.65	0.10	0.44	0.44	0.22	0.87	0.87	0.00
DTAD1	DTAD2	DTSP21	DTC2	DTC3	DTC4	DTC5	DTBA	DTBB	DTBC
3.70	4.67	0.76	1.42	1.40	0.00	0.00	1.48	-1.52	0.12
DTW	DTSP22	DTEST	DTECP1	DTECP2	DTEEP	DTEP	DTST	DTEL	DTSNOP
1.20	0.98	0.87	1.09	1.20	0.76	0.98	1.42	0.87	0.87
DTPCC	DTPCIN	DTPCCP	DTPCAI	DTPCB	DTPCC1	DTPCC2	DTPCT1	DTPCT2	DTPCU
-0.87	0.46	-0.44	0.76	-0.44	1.85	-3.81	-0.87	[illegible]	-0.44
DTAB1	DTAB2	A143	A144	A145	A146	A147	A148	A149	A150
3.59	1.52	-0.00	-0.00	-0.00	-0.00	0.00	-0.00	-0.00	-0.00
TWTAI1	TWTAI2	TWTAI3	TWTAI4	TWTAI5	TWTAI6	TWTAI7	TWW1	TWW2	TWW3
65.04	76.39	65.23	65.50	64.36	66.21	65.64	65.64	65.70	66.44
TWEST1	TWEST2	TWEST3	TWEST4	TWEST5	TWEST6	TWEST7	A168	A169	TAPHPC
66 11	64 85	65 37	64.98	66.11	66.00	65 15	0.00	0.00	462.75
TWEL1T	TWEL2T	TWEL3T	TWEL1B	TWEL2B	TWEL3B	TWPCA1	TWPCA2	TWPCA3	TWPCA4
65 39	65 37	65.18	65.83	65 26	65.53	65.18	65 43	65.31	66.27
THUAH1	THUAH2	TPC2	TPC3	TAPH	TAPC	TAMU	TA25	TABIX	TSC
364.58	334.27	988.81	1028.31	810.06	884.25	996.25	943.00	86.30	118.38
TCCAR	TPCCAR	TSCAR	TCFLU	TPCFLU	TAPHT1	TAPHT2	TAPHT3	TAPHT4	TAPHT5
527.59	533.00	521.84	530.06	535.47	0.00	0.00	0.00	0.00	0.00
TWOT	TWIT1	TWIT2	TBIN	TBOUT	TAIPC	TAIMU	TAI25	TIOPC	TOILPL
66 44	64.60	64.27	76.91	92.53	426.67	842 22	486 23	834.16	63.26
FCT	FPCT	FST	TAC	A215	MAPC	MAMU	MA25	A217	MAC
4001.25	983.25	193 00	-0.00	0.00	1084.69	3303.25	6863 30	0.00	0.00
WCC	WPCC	WSORB	WOIL1	WOIL2	WCCAR	WPCCAR	WSCAR	WCFLU	SPARE
-8.60	75.61	-0 00	0.00	-0.00	47.06	25.15	0.00	49.07	100.00
WPCFLU	WCULL	WPCULL	WSULL	A235	A236	O2	A238	A239	A240
22 94	0.00	0.00	-0.00	-0.00	-0.00	0.22	0.00	0.00	0.00
TOTL-T	COAL-C	COAL-P	SORB-T	A245	A246	A247	A248	A249	A250
0.06	0.06	0 05	-0.00	0.00	0.00	0 00	0.00	0.00	0.00
A251	A252	SB-TIM	NOFIRE	A255	SHTA				
0.00	0.00	0.01	0.07	0.00	0.00				

Figure 4. Type 1 Data Output

FETS - ONLINE CALCULATED DATA REPORT — CELL 03

TEST NO. 3-0123 DATE 04/13/84
COAL TYPE OHIO/OHIO TIME 10:08:00

MAPC LBS/S	MAMU LBS/S	MA2S LBS/S	MOIL1 LBS/S	O2 %	PHI1O2	PHI2O2	MPCC LBS/S	MCC LBS/S	MSORB LBS/S
1.008	3.707	5.944	0.000	2.500	0.520	1.135	0.043	-0.015	0.000

TPREH °R	TAI2B °F	WTOTAL LB/S	PHI1	PHI2	HOPCT BTU/S	HOCT BTU/S	HOABT BTU/S	PST PSIA	PPC PSIA
1960.000	820.656	10.752	15.385	34.741	43.384	273.410	228.365	14.750	15.688

HEATIN BTU/S	PHLPCC %	PHLPCT %	PHLCT %	PHLAB %	GAPIPC INCHES	GAPOPC INCHES	VINPC FT/SEC	VOUTPC FT/SEC	VINAB FT/SEC
1600.208	33.094	3.865	29.918	17.683	4.000	9.100	77.234	412.074	178.217

HLPCT B/S/FT2	HLHECT B/S/FT2	HLC1 B/S/FT2	HLTAIT B/S/FT2	HLSP21 B/S/FT2	HLC2 B/S/FT2	HLC3 B/S/FT2	HLC4 B/S/FT2	HLC5 B/S/FT2	HLBT B/S/FT2
1.952	2.203	1.084	1.914	2.455	1.428	1.339	0.000	0.000	2.030

HLHT B/S/FT2	HLSP22 B/S/FT2	HLEXTT B/S/FT2	HLELBT B/S/FT2	HLABT B/S/FT2		PHIO1	VINMU FT/SEC	PDPCA1 PSID	PDPCST PSID
2.301	2.762	1.710	1.369	1.620		2.346	66.034	1.137	0.931

Figure 5. Type 2 Data Output

- SO_2
- NO_x/NO
- O_2
- CO_2
- CO
- HC

6.4 POST-TEST DATA

Following each test, slag captured in the slag tank and any slag hanging in the slag tap neck. along with material remaining in the scrubber, will be washed and weighed for slag recovery data. The head end closure shall be removed as requested for inspection of combustor slag coverage. The exit plug shall also be removed as requested by the project office. Slag samples shall be collected from the slag tank and scrubber. As requested by the project office, samples may also be collected from combustor walls and after-burner chamber.

Still photographs shall be taken after each test: additional photos as requested by the project office.

6.5 DATA ANALYSIS

A testing log book shall be kept on a daily basis by the test engineer. The log book shall contain a brief description of each test including purpose and approach, observations made during the test, and post-test observations, comments and recommendations.

Data shall be assembled by project personnel into a test results package at the conclusion of each test. The preliminary results shall be distributed to project personnel and discussed at periodic data review meetings, as determined by the project office. At the conclusion of the test program, a test report will be completed by the project office.

6.6 COAL ANALYSIS

Complete analyses of each coal type shall be performed by an outside lab prior to testing with the coal. The following will be performed:

- Ultimate analysis
- Proximate analysis
- Mineral analysis of ash
- Sulfur forms
- Water soluble alkalies
- Fusion temperatures of ash (reducing and oxidizing)
- T_{250}

In addition, a sieve analysis for mesh size distribution and approximate analysis of the coal shall be performed in the TRW lab as required by the project office.

6.7 SORBENT ANALYSIS

An analysis for particle size distribution was performed on Vicron.

6.8 SLAG ANALYSIS

Ash and chemical analysis of selected slag samples shall be conducted as requested by the project office.

APPENDIX D

TASK 6 TEST PLAN

TRW

TRW Inc.
Electronics &
Defense Sector

One Space Park
Redondo Beach, CA 90278

FSCM NO. 11982

TITLE

Test Plan, Task 6

ASCCS - Advanced Slagging Coal Combustion System Development

DATE

NO. ASCCS-II-85-119

REV.

SUPERSEDING: ____________

PREPARED BY: A. L. F. Egense
A. L. F. Egense
Project Engineer

APPROVAL SIGNATURES:

______________ DATE

______________ DATE

A. Solbes 1/3/86 DATE

______________ DATE

A. Solbes, Manager
Combustion and Power
Technology Department

______________ DATE

J. D. Kuenzly 6 Jan 86 DATE

J. D. Kuenzly, Manager
ASCCS Project

SYSTEMS 1391 REV. 7-83

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DOE PHASE II, TASK 6 TEST PLAN

1.0 INTRODUCTION

This test plan describes the Phase II, Task 6 testing to be conducted as part of the DOE sponsored Advanced Slagging Coal Combustion System (ASCCS) Research and Development Project. The tests will be performed on the TRW 34 inch combustor system located at TRW's test facility in San Clemente, CA.

The combustor system, shown in Figure 1, has been modified to include a secondary air register/windbox assembly, a boiler simulator and a convective pass section. The air register assembly is designed to allow for remote control of secondary air rotation in addition to providing a refractory lined burner throat that interfaces with the boiler simulator. Secondary combusiton takes place in the boiler simulator, a large volume chamber composed of 4, refractory lined modules with double wall construction for cooling water. Downstream of the boiler simulator is the convective pass section configured to simulate the convective pass section of a commercial boiler. The convective pass incorporates a tube bundle which utilizes cooling air to maintain the tube temperatures around 1000°F.

2.0 OBJECTIVES

The primary objective of these tests is to characterize the integration of the TRW combustor with a radiant furnace. Specific objectives include:

- o Evaluation of secondary combustion influence on emission levels.
- o Investigation of secondary flame transport properties and heat transfer characteristics.
- o Characterization of flue gas effects on simulated boiler components.
- o Validation that data obtained on TRW's research test facility corresponds favorably with data obtained on an actual system.

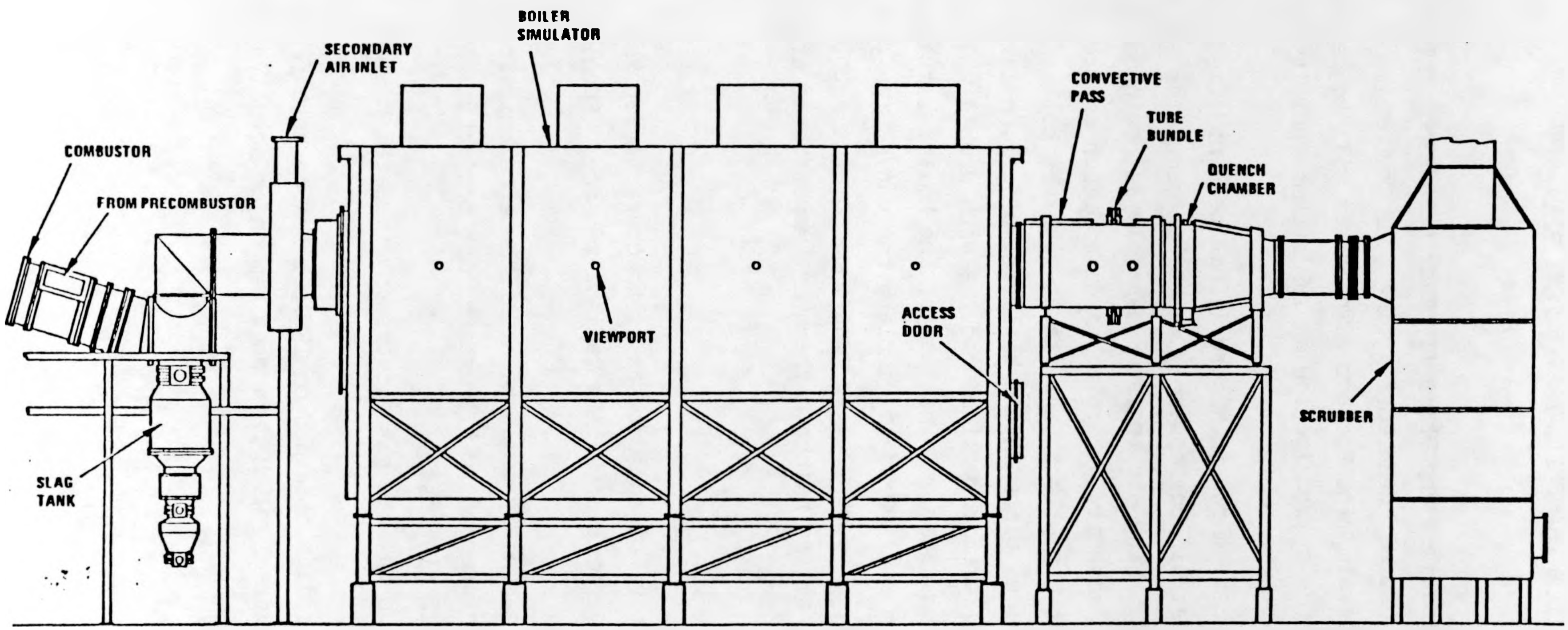


Figure 1. 34-Inch Combustion System

3.0 APPROACH

Prior to beginning the test matrix, a refractory cure and an acceptance test must be performed on the boiler simulator. These are defined respectively in Test Plans ASCCS-II-85-118 and ASCCS-II-85-114.

To meet the objectives of this test plan, testing will consist of steady state tests utilizing two coals in a pulverized (PC) form. (Analyses given in Appendix A). Figure 2 shows the test sequence logic that will be followed for each test. This will ensure that results are obtained only when the combustor system is running properly.

The data obtained on TRW's research test facility during this test program will be compared with data collected from the TRW Sponsored Cleveland Plant Demonstration Program (1). This will allow TRW to evaluate how well the boiler simulator represents an actual integrated system.

4.0 TESTING

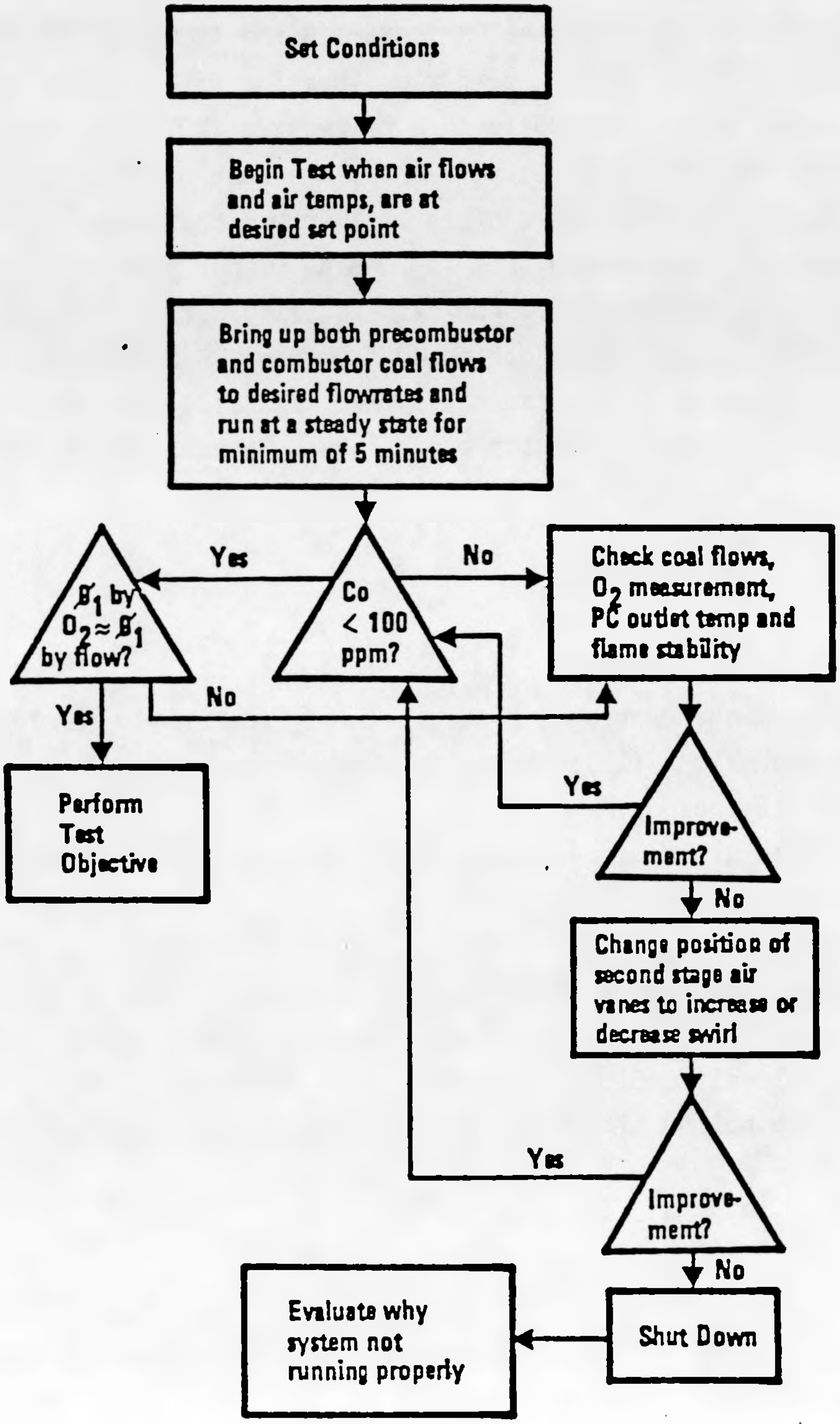
4.1 NEW INSTRUMENTATION CHECKOUT

Prior to performing functional tests,the newly installed, remotely controlled instrumentation will be manually checked to ensure proper operation. This will include:

- o Operating the air register actuator and confirming actual vane position with indicated position.
- o Checking the level controller/flow control valve system on the boiler simulator modules and confirming: 1) water flow to the modules for a low level condition; and 2) a cease in water flow for a high level condition.
- o Checking the boiler simulator manifold water supply fill valve.

(1) TRW's 50 MM Btu/hr Combustion System intergrated with an existing industrial boiler.

Figure 2. Steady State Test
Test Sequence Logic Flow Diagram



4.2 COLD FLOW FUNCTIONAL TESTS

Cold flow testing will be conducted to verify the operational status of overall systems prior to the first hot fire test. These tests shall be performed, with the combustor and facility system completely assembled and operational, on the following:

- o Air supply system
- o Cooling water supply system
- o Oil supply system
- o Propane supply system o Coal transport system
- o GN_2 system
- o GO_2 system

All systems shall be tested over the flow rates specified in Table 1.

4.3 PROGRAM TESTS

Table 2 presents the Phase II, Task 6 test parameters. A brief description of each follows.

4.3.1 Checkout

Hot fire checkout test(s), combined with the boiler simulator acceptance test mentioned previously, shall be performed to ensure all aspects of the test facility are functioning properly. In addition, these tests shall provide the combustor with an initial coating of slag.

4.3.2 Baseline Testing

Baseline tests shall be performed on both fuels for multiple first stage stoichiometries to establish emission trends and overall combustor performance. Baseline data will be compared with data obtained during Phase I, Task 3 testing on the same coals.

4.3.3. Emission Performance Optimization

The goal of these tests are to achieve a minimum level of NO_x and CO without sacrificing slag recovery and secondary combustor performance. This shall be accomplished by varying the swirl imparted to the second stage air flow at selected first stage and overall stoichiometries.

Table 1. 34-Inch Coal Combustor Flow Requirements

System	Identification	Required Flow Min lb/sec	Required Flow Max lb/sec	Pressure at Combustor Inlet (psig)	Temperature at Combustor Inlet (F)
GN_2	Coal Fluidizing-Precombustor & Combustor Hoppers	0.02	0.13	0-150[1]	Ambient
	Coal Hopper Ullage-Precombustor and Combustor	0.10	1.00	0-150	Ambient
	Carrier Gas-Precombustor and Combustor	0.015	0.20	0-150	Ambient
		0.04	1.00	0-150	Ambient
	Make Up Air-Peak Load Operation	0.40	2.40	0-150	Ambient
GO_2	Make Up Air-Peak Load Operation	0.10	0.60	0-150	Ambient
Air	Precombustor Air	0.80	8.00	1-3[2]	250-600
	Precombustor Makeup Air	1.00	10.00	1-3	250-600
	Secondary Combustion Air	0.80	8.00	1-3	70-600
Oil	Precombustor	0.015	0.150	0-250	Ambient
Propane	Ignitor	0.0008	0.0012	0-15	Ambient
Coal	Precombustor	0.1	0.4	12-20	Ambient
	Combustor	0.4	1.5	12-20	Ambient

(1) Available Pressure

(2) Required Pressure for Operation

Table 2. Phase II, Task 6 Overall Test Matrix

Test Parameter	COAL TYPE Upper Freeport	Pittsburgh #8
Checkout	X	
Baseline	X	X
Emission Performance	X	X
Low Load		X
Peak Load		X
Turndown	X	
Secondary Combustion Performance	X	X

4.3.4 Low Load

Steady state tests at low load operation are planned to provide information on slag recovery and combustor performance. The minimum load for stable combustor operation shall be determined. These tests shall be run with the convective pass tube bundle in place to obtain information on tube deposits at low load conditions.

4.3.5 Peak Load

The combustor system shall be run at high load operation to simulate peak load firing. The convective pass tube bundle shall be in place for these tests.

4.3.6 Turndown

Tests are planned which cycle the system through load changes to determine how the combustor system performs under this type of operation.

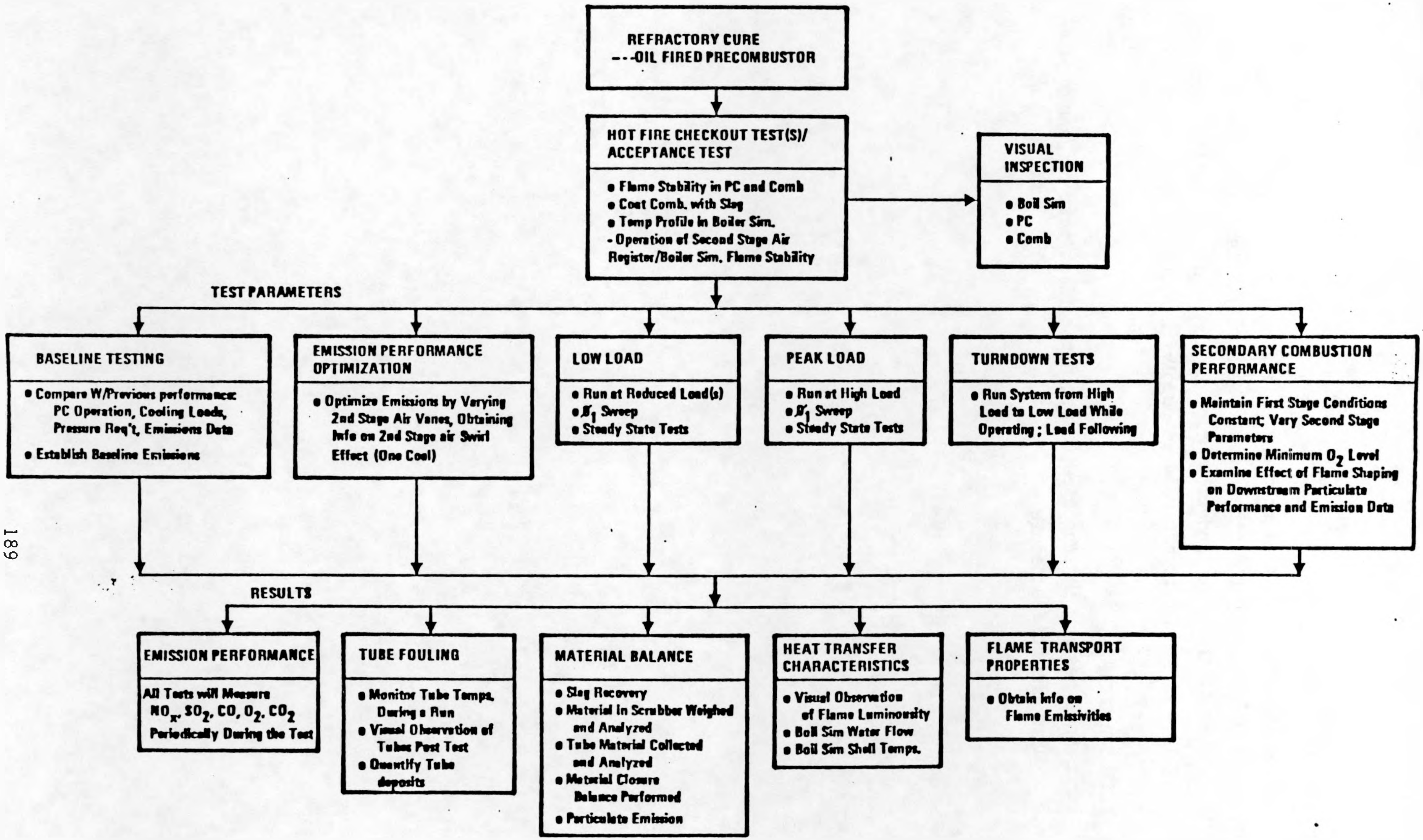
4.3.7 Secondary Combustion Performance

These tests will focus on secondary combustion operation while maintaining first stage conditions constant. Emphasis will be on evaluating the effect of flame shape on heat transfer characteristics and flame transport properties. With the convective pass tube bundle in place, indications of tube fouling can be obtained. In addition, the minimum O_2 level required shall be determined.

4.4 TEST PLAN LOGIC FLOW DIAGRAM

Figure 3 illustrates Task 6 test program logic. Following the hot fire checkout and boiler simulator acceptance test, an inspection of the system components will be conducted. Testing will proceed, systematically evaluating the test parameters. The information obtained from these tests is presented on the bottom row of the flow chart.

Figure 3. Overall Test Plan Logic Flow Diagram



4.5 DETAILED TEST MATRIX

A detailed matrix is presented in Table 3. All tests shall be steady state tests unless indicated otherwise. The specific test conditions will be distributed to the test conductor prior to the start of testing each day. Figure 4 shows the format used to supply this information.

4.6 TEST SCHEDULE

Functional testing is scheduled to begin the first part of January. Figure 5 gives the test schedule.

TABLE 3. DETAILED TEST MATRIX - PHASE II, TASK 6

TEST #	FUEL	TEST PARAMETER	TEST OBJECTIVES
1	Upper Freeport	Checkout/ Acceptance	• hot fire checkout test precombustor and combustor • boiler simulator acceptance test - operation under hot fire conditions - predicted temperature profile achieved
2,3	Upper Freeport	Baseline Testing	• $\emptyset_1$ sweep to establish baseline emissions w/boiler simulator • steady state at $\emptyset_1 \sim .8$ to coat combustor w/slag • obtain data to compare with previous Cell 3 data
4,5	Upper Freeport	Emission Performance Optimization	• $\emptyset_1$ at .8, .75 • rotate air register doors and observe any change in emission levels (3 different positions)
6,7	Upper Freeport	Turndown	• $\emptyset_1$ at .8, .50 MM Btu/hr load to begin • reduce load to 30 MM Btu/hr increasing $\emptyset_1$ to .9 • reduce load to 20 MM Btu/hr increasing $\emptyset_1$ to .95 • vary position of air register doors and evaluate emissions level
8-12	Upper Freeport/ Pittsburgh #8	Secondary Combustion Performance	• operate at nominal conditions: $\emptyset_1 \sim .75-.80$, 50 MM Btu/hr • reduce 2nd stage air flow while varying air door position and determine minimum O_2 level • systematically vary 2nd stage air doors and observe effect on flame shape, flame luminosit[y] and boiler simulator temperatu[re] profiles
24-17	Pittsburgh #8	Secondary Combustion Performance	• $\emptyset_1$ at .75-.80, 50 MM Btu/hr • maintain air register door position constant during test • evaluate tube deposit buildup • slagging run

TABLE 3. DETAILED TEST MATRIX - PHASE II, TASK 6 (Con'td)

TEST #	FUEL	TEST PARAMETER	TEST OBJECTIVES
13	Pittsburgh #8	Low Load	• ϕ_1 sweep at 35 MM Btu/hr
14	Pittsburgh #8	Low Load	• ϕ_1 sweep at 20 MM Btu/hr
15,16	Pittsburgh #8	Low Load	• ϕ_1 at .95, 20 MM Btu/hr • slagging run • evaluate tube deposit buildu particulate
17,18	Pittsburgh #8	Low Load	• ϕ_1 at .90, 35 MM Btu/hr • slagging run • evaluate tube deposit buildu particulate
19	Pittsburgh #8	Peak Load	• ϕ_1 sweep at 58 MM Btu/hr (.72, .77, .83)
20,21	Pittsburgh #8	Peak Load	• ϕ_1 at .77, 58 MM Btu/hr • slagging run • evaluate tube deposit buildu particulate
22,23	Pittsburgh #8	Peak Load	• ϕ_1 at .83, 58 MM Btu/hr • slagging run • evaluate tube deposit buildu particulate

ATMOSPHERIC COAL COMBUSTION DEVELOPMENT TEST BRIEF

Test # ______________ Test Date ____________________ Coal Type: Combustor ____________________________

Test Purpose ____ Precombustor ____________________________

Conditions								
Parameter								
WAPC, mlb/sec								
WAMU, mlb/sec								
WA2S, mlb/sec								
WOIL, mlb/sec								
WC COAL, lb/sec								
WCCAR RATIO								
WPC COAL, lb/sec								
WPCCAR RATIO								
ϕ_1								
ϕ_2								
COAL LOAD, MM Btu/hr								
Preheat Boost, °F								

Figure 4. Test Conditions Summary for Test Conductor

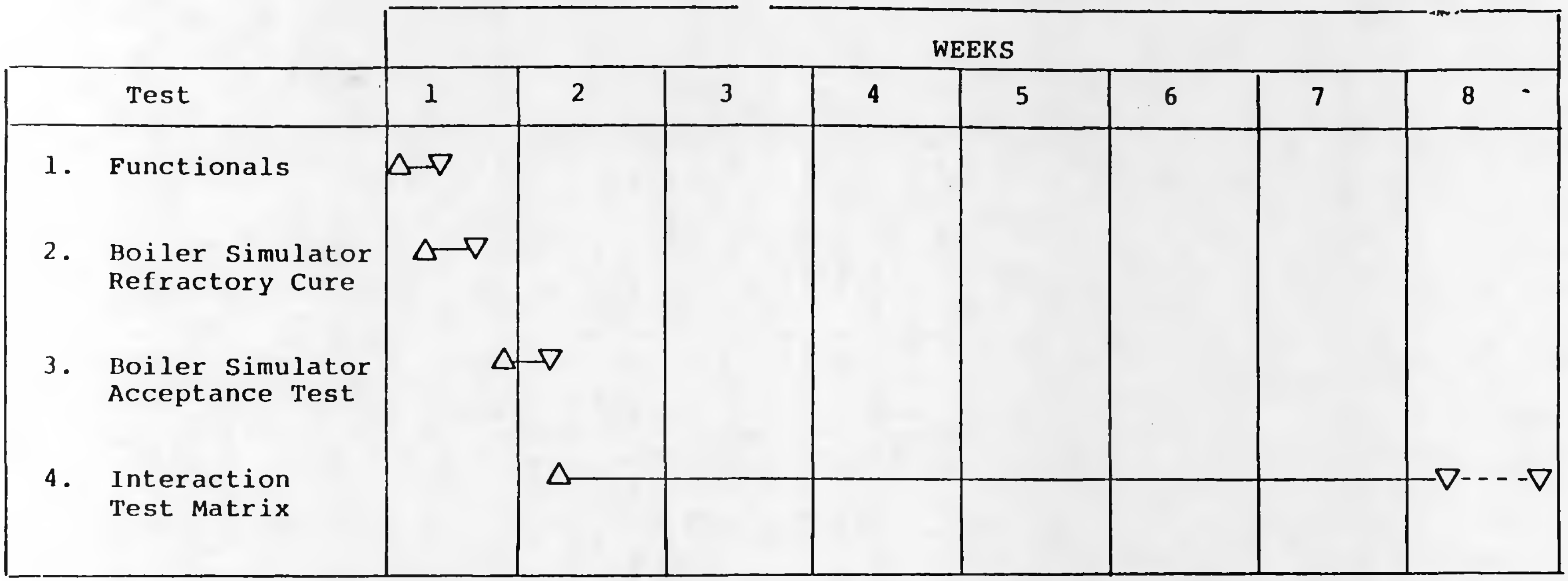


Figure 5. Task 6 ASCCS System Testing Scehdule

5.0 TEST FACILITY AND REQUIREMENTS

5.1 TEST HARDWARE

5.1.1 Combustor System

The 34 inch system, previously shown in Figure 1, shall be used for all tests. The system includes:

- o Coal-fired precombustor with commercially available propane ignitor plus diesel boost.
- o Combustor with slag baffle and batch slag tank.
- o Exit elbow in vertical configuration.
- o Duct assembly providing an interface between the elbow and air register assembly.
- o Air register assembly including a windbox, air register doors that can be remotely rotated, and a refractory lined burner throat.
- o Boiler simulator consisting of 4 separate modules, bolted and seal welded together. The boiler simualtor modules are of double water wall construction with a vent at the top. As the water evaporates, make up water is provided by the facilities cooling water system.
- o Convective pass, built as an uncooled, refractory lined chamber and includes a removable tube bundle. It is designed to simulate the convective pass of a commercial boiler. Cooling air, supplied by compressors, will maintain the tube temperatures at 1000°F.
- o Quench chamber with 20 fan, spray nozzles to cool the gases to a nominal outlet stack temperature of 250°F.
- o Scrubber with stack.

5.2 FACILITY REQUIREMENTS

The facility flow requirements (nitrogen, oxygen and fuel were presented in Table 1. Cooling water requirements are given in Table 4. Existing coal run hoppers will feed the combustor and precombustor.

5.3 CONSUMABLES

Consumables required for this program are based on 27 tests over a 6 week period. Estimated quantities are given in Table 5. The program has selected two coals, Upper Freeport (Pennsylvania) and a Pittsburgh #8 (W. Virginia), both in a pulverized form.

Table 4. 34-Inch Combustion System Water Requirements

Water circuit	Minimum Flow Rate (GPM)	Minimum Outlet Manifold Pressure Psig	MaxΔT (°F)	Steady State ΔT (°F)
Combustor Coolant Water	2400	50	60	10 - 20
Duct Assembly	270	50	60	10 - 20
Interface Plate (2)	20	30	--	--
Boiler Simualtor (1)	50	30	--	--
Quench Water/Scrubber	250	50	--	--

Table 5. Consumables (3)

Item	Grade/Specification	Maximum Quantity
GN_2	Commercial	4,900,000 ft^3
GO_x	Commercial	560,000 ft^3
Propane	Commercial	300 gallon
Oil	#2 Diesel Fuel Oil	6,600 gallon
Pulverized Coal	Pittsburgh #8	102,000 lbs.
	Upper Freeport	62,000 lbs.

(1) Open loop cooling circuit utilizing cooling tower water.

(2) Open loop cooling circuit utilizing domestic water supply.

(3) Based on six weeks of testing.

Diesel oil is required for the indirect fired air heater and the air compressors along with being utilized in the precombustor during the refractory cure cycle. Propane supplies the precombustor commercial ignitor. Oxygen and nitrogen provide the source for additonal air during peak load operation. In addition, nitrogen is used as carrier gas for pulverized coal, as hopper ullage and fluidizing gas, and as purge gas for various instrumentation and feed systems.

5.4 SPECIAL TEST EQUIPMENT

The following special test equipment, provided by the project office, shall be used for this test program:

a) Monitor Labs Data Logger Model 9350 with MX100 Printer

b) O_2 analyzer, Beckman, Model 7003

c) O_2 analyzer, Teledyne 9500-1

d) NOx analyzer, TECO Model 10AR (2)

e) CO analyzers, Beckman Infrared Model #864 and #865

f) CO_2 analyzer, Beckman Infrared Model #864 (2)

g) HC analyzer, Beckman Model 400

h) SO_2 analyzer, Western Research Model

i) Gas sampling probe

j) Pin hole TV cameras

k) Two - color pyrometer, Capintec Ratioscope - 8

l) Classical Scattering Aerosol Spectrometer, Partical Measuring Systems, Model CSAS - 100 - HTHP

The following interfaces are required:

o O_2, NOx, CO, CO_2 and HC analyzers

- 1/4" gas sample line connection to manifold
- 110 VAC unregulated
- 0 - 5 volt DC output
- recording channel to data hopper

o Two-color pyrometer

- mechanical adapter to allow installation on boiler simulator viewport
- 0 - 1 VDC output to recording channel of main computer

- o Aerosol spectrometer
  - sample probe
  - a metered sample gas and purge gas flow rate
  - 115 VAC supply
  - mechanical adapter to mount sensor on convective pass viewport

5.5 TEST PROCEDURE

The most recent test procedure prepared by the test conductor for the 34-inch coal combustor, FR-14P-04, shall be adhered to in this test series.

5.6 OPERATIONAL REQUIREMENTS

5.6.1 Operating Limits

The combustor is capable of operating at pressures up to 5 psig. Operating limits for the combustor cooling water and external skin temperatures are specified in the instrumentation data of Appendix B as high and low set points for each applicable parameter. Coal combustor air supply pressure should not exceed 1.3 atmosphere. The coal flow rate is nominally 2 ton per hour.

5.6.2 Procedural Requirements

- o Air heaters are to be started with an air lead condition.
- o Air preheat temperature or total mass flow rate increase is to be performed by increasing the air flow rate before increasing the fuel flow rate. Air preheat temperature or total mass flow rate reduction is to be performed by reducing the fuel flow rate before reducing the air flow rate.
- o Indirect air heater should be fired at least 1 hour prior to test for temperature stabilization.
- o Full air flow shall be supplied to the air preheater at all times utilizing Cell 1 as a by pass when full air flow is not required for operation.
- o Bolts should be torqued to nominally 40 ft-lb on initial buildup or after hardware changes.
- o Cooling water is to be supplied to the combustor prior to starting the combustor/air heaters.

5.6.3 Safety Requirements

- Maintain GN_2 blankets over all coal containing 5% or less moisture in tote bins, or as required by Project Office.
- Maintain GN_2 blankets in coal storage guppies.
- Remove coal collected in Torit after loading and transferring coal to avoid potential fire hazard. Remove coal to drums and flush thoroughly with water.

Operating requirements relating to safety will be addressed in other documentation.

5.6.4 Normal and Emergency Shutdown

The combustor test procedure, FR-14P-04, for the Cell 3 34-inch combustor must contain step-by-step instructions that cover combustor shutdown normal or emergency.

6.0 DATA REQUIREMENTS

6.1 PRE-TEST INPUTS

Variables and data reduction formulas required to perform on-line data reduction include coal and oil properties, calculated air preheat temperature and air inlet dimensions. These must be input prior to testing. Figure 6 presents the format employed for these inputs.

In addition, for the 34-inch combustor, water flow rates are pre-set and pressures recorded. Prior to each test, pressures are checked and adjusted, if necessary, to maintain desired cooling water flow.

6.2 ON-LINE DATA OUTPUT

The main computer scans transducer output every 800 msec and prints the data every minute. These data include pressures, temperatures, flow rates, and reduced data. The output formats used for testing are given in Figures 7 and 8. The key for the nomenclature is provided in Appendix B.

List of Variables to be Input
Prior to Every Test

Cell________________

Test #________________ Date________________

Combustor Fuel____________ Precombustor Fuel____________

HHVCC	=	Higher Heating Value of Combustor Coal, WWA	________
H_2OCC	=	Fraction of Water in Combustor Coal	________
OCC	=	Fraction of Oxygen in Combustor Coal, DWA	________
OFCC	=	Stoichiometric Oxygen to Fuel Ratio	________
		Combustor, DWA	________
HHPCO	=	Higher Heating Value of Oil	________
GAPOPC	=	Gap Out of Precombustor	________
GAPSS	=	Gap Into Second Stage	________
TPREH	=	Air Inlet Temperature (°R)	________
HHVPCC	=	Higher Heating Value of Precombustor	________
		Coal, WWA	________
H_2OPCC	=	Fraction of Water in Precombustor Coal	________
OPCC	=	Fraction of Oxygen in Precombustor Coal,DWA	________
OFPCC	=	Stoichiometric Oxygen to Fuel Ratio, DWA	________

Figure 6. Format for Pre-Test Inputs to Computer

FETS - CELL3 ANALOG INPUT POINTS VALUES 10:46:01 12/19/85

WWHEC1	WWHEC2	WWINP	A004	A005	WWCP	WWCINJ	WWC1	WWTAI	A010
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WWAD1	WWAD2	WWSP21	WWC2	WWC3	WWC4	A017	WWBA	WWBB	WWBC
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WWW	WWSP22	WWEST	WWECP1	WWECP2	WWEEP	WWEP	WWST	WWEL	WW3NOP
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WWPCIN	WWPCCP	WWPCB	WWPCC1	WWPCC2	WWPCT1	WWPCT2	WWDUC1	WWDUC2	WWDUC3
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WWDUC4	A042	A043	A044	WWSTW	A046	WWG1	A048	A049	A050
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PST	PPC	PBSEX	PDPCST	PDPCAT	PDHEEX	PDW	POTB	PDOTB	PWOT
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PWG	PWIT	PPRDIO	PPIOPC	PCPE	A066	A067	A068	PPCOAL	PCOAL
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
POIL	POILI	PCCAR	PCULL	PCFLU	PCMIX	PCINJ	PPCINJ	PPCCAR	PPCULL
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
PPCFLU	PSCAR	PSULL	PPCMIX	TBS1	TBS2	TBS3	TBS4	TBS5	TBS6
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TBS7	TBS8	POPC	POMU	PO2S	PDOPC	PDOMU	PDO2S	POX?3	PN22S
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DTHEC1	DTHEC2	DTINP	DTPCCP	DTPCIN	DTCP	DTCINJ	DTC1	DTTAI	A110
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DTAD1	DTAD2	DTSP21	DTC2	DTC3	DTC4	A117	DTBA	DTBB	DTBC
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DTW	DTSP22	DTEST	DTECP1	DTECP2	DTEEP	DTEP	DTST	DTEL	DT3NOP
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
DTPCB	DTPCC1	DTPCC2	DTPCT1	DTPCT2	DTDUC1	DTDUC2	DTDUC3	DTDUC4	TBTND
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TTUBE1	TTUBE2	TTUBE3	TTUBE4	TTUBE5	TTUBE6	TTUBE7	TTUBE8	TTUBE9	TTUBE0
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TWTAI1	TWTAI2	TWTAI3	TWTAI4	TWTAI5	TWTAI6	TWTAI7	TWW1	TWW2	TWW3
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TWEST1	TWEST2	TWEST3	TWEST4	TWEST5	TWEST6	TWEST7	TWBSIN	TBSRF1	TBSRF4
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TWEL1T	TWEL2T	TWEL3T	TWEL1B	TWEL2B	TWEL3B	TPLREF	TPLINS	TPLOT1	TPLOT2
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TAIT2I	TAIT2O	TPC2	TPC3	TAPH	TAPC	TAMU	TA2S	TOSCMI	TSQ
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TCCAR	TPCCAR	TSCAR	TCFLU	TPCFLU	THSTT	THSTB	TOX2S	TPCAUP	TN22S
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TWOT	TWIT1	TWIT2	TWGIN	TMUR3	TAIPC	TAIMU	TAI2S	TIGNPC	TOILPL
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FCT	FPCT	FST	TPRDIG	TMUR1	WAPC	WAMU	WA2S	TOTB	WTBAIR
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WCC	WPCC	WSORB	WOIL1	WOIL2	WCCAR	WPCCAR	WSCAR	WCFLU	SPARE
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WPCFLU	WOX2S	WN22S	WPRDIG	WOIL41	WOIL42	O2	NOX	SO2	TOSCPO
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TOTL-T	COAL-C	COAL-P	SORB-T	BSWL1	BSWL2	BSWL3	BSWL4	WOIL12	ARDPOS
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WATERT	SLAQT	SB-TIM	NOFIRE	WOIL22	SHTA				
0.00	0.00	0.00	0.00	0.00	0.00				

Figure 7. Type 1 Output Data

FETS - ONLINE CALCULATED DATA REPORT -- CELL #3

TEST NO. 3-121B
COAL TYPE OHIO6E

DATE 12/19/85
TIME 10:47:21

WAPC LBS/S	TAIPC *F	WAMU LBS/S	TAIMU *F	WA2S LBS/S	TAI2S *F	WCTO2 LBS/S	WPCC LBS/S	WCC LBS/S	WSORB LBS/S
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

WOIL1 LB/S	WPROIC LB/S	PHIO1	PHI1	PHI102	PHI2	PHI202	O2 %	ARDPOS DEG	WATER LB/S
0.000	0.000	9223371*	9223371*	9223371*	9223371*	1.000	0.000	0.000	0.000

HEATIN BTU/S	HOPCT BTU/S	HOCT BTU/S	HOCB BTU/S	HOC4EL BTU/S	HODUCT BTU/S	PHLTOT %	PHLPCT %	PHLCB1 %	PHLDB %
0.000	0.000	0.000	0.000	0.000	0.000	-922337*	9223371*	-922337*	-922337*

HLPCT B/S/FT2	HLHECT B/S/FT2	HLC1 B/S/FT2	HLTAIT B/S/FT2	HLSP21 B/S/FT2	HLC2 B/S/FT2	HLC3 B/S/FT2	HLC4 B/S/FT2	HLDUCT B/S/FT2	HLBT B/S/FT2
0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000

HLWT B/S/FT2	HLSP22 B/S/FT2	HLEXTT B/S/FT2	HLELBT B/S/FT2		PDPCAT PSID	PDHEEX PSID	PDOTB PSID	PPC PSIA	PST PSIA
0.000	0.000	0.000	0.000		0.000	0.000	0.000	0.000	0.000

Figure 8. Type 2 Output Data

6.3 EMISSIONS DATA

Emissions data shall be monitored and recorded at least once for each test condition. During steady state testing, data shall be recorded every 15 minutes or as specified by the South Coast Air Quality Management District. The following emissions shall be monitored:

- SO_2
- NO_x
- O_2
- CO_2
- CO
- HC
- Particulate

The gas stream shall be sampled in the convective pass. There is provision for sampling in the exit elbow, slag tank and stack; these locations will be used only at the request of the project office.

An emissions log book shall be maintained at the request of the South Coast Air Quality Management District. Cell 3 testing is subject to limits on NOx and SOx as shown below:

NOx - Maximum 117 lbs/day
SOx - Maximum 193 lbs/day

6.4 POST-TEST DATA

Following each test, slag captured in the slag tank and any slag hanging in the slag tap neck, along with material remaining in the scrubber, will be washed and weighed for slag recovery data. The head end closure shall be removed as requested for inspection of combustor slag coverage. The exit plug shall also be removed as requested by the project office. Slag samples shall be collected from the slag tank and scrubber. As requested by the project office, samples may also be collected from combustor walls.

The boiler simulator and convective pass shall be inspected and material removed and weighed as requested by the project office. The convective pass tube bundle shall be removed and deposits collected as requested by the project office. Samples shall be taken as requested by the project office.

Still photographs shall be taken after each test: additional photos as requested by the project office.

6.5 DATA ANALYSIS

A testing log book shall be kept on a daily basis by the test engineer. The log book shall contain a brief description of each test including purpose and approach, observations made during the test, and post-test observations, comments and recommendations.

Data shall be assembled by project personnel into a test results package at the conclusion of each test. The preliminary results shall be distributed to project personnel and discussed at periodic data review meetings, as determined by the project office. At the conclusion of the test program, a test report will be completed by the project office.

6.6 COAL ANALYSIS

Complete coal analyses of each coal type shall be performed by an outside lab prior to testing with the coal. The following will be performed:

- o Ultimate analysis
- o Proximate analysis
- o Mineral analysis of ash
- o Sulfur forms
- o Water soluble alkalies
- o Fusion temperatures of ash (reducing and oxidizing)
- o T250

In addition, a sieve analysis for mesh size distribution and approximate analysis of the coal shall be performed in the TRW lab as required by the project office.

6.7 SLAG ANALYSIS

Ash and chemical analysis of selected slag samples shall be conducted as requested by the project office.

6.8 PARTICULATE ANALYSIS

Particulate collected during a test, along with tube bundle deposits shall be analyzed as requested by the project office. In addition, any samples collected in the boiler simulator and the convective pass shall be analyzed as requested by the project office.

APPENDIX A

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 1919 SOUTH HIGHLAND AVE., SUITE 210-B, LOMBARD, ILLINOIS 60148 • (312) 953-9300

...OYD W. TAYLOR III
...ANAGER
MIDWEST DIVISION

PLEASE ADDRESS ALL CORRESPONDENCE TO:
16130 VAN DRUNEN RD., P.O. BOX 127
SOUTH HOLLAND, IL 60473
OFFICE TEL. (312) 264-1173
TELEX: 283527

TRW INC.
One Space Park
Redondo Beach, CA 90278
ATTN: A. Egense, Bldg. 127/1360

November 8, 1985

Kind of sample reported to us: Coal

Sample taken at: -----

Sample taken by: TRW Inc.

Date sampled: -----

Date received: 10/31/85

Sample identification by TRW Inc.

TRW Sample 1
-Upper Freeport "B"
(UPFRB) Coal
UPFRB1

P.O. No. D716244D5A

Analysis report no. 71-14675

PROXIMATE ANALYSIS	% Weight As received	% Weight Dry basis
Moisture	3.03	xxxxx
Ash	10.17	10.49
Volatile	32.31	33.32
Fixed Carbon	54.49	56.19
	100.00	100.00
Btu/lb.	13062	13470
Sulfur	1.78	1.84
Alk. as Na_2O	0.21	0.22
SULFUR FORMS		
Pyritic Sulfur	0.98	1.01
Sulfate Sulfur	0.22	0.23
Organic Sulfur	0.58	0.60
WATER SOLUBLE ALKALIES		
Na_2O	----	----
K_2O	----	----

FUSION TEMPERATURE OF ASH	Reducing	Oxidizing
Initial Deformation	2080 °F	2460 °F
Softening (H=W)	2220 °F	2520 °F
Softening (H=½W)	2335 °F	2580 °F
Fluid	2450 °F	2635 °F
% EQUILIBRIUM MOISTURE	----	
HARDGROVE GRINDABILITY INDEX	----	
FREE SWELLING INDEX	----	

H is Cone Height
W is Cone Width

ULTIMATE ANALYSIS	% Weight As received	% Weight Dry basis
Moisture	3.03	xxxxx
Carbon	73.33	75.62
Hydrogen	4.53	4.67
Nitrogen	1.34	1.38
Chlorine	0.16	0.17
Sulfur	1.78	1.84
Ash	10.17	10.49
Oxygen (diff)	5.66	5.83
	100.00	100.00

MINERAL ANALYSIS OF ASH	% Weight Ignited Basis
Silica, SiO_2	46.97
Alumina, Al_2O_3	23.14
Titania, TiO_2	1.08
Ferric oxide, Fe_2O_3	19.55
Lime, CaO	2.15
Magnesia, MgO	1.15
Potassium oxide, K_2O	2.82
Sodium oxide, Na_2O	0.21
Sulfur trioxide, SO_3	1.48
Phos. pentoxide, P_2O_5	0.60
Strontium Oxide, SrO	0.12
Barium Oxide, BaO	0.37
Manganese Oxide, Mn_3O_4	0.05
Undetermined	0.31
	100.00

Silica Value	67.27
Base: Acid Ratio	0.36
T_{250} Temperature	2458°F
Fouling Index	0.08
Slagging Index	0.66

Respectfully submitted,
COMMERCIAL TESTING & ENGINEERING CO.

David W. Cox

David W. Cox, Manager, South Holland Laboratory

Charter Member

F-467

COMMERCIAL TESTING & ENGINEERING CO.

GENERAL OFFICES: 1919 SOUTH HIGHLAND AVE., SUITE 210-B LOMBARD, ILLINOIS 60148 • (312) 953-9300

'D W. TAYLOR III
-NAGER
MIDWEST DIVISION

PLEASE ADDRESS ALL CORRESPONDENCE TO:
16130 VAN DRUNEN RD., P.O. BOX 127
SOUTH HOLLAND, IL 60473
OFFICE TEL. (312) 264-1173
TELEX: 283527

SINCE 1908

TRW INC.
One Space Park
Redondo Beach, CA 90278
ATTN: A. Egense, Bldg. 127/1360

November 8, 1985

Kind of sample reported to us: Coal

Sample identification by TRW Inc.

TRW Sample 2
-Pittsburgh 8 "B"
(PIT8B) Coal

PITSG1

P.O. No. D716244D5A

Sample taken at: -----

Sample taken by: TRW Inc.

Date sampled: -----

Date received: 10/31/85

Analysis report no. 71-14676

PROXIMATE ANALYSIS	% Weight As received	% Weight Dry basis
Moisture	2.33	xxxxx
Ash	11.22	11.49
Volatile	37.58	38.48
Fixed Carbon	48.87	50.03
	100.00	100.00
Btu/lb.	12815	13121
Sulfur	2.53	2.59
Alk. as Na_2O	0.19	0.19
SULFUR FORMS		
Pyritic Sulfur	1.72	1.76
Sulfate Sulfur	0.03	0.03
Organic Sulfur	0.78	0.80
WATER SOLUBLE ALKALIES		
Na_2O	----	----
K_2O	----	----

ULTIMATE ANALYSIS	% Weight As received	% Weight Dry basis
Moisture	2.33	xxxxx
Carbon	71.09	72.79
Hydrogen	4.66	4.77
Nitrogen	1.46	1.49
Chlorine	0.09	0.09
Sulfur	2.53	2.59
Ash	11.22	11.49
Oxygen (diff)	6.62	6.78
	100.00	100.00

MINERAL ANALYSIS OF ASH	% Weight Ignited Basis
Silica, SiO_2	46.64
Alumina, Al_2O_3	22.06
Titania, TiO_2	0.92
Ferric oxide, Fe_2O_3	23.22
Lime, CaO	1.16
Magnesia, MgO	0.82
Potassium oxide, K_2O	2.11
Sodium oxide, Na_2O	0.25
Sulfur trioxide, SO_3	0.71
Phos. pentoxide, P_2O_5	0.20
Strontium Oxide, SrO	0.14
Barium Oxide, BaO	0.05
Manganese Oxide, Mn_3O_4	0.05
Undetermined	1.67
	100.00

FUSION TEMPERATURE OF ASH	Reducing	Oxidizing
Initial Deformation	2150 °F	2475 °F
Softening (H=W)	2240 °F	2550 °F
Softening (H=½W)	2330 °F	2600 °F
Fluid	2410 °F	2650 °F

H is Cone Height
W is Cone Width

% EQUILIBRIUM MOISTURE	----
HARDGROVE GRINDABILITY INDEX	----
FREE SWELLING INDEX	----
Silica Value	64.92
Base: Acid Ratio	0.40
T_{250} Temperature	2415°F
Fouling Index	0.10
Slagging Index	1.04

Respectfully submitted,
COMMERCIAL TESTING & ENGINEERING CO.

David W. Cox

David W. Cox, Manager, South Holland Laboratory

Charter Memb

DWC/nk

APPENDIX B

APPENDIX B - Instrumentation

Alarm Limits

POINT ID	POINT NAME	POINT DESCRIPTION	HIV	HIL	LOL	LOV
1	WWHEC1	HEADEND CLOSURE #1	45.00	35.00	5.00	3.00
2	WWHEC2	HEADEND CLOSURE #2	45.00	40.00	20.00	15.00
3	WWINP	INJECTOR PLATE	45.00	35.00	15.00	10.00
4	A004	SPARE	45.00	45.00	25.00	20.00
5	A005	SPARE	45.00	25.00	8.00	5.00
6	WWCP	COAL PINTLE	45.00	35.00	15.00	10.00
7	WWCINJ	COAL INJECTOR	10.00	10.00	2.00	1.00
8	WWC1	CHAMBER #1	45.00	30.00	15.00	10.00
9	WWTAI	TANGENTIAL AIR INLET	500.00	450.00	270.00	250.00
10	A010	SPARE	45.00	30.00	15.00	10.00
11	WWAD1	AIR DAMPER #1	45.00	30.00	15.00	10.00
12	WWAD2	AIR DAMPER #2	45.00	40.00	25.00	20.00
13	WWSP21	SPACER 2 IN #1	45.00	40.00	25.00	20.00
14	WWC2	CHAMBER #2	45.00	40.00	25.00	20.00
15	WWC3	CHAMBER #3	45.00	25.00	10.00	5.00
16	WWC4	CHAMBER #4	45.00	40.00	20.00	15.00
17	A017	SPARE	45.00	40.00	14.00	12.00
18	WWBA	BAFFLE A	45.00	40.00	25.00	20.00
19	WWBB	BAFFLE B	45.00	40.00	25.00	20.00
20	WWBC	BAFFLE C	50.00	30.00	10.00	5.00
21	WWW	WEDGE	200.00	175.00	125.00	100.00
22	WWSP22	SPACER 2 IN #2	45.00	40.00	15.00	13.00
23	WWEST	EXIT SLAG TRAP	400.00	375.00	250.00	225.00
24	WWECP1	EXIT CLOSURE PLATE 1	8.00	5.00	2.00	1.00
25	WWECP2	EXIT CLOSURE PLATE 2	45.00	40.00	25.00	20.00
26	WWEEP	EXIT ENDPLATE #1	45.00	40.00	19.00	16.00
27	WWEP	EXIT PLUG	45.00	40.00	12.00	10.00
28	WWST	SLAG TANK	100.00	80.00	14.00	10.00
29	WWEL	ELBOW	350.00	325.00	230.00	200.00
30	WWSNOP	SLAG NECK OR PLATE	45.00	27.00	10.00	5.00
31	WWPCIN	PRE-COMB INJECTOR	45.00	35.00	10.00	8.00
32	WWPCCP	PRE-COMB COAL PINTLE	300.00	250.00	150.00	50.00
33	WWPCB	PRE-COMB BAFFLE	400.00	330.00	100.00	50.00
34	WWPCC1	PRE-COMB CHAMBER #1	20.00	15.00	5.00	4.00
35	WWPCC2	PRE-COMB CHAMBER #2	25.00	11.50	6.00	4.00
36	WWPCT1	PRE-COMB TRAN #1	45.00	40.00	15.00	10.00
37	WWPCT2	PRE-COMB TRAN #2	45.00	40.00	14.00	10.00
38	WWDUC1	DUCT ASSEMBLY #1	85.00	75.00	60.00	55.00
39	WWDUC2	DUCT ASSEMBLY #2	85.00	75.00	60.00	55.00
40	WWDUC3	DUCT ASSEMBLY #3	85.00	75.00	60.00	55.00
41	WWDUC4	DUCT ASSEMBLY #4	85.00	75.00	60.00	55.00
42	A042	SPARE	450.00	400.00	240.00	200.00
43	A043	SPARE	50.00	40.00	20.00	15.00
44	A044	SPARE	45.00	40.00	20.00	15.00
45	WWSTW	SLAG TANK WATER FLOW	50.00	40.00	10.00	5.00
46	A046	SPARE	120.00	100.00	35.00	25.00
47	WWQ1	QUENCH #1	300.00	250.00	100.00	90.00
48	A048	SPARE	70.00	60.00	25.00	20.00

			HIV	HIL	LOL	LOV
49	A049	SPARE	40.00	40.00	27.00	25.00
50	A050	SPARE	0.00	0.00	0.00	0.00
51	PST	SLAG TANK PRESSURE	20.00	18.00	14.00	5.00
52	PPC	PRE COMB PRESSURE	20.00	18.00	14.00	5.00
53	PBSEX	BOIL SIM EXIT	350.00	300.00	0.00	-5.00
54	PDPCST	PRE COMB/SLAG TANK	5.00	5.00	0.00	0.00
55	PDPCAT	PRE-COMB/ATMOS	5.00	5.00	0.00	0.00
56	PDHEEX	HEC TO EXIT	2.00	1.50	0.00	0.00
57	PDW	WATER PRESSURE DIFF.	5.00	3.50	1.00	0.00
58	POTB	TUBE BUNDLE ORIFICE	20.00	18.00	14.00	5.00
59	PDOTB	TUBE BUNDLE AIR DP	2.00	1.50	0.20	-0.50
60	PWOT	WATER OUTLET PRESS.	50.00	35.00	15.00	0.00
61	PWQ	QUENCH PRESS	80.00	70.00	50.00	40.00
62	PWIT	COMB. INLET PRESS	300.00	225.00	100.00	50.00
63	PPROIG	PROPANE IGNITOR	200.00	175.00	20.00	0.00
64	PPIGPC	PRE COMB PROPANE IGN	99.00	94.00	0.00	0.00
65	PCPE	CONV PASS EXIT	20.00	18.00	14.00	5.00
66	A066	SPARE	500.00	350.00	14.50	14.50
67	A067	SPARE	500.00	350.00	14.50	0.00
68	A068	SPARE	500.00	350.00	14.50	-5.00
69	PPCOAL	PRECOMB HOPP EXIT	200.00	200.00	20.00	14.50
70	PCOAL	COMB HOPP EXIT	50.00	50.00	12.00	12.00
71	POIL	OIL PRESSURE	500.00	500.00	40.00	0.00
72	POILI	OIL INJECTION PRESS	50.00	45.00	15.00	10.00
73	PCCAR	COMB CAR PRESS	500.00	500.00	0.00	0.00
74	PCULL	COMB ULLAGE PRESS	200.00	200.00	0.00	0.00
75	PCFLU	COMB FLUIDIZER	400.00	350.00	0.00	0.00
76	PCMIX	COMB MIXER PRESS	300.00	300.00	0.00	0.00
77	PCINJ	COMB COAL INJ PRESS	50.00	50.00	0.00	0.00
78	PPCINJ	PRE COMB COAL INJ.	50.00	50.00	0.00	0.00
79	PPCCAR	PRE COMB CARRIER	500.00	500.00	0.00	0.00
80	PPCULL	PRE COMB ULLAGE	105.00	100.00	0.00	0.00
81	PPCFLU	PRE COMB FLUIDIZER	500.00	500.00	0.00	0.00
82	PSCAR	SORBENT CARRIER	500.00	500.00	0.00	0.00
83	PSULL	SORBENT ULLAGE	300.00	300.00	0.00	0.00
84	PPCMIX	PRE-COMB MIXER PRESS	700.00	320.00	90.00	0.00
85	TBS1	BOIL SIM ROOF 1	250.00	230.00	190.00	170.00
86	TBS2	BOIL SIM ROOF 2	250.00	230.00	190.00	170.00
87	TBS3	BOIL SIM ROOF 3	250.00	230.00	190.00	170.00
88	TBS4	BOIL SIM ROOF 4	250.00	230.00	190.00	170.00
89	TBS5	BOIL SIM ROOF 5	250.00	230.00	190.00	170.00
90	TBS6	BOIL SIM ROOF 6	250.00	230.00	190.00	170.00
91	TBS7	BOIL SIM ROOF 7	250.00	230.00	190.00	170.00
92	TBS8	BOIL SIM ROOF 8	250.00	230.00	190.00	170.00
93	POPC	PRE COMB ORIFICE	20.00	20.00	0.00	0.00
94	POMU	MAKEUP ORIFICE	20.00	20.00	0.00	0.00
95	PO2S	2ND STAGE ORIFICE	20.00	20.00	0.00	0.00
96	PDOPC	PRE COMB DP	2.00	1.50	0.00	-0.50
97	PDOMU	MAKEUP DP	2.00	1.50	0.00	-0.50
98	PDO2S	2ND STAGE DP	2.00	1.50	0.00	-0.50
99	POX2S	2ND STG MAKE AIR OX	2.00	1.50	0.00	-0.50
100	PN22S	2ND STG MAKE AIR N2	0.00	0.00	0.00	0.00
101	DTHEC1	HEADEND CLOSURE #1	60.00	45.00	-2.00	-40.00
102	DTHEC2	HEADEND CLOSURE #2	60.00	45.00	-2.00	-40.00
103	DTINP	INJECTOR PLATE	60.00	45.00	-2.00	-40.00
104	DTPCCP	PRE-COMB COAL PINTLE	60.00	45.00	-2.00	-40.00
105	DTPCIN	PRE-COMB INJECTOR	60.00	45.00	-2.00	-40.00

			HIV	HIL	LOL	LOV
106	DTCP	COAL PINTLE	60.00	45.00	-2.00	-40.00
107	DTCINJ	COAL INJECTOR	60.00	45.00	-2.00	-40.00
108	DTC1	CHAMBER #1	60.00	45.00	-2.00	-40.00
109	DTTAI	TANGENTIAL AIR INLET	60.00	45.00	-2.00	-40.00
110	A110	SPARE	60.00	45.00	-2.00	-40.00
111	DTAD1	AIR DAMPER #1	60.00	45.00	-2.00	-40.00
112	DTAD2	AIR DAMPER #2	85.00	45.00	-2.00	-40.00
113	DTSP21	SPACER 2 IN #1	60.00	45.00	-2.00	-40.00
114	DTC2	CHAMBER #2	60.00	45.00	-2.00	-40.00
115	DTC3	CHAMBER #3	60.00	45.00	-2.00	-40.00
116	DTC4	CHAMBER #4	60.00	45.00	-2.00	-40.00
117	A117	SPARE	60.00	45.00	-2.00	-40.00
118	DTBA	BAFFLE A	60.00	45.00	-2.00	-40.00
119	DTBB	BAFFLE B	60.00	45.00	-2.00	-40.00
120	DTBC	BAFFLE C	60.00	45.00	-2.00	-40.00
121	DTW	WEDGE	60.00	45.00	-2.00	-40.00
122	DTSP22	SPACER 2 IN #2	60.00	45.00	-2.00	-40.00
123	DTEST	EXIT SLAG TRAP	60.00	45.00	-2.00	-40.00
124	DTECP1	EXIT CLOSURE PLATE 1	60.00	45.00	-2.00	-40.00
125	DTECP2	EXIT CLOSURE PLATE 2	60.00	45.00	-2.00	-40.00
126	DTEEP	EXIT ENDPLATE #1	60.00	45.00	-2.00	-40.00
127	DTEP	EXIT PLUG	60.00	45.00	-2.00	-40.00
128	DTST	SLAG TANK	60.00	45.00	-2.00	-40.00
129	DTEL	ELBOW	60.00	45.00	-2.00	-40.00
130	DTSNOP	SLAG NECK OR PLATE	60.00	45.00	-2.00	-40.00
131	DTPCB	PRE-COMB BAFFLE	60.00	45.00	-2.00	-40.00
132	DTPCC1	PRE-COMB CHAMBER 1	60.00	45.00	-2.00	-40.00
133	DTPCC2	PRE-COMB CHAMBER 2	60.00	45.00	-2.00	-40.00
134	DTPCT1	PRE-COMB TRAN 1	60.00	45.00	-2.00	-40.00
135	DTPCT2	PRE-COMB TRAN 2	60.00	45.00	-2.00	-40.00
136	DTDUC1	DUCT ASSEMBLY 1	60.00	45.00	-2.00	-40.00
137	DTDUC2	DUCT ASSEMBLY 2	70.00	55.00	-2.00	-40.00
138	DTDUC3	DUCT ASSEMBLY 3	60.00	45.00	-2.00	-40.00
139	DTDUC4	DUCT ASSEMBLY 4	60.00	45.00	-2.00	-40.00
140	TSTND	COMB INJ STAND	1000.00	700.00	45.00	32.00
141	TTUBE1	#1 TUBE OUT METAL	1300.00	1100.00	900.00	700.00
142	TTUBE2	#2 TUBE OUT METAL	1300.00	1100.00	900.00	700.00
143	TTUBE3	#3 TUBE OUT METAL	1300.00	1100.00	900.00	700.00
144	TTUBE4	#4 TUBE OUT METAL	1300.00	1100.00	900.00	700.00
145	TTUBE5	#5 TUBE OUT METAL	1300.00	1100.00	900.00	700.00
146	TTUBE6	#6 TUBE OUT METAL	1300.00	1100.00	900.00	700.00
147	TTUBE7	#7 TUBE OUT METAL	1300.00	1100.00	900.00	700.00
148	TTUBE8	#8 TUBE OUT METAL	1300.00	1100.00	900.00	700.00
149	TTUBE9	#9 TUBE OUT METAL	1300.00	1100.00	900.00	700.00
150	TTUBE0	#10 TUBE OUT METAL	1300.00	1100.00	900.00	700.00
151	TWTAI1	TAN AIR INLET 1	150.00	130.00	45.00	32.00
152	TWTAI2	TAN AIR INLET 2	150.00	130.00	45.00	32.00
153	TWTAI3	TAN AIR INLET 3	150.00	130.00	45.00	32.00
154	TWTAI4	TAN AIR INLET 4	150.00	130.00	45.00	32.00
155	TWTAI5	TAN AIR INLET 5	150.00	130.00	45.00	32.00
156	TWTAI6	TAN AIR INLET 6	150.00	130.00	45.00	32.00
157	TWTAI7	TAN AIR INLET 7	150.00	130.00	45.00	32.00
158	TWW1	WEDGE 1	150.00	130.00	45.00	32.00
159	TWW2	WEDGE 2	150.00	130.00	45.00	32.00
160	TWW3	WEDGE 3	150.00	130.00	45.00	32.00

			HIV	HIL	LOL	LOV
161	TWEST1	EXIT/SLAG TANK 1	150.00	130.00	45.00	32.00
162	TWEST2	EXIT/SLAG TANK 2	150.00	130.00	45.00	32.00
163	TWEST3	EXIT/SLAG TANK 3	150.00	130.00	45.00	32.00
164	TWEST4	EXIT/SLAG TANK 4	150.00	130.00	45.00	32.00
165	TWEST5	EXIT/SLAG TANK 5	150.00	130.00	45.00	32.00
166	TWEST6	EXIT/SLAG TANK 6	150.00	130.00	45.00	32.00
167	TWEST7	EXIT/SLAG TANK 7	150.00	130.00	45.00	32.00
168	TWBSIN	BOIL SIM WATER IN	195.00	140.00	45.00	32.00
169	TBSRF1	BOIL SIM REF MOD 1	3000.00	1100.00	900.00	700.00
170	TBSRF4	BOIL SIM REF MOD 4	2400.00	1100.00	900.00	700.00
171	TWEL1T	ELBOW 1 TOP	150.00	130.00	45.00	32.00
172	TWEL2T	ELBOW 2 TOP	150.00	130.00	45.00	32.00
173	TWEL3T	ELBOW 3 TOP	150.00	130.00	45.00	32.00
174	TWEL1B	ELBOW 1 BOTTOM	150.00	130.00	45.00	32.00
175	TWEL2B	ELBOW 2 BOTTOM	150.00	130.00	45.00	32.00
176	TWEL3B	ELBOW 3 BOTTOM	150.00	130.00	45.00	32.00
177	TPLREF	INTERFACE PLATE REF	1800.00	1500.00	300.00	300.00
178	TPLINS	INTER PL-INSIDE PL	300.00	250.00	100.00	50.00
179	TPLOT1	INTER PL-OUTSIDE PL1	300.00	250.00	100.00	50.00
180	TPLOT2	INTER PL-OUTSIDE PL2	300.00	250.00	100.00	50.00
181	TAIT2I	#2 TUBE AIR IN	250.00	200.00	100.00	50.00
182	TAIT2O	#2 TUBE AIR OUT	400.00	350.00	100.00	50.00
183	TPC2	PRE-COMB EXIT TEMP 2	2500.00	2500.00	45.00	32.00
184	TPC3	PRE-COMB EXIT TEMP 3	2500.00	2500.00	45.00	32.00
185	TAPH	AIR PRE-HEATER TEMP	700.00	550.00	300.00	250.00
186	TAPC	PRE-COMB AIR TEMP	1600.00	1500.00	500.00	490.00
187	TAMU	MAKEUP AIR TEMP	1600.00	1500.00	500.00	490.00
188	TA2S	SEC. STAGE AIR TEMP	1600.00	1500.00	500.00	490.00
189	TGSCPI	CONV PASS GAS IN	2600.00	2400.00	1800.00	1400.00
190	TSG	STACK GAS TEMP	300.00	235.00	45.00	32.00
191	TCCAR	COMB CAR GAS TEMP	600.00	600.00	460.00	460.00
192	TPCCAR	PRE-COMB CAR GAS TEM	600.00	600.00	460.00	460.00
193	TSCAR	SORBENT CAR GAS TEMP	600.00	600.00	460.00	460.00
194	TCFLU	COMB FLUIDIZER GAS	600.00	600.00	460.00	460.00
195	TPCFLU	PRE COMB FLUIDIZER	600.00	600.00	460.00	460.00
196	TWSTT	SLAG TANK TEMP TOP	1773.00	1773.00	200.00	60.00
197	TWSTB	SLAG TANK TEMP BOT	350.00	220.00	60.00	50.00
198	TOX2S	2ND STG MAKE AIR OX	750.00	650.00	460.00	400.00
199	TPCADP	PRE COMB DP	1773.00	1500.00	45.00	32.00
200	TN22S	2ND STG MAKE AIR N2	750.00	650.00	430.00	400.00
201	TWOT	OUTLET WATER TEMP	140.00	100.00	45.00	32.00
202	TWIT1	#1 INLET TEMP	195.00	140.00	45.00	32.00
203	TWIT2	#2 INLET TEMP	195.00	140.00	45.00	32.00
204	TWQIN	QUENCH INLET TEMP	195.00	140.00	45.00	32.00
205	TMUR3	MAKEUP AIR INLET 3	1700.00	1500.00	45.00	32.00
206	TAIPC	PRE-COMB AIR	1000.00	400.00	45.00	32.00
207	TAIMU	MAKEUP AIR TEMP	2500.00	2000.00	700.00	350.00
208	TAI2S	SEC STAGE AIR	1000.00	400.00	45.00	32.00
209	TIGNPC	PRE-COMB IGNITOR	1400.00	1000.00	45.00	32.00
210	TOILPL	OIL PUMP LINE TEMP	150.00	150.00	45.00	32.00
211	FCT	COMBUSTOR HOPPER WT.	10000.*	10000.*	220.00	175.00
212	FPCT	PRE-COMB HOPPER WT	0.00	0.00	0.00	0.00
213	FST	SORBENT HOPPER WT.	0.00	0.00	0.00	0.00
214	TPROIG	PROPANE IGNITOR TEMP	600.00	600.00	460.00	400.00
215	TMUR1	MAKEUP AIR INLET 1	1700.00	1000.00	45.00	32.00
216	WAPC	PRE-COMB AIR FLOW	10000.*	8000.00	320.00	0.00

			HIV	HIL	LOL	LOV
217	WAMU	MAKEUP AIR FLOW	15000.*	13000.*	550.00	0.0
218	WA2S	SEC STAGE AIR FLOW	15000.*	13000.*	350.00	0.0
219	TOTB	TUBE BUNDLE AIR TOT	900.00	700.00	550.00	500.0
220	WTBAIR	TUBE BUNDLE AIR TOT	5000.00	3000.00	1000.00	500.0
221	WCC	COMB COAL FLOW RATE	4000.00	3500.00	100.00	0.0
222	WPCC	PRE-COMB COAL FLOW	285.00	260.00	50.00	20.0
223	WSORB	SORBENT FLOW RATE	60.00	56.00	3.00	2.0
224	WOIL1	#1 OIL FLOW	59.00	50.00	15.00	10.0
225	WOIL2	#2 OIL FLOW	230.00	200.00	40.00	35.0
226	WCCAR	COMB CAR (.173)	140.00	130.00	10.00	5.0
227	WPCCAR	PRECOMB CAR(.1507)	80.00	60.00	5.00	1.0
228	WSCAR	SORB CAR(.1507)	80.00	65.00	5.00	1.0
229	WCFLU	COMB FLUIDIZER FLOW	100.00	80.00	30.00	20.0
230	SPARE	SPARE	0.00	0.00	0.00	0.0
231	WPCFLU	PRE COMB FLU FLOW	0.00	0.00	0.00	0.0
232	WOX2S	2ND MAKE AIR OX	0.00	0.00	0.00	0.0
233	WN22S	2ND STG MAKE AIR N2	0.00	0.00	0.00	0.0
234	WPROIG	PROPANE IGNITOR FLOW	0.00	0.00	0.00	0.0
235	WOIL41	AIR HTR OIL FLOW	0.00	0.00	0.00	0.0
236	WOIL42	AIR HTR OIL FLOW	0.00	0.00	0.00	0.0
237	O2	OX MEASUREMENT	0.00	0.00	0.00	0.0
238	NOX	NOX MEASUREMENT	11.00	10.20	-10.20	-11.0
239	SO2	SO2 MEASUREMENT	11.00	10.20	-10.20	-11.0
240	TGSCPO	CONV PASS GAS OUT	2600.00	2400.00	1800.00	1400.0
241	TOTL-T	TOTAL RUN TIME	0.00	0.00	0.00	0.0
242	COAL-C	COMB COAL TIME	0.00	0.00	0.00	0.0
243	COAL-P	PRE COMB COAL TIME	0.00	0.00	0.00	0.0
244	SORB-T	SORBENT RUN TIME	0.00	0.00	0.00	0.0
245	BSWL1	BOIL SIM H2O LEVEL 1	10.00	3.00	-1.00	-1.0
246	BSWL2	BOIL SIM H2O LEVEL 2	10.00	3.00	-1.00	-1.0
247	BSWL3	BOIL SIM H2O LEVEL 3	10.00	3.00	-1.00	-1.0
248	BSWL4	BOIL SIM H2O LEVEL 4	10.00	3.00	-1.00	-1.0
249	WOIL12	#1 OIL FLOW	59.00	50.00	15.00	10.0
250	ARDPOS	AIR REG DOOR POS	0.00	0.00	0.00	0.0
251	WATERT	WATER TIME	0.00	0.00	0.00	0.0
252	SLAGT	SLAG TANK SEQ TIME	0.00	0.00	0.00	0.0
253	SB-TIM	SLAG BREAKER TIMER	0.00	0.00	0.00	0.0
254	NOFIRE	10 SEC TURN OFF	10.00	3.00	-1.00	-1.0
255	WOIL22	#2 OIL FLOW	230.00	200.00	40.00	35.0
256	SHTA	SJORT FOR OFFSET	0.00	0.00	0.00	0.0