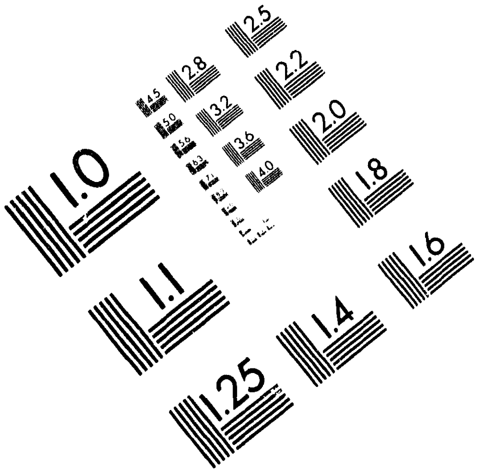

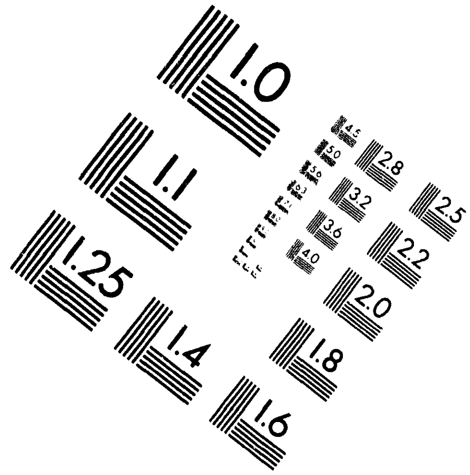

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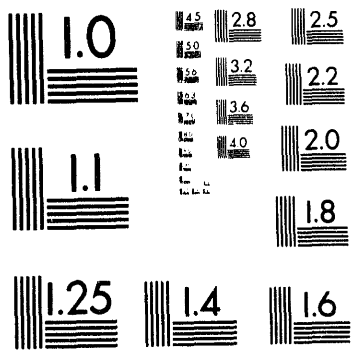

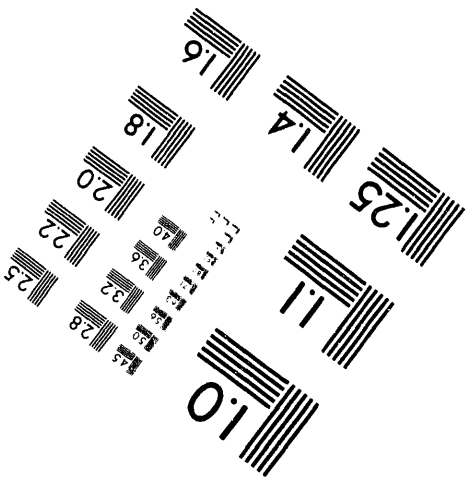

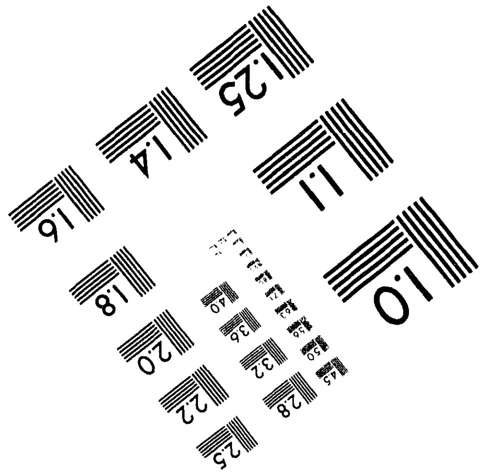

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Project: " DEVELOPMENT & TESTING OF INDUSTRIAL SCALE, COAL FIRED COMBUSTION SYSTEM, PHASE 3"

Contract: DE-AC22-91PC91162

Contract Period of Performance: 9/30/91 to 9/30/95

Eighth Quarterly Technical Progress Report

Period Covered by Report: October 1,1993 to December 31,1993

Contractor: Coal Tech Corp.
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Principal Investigator: Dr.Bert Zauderer, Phone No.(215)667-0442

Date Submitted: January 31,1994

Prepared for

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1. SUMMARY

In the fourth quarter of calendar year 1993, ten days of testing to complete the Task 3 "Proof of Concept Tests" were performed. This was double the number of test days completed in the previous quarter. 9 of these 10 test days were completed in a 30 day period between November 2nd and December 2nd. The tests provided important confirmation on the durability of the combustor and the reliability of computer control of the combustor's operation. A total of about 185 hours of combustor operation, of which 106 were on coal, were completed during the task 3 tests. This is within the range specified by the Work Statement.

The total operating time on this combustor since its installation in early 1987 is approximately 1700 to 1800, with about one-third on coal.

Testing ceased after the December 2nd test because the owner of the Williamsport test site planned to close the facility at the beginning of 1994. This decision will not have a significant impact on meeting the project objectives because the final test task, "Task 5-Site Demonstration Tests", will require refurbishment and redesign of the combustor facility. The work of tasks 1 to 4 have provided the data necessary to accomplish these modifications. Furthermore, they have provided us with a high degree of confidence that the task 5 tests will confirm that the combustor is commercially ready.

The following five key technical issues that determine the combustor's performance were solved in tasks 2 and 3 testing. They are:

- Reliable wall air cooling with slag replenishment of the combustor's refractory using fly ash injection was demonstrated.
- The addition of air cooling to the previously adiabatic, refractory exit nozzle of the combustor has allowed extended operation at high thermal load for continuous periods of 27 hour and 25 hours. A total of 185 hours of operation have been accumulated on the exit nozzle without refurbishment.
- A new coal feeder installed at the beginning of the task 3 tests has resulted in reliable pulverized coal and sorbent feeding to the combustor.
- Rapid and uniform mixing of coal, sorbent and combustion air immediately downstream of the inlet to the combustor has been achieved as a result of the development of a reliable multi-point coal and sorbent injection system.
- The combination of a quasi-automatic slag tap clearing device and added thermal input to the slag tap has resulted in reliable slag tap operation.

As a result of the multi-point coal injection system developed during the present reporting period, it was possible for the first time to operate the combustor with uniform coal and sorbent injection at full thermal input to the boiler. Specifically, injection of 1300 lb/hr of coal, equal to 16.7 MMBtu/hr, and 2.3 MMBtu/hr of pilot gas, yielded a peak of 19 MMBtu/hr. This is near the rated peak capacity of the boiler of 20 MMBtu/hr.

In addition, as a result of the uniform feeding capability, it was possible for the first time to operate the combustor with coarser coal particle size distributions. A 70% to 80% minus 200 mesh size distribution has been used since this combustor was placed in operation in 1987. In the November tests, brief trial firings were made with two size distributions in a Pittsburgh Seam coal. One has 44% passing 200 mesh, and the other had 30% passing 100 mesh. The latter size distribution can be achieved with a coal crusher instead of a ball mill pulverizer. This reduces the coal pulverizing cost by almost a factor of 10, which has a major impact on the economics of this technology.

In addition, two brief tests were performed with the injection of gypsum,(calcium sulfate) instead of limestone or calcium hydrate. These tests provided data on the rate of sorbent and slag desulfurization.

Tests were also performed on the impact of various degrees of combustion air swirl of combustion performance and slag retention.

Another important effort in the present reporting period has been to evaluate the results of combustion modeling that was obtained with the 2 dimensional Brigham Young University (BYU) computer code. These results are contained in a topical report to be submitted later. Based on the evaluation of the BYU results and of the task 2 and 3 test results it is concluded that the combustor must be lengthened to improve combustion efficiency and slag retention.

Following the final task 3 test on December 2nd, disassembly of the entire facility began in preparation to moving it to a new site for the task 5 tests. This provided an opportunity to examine the internals of the combustor, exit nozzle, combustor-boiler interface, and boiler.

The inspection as well as chemical analysis of the liner materials revealed that slag replenishment from fly ash injection was effective in relining the combustor walls. In addition, although the metal cooling tubes showed evidence of high temperature operation, ultrasonic testing of all the tubes showed thet there was no material loss on any of the tubes.

An in depth examination of the boiler by a boiler inspection expert revealed that after nearly 2000 hours of operation, involving numerous startups and shutdowns over the past 7 years ,the boiler's combustion side was in excellent condition., Ultrasonic examination of the all the water tube walls showed no evidence of erosion. The tubes had an average thickness of 0.11 inches, which is 0.020 inches above the minimum wall thickness specified by the boiler manufacturer.

Due to the many tests that were performed in the last 6 months, a substantial amount of data has not yet been reduced. It is anticipated that this will be accomplished in the next quarter.

The focus of the effort of the next quarter will be to reduce all the test data, select a test site for relocating the combustor, refurbish the combustor and extend its length, design and fabricate an air cooled exit nozzle, and modify the combustor-boiler interface to allow removal of slag or ash that is carried over into the boiler.

2. PROJECT DESCRIPTION

2.1. Objectives

The primary objective of the present Phase 3 effort is to perform the final testing at a 20 MMBtu/hr commercial scale of an air cooled, slagging coal combustor for application to industrial steam boilers and power plants. The focus of the test effort will be on combustor durability, automatic control of the combustor's operation, and optimum environmental control of emissions inside the combustor. In connection with the latter, the goal is to achieve 0.4 lb/ MMBtu of SO2 emissions, 0.2 lb/MMBtu of NOx emissions, and 0.02 lb particulates/MMBtu. Meeting the particulate goal will require the use of a baghouse or electrostatic precipitator to augment the nominal slag retention in the combustor. The NOx emission goal will require a modest improvement over maximum reduction achieved to date in the combustor to a level of 0.26 lb/MMBtu. To reach the SO2 emissions goal may require a combination of sorbent injection inside the combustor and sorbent injection inside the boiler, especially in high (>3.5%) sulfur coals. Prior to the initiation of this project, SO2 levels as low as 0.6 lb/MMBtu, equal to 81% reduction in 2% sulfur coals, were measured with boiler injection of calcium hydrate.

It was originally planned to meet the project objectives by a series of increasingly longer duration tests totaling up to 800 hours, with over 500 hours in the task 5 "Site Demonstration" effort. In the implementation of the first three project tasks, it was determined that this objective could met by daily cycling of the combustor in these three tasks, and by focusing the test effort on fuel flexibility and optimized combustion and environmental performance. Cycling without combustor refurbishment between cycles provides a more stringent test of combustor durability. The commercialization effort indicated that more emphasis was required in the area of fuel flexibility in order to expand the near term market potential of the combustor. The continuous operation tests will be performed in task 5.

The final objective is to define suitable commercial power or steam generating systems to which the use of the air cooled combustor offers significant technical and economic benefits. In implementing this objective both simple steam generation and combined gas turbine-steam generation systems will be considered.

2.2. Technical Approach

2.2.1. Overview

The work of this Phase 3 project will be implemented on Coal Tech's patented, 20 MMBtu/hr, air cooled cyclone coal combustor that is installed on an oil designed, package boiler. The task 2 and task 3 testsing will be performed at a manufacturing plant in Williamsport, PA, where this combustor was installed in 1987. The task 5 tests will be implemented at a site to be selected after the completion of the task 3 tests. The combustor has undergone development and demonstration testing since 1987. The primary fuel has been coal. Other tests, including combustion of refuse derived fuels and vitrification of fly ash, have been successfully performed.

The combustor's novel features are air cooling and internal control of SO2, NOx, and particulates. Air cooling, which regenerates the heat losses in the combustor, results in a higher efficiency and more compact combustor than similar water cooled combustors. Internal control of pollutants is accomplished by creating a high swirl in the combustor which traps most of the mineral matter injected in the combustor and converts it to a liquid slag that is removed from the floor of the combustor. SO2 is controlled by injecting calcium oxide based sorbents into the combustor to react with sulfur emitted during combustion. The spent sorbent is dissolved in the slag and removed with it, thereby encapsulating the sulfur in slag. Part of the sorbent exits the combustor with the combustion products into the boiler where it can react with the sulfur. The spent sorbent is either deposits in the boiler or it is removed in the stack particle scrubber. NOx is controlled by staged, fuel rich combustion inside the combustor. Final combustion takes place in the boiler.

As described in Section 2.1. excellent progress has been made in the past several years in meeting these combustor performance objectives. One of the most important objectives of this technology development effort is to demonstrate very high SO2 reduction in the combustor. Prior to the start of the present Phase 3 project, the peak SO2 reduction achieved with sorbent injection in the combustor had been 56%, (+/-) 5%. Of this amount a maximum of 11% of the total coal sulfur was trapped in the slag. On the other hand, up to 81% SO2 reduction has been measured with sorbent injection in the boiler immediately downstream of the combustor. Tests in the past several years have revealed the critical role played by optimum operating conditions in the SO2 reduction process. Specifically, combustor operation must be automatically controlled, and solids feed and air-solids mixing in the combustor must be optimized. Progress in both areas has been accomplished in the past 4 years by using a microcomputer to control the combustion process and by testing various methods of feeding and mixing the coal and sorbents. In the summer of 1992, tests performed in a prior project indicated that in excess of 90% SO2 reduction could be achieved by sorbent injection in the combustor.

Combustor durability is an essential requirement for commercial utility of the combustor. Due to the aggressive nature of the combustion process and the need to utilize refractory materials inside the combustor to withstand the 3000F gas temperatures, durability has been one of the key challenges in the development process. Here also the use of computer control has been the means whereby this problem is being solved. Since introduction of computer control four years ago, the need for frequent refractory liner patching inside the combustor has been sharply reduced. The durability issue can be addressed by accumulating running time in daily cyclic operation without combustor refurbishment between runs. This approach has been used in the latter task 2 and task 3 effort. All tests between May 1 and December 2, 1993, consisting of 26 hours of operation in task 2 and 185 hours in task 3 have been performed without significant internal combustor refurbishment.

The final project objective of placing the combustor in a viable industrial steam or power generating system will be accomplished by detailed engineering analysis on the use of the combustor in one or more steam generating cycles. This effort will also include an assessment of the requirements for commercializing the combustor for an industrial application.

2.2.2. Task Description

Task 1: Design, Fabricate, and Integrate Components

This task consists of three sub-tasks: Components design, component fabrications, and components integration, and shakedown tests. The 20 MMBtu/hr combustor will be modified to allow safe and environmentally compliant operation for periods of up to 100 hours.

Task 2: Preliminary Systems Tests

The modified combustor system will undergo a series of one day parametric tests of total duration of 100 hours to validate the design changes introduced in task 1, and to accomplish the project objectives and goals.

Task 3. Proof of Concept Tests

The durability of the combustor will be determined in a series of tests of between 50 and 100 hours of accumulated operation with no combustor refurbishment between tests. The total test period will be up to 200 hours.

Task 4. Economic Evaluation & Commercialization Plan

The economics of one or at most two different industrial scale steam based cycles using the combustor will be evaluated. A commercialization plan will be developed for marketing the combustor in an industrial environment both in the US and overseas.

Task 5. Conduct Site Demonstration

This task will be the final test activity in the project. Its objective will be to demonstrate the durability and hence the commercial readiness of the combustor for its intended industrial application(s). The effort will consist of two sub-tasks. In the first one any changes required as a result of prior tests will be made to the combustor. In the second one, a series of tests, each of up to 100 hours of continuous coal fired operation will be performed, with a total test time of 500 hours.

Task 6. Decommissioning Test Facility

The test facility will be removed from the boiler installation and disposed in accordance with required regulations.

3. PROJECT STATUS.

3.1. Task 3. Proof of Concept Tests

Ten days of testing were conducted during this reporting period. This completed the key test objectives planned for task 3. These tests as well as key results are described in this section in chronological order.

3.1.1. Test DP 15- October 20, 1993

The first test, coded DP 15, was performed on October 20,1993. The focus of the test was on combustion optimization. This was a brief one day test in which uniform coal injection was achieved by using 8 injector ports instead of the normal 4 injection ports used in most prior tests. Previous tests showed that the original four injection locations were limited to a total of about 750 lb/hr of uniform coal feed. The other four injection ports were previously used for sorbent injection. In prior tests where over a 1000 lb/hr of coal injection had been achieved, two of these four outer ports were used for coal injection.

For the present test, the coal flow from the coal feeder was divided into two pneumatic flow transport lines. One was used to feed the original four off-axis feed tubes, while the other was used to feed the other four feed tubes. Instead of separate injection of the sorbent, in this test it was mixed with the coal at the pneumatic line inlet. This freed the four sorbent lines for coal feeding. In addition, two of the added coal feed pipes had a pintle attachment at the outlets in order to deflect the coal in the off axis direction.

Coal firing was limited to several hours, as the purpose of the test was only to verify the suitability of this arrangement. The results confirmed the superiority of this arrangement. 30% of the slag was collected through the slag tap, which was the highest levels achieved in the tests in this project. An equal amount of slag was collected after the test at outlet of the exit nozzle inside the boiler. The scrubber solids retention was 25% , which was lower than the 35% level measured with the four point off axis plus axial pintle injection or the three point off axis and two point axial injection in the swirl section. This result is shown in figure 1 which shows the scrubber solids measured in the scrubber water as a function of various coal injection methods.

In addition, the measured SO2 reduction was in the 60% range which was also higher than the values measured in prior tests. Another significant result was that it was possible to bring the combustor to the full planned thermal input after a flameout using coal for restart, as opposed to No.2 oil. The wall temperatures increased very rapidly to steady state levels. In prior tests, after flameout, the use of coal only to reheat the combustor wall would result in slag and char buildup on the combustor wall followed by slag flow flooding of the slag tap once operating temperatures are achieved.

This test demonstrated the importance of rapid mixing of the coal, sorbent and air at the inlet section of the combustion chamber.

3.1.2. Test DP 16- November 2, 1993

This test was the first one to use 8 point coal injection on a regular basis. This allowed uniform injection at coal feed rates in excess of 900 lb/hr. The first three of the six hour coal fired period was performed at 1150 lb/hr with a total fuel input of 17 MMBtu/hr. Both fuel rich (SR1=0.8) and fuel lean (SR1=1.1) conditions were maintained in the combustor. As in the previous test, dual pneumatic feed lines were used.

Figure 3 shows the coal feed rate versus time for this test. This test was also the first one in which additional transport air controls were added to the pneumatic feed lines in order to balance the feed to all injection points. After 3 hours of operation, the input to the pneumatic feed line began to back up with coal forcing a cutback in coal feed. This was not implemented fast enough and a flameout occurred, as shown in figure 3. On restart, the gypsum injection test was performed in which various levels of $CaSO_4$ ($2H_2O$) was injected to test sorbent and slag desulfurization. These data have not yet been analyzed.

A key result of this test was the finding that several slight modifications were needed to the coal injection system. One was operational in that the proper pneumatic air flow rates were established. It was found that excessive transport air caused erosion of combustor liner refractory near the outer coal injection points. The other was the finding that the use of pintles in the off-axis injectors were not as effective as deflector plates in yielding rapid mixing of coal and air. These were minor adjustments compared to the key result that uniform high coal feed rates could be achieved. As previously reported in prior tests, uniform continuous feed rates above 900 lb/hr could not be maintained without an axial pintle was used. As shown in figure 1, the use of the axial pintle resulted in excessive ash carryover out of the combustor.

Figure 3A shows the combustor wall temperatures at various locations in the combustor liner wall. This test showed that the new computer operated wall temperature control could maintain a constant combustor wall temperature even at these higher feed rates. As has been previously reported, this new procedure was introduced early in the task 3 testing and it maintained peak combustor wall temperatures within a 50F range.

3.1.2. Test DP 17, 18, and 19- November 9,10 and 11, 1993

a) DP 17 & 18: These tests were the first in the accelerated test schedule which was necessitated by the decision of the test facility landlord to close the plant. The first two days of testing were devoted to a DOE-SBIR project on the control of dioxin emissions from high chlorine content waste fuels. However, a substantial part of the combustor operating data and combustor durability data is directly applicable to the present project, and those relevant results will be reported here. The data have been analyzed too late for timely inclusion in this report..

A key requirement of this dioxin test was to maintain the combustor at a steady condition for the entire period of the two test days in order to obtain dioxin stack gas samples meeting EPA test procedures. Accordingly, it was decided to perform all the test conditions at a steady 900 lb/hr of coal feed because insufficient operating time had been accumulated at the higher feed rates to assure reliable continuous operation.

Figure 4 shows the coal feed rate for the DP 17 test day, Two flameouts early in the test day were caused by a trip in the high pressure fan controller. This problem recurred several more times during the remaining tests. It was partly resolved by increasing the rating of the heater elements on the motor controller. However, it appears that there is some random defect in this controller, and if it continues to recur in task 5 testing, the controller will be replaced. The computer data collected for the next day's test, DP18 was lost during its retrieval at the end of the test day. Only the last hour's test data was saved. However, as all the test conditions until the last hour remained unchanged this data loss is not important.

b) DP19: After the successful completion of the dioxin tests on the 10th, the following day's test was devoted to continuing the higher coal injection rate tests and coarse coal injection tests.

A study of a 20 MW repowering project performed as part of task 4 showed that the cost of the coal pulverization system is a very substantial components in the cost of the plant. It is therefore of considerable interest to determine the performance of this combustor with coarser grind coals as this will allow the use of lower cost pulverizers and even lower cost coal crushers. Therefore, the first part of this test was devoted to injecting, at a rate of 1000 lb/hr, 1 ton of coal having a 44% minus 200 mesh size distribution versus the normal 70-80% minus 200 mesh distribution. This was followed by full boiler thermal input operation at 1300 lb/hr of coal and 2.3 MMBtu/hr of gas, for a total of 19 MMBtu/hr heat input. Figure 5 shows the coal flow for this test. At both flow rates, fuel rich and fuel lean conditions were used in the combustor.

One important observation was that the combustor wall temperature was substantially higher than had been the case in the tests prior to the initiation of the high coal flow rate tests on November 2nd. Once this was recognized, it was nevertheless possible to maintain the combustor air cooled metal tubes at a safe temperature. However, this was only accomplished by lowering the combustion temperature, which resulting in lower combustion efficiency and slag retention in the combustor. Before this corrective action was taken the average combustor wall heat transfer rate was about 20% higher than the previously measured peak levels. Furthermore, based on the measured refractory liner thickness in the roof section of the combustor after the combustor was disassembled in December, the local heat transfer rate in this roof section was about double the peak average value. That the metal cooling tubes survived this high heat flux is a measure of the effectiveness of the various combustor wall temperature control procedures that were introduced over the years since 1988. In early 1988 the combustor refractory roof section failed completely and the cooling tubes partially melted at fuel firing rates that were lower than those attained in the present tests.

Rather than refurbish the combustor roof section, we decided to implement ash replenishment procedures in the following tests. This will be reported below.

c) Boiler Performance.-*Sticky Deposits* The dioxin control tests, DP 17 & 18 had an effect on the boiler performance that is some significance in evaluating the impact of this combustor on oil designed boilers. One of the key concerns on the applicability of the present test effort to commercial operation is the relatively short total test time accumulated. Since the test effort on this combustor-boiler system was initiated in 1987, about 1800 hours of total operating time, with about 1/3 on coal, have been accumulated. Therefore, one may question the relevance of this relatively short operating time in evaluating the impact of the combustor on the boiler. The dioxin tests suggest that this is more than sufficient time for the combustor to impact the furnace section of the boiler.

During these tests, a salt, CaCL2, was injected at a rate sufficient to reach chlorine concentrations of 2.4% (by weight) of the coal flow. After the completion of these tests internal inspection of the boiler revealed a 3/8 inch thick deposit of a sticky material that covered the entire downstream half of the furnace section roof, end wall and two side walls, as well as the initial set of water tubes in the convective section of the boiler. It was found that this material could be washed off completely with cold water. This cleaning was implemented in the week after the tests, prior to the next test on November 18th.

It was initially thought that this entire deposit consisted of calcium chlorate dihydrate which is very soluble in cold water. However, a chemical analysis of the deposit revealed that only about 3% of the this material consisted of chlorine. It was, therefore, concluded that the chlorine compound acted as a glue which bonded successive layers of fly ash to the boiler tubes. This result shows that if any low temperature compounds had existed at any time in the past 7 years of coal fired operation, the boiler wall would have long since developed thick deposits on the tubes. The fact that this did not occur shows that normal operation of this combustor will not lead to slag buildup of the boiler tubes.

d) Boiler Performance- *Soot Blowing*: Another measure of the impact of this combustor on the boiler is the effect of sootblowing on boiler performance. All oil designed package boilers have soot blowers in the downstream end of the convective tube bank. In this boiler the sootblowers use steam from the boiler. Due to oversight, the sootblowers were not used in the task 2 tests and in the task 3 tests prior to the September 23rd test. By that time well over 100 hours of coal fired operation had been accumulated. As the task 3 tests proceeded, it was noted that the gas temperature at the boiler outlet, i.e. the base of the stack, gradually increased from about 500F to over 600F. This compares with a 450F stack temeprature with oil. During the 9/23/93 test, a short 10 second burst of sootblowing was implemented about 15:45 hours. This immediately decreased the stack gas temperature from 620F to 500F. A second 10 second burst near the end of the test decreased the temperature to 450K, the same as with oil. The impact of the sootblowing can be seen in figures 6 and 7. Figure 6 shows the increase in steam flow from about 12,000 lb/hr to 13,000 lb/hr after sootblowing at 15:45 hours. Figure 7 shows that the corresponding total heat input as computed from the steam flow.

Subsequent to this test soot blowing was implemented on a regular basis at the end of each test day. The stack gas temperature at the base of the stack was maintained in the 450 to 500F range for all subsequent tests. The significance of this result is that it demonstrates that the deposits on the boiler tubes are basically dry ash and they are readily removable. Therefore, with suitably placed soot blowers it should be simple to maintain steady long term operation in these oil designed boilers.

e) Boiler Performance-*Ash Deposition::* It has been reported previously that an ash blowing device had been installed inside the boiler furnace section early in the task 3 tests. This device was located on the opposite wall from the convective tube section. It was effective in blowing ash toward the other wall. In the present three day tests, over 9 tons of coal were consumed, and 1820 lbs of slag and ash were removed from the combustor, boiler, and scrubber during and after the tests. 35% of this mineral matter was dry ash that accumulated on the furnace floor and 7.5% accumulated at the bottom, upstream end of the convective tube section. This relatively high carryover of mineral matter from the combustor was due to a number of factors, the most important of which was combustion efficiency. As noted above, it was necessary to maintain a lower than normal combustion gas temperature to limit the wall heat transfer rate to the combustor wall. This adversely affected the combustion efficiency. In any case, there was no means to remove this ash while the combustor was in operation. This situation will be rectified for the task 5 tests. A small ash hopper will be placed beneath the upstream end of the mud drum. Also, the front face of the boiler will be moved upstream in order to allow installation of an access doors which will be used to remove furnace dry ash and slag carried over from the combustor.

f) Boiler Performance--*Boiler Restoration Inspection:* Following the completion of the task 3 tests on December 2nd, the combustor was disassembled and removed from the boiler. Since our contract with the site owner called for restoring the boiler to its prior use, we retained a boiler inspection specialist to carefully examine the boiler internals. This boiler is a Keeler-D Frame unit rated at 250 psig saturated steam and 17,5000 lb/hr. A detailed ultrasonic inspection of all the accessible boiler tubes was made, including all the tubes in the furnace section and the convective tubes. The upstream end of the tubes were accessed from the furnace side while the downstream convective tubes were accessed from the stack side. All tubes were found to have an average wall thickness of 0.11", which is 0.020" higher than the minimum allowed by the manufacturer. There was no evidence of any tube erosion.

In addition, no corrosion was found underneath the refractory floor tiles which are placed on top of the floor boiler tubes. The use of floor tiles was generally discontinued in the late 1970;'s in favor of a web construction. The reason for this was that moisture would accumulate underneath the tiles which would lead to corrosion of the tubes. Since we operated the boiler intermittently over the past 7 years, there was concern that moisture from condensation would form underneath the tiles. However, inspection revealed no evidence of corrosion. It is hypothesized that the reason for this is that some of the coal particles were carried out of the combustor and deposited on the boiler floor. This coal char would continue to smolder for several days after a test. In addition, slag flowing out exit nozzle provided another heat source to limit condensation. In fact, it took a minimum of 3 days before the boiler cooled off.

The one area that needed replacement is the front plate and part of the refractory of the furnace section of the boiler. This plate was perforated with various holes that were inserted for the combustor exit nozzle and final combustion air.

In conclusion, the operation of the combustor did not have an adverse effect of the boiler's fire side components during the past 7 years of operation.

3.1.3. Test DP 20- November 18, 1993

This test had three objectives.

- To perform ash replenishment of the combustor wall at a low thermal input.
- To determine the effect of swirl on the combustor performance.
- To fire with a very coarse coal size distribution, namely 30% minus 100 mesh.

Ash Replenishment: As noted above, during the high coal thermal input test earlier in the month, the combustor wall heat transfer exceeded the previous peak values. This resulted in thinning of the refractory liner, especially on the combustor roof. It was estimated that the roof section was only 1/3 of its thickness at the completion of the refurbishment in the Spring of 1993. Rather than rebuilt the liner, it was decided to use ash replenishment which had been tested successfully under the prior DOE-SBIR Ash Vitrification Project. 200 lb/hr of a western coal fly ash was injected with the combustor operating at 750 lb/hr of coal. Figure 8 shows the coal flow for the entire tests was maintained at 750 lb/hr.

The hot side ceramic liner thermocouples (i.e. those nearest the liner-gas interface) failed due to overheating during the high coal feed rate tests. While they were replaced, it was not possible to place them at the exact same location in the liner. Therefore, a comparison of the wall temperature before and after liner replenishment with fly ash would not be meaningful. Instead the thermocouples in the rear of the liner near the air cooled metal tubes were used. Figure 9 shows a thermocouple at this location for test DP19, (Nov.11) before ash replenishment. Note that after steady operation was reached, at about 13:30 hours, the temperature averaged 1400F. Figure 10 shows the same thermocouple reading for the present test ,DP20. Once steady state has been achieved at about 13:00 hours, the temperature averaged 1300F, which is 100F lower than in the previous test. This indicates that the slag layer thickness has increased compared to the previous test.

The replenished liner thickness is determined by the slag liquid flowing temperature, which was in the range of 2200-2500F depending on the slag properties. The thermal conductivity of slag is lower than that of alumina based refractories. It is about 0.75 Btu/hr-ft-F between 1500 and 2500F. [See Appendix C, Combustion, J.G.Singer, Ed. CE, Windsor,CT,1981]. Therefore, for the 20,000 to 30,000 Btu/hr-ft2 heat transfer rates at which these tests were implemented, a slag liner thickness of only 0.3 to 0.45 inches is sufficient to provide the necessary temperature drop of about 1000F between the above measurement and the slag melting temperature.

Several more ash replenishment operating periods were implemented in the remaining four test days in task 3. After the combustor was disassembled in December, there were two distinct refractory regions on the side walls of the combustor. An outer liner which consisted of the replenished liner thickness was approximately 0.5 inches, and an inner liner of the same thickness. A chemical analysis revealed that this layer was enriched in slag in that its silica content was 31% (by weight) while the alumina content (which was the original liner material) was 30%. The alumina in the coal ash was about one-half that of the alumina. Therefore, only about 15% of the original liner material was present in this outer layer.

The chemical analysis of the inner liner was 56% alumina while the silica content was 12%. This shows that this layer consisted mostly of the original liner.

The roof section of the combustor liner was half the thickness of the side walls. A chemical analysis of a sample of this section had an alumina content of 45% and a silica content of 21%. This showed that it was mainly the original liner, but with a higher penetration of coal slag. This analysis indicates that the replenishment was not effective on the roof section. Since the upper section is hotter, the mass flow rate and hence the tube air side heat transfer coefficient is lower than on the floor section. In addition, due to the effect of gravity, the liquid slag layer thickness is always thinnest on the roof and it gradually increases down the side walls. Therefore, to replenish the roof section, the air flow rate on the top half of the combustor must be increased relative to the lower half. Overall, the result of the ash replenishment tests show that is effective in rebuilding the refractory liner of the combustor.

Effect of Swirl Velocity of Combustion : Since no data was available at low swirl in the combustor, the swirl inlet pressure was lowered by 50% from its normal value. This test was performed for 1 hour at 750 lb/hr of coal and fuel lean conditions, after the completion of the ash replenishment. This was followed by a low swirl 1 hour test at fuel rich conditions and the same feed rate. This data has not been analyzed in detail. However, no significant difference in performance was observed at the lower swirl values.

Coarse Coal Combustion Test: After the completion of the above tests, a 1000 lb of the coarse (35.5%-100 mesh) coal was fed at 750 lb/hr. The first test conditions was fuel lean with calcium hydrate injection.. When it became apparent that the large coal particles were blowing out of the combustor, the hydrate was replaced with fly ash and this improved the retention of larger particles. The data from this test have not yet been analyzed.

During all these tests, a wire basket was used to catch the slag passing through the slag tap. This allowed a determination of the slag flow rate for each test condition. This is not perfect determination because slag from a previous conditions can melt and flow out at the next condition. The results have not yet been analyzed in detail. One result was that at most of the test conditions the slag tap passed about one-half of the total slag, with the balance collected at the outlet of the combustor exit nozzle inside the boiler. This provided further confirmation that the combustor should be lengthened to provide better carbon burnout and slag retention in the combustor.

3.1.4. Test DP 21- November 22, 1993

The previous test had been performed with alternating periods of fly ash injection for slag replenishment, followed by injection of calcium hydrate for SO2 control. In the present test, the primary objective was to inject a 50%-50% mixture of fly ash and calcium hydrate in order to perform both functions simultaneously. Another objective was to operate at full thermal input to the combustor with a coal feed rate of 1300 lb/hr and a total heat input of 19 MMBtu/hr..

Figure 11 shows the coal feed rate for this test. The initial 4 hour test period was at 1000 lb/hr, followed by 2 hours at 1300 lb/hr.

Scrubber Performance: At the end of the above test time, 17:00 hours, the scrubber fan motor failed when a bolt sheared and shorted the power leads into the motor. In January 1993, one of the three windings in this motor had failed and it was taken by our maintenace sub-contractor to a motor shop to be rewound. After the present failure we sent the motor to a local repair shop. We learned that the previous repair shop used by our sub-contractor at that time had replaced the motor instead of rewinding it. It is interesting to note that the original 30 hp scrubber fan motor as well as the 5 hp primary air fan motor, which failed last year, were both manufactured by a the foreign company. Both motors failed after only 1000 to 1500 hours of operation.

Another interesting scrubber related result was the observation that after this test the scrubber fan was again out of balance. It had been previously balanced in April and September. The fan bearings were also replaced in April. In addition, the entire fan housing was replaced in April because of severe wall corrosion. At first the vibration problem was attributed to lack of maintenance of the bearings. However, this could not account for this last vibration problem which occurred with only about 50 hours of operation. The only explanation was that very fine ash particles deposited on the fan blades, which drove them out of balance. This is especially a problem in the present application where the high CaO content of the fly ash yields a cementitious ash. A baghouse stack cleanup system that uses a stack ID fan should be much less susceptible to this problem. For a wet scrubber it will be necessary to add a grit removal device to the fan to remove these deposits and keep the fan in balance.

In some of the tests in August it was observed that the scrubber performance deteriorated under variable and heavy solids loading conditions. On discussing this problem with the manufacturer, they attributed it to too high a gas inlet temperature to the scrubber. As noted in a previous section, the stack temperature was as high as 620F before we instituted regular soot blowing. The scrubber does not function well with gas inlet temperatures above 250F. On examining the scrubber water spray system at its inlet, we concluded that the manufacturer's design for cooling the scrubber inlet gases to this required temperature was ineffective. Accordingly, in September we designed and installed a spray cooling system that was located further upstream of the manufacturer's system. This proved to be very effective in cooling the stack gases, and the measured temperatures at the scrubber inlet were in the 130-140F range. This dramatically improved the scrubber performance even at heavy particle loading conditions. In fact the initial cooling design was too effective in that considerable wet ash deposits formed at the scrubber inlet to the point were after one day's operation half the inlet cross section was blocked with ash sludge. This blockage was an artifact of the present duct design between the existing boiler stack and the scrubber duct system. Relocating our gas cooling system closer to the scrubber vessel inlet sharply reduced the duct blockage without any measurable increase in the scrubber inlet gas temperature.

The overall conclusions concerning scrubber performance from all the task 3 tests are that duct layout and stack gas cooling mehtod are key parameters in efficient scrubber performance and blockage free operation. Also, a cleaning device must be added to the scrubber fan to prevent deposit buildup on the fan blade which can rapidly

DP21 Test Results: Figure 11 shows the coal flow rate for this test. At 11:30 a flameout occurred when the primary air fan tripped. As noted above, it is believed that these trips were due to a defect in the motor control circuit. Initially a mixture of 115 lb/hr of fly ash and 115 lb/hr of calcium hydrate was injected with the coal. In addition, 100 lb/hr of limestone was injected separately. Again these results have as yet not been analyzed. One major observations noted during the test was the tendency of the ash-hydrate mixture to clump and block the pneumatic feed lines. This was probably due to the absorption of moisture by the hydrate in the mixing process prior to placing the mixture in the feeder. Therefore, beginning at 13:00 hours the mixture feed rate was reduced to 100 lb/hr. The resultant impact of this ash injection on slag wall replenishment is shown in figure 12. At the high ash injection rates to 13:00 hours, the temperature, at the same cooling tube locations as in figure 9 and 10, averaged 1200F. This is 100 F lower than the previous ash replenishment result. When the ash injection rate was lowered to 50 lb/hr at 13:00 hours, the wall temperature increased to the 1300 to 1400 F range. However, this was still lower than without ash replenishment, as shown in figure 9.

Between 14:26 and 15:00 hours , 300 lb/hr of gypsum was injection instead of the above ash-hydrate mixture. The purpose of this test was to measure the SO2 concentration at the combustor exit nozzle outlet with a probe inserted through the rear boiler wall. This measurement had been overlooked in the previous gypsum injection test. At 15:00 hours, fly ash injection (without hydrate) at 100 to 120 lb/hr continued for the balance of the test. Note that this mode of injection was not as effective as the 50-50 ash-hydrate injection in lowering the liner temperature. On the other hand, increasing the coal fee rate by 30% to 1300 lb/hr at 15:00 hours did not increase the wall temperature. This is shown in figure 12.

3.1.5. Test DP 22, 23, 24 November 30, December 1, 2, 1993

The objective of the final three tests in task 3 were to verify the repeatability of the combustor's operation, and to complete the minimum total test time planned for task 3. Basically these tests duplicated the performance observed in the previous tests. Figure 13, 14 and 15 show the coal flow rates for the three test days. Again these data have not been completely analyzed. However, several interesting observation were noted during the tests.

The flameout at 13:00 hours in DP22 test was due to shutdown of the rented air compressor when it ran out of fuel oil. Another interesting result of this days test was the repeated extensive slag blockage of the exit nozzle, which reached levels as high as 60%. In each case, the blockage was cleared with a ram that was inserted through the rear wall of the boiler while the combustor remained at steady state firing conditions. This blockage occurred when the combustor operated at fuel lean conditions. Blockage generally occurs at this condition due to freezing of the slag as the combustor exhaust gas encounters the air injected into the furnace at the exit nozzle outlet.

The combustor wall temperatures were in the same 1200 to 1350 F range as in the previous tests even without added fly ash injection.

The only interesting event of the second days test, DP23, concerned the coal supply. On all these tests, the 20 ton coal tanker truck was parked outside the boiler house, (see figure 16) and the 4 ton coal bin was replenished from the coal in this tanker when it reached the low level indicator. Since this was the last test in task 3, we planned to empty all the coal in the tanker and the 4 ton bin by the end of the three days of testing. Therefore, prior to this test we asked our supplier to weigh the tanker to assure that sufficient coal remained in the tanker. However during the refilling operation on mid-day of the December 1 it was observed that the tanker was empty. After we were assured that an additional 4 tons of coal could be pulverized that evening and delivered the next day, we decided to conserve the remaining coal in the bin in order to at least complete a full day's operation. This was done by cutting the coal feed rate to 400 lb/hr and augmenting the balance of the heat input with No.2 fuel oil. Since there was still not sufficient coal, we used the remaining 800 lbs of the coarse coal (30%-100 mesh) for the final two hours of operation. This provided an additional data point of coarse coal combustion at a low feed rate but high thermal input.

In addition, at 15:00 hours fly ash was injected at the rate of 140 lb/hr to further simulate high solid fuel firing. Figure 17 shows the combustor wall temperature. Note that after 15:00 hours, when the fly ash was injected, the wall temperature decreased to 1200F. (This temperature measuring location is the same as in figure 9,10, and 12).

Figure 15 shows the coal feed rate, 1000 lb/hr and 1100 lb/hr, for the final test day, 12/2/93, Test DP24. The major events of that day, where a general local power failure at 14:40 hours that shut everything down, and a repeat of the combustion air fan trip at 17:30 hours. The test terminated when the coal supply in the 4 ton bin was consumed. There was no ash replenishment on this test day, and as a result the wall temperature was somewhat higher than on the previous day. It was in the 1300-1400F range, which is still lower than prior to initiating ash replenishment.

3.1.6. Ash/Slag Mass Balance in the Combustor-Boiler-Scrubber

One key objective of the these November tests was to obtain a mass balance of the mineral matter, (coal ash, fly ash, sorbents), as a function of operating conditions. This required a partition of the ash and slag between the combustor and exit nozzle, the boiler, and the scrubber. The slag and ash weights inside the boiler cannot be obtained in real time. It takes about 3 to 4 days for the boiler to cool off. Therefore, it was possible only to obtain the weights of slag and ash in the boiler after each weeks group of tests. The boiler was cleaned after the November 2nd test, the three day November 9-11 tests, and after the December 2nd test. In addition, for each test condition, the slag passing the slag tap was collected in a wire basket and weighed. The solids in the scrubber water were sampled every 30 minutes, and these were filtered and weighed. Knowing the scrubber water flow rate, the total solids retained by the scrubber can be obtained. In addition, the carbon in the scrubber provides a key input to the combustion efficiency. The other data needed to compute combustion efficiency is the stack gas analysis. In addition, all the sludge deposited at the inlet of the scrubber was removed after each tests day.

Due to the considerable number of tests performed in the present quarter, the stack gas analysis for the tests since early August have not been completed to date. The slag and ash balance for all the November tests is mostly complete. However, it will not be reported in detail in this document because the analysis revealed the need for additional evaluation of samples, and additional analytical effort, as will be now explained. Therefore, this section is a status report of the work completed. It provides a reasonable good overview of the combustor performance. It also shows the direction of further analysis of the data that must be made to obtain a complete picture of the distribution of mineral matter in the entire system. Furthermore, the results analyzed to date confirm that the combustor must be lengthened in order to improve slag retention in the combustor.

The first step in the ash/slag analysis is to separate the carbon content from the ash in the scrubber. In most prior tests before November, the carbon content was generally in the 40% range. Due to the high cost of laboratory analysis of these samples, we generally sent two to four scrubber samples for each tests day, or one per test condition, to a laboratory for detailed chemical analysis. The other samples, which were collected every 30 minutes during each test, were dried and weighed by Coal Tech. However, when some of the early November scrubber results were reported in December by the analysis laboratory, the carbon content was found to range from a low in the 20% range to a high in the 50% range. Unfortunately, only the dried scrubber samples from the last three days of testing on Nov.30-Dec.2 remained. These two dozen samples were submitted to the lab for a carbon analysis. The results, which were received in January, too late for inclusion in this report. They showed a range from 15% to 51% carbon, with most of the samples in the 40-50% range. Prior to receipt of these latest results, the average of the samples per test day was used to compute the ash composition of the scrubber solids for each test, and the results reported here are based on this latter assumption.

The next item in the ash/slag analysis was to allocate the slag collected inside the boiler that flowed out from the exit nozzle to each test day. This slag is part of the combustor slag retention. However, since tests were performed every week in November, it was not possible to enter the boiler between all the tests and remove the ash and slag in the boiler. Therefore, for the three consecutive day tests, the sum of the boiler ash and slag was collected and weighed as a unit. The ash and slag were allocated according to the total coal and sorbent and fly ash injected during the three days of testing.

The preliminary results of the mass balance revealed that about 1/3 of the injected coal ash, CaO, and fly ash was retained in the combustor and exit nozzle as slag, 1/3 was deposited in the boiler as dry ash, and 1/3 was collected by the scrubber. Of the slag retention about 1/2 passed through he slag tap while the other half flowed out of the exit nozzle. These levels of slag retention are lower than historical values. The slag retention is a strong function of combustion efficiency, and until the combustion efficiency analysis is performed the impact of combustion of slag retention cannot be determined. The following are therefore preliminary conclusions. Table 1 shows the averaged slag and ash mass balance for three sets of tests: November 2nd, November 9 to 11, and November 30 to December 2.

TABLE 1:SLAG & ASH IN THE COMBUSTOR, EXIT NOZZLE, BOILER, AND SCRUBBER
(Shown as % of mineral matter injected into combustor)

Test Dates	Slag Tap (%)	Slag Tap+Exit Nozzle (%)	Boiler (%)	Scrubber (%)	Total Collected as % of Total Injected
11/2/93	18	34	26	35	95
11/9-11/93	31	40	22	41	102
11/30-12/2/93-	14	28	23	33	84

Column 3 shows the slag collected at the outlet of the exit nozzle into the boiler added to the slag collected from the slag tap. They are combined because they are the result of combustion in the combustor and exit nozzle. There was no slag in the boiler.

The results in Table 1 are in the same range as those in prior tests, as shown in figure 2, although the slag removed from the slag tap is very low. One possible explanations for the low slag retention is due to operation at high coal firing rates. As noted in previous sub-sections, while ash replenishment was effective in relining the combustor, it was not as effective in the roof section of the combustor liner. As a result, it was necessary to operate at a lower combustion temperature, which adversely affected the combustion efficiency, which in turn lowered the slag retention.

However, this explanations does not account for the generally lower slag retention in this project compared to earlier tests in the Clean Coal Project in 1988-1990. One major difference was in the nature of the injected material. In the Clean Coal tests only limestone, whose size distribution was about the same as for coal, namely 70-80% minus 200 mesh, was used. In the subsequent tests, including the present tests, most of the mineral matter injected consisted calcium hydrate and in some of the tests fly ash, both of whose mean particle size is only 7 microns. The retention of this material in the combustor is very low compared to ash from combustion of the coal particles and from calcination of limestone. Due to the low retention of the hydrate, a small amount of limestone was injected in order to condition the slag to the proper slag melting temperature.

Therefore, an analysis of slag retention in the combustor and the ash/slag mass balance in the entire system must be further partitioned between the mineral content due to coal and that due to the hydrate. This partitioning can be obtained from the concentration of the silicon dioxide, which is due to the coal ash, and the calcium oxide which is due to the sorbent. Using this method, the slag retention in the combustor due to the coal ash increased to above 50%. This is still low. As noted in the previous paragraphs, it can be tentatively attributed to the lower temperatures used in these tests,.

This issue will be further clarified once the remaining ash/slag results are analyzed and the combustion analysis is completed. However, the results to date confirm our assumption since early in this project that the combustor needs to be lengthened. It is planned to increase the combustor length for the task 5 tests.

3.1.7. Exit Nozzle Heat Transfer Results

As reported previously, air cooling pipes were inserted in the refractory wall of the exit nozzle in March 1993 in order to convert the quasi-adiabatic exit nozzle to an actively air cooled nozzle. The exit nozzle consists of a concentric ring of refractory material, with an inner ring of a high temperature, slag resistant fused refractory, surrounded by a alumina refractory. Eleven cooling tubes were installed along the length of the exit nozzle from the boiler side at a radius that was about double that of the inner radius of the nozzle. In February 1993, prior to the installation of the air cooling tubes, a series of tests were performed with No.6 oil in which the combustion temperature reached such a high value that part of the fused inner refractory liner of the exit nozzle melted to a radial depth of up to 1 inch. Since it was too costly to replace the entire inner fused refractory section, the lost material was replaced with an alumina plastic refractory.

A two dimensional heat transfer analysis was performed to determine the temperature and heat transfer distribution in this air cooled exit nozzle as a function of the number of cooling tubes placed around the circumference. Based on this analysis, it was decided to install 12 tubes. However, this was reduced to 11 due to concern that the lowest tube, at 6 o'clock would rapidly become covered with slag flowing our of the exit nozzle. This would block the air flow in this tube. Figure 18 shows the temperature distribution in one of the 10 exit nozzle slices. The position of the cooling tube is shown on the X axis at a numerical radius value of 13.5. Also, shown are the placement of three thermocouples mid-plane between two adjacent cooling tubes, TC1,2, and 3. as well as a thermocouple that was placed inside the air cooled tube to measure the approximate air temperature, TC4.

The table shown in figure 18 compares the experimental results with the analysis for one of the early tests after the cooling system was installed. The key results is shown in the extreme lower right box. Here the average temperature at a radius equal to that of the air cooling tube location is shown. This average was obtained by two methods. One was to take the average of the air cooled tube metal temperature and the refractory temperature at this same radius, TC2. The other was to compute the temperature at this radius from the heat transfer rates deduced from the inner exit nozzle temperature, the measurements at the other thermocouples, and the heat removed by the cooling air. The two temperatures of 757F and 760 F are in excellent agreement with each other.

Also note that the total heat transfer between the measured and analytical result are in fair agreement. The analysis yielded a value of 80,000 Btu/hr between the nozzle ID which was assumed at 3000F. Based on the slag chemistry used in this test, the slag fluid temperature was 2275F. It is therefore unlikely that the inner wall temperature was much higher than this value. On that basis the computed heat transfer at the cooling tube radius is 54,000 Btu/hr. By way of comparison, these values are less than 10% of the heat transfer to the combustor wall. This confirms that the exit nozzle is still quasi adiabatic even with the air cooling.

Figure 19 shows the average temperature measurement at the three radial locations corresponding to TC 1, 2 and 3 in figure 18 as a function of the test number since the installation of the cooling tubes. Note that with increasing time the innermost temperature, TC 1 gradually increased from 1100-1200F to 1800F. This indicated that the inner wall material was melting due to slag action. This was confirmed by internal measurement between tests and by accurate measurement after disassembly of the combustor. It was determined that the entire alumina section that had been inserted inside the fused refractory liner had dissolved in the slag. The fused refractory remained intact with the exception of the usual radial and longitudinal cracks due to thermal cycling.

The nozzle operated for over 200 hours during the latter part of the task 2 and all the task 3 tests without any refurbishment. The test results strongly suggest that if the entire inner liner had been replaced with the fused refractory during the installation of the air cooling tubes it would have survived intact. Even in the present situation, the liner condition remained essentially unchanged from the time when the inner alumina plastic refractory had melted in the August test until the final December 2nd test. Well over 100 hours of additional operation had been accumulated in this final interval.

One final note of interest concerning the exit nozzle concerns the method of installing the air cooling pipe system. The nozzle cooling pipes were connected to a pipe assembly that was placed on the inner refractory wall of the front boiler wall. This assembly was then routed to a single large pipe that penetrated the front metal wall and was connected to the cooling air supply. The entire pipe assembly in the boiler was covered with a plastic refractory material for thermal insulation that was several inches thick.. However, during installation, no provision was made for differential expansion between this refractory covering and the exit nozzle. As a result in the December tests lateral cracks developed in parts of this tube covering section due to differential thermal expansion. This required patching with cement it shut. This is an installation problem which could have been avoided by placing expansion cracks in the front wall refractory during installation.

In conclusion, the exit nozzle cooling air assembly was effective in maintaining the nozzle assembly within a safe operating range and this design could have been used for more extended operation.

The general conclusion from all the above tests is that the combustor can be repeatedly cycled from a cold start on a daily basis with refurbishment. Wall material loss can be corrected with ash replenishment of the combustor walls and with computer control of wall cooling and combustion temperature. The only remaining task is to lengthen the combustor to improve slag retention and combustion efficiency.

3.1.8. Combustion Modeling with the BYU Code.

Evaluation of the BYU modeling of the present combustor suggests that the current length of the combustor is too short to complete combustion inside the combustor at the higher fuel feed rates. This result is borne out by the test data obtained to date. The lengthening will be implemented in task 5. The results of the evaluation of the BYU code are contained in a Topical Report that will be submitted later.

3.1.9. Conclusions on the Task 3 Effort

The major accomplishments of the task 3 test effort are:

• A reliable method of feeding coal and sorbent into the combustor and in assuring uniform mixing has been demonstrated.

• The reliability of air cooling and ash replenishment in maintaining the combustor wall integrity even after the loss of substantial wall refractory has been demonstrated. This result provides considerable confidence in the use of air cooling for both the combustor and the exit nozzle.

• The operation of the combustor has not adversely affected the combustion side surfaces of the boiler during the entire test effort beginning in 1987.

• The heat transfer and combustion performance appear to be in general agreement with the modeling codes used for analysis.

• Reliable slag tap operation has been achieved. This is a major accomplishment because slag tap plugging has been a source of considerable difficulty in prior operation.

• Reliable computer control of the combustor's operation has been achieved. This includes the development of a redundant flame safety system. As evidence for this statement, we note that the flameouts in the final intensive November test periods were caused by power failure, motor trips, electric motor failure, or fuel oil loss.

• The design changes needed to achieve continuous and reliable combustor and boiler operation in task 5 have been identified.

3.2. Task 4. Economics/Commercialization

This task consists of two sub-tasks. Task 4.1 consists of the study of various steam and power systems to which the air cooled, slagging combustor offers significant performance and economic benefits. Task 4.2 involves the investigation of commercial applications of these systems.

During the present reporting period, a series of meetings were held with a developer of independent power projects and with the engineering staff at the site proposed for the 20 MW repowering project that was reported in the previous Quarterly Report. [Note that the results of this 20 MW repowering study are complete, buit due to the press of other project activties they have not been fully documented. It is planned to include them in a future Technical Progress Report.] The purpose of the meetings was to developed a preliminary plan for third party financing of the project and to develop a schedule for this project. For example, a previously unanticipated task that must precede the beginning of the project is a 12 to 18 month analysis of the wind and environmental factors at the site. This would requires the erection of a weather tower at a height equal to that of the proposed stack. However, as the site already has such a tower, several months can be reduced from this schedule. In any case, the Developer estimated that if the go ahead on feasibility was given on 1/1/94, the plant would not go on line before 1998. Our original plan had been to sell the power to another utility. However, in the interim, the other utility lowered its power purchase rates by about 20%, which made such sales very marginally attractive. The site owner on the other hand would require the entire 20 MW output by 1998, and the proposal was refocussed on this option. This, however, created a new problem. The repowering site has at present capacity that is scheduled to be written off in the year 2004. There is the possibility that the site would be closed at that time. All these factors were discussed at a meeting in early November with the site owner engineering personnel. After several weeks of reflection on this matter, the site manager decided that a decision on which way to proceed would not be possible before mid-1994, which is where the matter now stands.

The above history is described to indicate the difficulties encountered in bringing independent power projects on line. This extended time table is normal for these type of projects. The Developer stated that it can take about two years to sign an agreement to proceed with a even a small power projects. We should note, that we originally identified this site in November 1992. In addition, due to all the development and financing costs, projects less than $10 million cannot be profitably financed by third parties. This represents a significant barrier to the gradual introduction of low cost, new technolgoies, such as the present combustor.

A meeting was held in early November at a paper mill on the application of the Coal Tech combustion system for process steam and power generation at the mill. This led to a request for a proposal on the installation of a new power system capable of producing 8.5 MW of power and 125,000 lb/hr of process steam. A letter proposal was submitted in late November offering several options ranging from a waste coal fired combustion system that would be connected to the existing steam-feedwater lines to a totally new power system. The former option, which cost about 1/4 that of the latter, would continue to utilize the existing 3+MW on site power generation capacity, while the latter option would require for a new 8.5 MW turbine. The first configuration is similar in design as the planned task 5 site demonstration effort.

After review of the proposal and submission of responses to written questions, the plant manager asked us to submit a proposal in which a third party would finance the project, and sell the steam and power to the mill. However, the cost of the project is too low (considerably less than $10 million) to justify third party financing. Methods for financing of such relatively low cost projects will be explored in the next reporting period. One possibility is to bundle several projects together.

3.3. Task 5. Site Demonstration

Even prior to notification by the present test site owner of the decision to close the test site, it had become obvious that performing the task 5 tests at that site would not meet the commercialization objective of this project. The task 4 effort showed that a fully operational system and performance warranties are necessary to obtain orders for the combustor system. This requires operation of the combustor extending over 1000 hours, which can only be accomplished if the energy produced during operation is sold to the host site in order to defray part of the operating costs.

To accomplish this goal, the combustor will be relocated to a site that can at a minimum utilize the 17,500 lb/hr steam production from the present 20 MMBtu/hr combustor. Subsequently, this steam output could be used to generate about 700 kW of power from saturated steam at 200 psi in a condensing turbine. To implement this relocation, a search was initiated in November, 1993 for a suitable site which meets these requirements. To minimize the total cost of the relocation, the site must be within a 40 mile radius of Philadelphia. Sites under consideration were public institutions, large industrial parks, and industrial plants with round the clock operation. A promising University site was eliminated due to objection of the steam plant operators.

Several paperboard recycling plants fit the requirement for year round steam use. However, inspection to date of the boiler operations at six plants revealed several major difficulties. In most cases, there was insufficient room in or near the existing boiler house to install the combustor, boiler, fuel and sorbent storage, and stack cleanup equipment. A site further removed from the boiler hosue would have required construction of a new building which would be beyond the resources of this project. Another problem is the difficulty of obtaining permitting at two of the sites due to proximity to residential areas. Another paper plant had a suitable building, but their steam pressure requirements were 300 psi.

At present the primary focus is on relocating to the industrial park that was identified in the original Program Plan as the site for task 5 activities. This site can utilize all the steam output during the heating season, and it would be a candidate for power throughout the year. Permitting and lease negotiations are currently in progress and we anticipate reaching an agreement in the middle of the next quarter. As the list of potential sites in this region has by no means been exhausted, we will also continue the effort on selecting an alternate site. The key criteria are on site energy need and implementation of the task 5 tests with no interference between the site owner and the test operation.

As of the date of this report, the combustor has been fully disassembled. Refurbishment of the combustor parts is in progress. A half dozen offers to purchase a suitable used boiler have been received. Quotations for a stack baghouse to replace the scrubber have been received. This will meet the more stringent air emission standards in this region. The existing boiler has been almost completely refurbished, and we are waiting a response from the site owner to our offer to purchase the boiler.

The November test results have indicated that the combustor can burn a considerably coarser coal particle size distribution. A quotations has been received for a coal crusher capable of processing raw coal on site. Tests will be performed to determine the performance capability of coal crushers for the present application. The design of the coal delivery and crushing system will begin in January.

4. Effort of the Next Quarter

The two primary activities in the next quarter will be to continue to analyze the task 3 test data, and to continue with the site relocation for the task 5 tests. The latter effort began in

December and the status to date has been described in the previous sub-section. In addition, the following effort is currently in progress.

• After due consideration it has been decided to retain the swirl inlet section and to repair the water leaks. As of this report date, this work is almost complete.

• A design has been developed to increase the combustor length and to add a new air cooled exit nozzle in place of the present refractory nozzle. The slag tap will be relocated to this extended combustor section.

• A used boiler will be purchased and modified to allow real time removal of slag and ash carried over into the boiler. The conceptual design for the modification is complete.

• The combustor safety controls will be converted to a PLC system.

• The combustor liner will be refurbished for the first time since 1988. As of this date, the old liner has been removed. The installation of a new liner will begin in late February. Extensive analytical modeling of the air cooled liner design has already been completed.

• An improved system for slag removal from the slag tank beneath the combustor will be designed and installed

Finally, it should be noted that none of the above modifications or additions do not represent a basic change in the combustor design or operation. The above changes will be used in the commercial unit, and it is the basis on which the various proposals noted in connection with task 4 have been prepared. The task 5 effort will validate the upgraded design, and more importantly it will provide confidence to potential users of the technology that it is commercially ready.

Figure 1: Average Scrubber Particle Retention

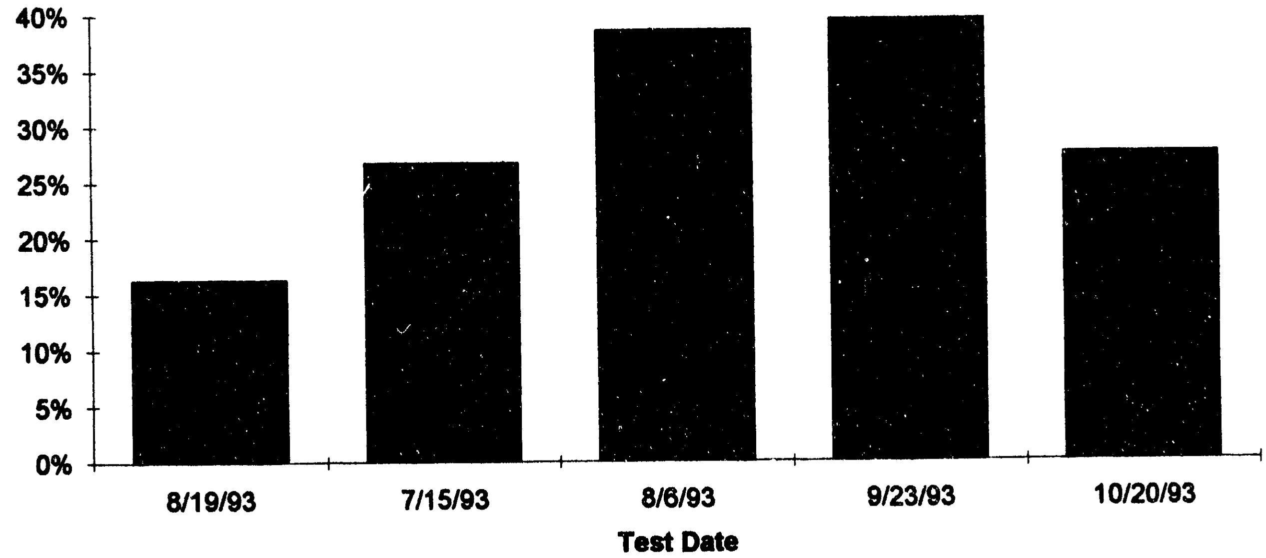


Figure 2:Total Ash & Slag Retention versus Project Test No. (8/92 to 10/93)

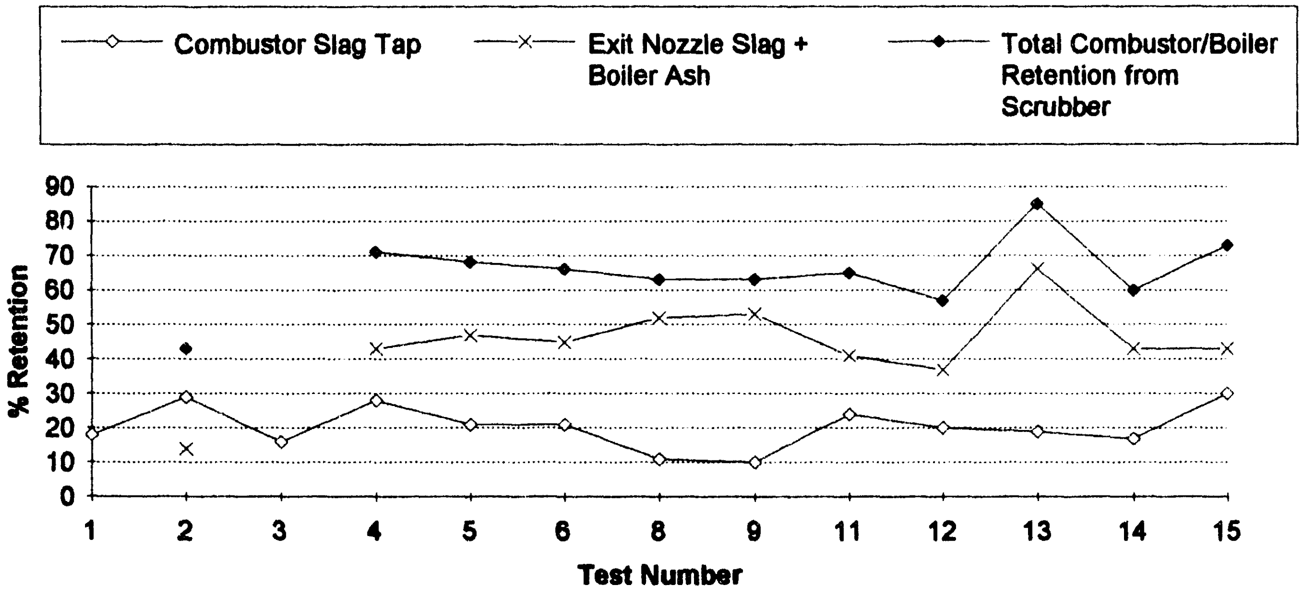


Figure 3: Coal Flow-11/2/93 Test

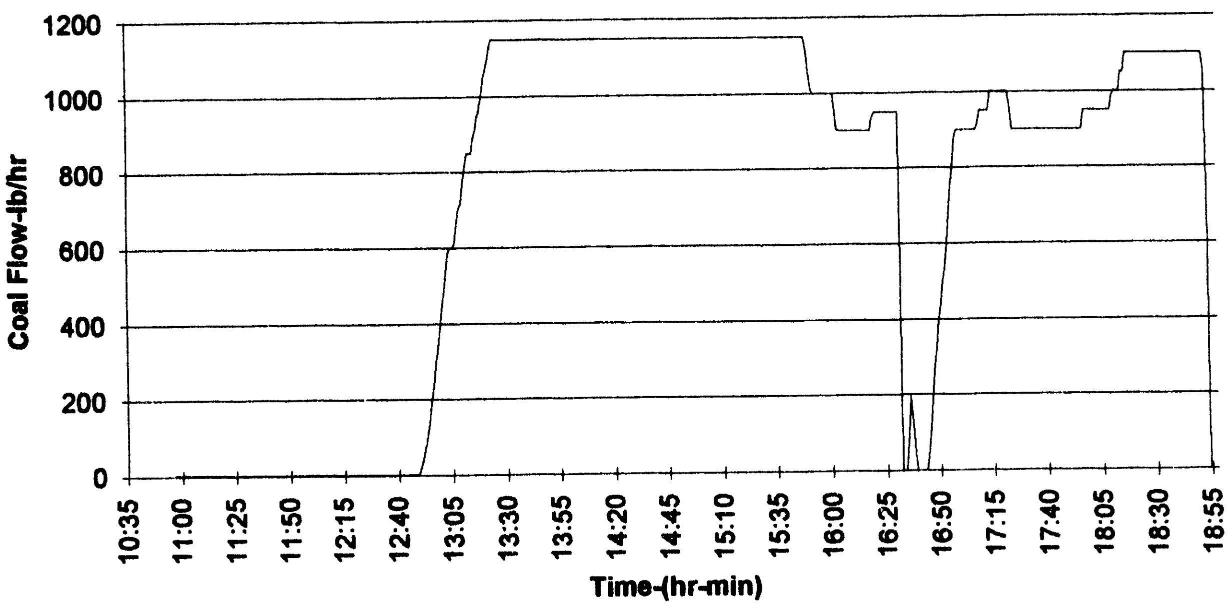


Figure 4:Coal Flow-11/9/93 Test

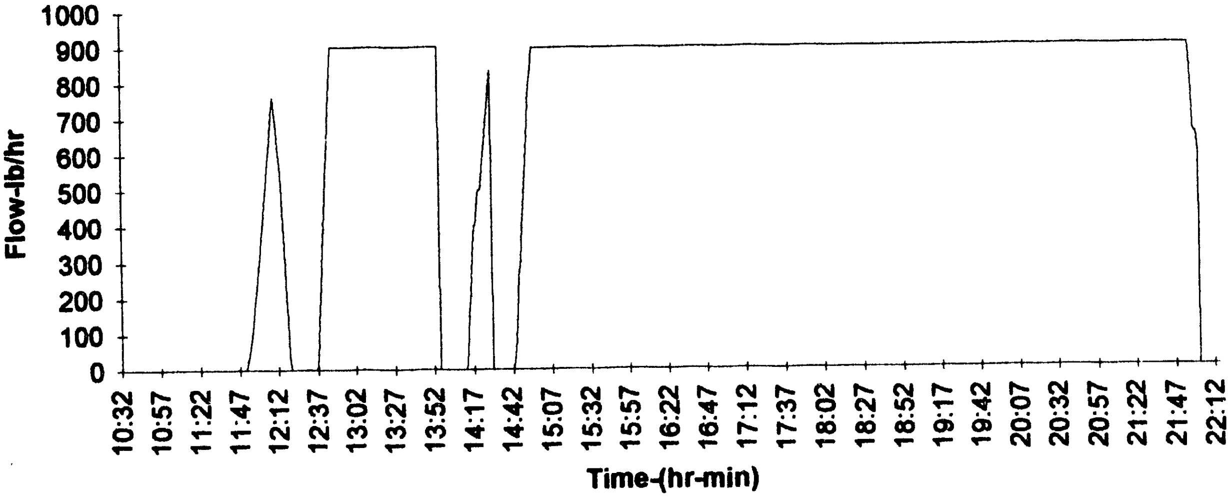


Figure 5: Coal Flow- (lb/hr) -11/11/93 Test

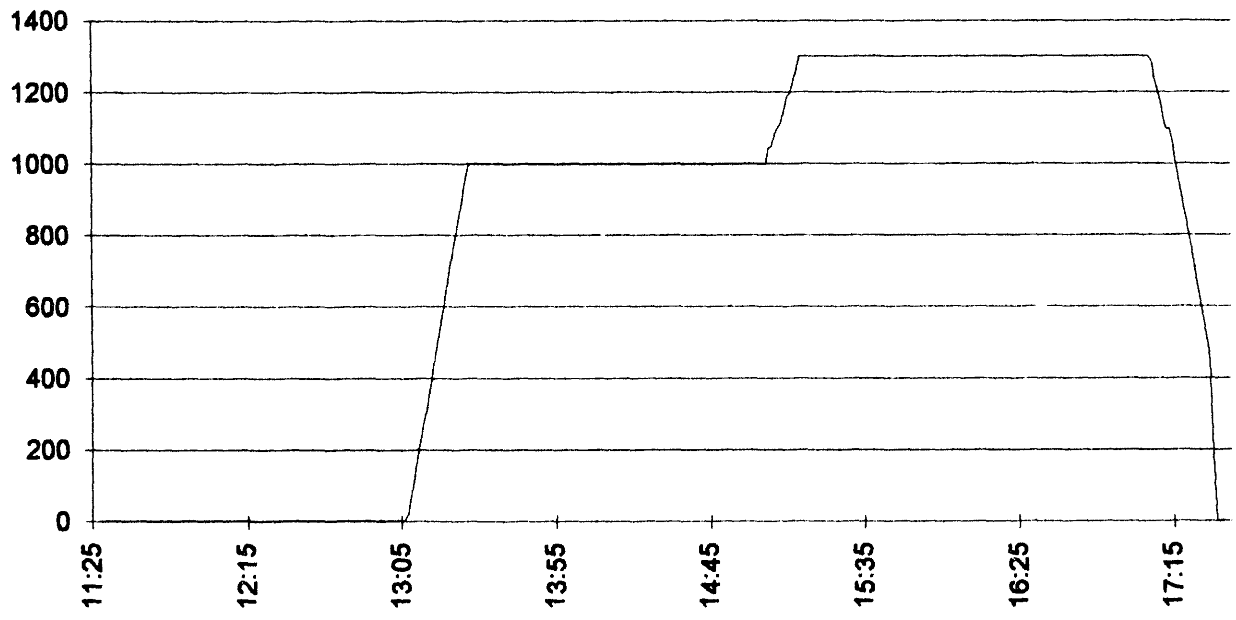


Figure 6: Steam Flow From Flow Sensor-9/23/93 Test

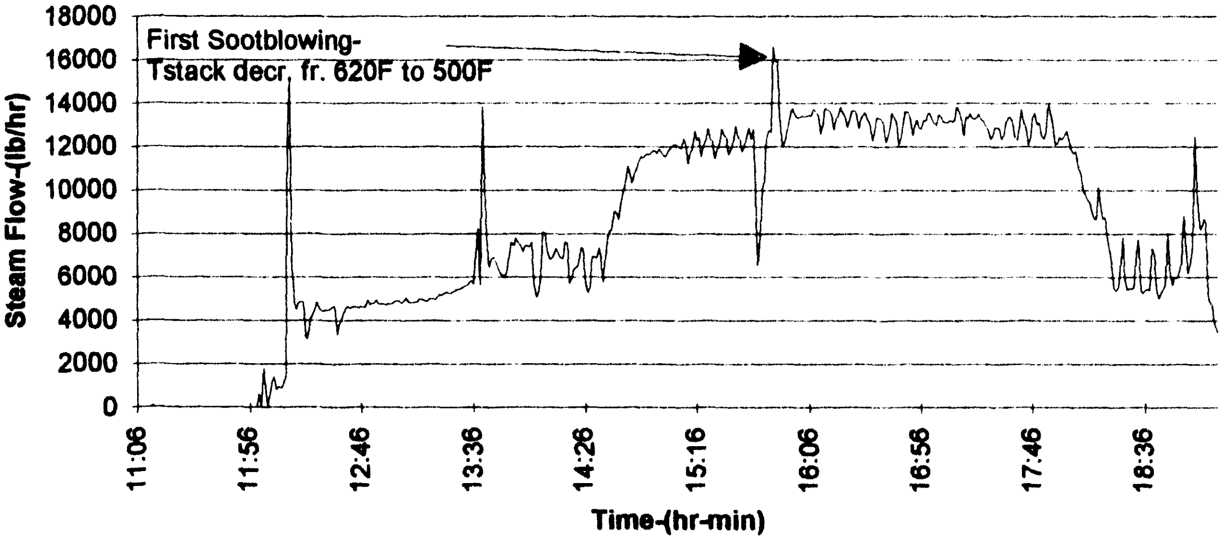


Figure 7: Heat Input from Steam Flow & Based on 450F Stack Temp. -9/23/93 Test

Results not adjusted for boiler efficiency change due to soot on boiler tubes

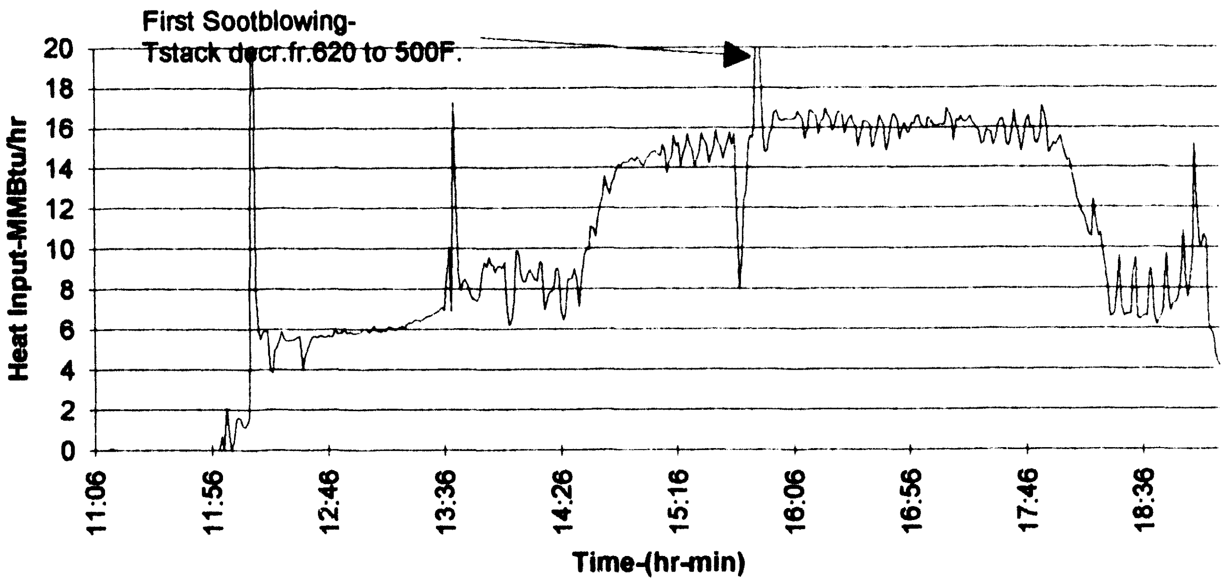


Figure 8: Coal Flow-(lb/hr) 11/18/93 Test

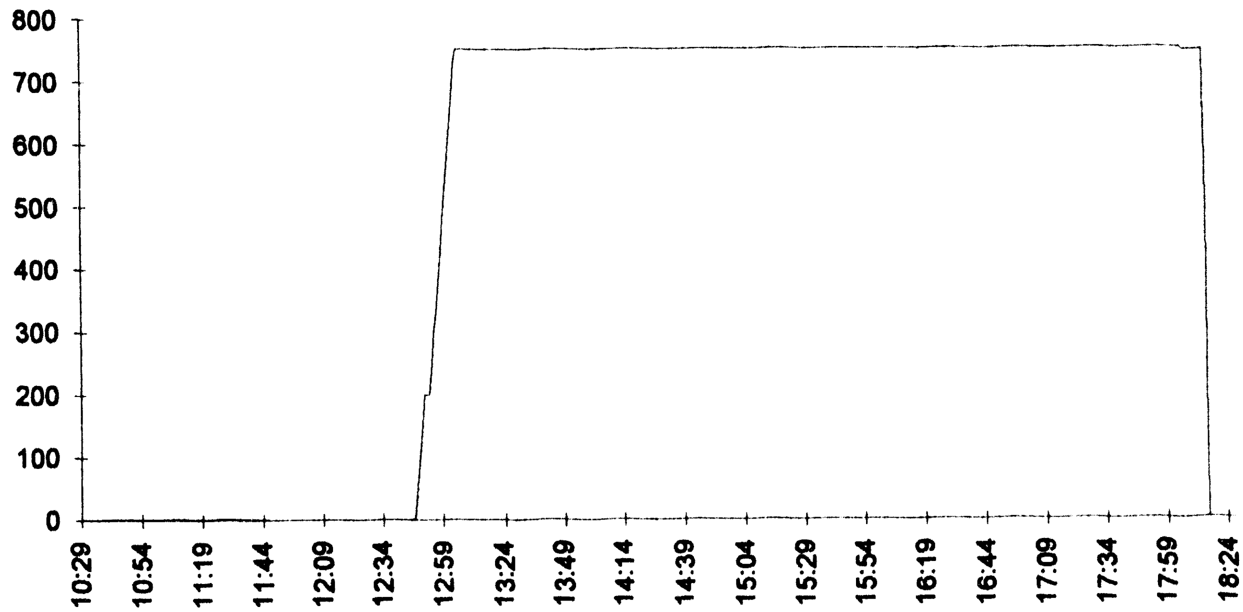


Figure 9: Combustor Wall Temperatures- 11/11/93 Test

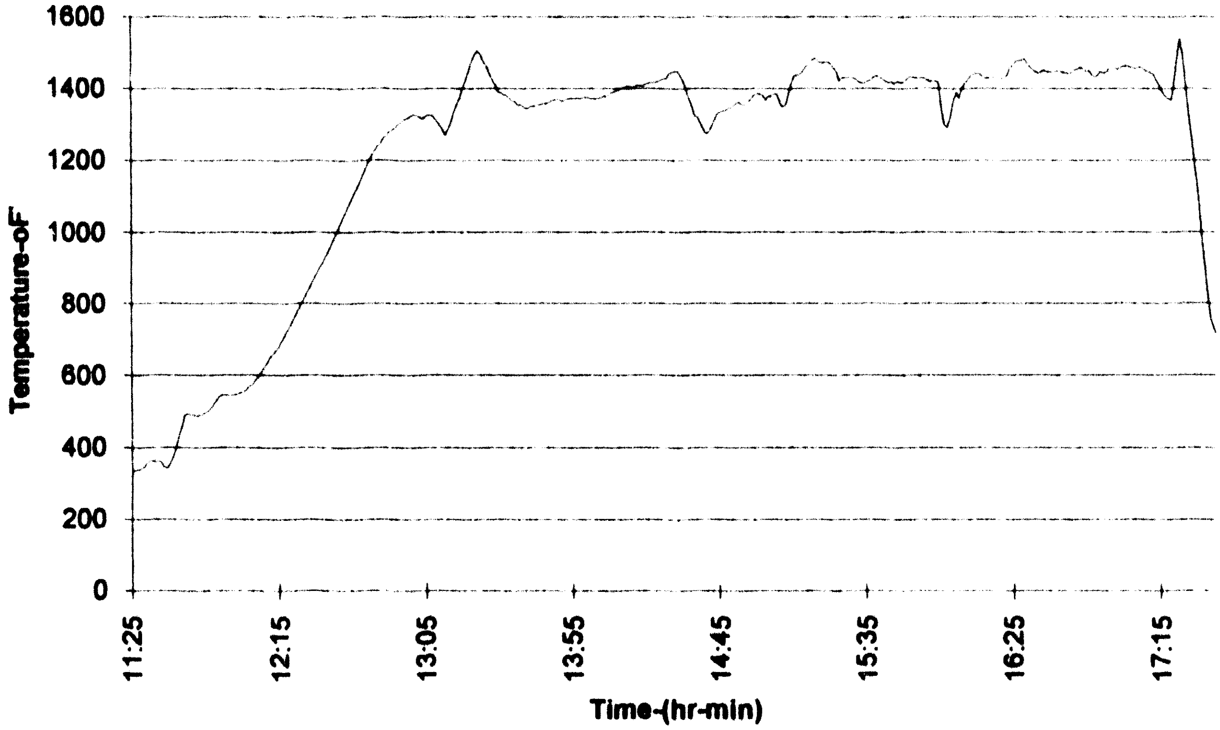


Figure 10: Combustor Wall Temperature-11/18/93 Test

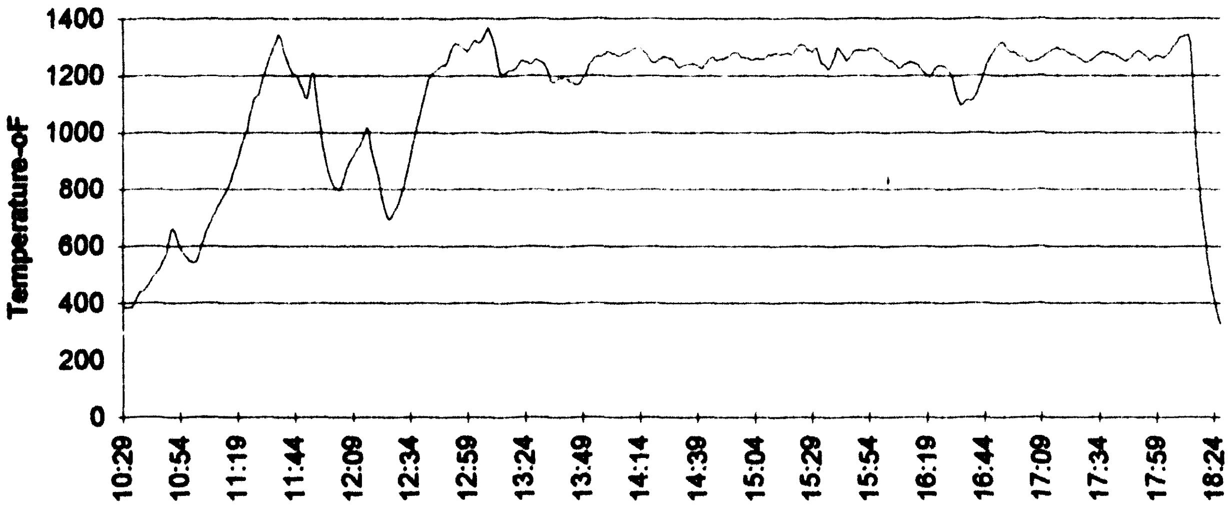


Figure 11:Coal Flow Rate (lb/hr)-11/22/93 Test

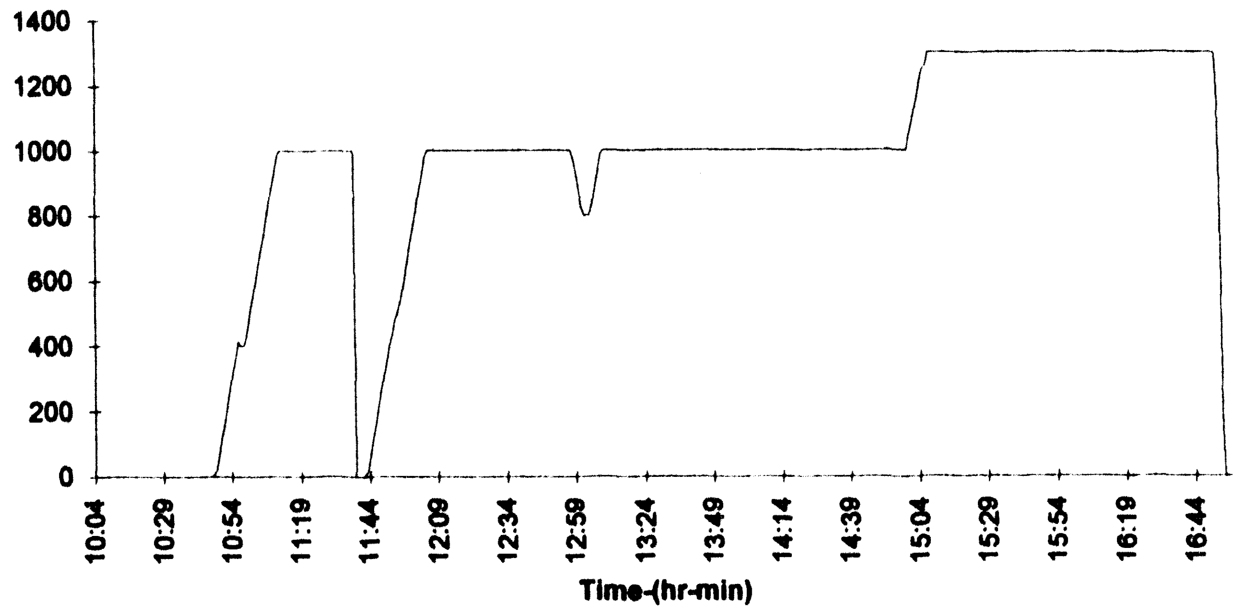


Figure 12: Combustor Wall Temperature-11/22/93 Test

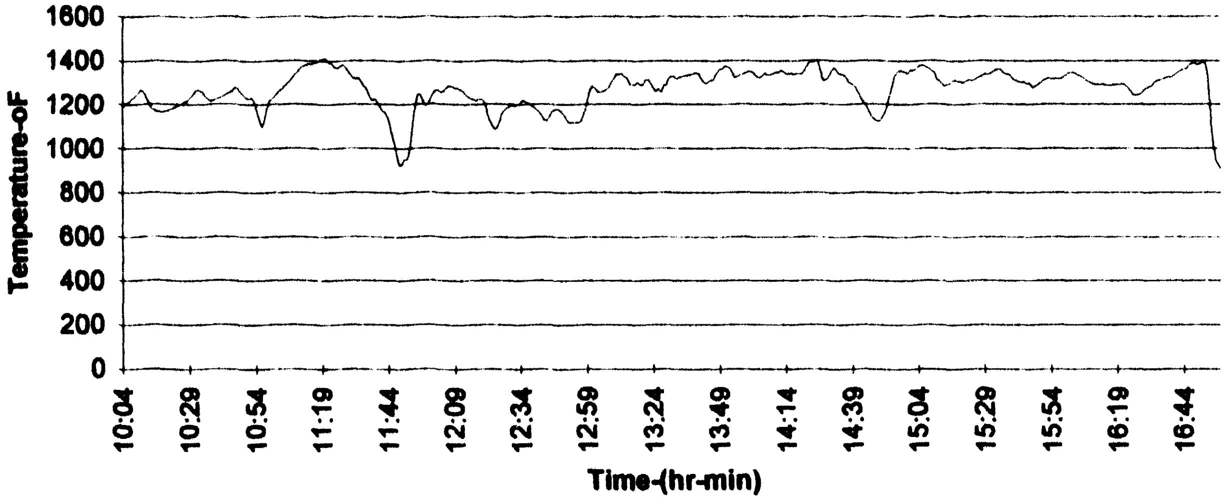


Figure 13: Coal Flow (lb/hr) 11/30/93 Test

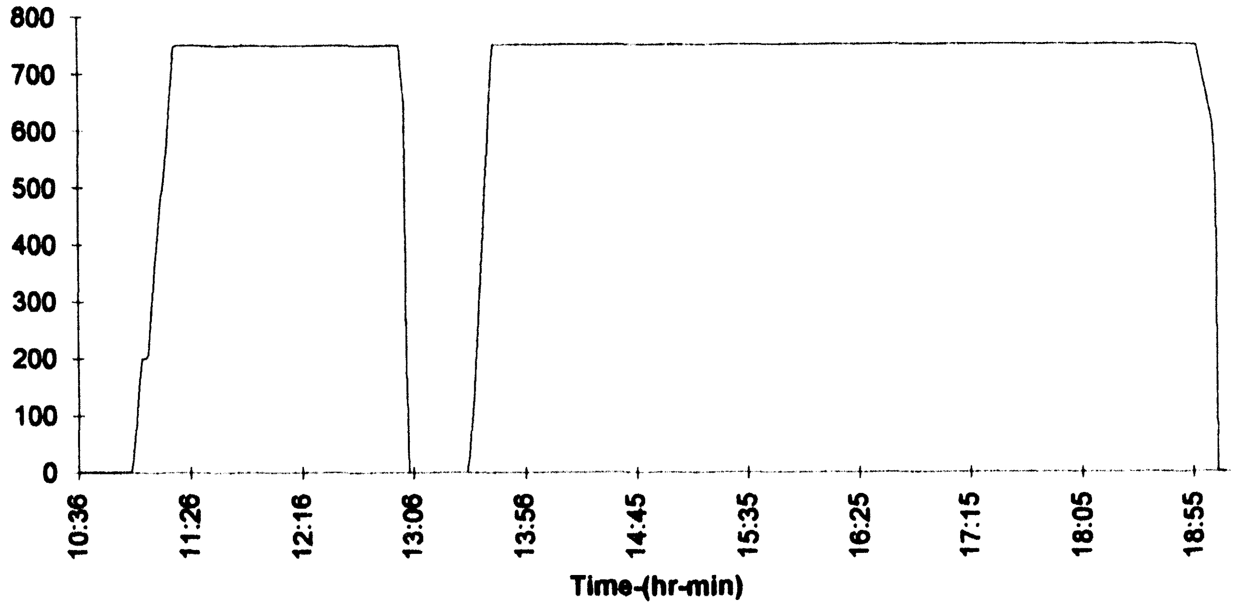


Figure 14: Coal Flow Rates-lb/hr- 12/1/93 Test

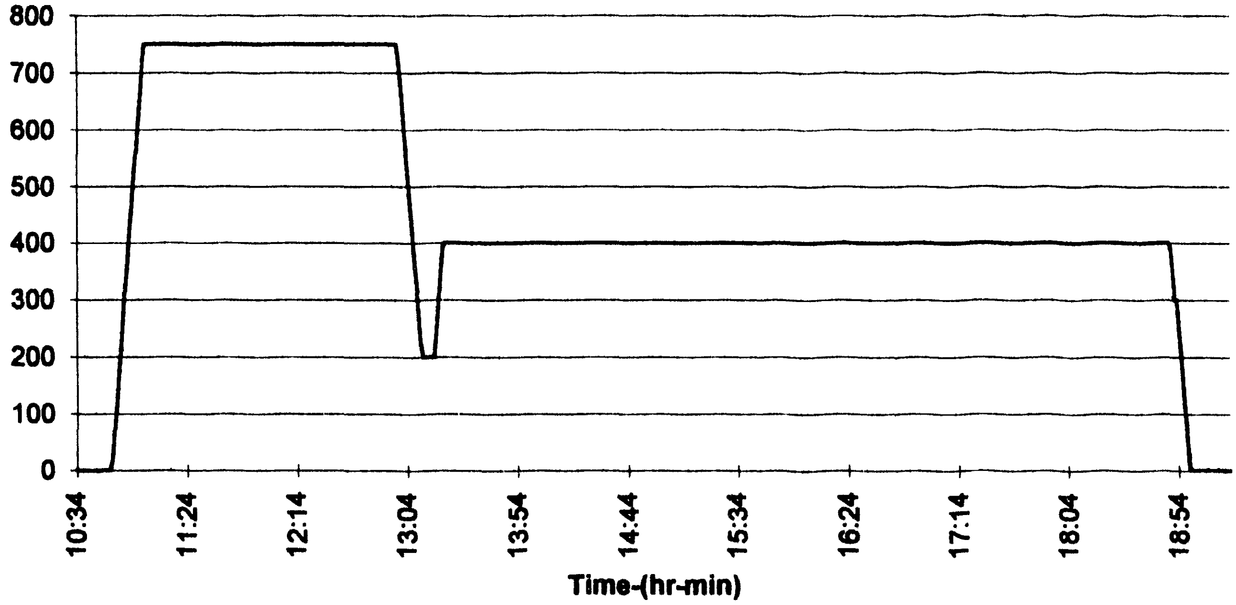


Figure 15: Coal Flow-12/2/93 Test
Coal on-10:07,Coal Off 18:45, Power Failure-14:30, Fan Trip-17:30

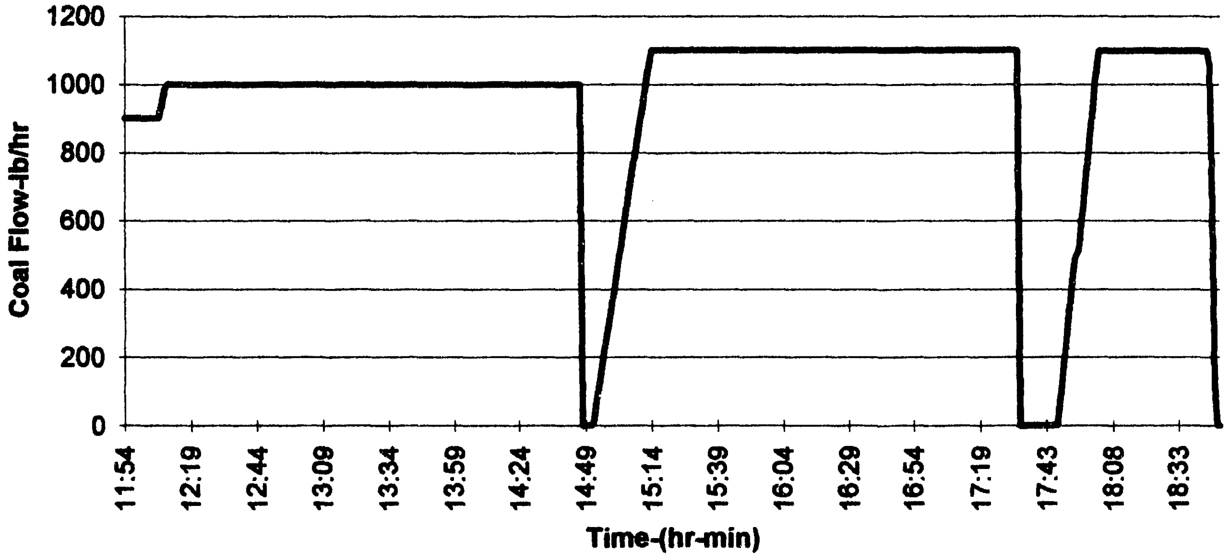


FIGURE 16

4 TON COAL BIN REFILL FROM TANKER

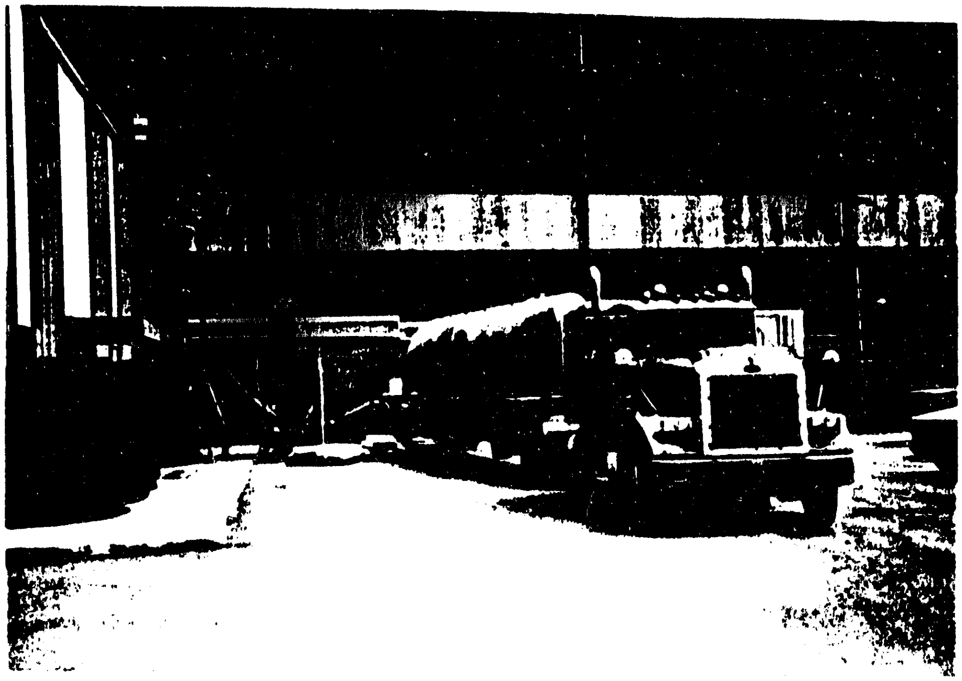


Figure 17: Combustor Wall Temperature- 12/1/93 Test

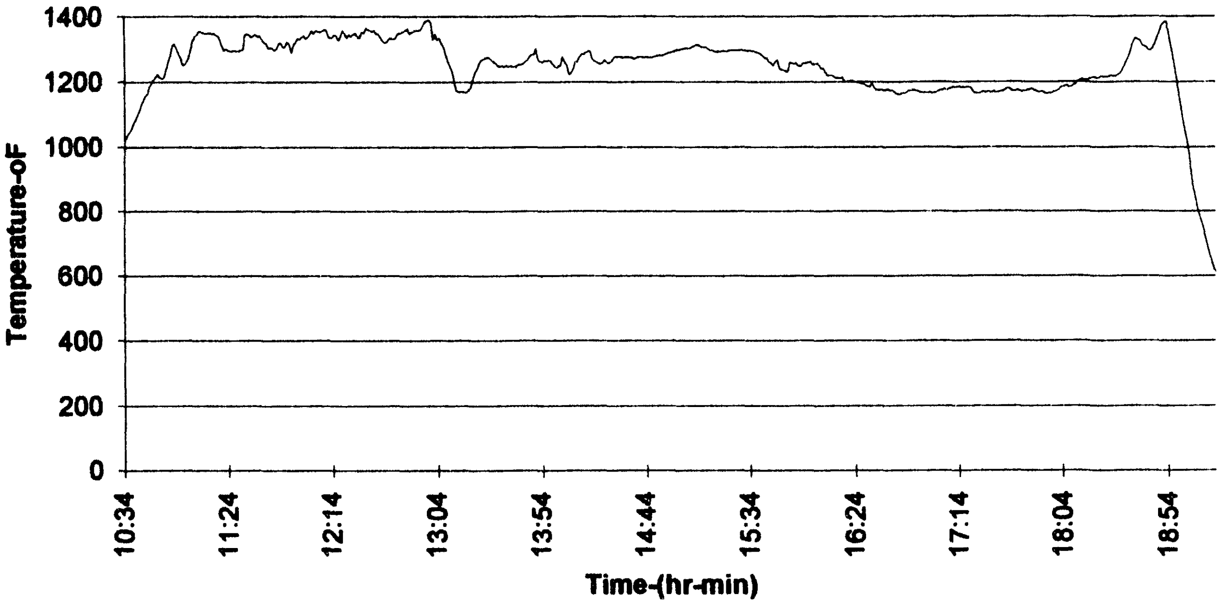
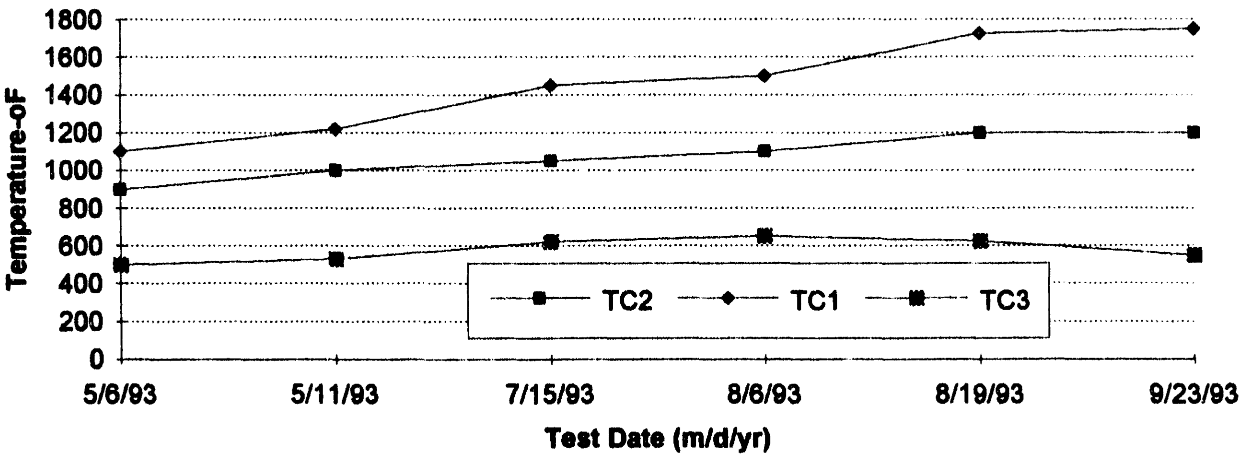


Figure 19: Exit Nozzle Temperatures since Installation of Air Cooling (For location of T.C 1,2,3-See fig.18)



DATE FILMED

7/6/94

END

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