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U.S. DOE-CLEAN COAL PROGRAM

"THE DEMONSTRATION OF AN ADVANCED CYCLONE COAL COMBUSTOR, WITH INTERNAL SULFUR, NITROGEN, AND ASH CONTROL FOR THE CONVERSION OF A 23 MMBTU/HOUR OIL FIRED BOILER TO PULVERIZED COAL"

FINAL TECHNICAL REPORT

APPENDIX I. Chronological Description of the Clean Coal Project Tests

REPORTING PERIOD - March 9, 1987 to February 28, 1991

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TABLE OF CONTENTS

1. INTRODUCTION:

The following is brief description of most of the tests undertaken during the Clean Coal project. It purpose is to provide a historical record of the project and to show the procedures that were used to meet the project objectives and to resolve operational difficulties. The tests begin with the Phase 2 shakedown tests in November 1987 and end with the final 4 day test in May 1990. The descriptions contained in this Appendix are mostly contemporaneous with the period during which the individual tests were conducted. The final data analysis, evaluations, and conclusions are contained in the Final Report Section of this Report, as well as in Appendix II. Beginning on page A-I-43, a tabular listing is given of the total thermal input, percent coal input, first and second stage stoichiometries for all the tests with the second combustor wall liner. The first test in this table, PC9, corresponds to the 11th test, performed on 5/24,25,1988, (see page A-I-7), and the last one, PC26, is the final test in the Clean Coal project.

2. TEST HISTORY

First Test: (PII-A); 11/10/87. Test Goals: hot shakedown of combustor on coal water slurry (CWS). Major discoveries/results:

-Noted excessive vibration in, and noise from, the high pressure cooling/combustion air fan. According to the manufacturer, problem was mainly caused by operation of the fan in the surge mode as well as the set-up of standing waves in the downstream piping. The short-term solution was to operate above the surge mode and put acoustic insulation on the piping. This proved only partially effective. The long-term solution was to reduce the fan outlet pressure by returning the fan to the manufacturer for replacement of the fan wheel. This was implemented prior to the Tenth Test at no cost to Coal Tech and it eliminated the noise problem entirely.

-Combustion efficiency on CWS estimated to be near 100%.

Second Test: (PC-1); 11/19/87. Test Goals: first attempt at pulverized coal (PC) operation. Major discoveries/results:

-Operated for 6 hrs on PC at total fuel heat inputs of 14 to 16 MMBTU/hr.

-Stack particulate scrubber performed well, giving a clean white steam plume at venturi delta-P = 14" WC.
-Experienced numerous nuisance UV fire eye trip-outs due to shadowing of the view port by the emerging coal stream. Modified coal injection (modification #1) prior to next test.
-PC estimated combustion efficiency < 80% plus significant slag/ash carry-over into the boiler.
-Oscillation in PC flow of ± 7% at 900 PPH. Attributed to excessive interaction of PC pneumatic line with of coal feed hopper. Before the next test, piping was rearranged to reduce this interaction.

Third Test: (PC-2); 12/8/87. Test Goals: evaluate modified PC injection for fire eye, combustion efficiency, and slag/ash carry-over effects: evaluate rearranged pneumatic feed line for PC flow effects. Major discoveries/results:

-PC in the feed hopper was caked or in clumps, resulting in PC flow surges causing upsets in combustor pressure. This prevented evaluation of eductor operation.

-Modified PC injection did not improve PC combustion efficiency or solids retention in the combustor. The quality of the PC, as noted above, may have been a contributing factor to this result. It appears that moisture or tramp material had entered the coal supply at the pulverization company site.

-Scrubber performance was poor. Due to surging PC flow it was decided to evaluate scrubber performance during another test with better PC flow conditions.

All the above tests were performed with coal fuel pre-heat of the combustor.

Fourth Test: (PC-3); 12/16/87. Test Goals: attempt to improve PC combustion efficiency and combustor solids retention by pre-heating combustor with high thermal input oil burner; evaluate second pneumatic line rearrangement for PC flow effects. Major discoveries/results:

-No significant combustor pre-heating was achieved due to use of a too narrow light oil gun spray angle.

-PC flow oscillations were reduced to ±3% at 600 PPH but scrubber still performed poorly, pulling only 8" WC delta-P. It was subsequently discovered that significant amounts of unburned coal had deposited in the boiler passages, presumably during the previous test, thereby choking gas flow to the scrubber and reducing its efficiency. Boiler and gas flow train were cleaned prior to the next test.

-PC combustion efficiency and combustor solids retention were still too low.

<u>Fifth Test:</u> (PC-4); 1/6, 7/88. Test Goals: evaluate scrubber performance; again attempt to improve PC combustion efficiency and combustor solids retention by pre-heating combustor with high thermal input light oil burner, but this time with a wide angle spray nozzle; evaluate modified (modification #2) PC injection effects on PC combustion efficiency and combustor solids retention. Major discoveries/results:

-Scrubber operation was once again good.

-Use of wide angle light oil spray nozzle resulted in effective combustor pre-heating.

-At 700 PPH PC oscillations in flow were back at ±7%.

-PC combustion efficiency was not improved.

-Combustor solids retention qualitatively improved. Visual observations indicated that slag very viscous and flowing poorly. Some slag did come through the tap; however, the bulk of the slag remained on the combustor walls and hearth. Subsequent lab analysis showed that the glass-like slag composition corresponded to coal ash with no carbon present. Analysis of coal ash indicated that it was highly refractory, having a T-250 = 2800 F, and therefore requiring additives for fluxing. To help in this area a different coal was requested from PP&L, having a lower fusion temperature ash. This coal was received before the next test.

-Attempt to inject limestone to flux the slag failed due to blockage in the limestone feed. System upgraded prior to next test.

-Inspection of the PC eductor showed excessive wear. The eductor was replaced by a higher quality unit.

Sixth Test: (PC-5); 1/19, 20,/88. Test Goals: evaluate upgraded limestone (LS) feed system and effects of LS injection and new coal on slagging. Major discoveries/results:

-LS feed system worked well and had desired effect on coal ash/slag, fluxing the residual slag from the last test and producing copious amounts of liquid slag in the combustor. However, the slag tap blocked early on due to slag flooding and poor air/fuel ratio adjustment on the slag tap heater which allowed the slag in the tap to cool too quickly. Slag tap heating properly adjusted prior to next test. In addition, coal ash chemical analysis showed that the new coal (PC #2) had almost the same T-250 as the old coal (PC #1) and was therefore of no benefit in the effort to improve slagging.

-New PC eductor resulted in flow oscillations of ± 11% at 1000 PPH.

-With first time LS injection reductions of 7 to 36% in SO2 were measured at the boiler outlet at Ca/S = 2 to 4. Subsequent analysis of the slag showed the presence of significant amounts of sulfur only in the presence of CaO from the LS. In addition, 98.5% of this retained sulfur was unreactive as per the EPA Reactivity Test for sulfides, i.e. evolved sulfide < 48 mg/kg vs. limit of 500 mg/kg. Further, cyanide reactivity was found to be < 0.5 mg/kg vs. limit of 250 mg/kg; this result was duplicated for slag samples from the eighth and ninth tests.

-With staged combustion, NOx levels at the boiler outlet were reduced by 60% from the unstaged, excess air (XSA) values. This corresponds to about 200 ppm, normalized to 3% oxygen, or 75 ppm at gas turbine outlet conditions, namely 15% oxygen.

-PC combustion efficiency was estimated to be = or < 95%.

-Slag sample chemical analysis, available on a two week turn-around, showed evidence of chemical interaction between the liner refractory material and the slag even though the slag still retained the same glassy appearance as previously. Visual observations indicated minimal liner degradation.

<u>Seventh Test:</u> (PC-6); 2/3, 4/88. Test Goals: gauge effects of properly adjusted slag tap burner (STB) on slag tap operation. Major discoveries/results:

-Due to presence of rocks in the PC delivered by the grinding company, the PC flow splitter blocked and the PC screw feed motor coupling sheared when the screw jammed, resulting in early termination of the test. It was later determined that this contamination may have been wilful.

<u>Eighth Test:</u> (PC-7); 2/16, 17/88. Test Goals: gauge effects of properly adjusted slag heating (STB) on slag tap operation. Major discoveries/results:

-Properly adjusted STB plus continued use of LS to flux the coal ash/slag resulted in good slag flow through the tap and into the slag quench tank (SQT). After 7 hrs on coal the tap was still open at the end of the test. A mass balance of combustor solids yielded a <u>combustor slag rejection of 70 to 80%.</u>

-PC flow averaged 800 PPH with an oscillation of ± 5%. Post- test examination showed two coal ports blocked. Probably not thoroughly cleared after the preceding test. This resulted in limited coal flow. All PC lines cleared prior to the next test.

-PC combustion efficiency was estimated to be = or > 95%.

-With LS injection at Ca/S = 3 to 5, reductions in SO2 of 16 to 39% were measured at the boiler outlet. Slag samples again showed significant amounts of sulfur only if LS-CaO also present.

-Slag chemical analysis again gave evidence of chemical reaction between liner and slag. Slag contaminated with liner materials was, during this test, highly porous in appearance and yielded sulfide reactivities about 30% higher than the limit. Slag leach testing (EP Toxicity Test) for hexavalent chrome yielded < 0.01 mg/L (chrome standard = 5 mg/L) even with significant chrome in the slag.

Ninth Test: (PC-8); 2/24/88. Test Goals: attempt to duplicate good overall combustor performance at higher PC flows and with a richer first stage. Major discoveries/results:

-There was good slag flow through the tap and into the SQT. The slag tap remained open throughout the test.

-With all four coal ports open the average PC flow was 800 PPH with an oscillation of ± 17%. Oscillation was believed to be due to continued excessive interaction between the pneumatic line and the coal feed hopper. Prior to the next test the pneumatic line was further modified to try to further this interaction effect.

-Owing to the very high oscillation in the coal flow, the first stage stoichiometry was not adjustable.

-Persistent over-temperature readings on one of the combustor thermocouples (TC's) brought about early termination of the test. Post-test evaluation of the combustor liner gave evidence of partial liner failure due to thermal and chemical causes. Initial assumption was that the cause of liner failure was refractory nature of the coal ash, requiring LS injection and high liner temperatures to achieve sufficient fluidity for slagging. Solution was threefold: (1) request from PP&L a new coal (PC #3), having a less refractory ash; (2) install a new liner material having thermal and chemical properties more compatible with the coal types used or anticipated; (3) implement a new TC arrangement to directly monitor liner temperatures. Post test liner materials analysis by X ray diffraction and other tests, as well as a liner stress analysis showed that the liner failure was due to thermal stresses caused in large part by poor fabrication of the liner assembly.

-Analysis of total suspended solids in the scrubber water indicated that the discharged levels of cadmium, copper, and selenium were well below the limits prescribed by the Williamsport Sanitary Authority.

-Slag analysis showed presence of liner; resultant porous slag had sulfide reactivity about 10% above the limit.

<u>Tenth Test:</u> (CC-1); 5/10, 11/88. Test Goals: thermally cure new combustor refractory liner; develop thermal "calibration" data and a heat-up/cool-down procedure for the new liner on light oil; evaluate suitability of new TC arrangement for combustor operation control. Major discoveries/results:

-A "calibration" curve of wall heat flux vs. total fuel heat input (Q_t) as well as heat-up/cool-down procedures were developed.
-The new TC arrangement proved adequate for combustor control and yielded reasonable values for liner temperatures.

<u>Eleventh Test:</u> (PC-9); 5/24, 25/88. Test Goals: evaluate new liner and operating procedures on PC (PC #3). Major discoveries/results:

-PC combustion efficiency estimated = or < 95%. PC average flow 420 PPH with oscillation = ± 3%.

-Measured wall heat flux agreed with "calibration" curve.

-With no LS injection the measured SO2 was reduced by 39% between the boiler outlet and the scrubber stack. With LS injection at Ca/S = 1 there was a 34% reduction in SO2 at the boiler outlet; however, at the scrubber stack there was no additional decrease in measured SO2.

-With LS injection there was good slag flow through the tap and into the SQT; however, plugging of the tap seemed imminent near the end of the test. Analysis of the coal ash composition yielded T-250's = 2725 F (oxidizing) and 2450 F (reducing), which are only slightly better than the previous coals. Prior to the next test a refractory extension to the slag tap chamber was installed to try to forestall slag hang-up or attachment in that area of the slag drop-out chute.

Twelfth Test: (PC-10); 6/7, 8/88. Test Goals: attempt to duplicate good results of previous test, evaluate performance of refractory slag tap chamber extension, and clarify SO2 capture results. Major discoveries-results:

-Test was terminated early due to slag tap blockage. Post-test inspection showed that the blockage started in the recently installed refractory extension. This extension was removed prior to the next test.

-PC flow was 385 PPH ± 12%. Besides pneumatic line suction effects it appeared that the PC was hanging up in the screw feed hopper such that the operation of the high level switch, which controls rotary valve feed to the hopper, was being interfered with. To try to deal with this, a vibrator was installed on the hopper before the next test. In addition the pneumatic system was reconfigured to prevent fugitive coal dust emissions to atmosphere.

Thirteenth Test: (PC-11); 6/29/88. Test Goals: evaluate effects of hopper vibrator and fugitive dust collector on PC feed. Major discoveries/results:

-PC feed averaged 800 PPH ± 8%. This is worse than the ± 3% obtained in the tenth test. Evaluation of hopper-fill rotary valve operation during the test indicated that the vibrator was not adequately dislodging PC accumulated on the hopper walls such that the PC hopper bed height fluctuated over a wide range. After discussions with the vibrator manufacturer it is planned to install a second vibrator to attempt to minimize wall hang-up. In addition, analysis of all available coal flow data suggested that the fugitive coal dust collector offered too much flow resistance for the pneumatic line to operate properly. Modifications to the dust collector were made to overcome this problem.

-PC combustion efficiency estimated near 100%.

-No reduction in measured SO2 at the boiler outlet occurred with LS injection at Ca/S = 0.5 to 2.5, but first stage inverse equivalence ratio was not optimized for this test. However, there was a 46% reduction in measured SO_2 between the boiler outlet and the scrubber stack.

Fourteenth Test: PC 12; 8/16/88. Test Goals: evaluate effects of a added heat input to slag tap on tap operation; evaluate effects of a new coal (PP&L PC #4: HHV = 12,590 Btu/lb; Moisture = 2.65 %; Volatile Matter = 34.3 %; Carbon = 68.0 %; Ash = 13.0 %; Sulfur = 2.48 %) on coal combustion and slagging properties; evaluate effects of second feed hopper vibrator as well as additional pneumatic line modifications on coal flow stability. Major discoveries/results:

- With about two hours on coal the average flow was 1027 PPH ± 3 %; the flow variability being reduced considerably.

- Coal combustion efficiency 94 to 99 % based on stack gas and particulate analysis.

- At Ca/S = 1.0 to 1.4 the measured reduction of SO^2 in the boiler outlet was 30 to 35 % with a near stoichiometric first stage; similar to the results of Test Nine, the scrubber had no effect on measured SO_2 when sorbent was injected into the combustor.

- Slag samples showed the presence of extraneous refractory material. Since there were up to four potential sources for material having the observed general composition, the origin was not clear although it did not appear to be from the liner or slag tap. By inference, it was thought that the source was the refractory cement used to fabricate the slag dam in the exit nozzle throat or possibly exit nozzle material; if so, gradual loss of the dam was no cause for concern as it was being replenished by slag.

- Test was stopped when slag tap blocked. Prior to the next test, the slag tap was modified to provide access ports for a mechanical breaker to be used if the slag tap became blocked.

In addition, the bare metal section of the slag tap was coated with refractory since this area had been identified as a source of slag freezing, leading to eventual blockage.

<u>Fifteenth Test</u>: (PC-13); 9/12/88. Test Goals: aim at trouble-free slag tap operation or, in the event of slag tap blockage, evaluate the use of a mechanical breaker for reopening the tap. Major discoveries/results:

- After only about a half-hour on coal the test had to be terminated when hot combustion gases broke out into the room through the slag chute flange. This occurred because the flange gasket was improperly installed.

- Slag samples, which were residual from Test Twelve, again showed "extra" high-non-coal slag refractory material plus some iron oxide. This refractory was again thought to be from the slag dam while the iron was attributed to the chute which had become red-hot at one point during the preceding test when slag collected on a metal section of the slag tap section.

<u>Sixteenth Test</u>: (PC-14); 9/22/88. Test Goals: aim at trouble-free slag tap operation or, in the event of slag tap blockage, evaluate the use of the mechanical breaker for reopening the tap. Major discoveries/results:

- Coal flow over two hours averaged 1220 PPH ± 1.5 %, i.e. there was almost no flow fluctuation.

- Test ended with slag tap still open.

- Measured combustor slag rejection was 70 to 80 %.

- At Ca/S = 0.7 to 1.8, the measured reduction in SO_2 in the boiler outlet was 14 to 20 % with the first stage near stoichiometric.

-Test ended when hot combustion gases vented into the room through small openings in the boiler access door while a fairly wide section of the front boilerplate surrounding the exit nozzle became red-hot. Detailed thermomechanical and heat transfer analysis has led to the conclusion that failure was mainly due to poor insulating and thermal resistance properties of original refractories installed in the boiler which were not removed when the combustor was retrofitted to the boiler. In retrospect, evidence of the onset of this problem occurred at the end of Test Eleven when hot combustion gases vented into the room through the gap between the exit nozzle flange and the front boilerplate. This development was originally, as it turned out, erroneously attributed to leakage originating from the Tertiary Air ports. The solution at that time was to make the ports and the flange/boilerplate interface gas-tight by welding the gaps shut. This actually aggravated the problem by eliminating that gas relief point, and led to the refractory breakdown in the boiler front wall.

-New materials and installation design were implemented following a detailed two dimensional heat transfer analysis of the combustor exit nozzle-boiler interface.

<u>Seventeenth Test</u> : CC-2; 11/3/88. Test Goals: on light oil only, cure new refractories used to repair the exit nozzle/boiler front wall and obtain their thermal characteristics via embedded TC's for future diagnostic monitoring. Major discoveries/results:

- With about 6 to 8 MMBtu/hr light oil input, the exit nozzle was brought up to around 1000 to 1200 F at the prescribed rate. Liner thermal performance was the same as in the original calibration test, CC- 1, of 5/10,11/88.

<u>Eighteenth Test</u>: (PC-15); 11/8,9/88. Test Goals: evaluate operation of a newly installed hot gas bypass line to establish fuel rich conditions in the combustor, and collect time resolved data/samples for slag, scrubber water, and boiler outlet plus fan stack gases. In addition, evaluate the utility of new and very novel mechanical slag breaker equipment installed in the slag chute for clearing away slag blockages in the tap. Major discoveries/results:

- The hot gas bypass line was too small and did not allow enough air bleed to desired fuel conditions in the combustor. It was decided to install a larger line prior to the next test.

- The unit was operated at 5 to 10 MMBtu/hr at first stage theoretical air fractions of 1.1 to 2.0, consuming about 1.2 tons of PC. Overall combustion efficiency exceeded 98%.

- The measured combustor slag rejection was > 70%. Slag was perceived as too viscous, resulting in periodic tap blockages. Mechanical means were only partially effective in removing slag blockages. The slag viscosity was subsequently attributed as the cause of this blockage.

- The temperature response time of the newly installed boiler refractory wall (part of the exit nozzle/boiler refractory rebuild), with regard to gross changes in thermal conditions, was measured. It was determined that an additional modifications to the wall thermal profile was indicated, and this was implemented prior to the next test. Without this change, continuous long duration operation would have been more complicated.

- At Ca/S = 0.5 to 3.0, the measured reduction in SO_2 in the boiler outlet was 0 to 18 %. However, with and without limestone (LS) injection the scrubber removed from around 10 to 35 % of the SO2; the details of this interaction are not yet clear.

<u>Nineteenth Test:</u> (PC-16); 12/13,14/88. Test Goals: evaluate new hot gas bypass line for establishing desired combustor conditions and collect data as noted for test PC-15. Evaluate combustor-boiler interface thermal profile with new modification. Evaluate general performance of new slag chute features for keeping the tap open. Perform a consecutive, two-day test on PC with the first day at fuel-lean conditions, and the second day at fuel-rich combustor conditions. Major discoveries/results:

- The modified combustor-boiler interface maintained this region at the desired temperatures.

- Evaluation of the new bypass line to establish desired combustor conditions on the second test day was not attempted due to the unscheduled termination of the test due to development of a cherry red glow at the top of the new slag chute. This was caused by accumulated partially frozen slag. The test ended with the slag tap still open.

- As in test PC-15, attempts to clear away large slag formations (which eventually formed even with the combustor liner at or above the slag fluidizing temperature) in the slag tap section by use of mechanical means were partially successful in that only small holes could be made in the hot slag. However, with technical input from the DOE project officer, who was on site during the second day, it was agreed that the new thermal input designed to keep the slag tap open was accomplishing its design function. However, it was not possible to properly test it due to a lack of sufficient water pressure at the slag chute. Prior to the next test a booster water pump was installed to overcome this deficiency.

- During the two day period, the combustor was fired at 10 to 15 MMBtu/hr at first stage theoretical air fractions of 1.0 to 1.4. About 1.7 tons of PC were consumed during this run. Overall combustion efficiency exceeded 95 %.

- At Ca/S = 1.0 to 2.4, the measured reduction in SO2 in the boiler outlet was 0 to 31 %. However, with LS injection the SO2 removal in the fan stack was around 30 %; the details of this interaction are not yet fully understood.

<u>Twentieth Test</u>: (PC-17); 1/10,11/89. Test Goals:(1) operate combustor at target fuel rich condition (viz. inverse equivalence ratio or theoretical combustion air fraction = 0.7) by manipulation of swirl air to the combustor. A modification to allow this manipulation was installed prior to Test PC-16. This was the 1st test in which this flow arrangement was used to evaluate fuel rich effects on environmental control; (2) evaluate operation of new slag tap cooling circuit; and (3) evaluate slag tap heating as an aid to keeping the tap open. Major discoveries/results:

-The combined control of swirl air inlet positioning and gas bypass flow allowed reduction of first stage combustion air to the required value. However, an air fraction of 0.85 was found to be a practical minimum owing to very poor overall combustion efficiency at lower stoichiometries. The poor combustion efficiency at lower stoichiometries was attributed to poor fuel/air mixing at reduced firing rates, which results in relatively low total mass flow/velocity momentum at these operating conditions. This conclusion is suggested by the low swirl air pressure levels. Previous successful operation at lower stoichiometries was likely due to better mixing at high thermal heat inputs to the combustor where higher combustion swirl air injection velocities were obtained. Thus, a thermal input threshold appears to exist for good combustion performance at reduced loads and fuel rich conditions. Another factor that could influence the poor combustion is the low temperature in the furnace region of the boiler which would impede final fuel burnup.

- At Ca/S = 0.8 to 1.9, the measured reductions in SO_2 at the boiler outlet were 11 to 15 %. In line with previously reported results, the scrubber further reduced the measured SO_2 to provide overall reductions of 17 (without sorbent injection) to 38 % with sorbent injection. Calculations suggest that scrubber sulfur removal capacity is controlled by an equilibrium phenomenon, probably involving the solubility of sulfur-containing species.

- Owing to the difficulties in trying to establish fuel rich operation, no reliable slag rejection data were obtained. However, chemical analysis showed about 5 % of the total sulfur present in the slag for fuel rich operation and only 0.6 % for excess air conditions. These samples showed essentially the same level of sorbent. This result is encouraging in terms of qualitative validation of the Coal Tech's sulfur capture concept.

- The slag tap heating system worked well, except as noted below. Owing to upsets associated with efforts to establish fuel rich conditions, it was not possible to gauge effects of this new method of heating on tap performance; however, at the end of the test the bottom of the slag chamber was only lightly covered with easily removable slag.

- Inadequate cooling of the slag tap was noted when the discharge water became hot and occasionally steamed. It was decided that prior to the next test the water flow rate would be further increased.

Twenty-first Test: (PC-18); 1/23,24/89. Test Goals: attempt to operate combustor at target fuel rich condition with good combustion performance by raising swirl air pressure (velocity) to the combustor. Test another sulfur sorbent and its effect on SO_2 capture. Major discoveries/results:

- The unit was operated at about 11 MMBtu/hr. However, owing to an error in the cooling/combustion air flow reading, the first stage theoretical air fraction was inadvertently set to 1.2 to 1.3, instead of 0.7.

- Based on scrubber solids carry-over, the calculated combustor/boiler slag retention was near 70 %.

- With limestone (LS) injection at Ca/S = 1.7, the measured reduction in SO_2 in the boiler outlet was 10 to 14 %. With the other sorbent at an equivalent level of Ca/S = 0.5, the corresponding reduction was around 16 %. Based on the relative calcium utilization for the sorbents the latter material was 3 to 4 times more effective than the LS in removing SO_2. This result is believed to be due to chemical differences in the two sorbents and/or a difference in size distributions. For either sorbent injection, the scrubber further reduced the measured SO_2 to yield an overall reduction of about 30 %.

-The higher water flow rate to the slag tap solved the overheating problem experienced during the last test.

- On 2/2/89 two new operational procedures were developed:

1. A hand held torch was successfully bench tested for melting large pieces of slag. It was planned to use this torch to melt slag tap blockages via insertion into one of the slag chute ports.

2. Steady state fuel rates and air flows plus combustor thermal conditions were determined to allow overnight combustor firing on NG, thereby saving several hours heatup the next day. To accomplish overnight firing required some piping modifications to the air system. In addition, safety interlocks were identified and upgraded where necessary to allow unattended operation. This system was in place for the multi-day test (PC-20).

Twenty-second Test: (PC-19); 2/13/89. Test Goals: re-attempt to operate fuel rich as per Test PC-18. Evaluate operation of a recently purchased and installed slag conveying system. Confirm apparently higher sulfur capture with the new sorbent vs. LS. Major discoveries/results:

- Efforts to adjust combustion air velocity/pressure to obtain good combustion performance at reduced loads and theoretical air fraction = 0.7 resulted in poor second stage burnout as well as several flameouts. For this reason the test was conducted at near stoichiometric or excess air conditions. The inability to operate at the target stoichiometry, even with increased swirl air velocity, essentially duplicated Test PC-17 results, reported above, and strongly suggests that higher fuel heat inputs are needed to operate at the lower stoichiometries.

- The slag conveyor worked well during this test.

- Slag and scrubber discharge chemical analysis data have not been sufficiently evaluated for inclusion and discussion at this time. This information will be presented in a later report if results are new or inconsistent with historical trends.

- At LS Ca/S = 1.5 to 2.0, the measured reduction in SO2 in the boiler outlet was 11 %. With the other sorbent at an equivalent Ca/S = 1.1, the corresponding reduction was 22 %. This result is in agreement with that obtained in Test PC-18 and confirms that the new sorbent performed significantly better than LS as a sulfur "getter" for the operating conditions employed in the present combustor /boiler system. With the new sorbent, the overall SO_2 removal, in the scrubber fan stack, was around 49 %.

- As in the preceding test, the slag tap blocked toward or during the end of the test but the slag in the chamber was easily removed after the test was complete.

<u>Twenty-third Test</u>: <u>The 1st Continuous 4 Day Test</u>: (PC-20); 3/6,7,8,9/89. Test Goals: major objective is to demonstrate continuous combustor operation over a multi-day period. The emphasis for this test was placed on experimental observables related to operation rather than on parametric studies. The combustor was operated near stoichiometric conditions and the unit was placed on aytomatic overnight operation on gas fuel to minimize the next day's heat-up time to reach coal operating temperatures. Major discoveries/results:

<u>Day 1</u>: The combustor startup at 8 AM. During the day a level of about 12 MMBtu/hr was reached. In the evening, the combustor was shifted to gas fuel and placed on automatic control for the night. At 11 PM, the unit shutdown for an undetermined reason. Although the shutdown was not planned, it did confirm the reliability of the newly installed unattended automatic shutdown procedure and equipment. The combustor was restarted at 6 AM the following day.

- Although the slag conveyor had worked successfully in previous tests, continued operation during this test revealed design flaws which eventually caused the conveying belt to finally jam. Necessary modifications were discussed with the vendor and the unit was been taken out and repaired.

- The various slag tap and chute features designed to prevent slag tap blockage appeared to delay but not prevent blockage, which eventually occured after about two hours. However, these features did restrict the blockage formation to a region of the slag chute where it was more accessible and/or more easily removed than before these features were introduced.

- As had been determined from earlier testing, mechanical slag breakers can be partially or fully successful in keeping the tap open. However, the present test showed that it is essential to design a breaker capable of clearing the tap while the combustor is at normal thermal input power. The mechanical breakers used in the present test did not have this feature, and it was necessary to lower the combustor thermal input to operate them. This caused a major buildup of slag deposits at various locations in the combustor. In fact, on the 4th day of the test, the slag buildup in one region of the combustor reached the point where shutdown was necessary to eliminate unstable combustor operation. To correct this problem, design and fabrication of a slag breaker capable of operating in a hot gas environment began, in time for testing in May 1989.

<u>Day 2</u>: Combustor heat input reached 9 MMBtu/hr on coal.

- Overnight heating of the combustor, even at low levels, revealed that the refractory insulated boiler wall, unlike the air cooled combustor, runs near-adiabatic, retaining much of its thermal storage. This resulted in initiation of slag formation in the exit nozzle, probably in addition to combustor wall slagging. While this had been observed in the one day tests, the effect was more pronounced in the present test.

- The combustor wall temperature dropped significantly during the test at steady state operation. This had been observed in earlier tests and was attributed to slag buildup on the combustor wall. This effect appeared to be localized, with other regions of the combustor remaining at normal temperature.

- The slag tap blocked at end of the test but was easily cleared upon cooldown. The combustor remained on gas fuel all night, with no automatic shutdowns.

<u>Day 3:</u> Combustor operated at about 12 MMBtu/hr with coal.

- Owing to operational problems, noted above, the slag conveyor was removed at the beginning of the test day. Screen mesh buckets were used instead to collect slag.

- After about two hours the tap became blocked. Efforts to mechanically clear the tap of hot slag were only partially successful. After the slag was allowed to cool by discontinuing firing, the tap was cleared with some difficulty. The unit was then restarted and coal operation continued.

- As the consecutive-day test proceeded, slag initiation seemed to occur preferentially in the nozzle rather than in the combustor, such that at the end of the test the exit nozzle was partially blocked with slag. This phenomenon could be detrimental to the Phase III test goal of multi-day firing if not corrected. Post-test inspection revealed large ash, not slag, deposits inside the combustor. This observation, in itself, suggests that the combustor walls were running too cold, possibly as a result of the above difficulty encountered with the wall temperature measurement. This may account for most of the exit nozzle slagging and therefore might also provide a remedy, namely, operation with a hotter combustor wall. Refurbishment of the wall temperature control was performed prior to the next test.

<u>Day 4</u>: Again the combustor remained on line with gas fuel all night. The combustor was then fired to about 13 MMBtu/hr on coal.

- Owing to continued slag buildup in the exit nozzle, potentially leading to excessively restricted combustion gas flow, the test was terminated in the early afternoon of the 4th day. The combustor had been on-line for a total of 65 hours out of a total elapsed time of 80 hours.

- After shutting off the main burners, the slag tap was found to be almost half open. The hand held torch was tested to see if it would improve the situation, but the blockage was not in a location where the torch flame impinged and therefore had no effect. However, it seemed that this approach would be efficacious in opening the tap if it were more fully blocked.

- Based on the weight of solids collected from the slag quench tank during the test, the material retrieved from the combustor and boiler floor after the test, and the measured discharge rate of scrubber solids, the cumulative combustor/boiler solids retention was calculated to be near 80 %.

-Preliminary evaluation of the chemical composition of ash samples obtained from inside the combustor after the test showed up to 25 % of the total sulfur present in the ash along with high CaO levels. Previous highs, obtained from rejected slags, were only about 5 %. <u>This amount of sulfur retention was the highest in the project to that date, and it appeared to confirm the Coal Tech concept of "in situ" sulfur capture by injected sorbent; the requisite corollary being rapid rejection and removal with the slag to prevent desulfurization.</u>

Twenty-fourth Test: (PC-21); 5/16,17/89. The test goals were:
-To evaluate the effectiveness of a mechanical slag breaker in keeping the slag tap open.
-To operate combustor at target fuel rich condition, namely inverse equivalence ratio or theoretical combustion air fraction = 0.7.
-To observe the effect of a reconfigured tertiary air piping designed to enhance the mixing of second stage air and first stage combustion gas
-To operate the recently refurbished slag conveyor.
-To evaluated and a check the sorbent screw feed calibration.

Major discoveries/results:

- With oil firing the slag breaker was tested and a hot spot developed. Modification of the operating procedure on the second day solved this problem.

-After a short interval on coal, the rotary coal feed valve jammed. Inspection indicated the presence of pieces of metal in the PC. Several efforts were made to clear the valve and dump some of the coal. This would have solved the problem if the tramp metal was localized in the lower portion of the storage bin. Unfortunately, the valve repeatedly jammed, thus aborting the first day's test.

- On the second day a screen was inserted above the rotary valve but without vibration the sieved PC flow was too low to conduct useful tests. Later discussions with the pulverization company could not clearly identify the source of the tramp material. All contaminated coal was removed from the bin prior to the next test.

- No environmental data were obtained owing to the coal feed problems; however, visual observation of second stage combustion indicated improved operation during staged combustion on oil.

- The flow calibration check of the sorbent screw feed showed that limestone flows were actually somewhat higher than previously thought while flows of the second sorbent agreed with the previous values.

- The control thermocouples which were upgraded after the last test operated well and indicated there was some slag deposit buildup on the combustor walls due to the erratic coal operation.

<u>Twenty-fifth Test</u>: (PC-22); 6/19,20/89. The test goals were:
-To evaluate effectiveness of the new mechanical slag breaker in keeping the slag tap open.
-To operate combustor at target fuel rich condition, namely inverse equivalence ratio or theoretical combustion air fraction = 0.7.
-To observe effects of the reconfigured tertiary air piping in providing

enhanced mixing of second stage air and first stage combustion gas.
- To continue operation of the recently refurbished slag conveyor.

Major discoveries/results:

- The unit was operated at about 12 to 13 MMBtu/hr, averaging around 870 PPH PC and consuming about 1.4 tons of coal. The first stage inverse equivalence ratio was 0.89 to 1.26 with overall combustion efficiencies near 100 %. The second stage burnout was visually improved. Obtaining a lower theoretical air fraction at the above firing rates was found to be difficult owing to the dynamic interaction of the several cooling/combustion air streams. At higher firing rates operation at target combustor air level should be more easily achieved.

- Test resulted in high slag rejection into the tap and slag quench tank (SQT). The onset of slag tap blockage was noted several times. However, the slag breaker proved to be effective in knocking out slag blocking the tap without imposing a down-time penalty, i.e. without requiring banking or turning-down the combustor. This result essentially removed a major barrier to long duration testing.

- With limestone (LS) injection at Ca/S = 1.25, the measured reduction in SO_2 in the boiler outlet was 16 to 30 %. At the scrubber stack the measured reduction in SO_2 was 33 to 47 %.

- NOx levels agreed with historical values.

- The peak wall heat flux levels corresponded to the highest measured fluxes, obtained in Test PC-18 of 1/23,24/89. Data from both tests show that calculated liner wall temperatures were higher than in most tests.

-Presumably the slag layer was thin in these tests. Operationally this may be the desired running condition. However, liner degradation could be a concern at this operating condition. Evaluation of slag chemical composition is a key parameter in clarifying this matter. In addition, combustion air swirl pressure had a significant impact on heat flux for comparable thermal input. This phenomenon had been noted in previous tests.

- The slag conveyor jammed when a large piece of slag dropped on it after being dislodged by the slag breaker. The conveyor was removed from the SQT with some difficulty. On inspection small pieces of slag were found to have accumulated near the bottom of the conveyor. They were jamming the guides. Further design modifications were implemented before the next test to allow movement of the conveyor in the SQT.

Twenty-sixth Test: The 2nd Continuous 4 Day Test (PC-23) 7/30/90 to 8/3/90

Summary: This 4 day, 92 hour duration test took place between 7/30/89 and 8/3/89. Combustion occurred for 87 hours. 50 hours were unattended overnight operation with natural gas, 21 hours were on heatup and cooldown with oil. 16 hours were on coal firing. 8 tons of coal were consumed. Coal firing occurred at a steady 14 million Btu/hr during the entire test period. The first 3 days of coal firing were under fuel lean conditions. The 4th day was under fuel rich conditions to optimize sulfur capture in the combustor. All the test objectives were met. The total operating time of the combustor approached 600 hours by the end of this test.

Test Description: The test consisted of four days of round-the-clock operation, beginning on Sunday evening and ending on Thursday evening, using the following schedule:

On Sunday evening, the combustor was fired with natural gas at a low thermal input for pre-heating the combustor and boiler. The combustor was placed on automatic, unattended operation until the following morning. At that time, gas/oil thermal input was increased until the combustor reaches normal operating temperatures. The fuel was then changed from oil to pulverized coal firing. Coal firing was maintained at a constant thermal input level for periods ranging up to about 8 hours. The fuel was then switched to oil, and the combustor was cooled to a thermal input level at which unattended overnight operation on natural gas can be maintained. This procedure was repeated on all four days. However, in the first 3 days, the emphasis was on durability testing under optimum combustion efficiency. Therefore, the combustor operated at fuel lean conditions. On the 4th day the emphasis was on sulfur reduction in the combustor, and the combustor operates under very fuel rich conditions. In this case, the combustion efficiency was somewhat lower.

-DAY 1: Combustion began with natural gas at 9PM Sunday, the 30th. The combustor operated on automatic unattended control all night. Beginning at 7:30 AM Monday morning the thermal input to the combustor was increased by adding oil fuel. At noon, the thermal input was about 14 MMBtu/hr. The combustor stoichiometry was fuel lean. At noon, rapid conversion to coal firing began. The combustor remained at this thermal input level, which corresponds to approximately 1/2 ton/hour of coal flow until 4 PM, when a flameout occurred. The cause of the flameout was not determined, and the combustor was restarted.

It was noted that thermocouples located in the front wall of the boiler in the region of the exit nozzle were recording higher temperatures than had been previously encountered. Also, visual inspection of the front refractory wall of the boiler in the region of the exit nozzle during the flameout period revealed an apparent loss of refractory. Also noted was the formation of a slag dam across the bottom of the nozzle, at its exit to the boiler. It was, therefore, decided to immediately shift to oil firing. The thermal input to the combustor was gradually lowered to a level suitable for unattended overnight operation. This was accomplished and the combustor remained on natural gas fuel until 7:30 AM, Tuesday.

-DAY 2: At 7:30 AM, the fuel was shutoff. A rod was inserted in the combustor to dislodge the slag at the bottom of the exit nozzle. It broke off readily and fell into the floor of the furnace. Inspection of the combustor and the exit nozzle revealed no apparent damage. However, the erosion of refractory in the downstream end of the exit nozzle which had been observed visually the day before was confirmed. The inside wall of the combustor was in excellent shape, and the slag tap was open. Therefore, the combustor was restarted by 8:30 AM, and the procedure of the previous day was repeated.

The only changes made were to substantially lower the swirl in the combustor, as this may have caused the exit nozzle erosion. In addition, it was decided to stop coal firing and begin cooldown when the temperature in the front wall of the boiler at the exit nozzle reached the same temperature as on Monday evening. It was also decided to repeat the internal inspection of the combustor and boiler and to break out any accumulated slag in the exit nozzle on every subsequent morning of the four day test. Coal firing at the 14 MMBtu/hr level commenced at about 1PM on Tuesday and continued until about 5 PM, when the boiler front wall thermocouples reached the designated temperature. The combustor was cooled down, and placed on unattended overnight operation until 7:30AM on Wednesday.

-DAY 3: Visual inspection on Wednesday morning revealed no change from the exit nozzle condition on the previous day, operations resumed by 8:30 AM, as planned. About 1 hour latter, a thermocouple located at the bottom of the combustor, near the slag tap overheated. When it was removed, a flame shot out from the 1/4 inch diameter opening. The combustor was shut down. After a brief consultation, it was recalled that in one test in early 1988, fugitive gases from the slag tap had produced a similar occurrence. It may have been caused by slag blockage. The thermocouple was replaced and the slag tap heating system was restarted, and the temperature at that location again rose rapidly. The slag tap heating system was shut down, and the main combustor was relighted. This time, the temperature at this thermocouple remained within its normal operating range.

It was decided to continue the test without the slag tap heating system and to rely solely on the mechanical slag breaker for slag tap clearing. Accordingly, the thermal input to the combustor was increased and the test continued. This second shutdown took 1 hour. The operating sequence of the previous two days was repeated.

The combustor was switched back from a steady 14 MMBtu/hr coal firing after nearly four hours, when the thermocouples in the boiler front wall reached the pre-selected temperature. The combustor was then shifted to unattended overnight operation .

SUMMARY RESULTS OF THE FIRST 3 DAYS:- The performance results of the first three days of testing were essentially identical and repeatable.

-The thermal input was about 14 MMBtu/hr.

-Coal feed was very stable.

-Slag removal from the combustor was measured by weighing the collected slag passing through the tap at the end of each day's tests. The average hourly rate of slag collection was within 10-20% in all 3 days.

-The slag passing through the tap was also measured by collecting the slag lifted out by the slag conveyor in a random 10 minute period. This measurement excluded the slag freed by the mechanical slag breaker. The results agreed within 10% on the 1st two days, when the slag heating system was in operation. On the third and 4th day, the results also agreed with each other within 10%, but the flow rate in the conveyor was 40% less. This meant that more slag was being removed by the mechanical breaker on the last two days, without the heating system, than in the 1st two days, with the heaters.

-Another important operating result was that pulverized coal was delivered on Tuesday, Wednesday, and Thursday by a tanker truck. It was loaded into the on-site coal bin while the combustor was operating on coal. This delivery procedure validated the operating plan for continuous coal firing.

SLAG REMOVAL FROM THE COMBUSTOR: Perhaps the most important result of the test was the excellent performance of the new mechanical slag tap breaker. This device was designed and tested successfully in a two day period in June, 1989. During the present 4 day test it was used regularly. The slag tap was always open, and coal fuel input was constant. All prior mechanical slag tap clearing procedures that we used required a major reduction in coal fuel input. This prevented continuous operation at a constant fuel input. Slag tap blockage has been the primary factor in limiting extended continuous combustor operation.

-DAY 4:- The 4th day of the test was devoted to sulfur control with fuel rich combustor operation. After verifying on the morning of the 4th day, Thursday, that the combustor internals were unchanged, the daily heatup sequence began. However, on this day the combustor was operated fuel rich. After about two hours of steady coal fuel input at 14 MMBtu/hr, a flameout occurred. Visual inspection from the rear of the boiler revealed a pile of char/slag on the upstream floor of the combustor. On immediate restart of the combustor, it was visually observed that the pile disappeared in a matter of minutes at a low thermal input. This suggested that the pile was unburnt char, and that the combustor had been too fuel rich or that proper operating conditions had not been established for complete char gasification in the combustor.

There was insufficient time to optimize fuel rich combustion in the combustor. It was, therefore, decided to continue operation of the fuel rich test with a mixture of coal and oil in the ratio of about 4 to 1. Oil provides a high preheat, and combustion optimization is not as critical. The balance of the 4th day test was performed at two different limestone injection mass flow rates. A quick reading of the SO2 stack gas gauge indicated that major reductions in SO2 emissions were taking place.

EXIT NOZZLE OF THE COMBUSTOR:- The front wall of the boiler had been rebuilt in October 1988. Subsequent tests revealed that a modest additional amount of cooling was required to allow round the clock operation on coal and at full thermal input to the combustor. However, for the cycling operation planned for this project, the cooling design was adequate.

The four day test in March 1989, revealed that the new refractory material used in the inner front wall of the boiler was not suitable for extended operating periods. On the other hand, the inner wall material in the exit nozzle performed satisfactorily since its installation in early 1987 until the end of the Clean Coal tests in May 1990. (By May 1990 it had accumulated nearly 900 hours of total operating time.) A decision was made after the first 4 day test in March 1989 to use the high quality material in the downstream end of the exit nozzle, i.e. the boiler front wall, if further testing revealed that the present material was eroding rapidly. However, as no extensive materials loss had occurred it was decided to continue testing with the existing refractory and order the high quality refractory for possible future use.

<u>Twenty-seventh Test: The 3rd Continuous 4 Day Test</u>:(PC24), 9/24 to 9/28/89

SUMMARY: The third of the planned 4 day long duration tests took place between 9/24/89 and 9/28/89. Combustion occurred for 90 hours. 45 hours were unattended overnight operation with gas. 29 hours on heatup and cooldown with oil. 16 hours were on coal firing, in equal increments of 4 hours per day. 6 tons of coal were consumed. Coal firing occurred at a steady 12 million Btu/hr during the 1st day, 13 MMBtu/hr on the 2nd day, and 16 to 17 MMBtu/hr on the 3rd and 4th days. The latter level is the capacity of the scrubber fan at current operating conditions. Daily coal fuel shutdown were as per schedule. All 4 days of coal firing were at fuel rich conditions, at stoichiometric ratios of 0.7 to 0.85. Coal combustion efficiencies were good on all 4 days.

During the 1st 3 days, the same coal as in the August tests was used. It had a nominal 2.5% sulfur, and 30% volatile matter, VM. On the 4th day, a low 20% VM, high melting point ash, coal was used. Again combustion was excellent despite relatively high coal feed fluctuations caused by excessive residual moisture in the coal. The high moisture level was caused by the pulverization supplier, and it will not recur. The latter coal had been used at the beginning of the present Clean Coal project in 1988. At that time combustion efficiency was poor even at fuel lean conditions. The present high combustion efficiency with this coal is a measure of the progress that has been made upgrading the combustor performance. Sulfur capture was lower than in the prior tests. This was attributed to the use of a different auxiliary fuel input configuration which probably caused "deadburning" of the sorbent. There was only one flameout in the entire 4 day period, and it was caused by high fuel feed fluctuations. The total operating time of the combustor approached 700 hours. The operation of the entire combustor-boiler system was excellent.

Post test inspection of the combustor-boiler internals revealed no ceramic material loss in the combustor or exit nozzle. There was no slag dam, nor any slag flow from the exit nozzle into the boiler. Both these phenomena had been observed in earlier tests. There was a dry ash deposit on the floor of the furnace region of the boiler. This deposit may have been caused by either the operating conditions, or more likely by the high feed fluctuations on the 4th test day.

DESCRIPTION OF THE TEST: The only difference between this and the previous 4 day test was that fuel rich operation was used on all four days. As the reductions in sulfur and nitrogen oxides emissions are optimum under fuel rich operating conditions, operation at fuel rich conditions is clearly preferred.

Prior to the present test, some of the refractory in the front wall of the boiler which joins the combustor exit nozzle was replaced with the same material because the new refractory had not arrived. In addition, the refractory in the slag tap, which had been damaged by mechanical slag tap clearing operations, was replaced. Finally, several patches on refractory mortar were placed on one section of the combustor liner, which had thinned out after the prior runs dating back to the Spring of 1988. This was done only as a precaution, as it has been found that slag can rebuilt the liner thickness.

The test procedure was the same as the previous 4 day test so that on ly changes will be noted for the balance of this Appendix.

-DAY 1: Due to the late arrival of one of the test persons, coal firing did not begin until early afternoon. The combustor stoichiometry was initially fuel lean. After noon, conversion to fuel rich operation with oil/gas was implemented. As this is a manual process it is very time consuming. At about 1:30 PM coal firing began. Due to the very fuel rich operating conditions, auxiliary oil/gas fuel was maintained at about 25% of total thermal input. The combustor remained at this thermal input level, which corresponds to approximately 1/3 ton/hour of coal flow until 6 PM. At that time conversion to only oil/gas was implemented and the thermal input was reduced to the level required for automatic overnight operation.

The test was performed at limestone injection levels which produced a higher slag viscosity than in previous tests. This required more frequent operation of the slag tap breaker. Nevertheless, it was possible to keep the slag tap open throughout the test. On several occasions the mechanical breaker became stuck in the tap, which required extra effort to free it. On one occasion the breaker was stuck for at least 5 minutes and as a precaution against its melting, the coal feed was shut off. However, the breaker was soon cleared and operation resumed. It was concluded that the problems with the breaker were caused by the low slag flow rate and the high slag viscosity. It was therefore decided to increase the coal feed on the second day, and to slightly reduce the slag viscosity. No other problems were encountered.

Unlike all previous tests, no ash or slag deposits were formed in the exit nozzle, and there was no slag flow into the boiler.

-DAY 2: The only changes made were to increase the fuel input to 13-14 MMBtu/hr. Coal firing at the 14 MMBtu/hr level was scheduled to commence at about 11AM on Tuesday. However, the damper on the outlet of the stack remained stuck in the open position. After fruitless attempts to repair the electric operator, a technician climbed up the stack and freed the damper mechanically.

Slag tap clearing operations were implemented without any difficulty. On the second day, a different auxiliary fuel firing configuration was used in an attempt to improve the very fuel rich combustion efficiency. The improvement, if any, was not significant. No ash or slag deposits were observed in the exit nozzle, and no slag flowed into the furnace. However, as anticipated some loss of the new refractory in the front furnace wall was observed.

Halfway during the test, the limestone was replaced with another sorbent. The latter sorbent had produced better results in reducing sulfur levels in prior tests in the Spring of 1989. However, it was soon determined that the slag viscosity was increasing to unacceptably high levels. Also, no visible improvement in sulfur capture was observed. Therefore, the sorbent was removed from the limestone feed bin and the limestone was used again. During this shift-over process a period of poor slag flow occurred.

-DAY 3: Coal firing resumed at fuel rich conditions with a thermal input level was increased to 16 MMBtu/hr. On all 3 days, fuel feed was extremely steady. Due to a late delivery of coal, 25% oil firing was maintained to conserve the coal in the bin for a full day test.

-DAY 4:- After verifying on the morning of the 4th day, Thursday, that the combustor internals were unchanged, the daily heatup sequence began at 8:30 Am, after a 1 hour shutdown. Coal firing resumed with the thermal input between 16 and 17 MMBtu/hr. Unlike the previous three days, where the coal feed was very steady, the new coal produced feed fluctuations of the order of 10% in minute time periods. It was subsequently determined that the pulverization vendor had reduced the coal drying because he wished to maintain the volatile matter level in the coal. Despite the higher fluctuations, combustion efficiency was still excellent. However, when we attempted to completely eliminate the oil auxiliary fuel, a flameout occurred. This is attributed to the high fluctuations. After the flameout, the combustor was immediately restarted and operation at the previous condition, with 25% auxiliary fuel firing resumed. The combustor was shutdown a little after 7 PM. It had been on line for 90 of the intervening 94 elapsed hours since Sunday night.

On the 4th day, a modest level of ash/slag deposits were observed in the exit nozzle. This was attributed to the high feed fluctuations. The balance of this coal was used in subsequent tests, but the coal was dried to normal operating levels. The results with this low VM coal was a measure of the degree of progress that has been made in the project. In late 1987, the use of this coal resulted in very poor combustion even under fuel lean conditions. The excellent combustion during this 4 day tests was the result of numerous improvements in coal feed, coal and sorbent injection, air injection and mixing, auxiliary fuel application, liner material, exit nozzle design, tertiary air injection design, slag tap operation.

SUMMARY RESULTS OF THE 3rd 4 DAY TEST:- The performance of the combustor on all four days of testing was essentially identical and repeatable.

-The thermal input was maintained at a constant level each day, increasing from 12 MMBtu/hr on the 1st day to 16-17 MMBtu/hr on the 3rd & 4th days.

-Coal feed was very stable with no detectable fluctuation on the 1st three days, and with about 10% fluctuation on the 4th day. This was due to excessive moisture in the coal supplied for the 4th day test.

-The slag tap remained open throughout the 4 day test. This was accomplished by using the mechanical slag breaker.

-The slag conveyor performed nearly flawlessly. It was necessary to remove it only once from the tank during the 4 days to replace a bent bolt. This is in sharp contrast to the experience in the previous 4 day test where the conveyor had to be moved every time the mechanical breaker was used.

-Slag removal from the combustor was measured by weighing the collected slag passing through the tap at the end of each day's tests. The average hourly rate of slag collection varied considerably during the test because the slag viscosity was varied as different sorbent and coal types were used. As a result there remained a considerable quantity of slag and ash on the walls of the combustor.

SULFUR REDUCTION RESULTS: In view of the fact that the entire test was implemented under very fuel rich operating conditions, ranging from stoichiometric ratio of 0.7 to 0.85, excellent sulfur reduction was anticipated. Instead, it was found that the sulfur reduction was worse than had been observed in earlier tests under similar operating conditions. In general, the sulfur reduction was very small, from less than 10% to less than 20%, throughout the test. Since auxiliary oil firing was used during the test, it is assumed that the sorbent was "deadburned" by the oil. This was confirmed by several observations.

-One, the oil injectors were modified to improve the auxiliary heat performance. This resulted in even lower sulfur reduction.

-Two, unlike in previous tests, the other sorbent did not improve the sulfur reduction. Its use resulted in large ash deposits around the injection ports, which provides further evidence that the sorbent was being "burned" by the oil.

POST TEST INSPECTION: An internal inspection of the boiler and combustor was made after complete cooldown. After the present test, no material loss was observed. Instead a thin slag layer coated the inside of the combustor liner and exit nozzle.

Twenty-eighth Test: The 4th Continuous 4 Day Test: (PC25), 2/11 to 2/15/90

A major objective of this test was to operate the combustor with very high (4%) sulfur coal, under very fuel rich conditions.

Prior to the performance of this test, a series of five 24 hour duration tests were performed on the combustor facility in November, December 1989, and January 1990. These tests were performed as part of two projects sponsored by the DOE and EPA on ash vitrification. In the course of performing these tests, it was noted that the cyclone separation chamber in the stack particulate scrubber had eroded. A new steel plate was welded to chamber at the eroded section. During the 1st test after this repair, steel scrap material was drawn through the induced draft fan at the outlet of the scrubber vessel, and it severely unbalanced the fan wheel. A new fan wheel and bearing assembly was installed on the fan.

A second item of relevance from the ash tests to the present project concerns sulfur capture in the combustor-boiler hot gas flow train. As part of the ash injection tests, it was necessary to inject limestone/lime sorbent into the combustor and separately into the furnace region of the boiler. During one of these sorbent injection tests, it was observed that the injection of the lime reduced the SO_2 emission produced by the coal fuel by 81%. This compares with 40-50% reduction in SO_2 that was the best result observed in prior combustor sorbent injector tests in the Clean Coal project. Accordingly, sorbent injection tests in the furnace was included in the 4th four day test.

Several diagnostic tools were added in the ash injection tests, and they were included in the test plan for this Clean Coal 4 day tests. These diagnostics were:

-A water cooled probe had been placed at inlet to the convective tube section of the boiler to collect particulates from which the products of sorbent-flue gas reactions can be analyzed.

-A fiber glass filter connected in an approximately isokinetic mode was used to sample particulates at the stack exhaust from the scrubber fan.

-The same stack sampling line was used to collect condensables and particulates from the stack exhaust in water .

DAY 1: The test procedure was the same as in the prior tests, with operations commencing on Sunday evening at about 7 PM, when the combustor was fired with natural gas, and placed on automatic, unattended overnight operation. It was planned to operate at very high fuel rich conditions with a stoichiometric ratio of about 0.7 to 0.75. In prior tests, operation at this fuel rich condition resulted in significant rejection of unburnt coal char. In an attempt to achieve better combustion in the combustor, it was decided to operate the combustor at higher thermal inputs than in prior fuel rich tests. During the first day the thermal input ranged from 13.3 to 15.4 MMBtu/hr, and the SR ranged from .68-.81. Coal firing began shortly before noon and continued for nearly 6 hours.

Analysis of a sample of the coal revealed a sulfur content of slightly over 3%. This coal also had an extremely high iron content in the ash, i.e. over 20%. As a result, it slagged reasonable well without the addition of a sorbent. However, iron is very aggressive on the ceramic liner at the fuel rich conditions used in the test. Therefore, the initial period of coal only firing was limited to somewhat over 1 hour. This period was used for establishing a performance baseline. At the end of this time, lime was injected in the furnace region of the boiler for about 15-30 minutes. This was followed by injection of lime and then limestone into the combustor. To achieve a higher sorbent injection rate, one of the four coal injection ports was used in addition to the sorbent injection ports, for sorbent injection.

In both cases, i.e. with and without the sorbent injection in the combustor, excellent slag flow was obtained through the slag tap, with negligible unburnt carbon . This indicated that good combustion efficiency was being obtained. The major difference between coal only, and coal+ sorbent operation was that in the latter case the combustor liner wall temperature decreased. This suggests that the slag layer thickness on the combustor wall was increasing with the addition of sorbent, and in fact the T250 temperature of the slag increased somewhat with limestone addition.

The coal feed, as well as the combustor-boiler operating conditions, remained very steady throughout the period of coal fired operation. For this reason, and in order to limit costs of overtime to test personnel, it was decided to cease the day's coal fired operation at about 5 PM after nearly 6 hours of operation. The combustor was cooled down and placed on overnight standby operation on gas.

-DAY 2: The thermal input on the 2nd day was about the same as on the 1st day. It ranged from 12.7 to 14.9 MMBtu/hr. The stoichiometric ratio [SR] ranged from 0.74 to 0.86. The coal feed rate was again very steady. Combustor operation on coal continued for nearly 6 hours, at which time the combustor thermal input was again lowered for automatic overnight operation on gas.

On the second and third days of this test, two technicians from an independent testing laboratory selected by DOE-METC, were at the test site to collect slag, stack particulate and water samples. This data will be analyzed by DOE as part of a general study of the environmental impact of waste discharges from the several Clean Coal Projects. The technicians completed they planned sample collection on the 3rd day.

On the 2nd day, additional sorbent injection tests at two locations in the boiler were performed. One location was near the front of the boiler, while the second one was near the end of the boiler. There was no SO_2 reduction in the latter section, while former section produced 82% reduction at a Ca/S of 3.

DAY 3: The 3rd day of the test was performed at higher thermal input levels, namely 13.4 to 17 MMBtu/hr. The SR ranged from 0.63 to 0.77, which was the most fuel rich condition utilized to date. Again based on visual observation of the slag, it appeared that good combustion efficiency was obtained in the combustor. It was noted that during coal only operation, the combustor heat transfer rates during the 3 days was at the highest levels observed to-date, with the highest levels reached during the 3rd day. As noted, these rates decreased significantly with sorbent injection. One problem encountered on the 2nd day was erratic readings from the thermocouples used to monitor the combustor wall temperature. Accordingly, the combustor was briefly shut down for about 1 hour on Wednesday morning to effect temporary repairs on several of the thermocouples. These repairs were only moderately successful, and more permanent repairs were implemented later. Post test observation revealed that the thermocouple tips had been eroded, and in one location in the combustor wall significant reduction in liner thickness occurred. It is believed that this occurred primarily during the coal only firing, where the iron attack would be most severe.

On the morning of the 3rd day, the coal pulverization supplier informed us that the ball mill broke down. The earliest that he could deliver fresh coal was on Thursday afternoon. A 6 ton pulverized coal supply had been prepared for this 3rd test, as this had been the maximum amount of coal consumed in each of the prior two tests. By the morning of the 3rd day, about 5 tons of coal had been consumed, and only 3 tons of coal remained in the bin. Rather than cut the 1/2 ton/hour coal firing rate that had been used since the beginning of the 2nd day, it was decided to use the contents of the bin on the 3rd day. This allowed about 6 hour of steady coal firing, which was completed at 5 PM.

Rather than shut down the combustor, the 4th day of the test was devoted to an ash vitrification test using oil as the heat source. This has the effect of simulating the operation of coal firing. However, the test was devoted to the ash project. The thermal input on the 4th day was about 10.5 MMBtu/hr.

PRELIMINARY RESULTS:

-The combustor remained on line for approximately 92 hours in a 4 day period. Of this time, 72 hours were devoted to the Clean Coal project test, while the remaining 18 hours were used for the ash test.

-Of the 72 hour period of the Clean Coal Test, about 18 hours were on coal fired operation in a 3 day period, 36 hours were on automatic overnight gas fired operation, and the balance was on oil fired heat up and cooldown.

-A total of 8 tons of coal were consumed in the three day period, compared with a 6 ton maximum in the prior two 4 day test periods.

-The total operating time of the combustor to-date, including the brief 40 hour test period on coal-water slurry prior to the start of the Clean Coal project and the several fly ash to coal conversion tests, is approaching 800 hours

-For a given coal feed, the combustor operation, as measured by the steam rate, was very steady. This indicates a very steady coal feed rate.

-Coal firing ceased each evening on schedule. There were no flameouts during the test, despite the extremely fuel rich operation. This is attributed to the high combustion efficiency as well as to the new multi-point flame detection system that has been in place since late last year.

-The test coal sample analyzed had a sulfur content of slightly over 3%, compared to a 4% nominal sulfur level content promised by the coal supplier. However, the sulfur content varies widely in each truck load. In fact by mistake the coal pulverization supplier delivered a low sulfur coal for two of the three days of testing, so that the high sulfur coal was used in only part of the test.

-The iron oxide content of the coal was very high, over 20%. This resulted in good slag flow without flux addition. However, it is well known that iron, especially under fuel rich conditions is very aggressive in ceramic wall material attack. Evidence of wall material removal was noted in the high wall heat transfer. Indeed post test internal examination of the combustor liner revealed wall material thickness reduction in one small section of the combustor liner. The post test inspection also revealed that the slag tap block was mostly removed which was due to either the slag breaker action or slag attack. On the other hand, post test analysis showed no significant ceramic or slag loss on the wall of the exit nozzle. This is the opposite of prior experience with fuel lean operation.

-Based on wall thermocouple readings, the ceramic liner temperatures were a strong function of the slag properties in the combustor. During coal only firing periods, the temperatures were generally high indicating that the iron in the slag was removing accumulated slag and ceramic wall material. As noted, this was confirmed by post-test visual observation. By adjusting the slag properties with sorbent, it was possible to lower the temperature readings, indicating a thickening of the slag layer.

-The present liner has been in place since March 1988, and it has been patched in several small sections with ceramic mortar only two or three times times since then. The last time was in early September 1989, which was prior to the second 4 day test. Since that time, between 250 and 300 hours of operation have taken place. It is only in this 4 day test that a significant wall material loss occurred. This is attributed to the very fuel rich operating conditions, and to the high iron content of the slag.

-In several prior multi-day tests, extensive ceramic material loss was experienced in the exit nozzle. However, since the September test no material loss has been observed. With the exception of the ash injection tests, this period has been one of fuel rich operation, while the prior period was one of mainly fuel lean operation.

-This was the first test that very fuel rich operation, i.e. stoichiometric ratio as low as 0.63, resulted in very good combustion efficiency. Combustion efficiency can be approximately determined by examining the slag rejected by the slag tap. Poor combustion results in a significant carbon content in the slag. This was not observed to any significant extent during the present test. The higher efficiency is attributed to the steady coal feed rate, and to the high thermal input used in this test series. It is not clear whether a new air pre-heat system, which installed and used for the first time in this test, was a significant factor in the higher combustion efficiency. The input averaged 14 MMBtu/hr on the 1st and 2nd day, and 16-17 MMBtu/hr on the 3rd day. SR ranged from 0.63 to 0.86.

-Sorbent injection in the combustor with limestone or lime produced 20-40% reduction in stack SO_2. Lime injection in the furnace produced 58%, 67%, and 82% measured reductions in stack SO_2 during various test periods. This reduction is based on the SO_2 reading prior to injection, not on the coal sulfur which varied considerably.

-The slag tap clearing system operated without problems on all 4 days, and the tap was always kept open. However, the slag tap port suffered severe materials loss which was attributed either to the iron in the slag or the slag breaker.

- A new result was the very strong odor of sulfur emanating from several of the large slag pieces that were removed from the slag tap. These samples were subsequently analyzed and they were found to contain up to 10% of the coal sulfur. This was the highest sulfur concentration measured in slag to-date.

CONCLUSION: The results exceeded the test objectives. The coal firing rate was so high that 8 tons of coal were consumed in 3 days, compared to a maximum of 6 in prior 4 day tests. The sorbent injection tests in the boiler, which were not part of the original test plan, yielded very high SO_2 reductions of up to 82% at a Ca/S of 3. In general, the test proceeded very well. The only area of some concern is the wall material loss in one small part of the liner, and the slag tap block materials loss, both of which may be attributed to the high iron content of the slag and the very fuel rich operating conditions.

Twenty-ninth Test: The Final Continuous 4 Day Test- (PC26), 5/21 to 24/90

Test Preparations: The refractory interface between the combustor and exit nozzle was rebuilt to correct a material loss problem that had recurred at that location in several prior tests during the course of the project. The root of this problem was a design defect caused by an incorrect thermal analysis of that region. The new installation has performed as per design in both the final 4 day Clean Coal test in a series of subsequent combustor tests to this date (Oct.1990). However, it was necessary to replace the exit nozzle refractory after this last Clean Coal Test as the installation at the interface section was incomplete. Since that time, the new exit nozzle section has operated with no observable materials loss.

The new secondary air pre-heat system produced no observable improvement in the fuel rich combustor performance. Instead it caused a local overheating problem in one section of the combustor, and it has not been used since the trial in the 4th 4 day test.

The March test showed that it was possible to maintain the thickness of the air cooled combustor wall refractory liner with proper thermal control. This would eliminate the need for periodic refurbishing of the liner wall. To implement this procedure and to take advantage of the operating experience gained in the prior three years, it was decided to proceed with computer control of the combustor's operation prior to the final Clean Coal test. While all the necessary components and computer equipment were in place prior to the last Clean Coal test, the system was not ready to assume control of the combustor's operation. It was therefore decided to proceed with manual control and to use the computer for limited data acquisition on a trail basis. In post Clean Coal tests the computer has been gradually introduced to control the combustor.

The Four Day Test: As this was the final test of the Clean Coal project, Coal Tech extended invitations to project sponsors, namely, DOE, PEDA, and PP&L, to observe the second day of the four day test. Messrs. Coates, Gyorke, and Watts of DOE, Bickley and Garbacik of PEDA, and Marston of Villanova U. attended the second day test.

Friday, May 18th: A final check of the operation of all the new equipment was made on the 18th. This included using both the computer and electrical potentiometers to manipulate all the new valves. The combustor was operated on gas and oil for a number of hours while all the new equipment was checked.

DAY 1- Monday, May 21st: The coal selected for this test had a nominal 2% sulfur content, and a 250 poise slag viscosity temperature that was several $100^{o}F$ higher than in the February tests. Coal firing began around noon and continued for about 5 hours. The thermal input was about 14 MMBtu/hr, and the stoichiometric ratio was about 0.77. One significantly different aspect which differed in this test from the prior Clean Coal tests was the injection of sufficient sorbent into the combustor to obtain a Ca/S ratio of 3 in the combustor. On this day, a range of Ca/S from 2.1 to 3.4.was used. To maintain proper slag flow at this high calcium content in the slag, fly ash from a PA bituminous coal was also injected in the combustor. The ash injection rate ranged from 160-350 lb/hr. Due to the high viscosity of the cash in the coal, the slag flow in this test was considerably slower than in the March test. This meant that the slag residence time in the combustor was greater allowing slag desulfurization. The SO_2 reduction at the stack was only 13-24%.

The only problem encountered on the first day, was with the slag conveyor. It jammed and had to be removed from the slag tank for cleaning. Due to the press of other test activities, it was not possible to reinstall the slag conveyor until the third day. It functioned properly for the balance of the test. This was the first time that the conveyor was removed during a test since late last year.

DAY 2: The combustor's internal were briefly inspected at 6:30 AM, and the preheat resumed. Coal firing began at about 10:30 AM. The visitors arrived after 11 AM. After an overview presentation, they visited the test facility between 1 and 2 PM. The visit at the test site included a demonstration of the computer control system, and observation of the combustor's operation on coal. Thermal input was about 11 MMBtu/hr at a stoichiometric ratio of 1.1 to 0.88. Coal firing continued to about 5 PM, at which time the combustor was placed on overnight pilot plant operation. Limestone injection at a Ca/S ratio between 1.6 and 3 produced a 27% to 34% SO2 reduction at the stack. Lime injection at a Ca/S of 2.4 produced SO_2 reductions of 40-47%. Simultaneous ash injection was at the rate of 70 lb/hr.

Due to the defective oil flow valve, computer operation was limited to combustor control during coal firing. However, certain flaws in the process control software required considerable rewriting of parts of the input instructions. As a result, the computer was only able to read the computer operating data on the first three days of the test. It was only on the 4th day, that very limited computer control of the combustor was attempted.

DAY 3: The objective of this day's test was to further reduce the stoichiometric ratio to improve sulfur capture. The high viscosity of the coal produced operational problems as the stoichiometric ratio was reduced. The slag removed from the combustor contained extensive char particles suggesting poor combustion. In addition, considerably slag flow was observed to cover the front wall of the boiler at the combustor exit. Eventually this flow was sharply reduced as a slag dam developed across the lower half of the nozzle exit. Due to an error, the cooling circuit to the mechanical slag breaker was not turned on, and the slag breaker became stuck in the slag on its first use. By the time it was removed, it was deformed and it was difficult to use thereafter. To improve the combustion in the combustor, the stoichiometric ratio was increased to an average of 0.8 during the balance of the test at a thermal input of 12.6 to 13.6 MMBtu/hr. This greatly improved the combustor performance but the combustion of unburnt char which had accumulated on the combustor wall, flooded the slag tap, which further increased the difficulty in slag tap operation.

Lime injection at a Ca/S of 1.6 to 2.5 produced SO_2 reductions of 23%/24% to 51%/58%, respectively.

One other problem that was encountered was caused by low water flow to the boiler house. This limited the water available to the water cooled parts of the combustor, and serious water hammer developed for a brief period until the water flow distribution adjusted. At the end of the coal firing period, an internal inspection of the combustor revealed a minute water leak, caused by the water hammer, inside the combustor at one of the water cooled sections. It was, therefore, decided to leave the combustor shutdown overnight, and to reinspect the combustor in the morning.

<u>DAY 4:</u> Internal inspection of the combustor revealed what appeared to be two pinhole water leaks. Since only a small part of the combustor is water cooled, and the leak appeared to be minute, it was decided to complete the fourth day of the test. During initial heatup, a significant quantity of moisture collected on the observation ports in the boiler, which was higher than would be expected from a small pinhole leaks. However, this moisture disappeared as the combustor heated up.

The primary objective of this final test day of the Clean Coal project was to study slag desulfurization by injection gypsum [calcium sulfate] instead of lime or limestone in the combustor. Coal firing began at about noon and continued for over 1 hour. However, after several uses of the slag breaker, it became increasingly difficult to remove it after becoming stuck in the slag. It was thus obvious that rapid slag flow could not be achieved with the extensive slag deposits in the slag tap. Therefore any slag samples collected would not provide a meaningful assessment of the fate of the sulfur after injection of the gypsum. For this reason, it was decided to stop the coal firing and continue with oil firing. This would allow testing of the computer control.

The computer operation test focussed on the procedure to be used to maintain the materials integrity of the combustor wall. The computer was generally able to accomplish this task. However, the operation revealed certain shortcomings during periods of rapid changes of input variables. This was corrected in subsequent tests. Computer control continued for several hours. Finally, an error in the control logic was detected when the computer cutoff the air flow to the combustor in an attempt to maintain constant thermal conditions. This resulted in a flameout. Since it was late in the day, it was decided to end the test.

Post Test Inspection: An internal inspection of the combustor the following week, revealed that a crack of several inches in length had been opened at one of the welds in one of the water cooled sections of the combustor, presumably during the period of water hammer conditions. The only apparent damage from the water leak was a loosening of several square inches of wall refractory at a point on the lower sidewall near the upstream end of the combustor. This was patched.

To prevent this water cooling problem in the future, the water flow to the affected part modified by adding a water pump in that location. It should be noted that the location of the weld crack was in the same place as a prior crack that had developed during reinstallation of the combustor after its disassembly in March 1988. The repairs were made after the May tests and no further problems have been experienced.

The ceramic in the slag tap was found to have been damaged due to the problems with the slag breaker and the affected parts were replaced. As noted this problem developed due to a human error, and it has not recurred.

Conclusions: The combustor operated about 68 hours, including the brief pre-heat period on the 18th, and the continuous period from Monday morning to Wednesday evening. Of this period, about 19 hours were on coal and about 6 tons of coal were consumed. The total combustor operating period since the beginning of the Clean Coal project was approximately 900 hour, including all fuels with about 100 hours from the ash tests. About 1/3 of that time was on coal.

The present test produced positive results and some disappointments. The failure to turn on the cooling to the slag probe on Wednesday morning was most probably the primary reason from the difficulties with the slag tap on the last two days. This resulted in incomplete SO_2 test results on that day, and the premature termination of the calcium sulfate injection test on the 4th day. The observed 58% peak SO2 reduction on the 3rd day suggests that possibly better results could have been obtained with proper very fuel rich operation.

One positive result is that all 5 four day tests in Phase 3 were completed with 4 days of testing in all cases. Fuel rich operation was implemented for most of this time, compared to the anticipated need to operate fuel lean for efficient combustion. Also, the preliminary results of the computer control modification were very promising.

On balance, the Clean Coal project yielded most of the results that were anticipated. The conditions for long duration operation have identified during the tests. Also, sufficient data was obtained which suggests that considerably higher sulfur capture and retention in the slag could be achieved. A series of tests have been identified that could rapidly resolve the remaining issues on sulfur capture in the combustor. On the other hand, the very high sulfur capture of 82% in the boiler furnace was unanticipated.

Perhaps a most significant result is that in the final 1-1/2 years of the project nearly all the scheduled test periods were completed. Even when unanticipated operational problems or equipment malfunctions arose, it was generally possible to repair them and proceed with the test without early termination.

This combustor was the first commercial scale operation of Coal Tech's combustor. The air cooled design concept is sound, and the design modifications, as well as the operational procedures needed for long duration operation have been identified. The next step is computer controlled round the clock operation on coal, as well as further optimization of the sulfur control process in the combustor.

GLOSSARY OF TERMS

TEST$	Test number and condition number. E.g. PC26-1a is test PC26, condition 1a.
HEATIN	Total fuel heat input in MMBtu/hr
PCTPC	Percent contribution of coal to HEATIN
SR1	First stage inverse equivalence ratio or fraction of theoretical combustion air.
SR2	Second stage inverse equivalence ratio.

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MYSTAT Editor
  Case         TEST$       HEATIN         PCTPC          SR1          SR2
    1          PC9-1       17.200        30.000        0.890        1.190
    2          PC9-2       17.800        38.000        0.900        1.190
    3          PC9-3       18.400        33.000        0.900        1.180
    4          PC9-4       18.200        40.000        0.900        1.190
    5          PC9-5       17.700        28.000        0.700        1.270
    6         PC9-6a       17.700        27.000        0.710        1.130
    7         PC9-6b       17.400        26.000        0.730        1.160
    8        PC10-1a       12.800        41.000        0.810        1.390
    9        PC10-1b       12.800        41.000        0.810        1.390
   10         PC11-1        6.730        81.000        1.680        2.750
   11         PC11-2        9.740        87.000        1.170        1.910
   12        PC11-3a       12.260        89.500        1.050        1.630
   13        PC11-3b       12.360        89.500        1.050        1.630
   14         PC11-X       15.070        91.400        0.860        1.340
   15        PC11-4a       13.560        90.400        1.010        1.540
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MYSTAT Editor
  Case         TEST$       HEATIN         PCTPC          SR1          SR2
   16        PC11-4b       13.560        90.400        1.010        1.540
   17         PC12-1       15.950        73.000        0.880        1.250
   18         PC12-2       15.630        92.000        0.950        1.330
   19         PC14-1       18.720        93.000        0.820        1.230
   20        PC14-2a       16.700        92.000        1.000        1.450
   21        PC14-2b       15.360        91.500        1.070        1.570
   22         PC14-3       15.570        94.000        1.090        1.580
   23         PC15-1        3.330         0.000        2.020        2.020
   24         PC15-2        4.170         0.000        1.870        1.870
   25         PC15-3        5.260         0.000        1.490        1.880
   26         PC15-4        5.960         0.000        1.510        1.870
   27         PC15-5        7.330        52.000        1.670        2.430
   28         PC15-6        9.240        65.000        1.330        1.910
   29         PC15-7        9.340        67.000        1.250        1.820
   30         PC15-8        9.340        68.000        1.360        1.930
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MYSTAT Editor
  Case          TEST$         HEATIN          PCTPC            SR1          SR2
    31           PC15-9         11.350         60.000          1.130         1.600
    32          PC15-10         10.050         63.000          1.420         1.950
    33         PC15-11a          9.950         57.000          1.450         1.990
    34         PC15-11b         10.350         67.000          1.390         1.900
    35          PC16-1a         13.270         58.000          1.150         1.290
    36          PC16-1b         15.090         58.000          1.120         1.470
    37           PC16-2          9.340          0.000          1.310         1.410
    38           PC16-3         11.440          0.000          1.130         1.580
    39          PC16-4a         10.480         75.000          1.190         1.700
    40          PC16-4b         10.480         81.000          1.410         1.930
    41          PC16-5a         10.820         91.000          1.370         1.870
    42          PC16-5b         11.830         57.000          1.000         1.450
    43          PC16-5c         11.950         67.000          1.120         1.550
    44          PC16-5d         10.930         65.000          1.240         1.730
    45           PC17-1         10.490         83.000          0.870         1.600
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MYSTAT Editor
  Case          TEST$         HEATIN          PCTPC            SR1          SR2
    46           PC17-2         10.190         83.000          0.900         1.650
    47           PC17-3         10.090         82.500          0.890         1.640
    48           PC17-4         11.350         84.000          1.360         1.500
    49           PC17-5         10.650         83.000          1.120         1.270
    50          PC18-1a         11.320         85.000          1.240         1.730
    51          PC18-1b         11.320         85.000          1.230         1.710
    52          PC18-1c         11.320         85.000          1.240         1.710
    53          PC18-2a         11.110         85.000          1.260         1.720
    54          PC18-2b         11.110         85.000          1.270         1.730
    55           PC19-1          9.470          0.000          1.270         1.270
    56           PC19-2         11.010         73.500          0.920         1.920
    57           PC19-3         15.740         69.500          0.990         1.160
    58           PC19-4         15.440         70.000          0.950         1.120
    59          PC20-1a         12.360         88.000          1.080         1.210
    60          PC20-1b         11.560         87.000          1.190         1.260
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MYSTAT Editor
  Case        TEST$      HEATIN        PCTPC          SR1          SR2
    61       PC20-1c      11.900       87.000        1.160        1.230
    62       PC20-2a      12.560       66.000        1.130        1.195
    63       PC20-2b      12.360       65.000        1.110        1.210
    64       PC20-3a      12.350       89.000        1.120        1.190
    65       PC20-3b      13.380       89.000        1.160        1.210
    66       PC20-3c      12.870       89.000        1.170        1.240
    67        PC20-4      13.870       87.000        1.010        1.120
    68        PC22-1      12.510       86.000        0.910        1.470
    69       PC22-2a      11.660       86.000        1.260        1.830
    70       PC22-2b      13.020       87.000        1.220        1.730
    71        PC22-3      12.710       87.000        0.975        1.520
    72        PC22-4      12.910       87.000        0.975        1.500
    73        PC22-5      12.910       87.000        0.925        1.600
    74        PC22-6      12.910       87.000        0.885        1.580
    75       PC23-1a      12.760       87.000        1.330        1.780
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MYSTAT Editor
  Case        TEST$      HEATIN        PCTPC          SR1          SR2
    76       PC23-1b      12.760       87.000        1.330        1.790
    77       PC23-1c      12.760       87.000        1.330        1.770
    78       PC23-1d      12.760       86.500        1.350        1.810
    79       PC23-2a      12.460       64.000        1.330        1.790
    80       PC23-2b      12.560       88.000        1.330        1.780
    81       PC23-2c      12.560       88.000        1.330        1.795
    82       PC23-2d      12.460       88.000        1.460        1.920
    83       PC23-2e      12.760       88.000        1.490        1.960
    84       PC23-2f      13.060       87.000        1.190        1.660
    85       PC23-3a      12.360       86.000        1.320        1.820
    86       PC23-3b      12.560       86.500        1.380        1.870
    87       PC23-3c      12.760       87.000        1.360        1.830
    88       PC23-3d      12.760       87.000        1.360        1.820
    89       PC23-4a      13.170       88.000        0.800        1.585
    90       PC23-4b      13.170       88.000        0.800        1.780
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MYSTAT Editor
  Case         TEST$      HEATIN       PCTPC          SR1          SR2
    91       PC23-4c      14.390      62.000        0.720        1.615
    92       PC23-4d      14.610      60.500        0.710        1.590
    93       PC23-4e      14.610      60.500        0.710        1.590
    94       PC23-4f      14.590      61.000        0.710        1.590
    95       PC24-1a      11.740      64.000        0.890        1.730
    96       PC24-1b      11.740      64.000        0.900        1.740
    97       PC24-1c      11.800      64.000        0.900        1.730
    98       PC24-1d      11.800      64.000        0.870        1.700
    99       PC24-1e      11.800      64.000        0.880        1.710
   100       PC24-2a      12.310      72.000        0.810        1.630
   101       PC24-2b      12.620      73.000        0.780        1.580
   102       PC24-2c      12.620      73.000        0.790        1.590
   103       PC24-2d      13.320      74.000        0.750        1.510
   104       PC24-2e      12.820      73.000        0.770        1.550
   105       PC24-3a      15.930      73.000        0.750        1.540
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MYSTAT Editor
  Case         TEST$      HEATIN       PCTPC          SR1          SR2
   106       PC24-3b      15.720      68.000        0.760        1.560
   107       PC24-3c      15.930      68.000        0.750        1.540
   108       PC24-3d      16.230      69.000        0.735        1.510
   109       PC24-4a      16.450      72.500        0.740        1.500
   110       PC24-4b      16.150      71.000        0.750        1.560
   111       PC24-4c      16.150      71.000        0.740        1.560
   112       PC24-4d      16.390      71.500        0.730        1.540
   113       PC24-4e      16.390      71.500        0.730        1.530
   114         FA3-6a      8.680      82.000        1.120        1.810
   115         FA4-1a     10.550      76.000        1.690        1.770
   116         FA4-1e     10.550      76.000        1.690        2.150
   117          FA4-3     10.800      76.000        0.750        1.430
   118          FA4-7     11.060      77.000        0.860        1.780
   119       PC25-1a      13.250      81.000        0.810        1.410
   120       PC25-1b      13.780      82.000        0.780        1.340
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MYSTAT Editor
  Case        TEST$        HEATIN        PCTPC          SR1          SR2
   121         PC25-1c        13.780        82.000        0.770        1.340
   122         PC25-1d        14.840        83.000        0.710        1.240
   123         PC25-1e        15.360        84.000        0.700        1.210
   124         PC25-1f        15.360        84.000        0.715        1.220
   125         PC25-1g        15.360        84.000        0.680        1.190
   126         PC25-2a        13.780        82.000        0.790        1.370
   127         PC25-2e        14.040        82.000        0.790        1.340
   128         PC25-2f        14.310        83.000        0.770        1.310
   129         PC25-2g        14.840        83.000        0.750        1.270
   130         PC25-2h        14.840        83.000        0.750        1.270
   131         PC25-2i        14.570        83.000        0.740        1.270
   132         PC25-2j        14.570        83.000        0.740        1.270
   133         PC25-2k        14.570        83.000        0.740        1.270
   134         PC25-2l        14.040        82.000        0.770        1.320
   135         PC25-2m        14.570        83.000        0.740        1.270
```

```
MYSTAT Editor
  Case        TEST$        HEATIN        PCTPC          SR1          SR2
   136         PC25-3a        16.420        85.000        0.660        1.240
   137         PC25-3c        15.890        84.000        0.680        1.280
   138         PC25-3d        16.690        85.000        0.650        1.220
   139         PC25-3e        16.690        85.000        0.650        1.220
   140         PC25-3f        16.950        85.000        0.630        1.190
   141         PC25-3h        16.690        85.000        0.630        1.200
   142         PC25-3i        16.420        85.000        0.630        1.210
   143          EPA1-1         9.310         0.000        1.270        1.970
   144          EPA1-2         9.310         0.000        1.270        1.970
   145          EPA1-3         9.310         0.000        1.150        1.850
   146          EPA1-4         9.740        44.000        1.090        1.730
   147         EPA1-5a         9.500        43.000        1.200        1.830
   148           FA3-1         8.680        81.500        1.250        1.940
   149           FA3-2         8.680        81.500        1.210        1.900
   150           FA3-3         8.680        81.500        1.210        1.900
```

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MYSTAT Editor
  Case       TEST$      HEATIN       PCTPC        SR1         SR2
   151       FA3-4       8.680      81.000       1.190       1.880
   152       FA3-5       8.680      81.000       1.160       1.840
   153       FA4-2      10.550      76.000       1.400       1.840
   154      FA4-4a      10.800      76.000       0.750       1.440
   155       FA4-5      10.550      76.000       0.790       1.470
   156       FA4-6      10.550      76.000       0.840       1.800
   157      FA5-1c      11.660      82.000       0.960       1.370
   158      FA5-1e      11.560      82.000       0.970       1.390
   159      FA5-1f      11.450      82.000       0.965       1.380
   160      FA5-1i      11.450      82.000       0.965       1.380
   161     PC25-3b      15.360      84.000       0.710       1.380
   162      FA4-1b      10.550      76.000       1.740       1.840
   163      FA4-1c      10.550      76.000       1.740       2.230
   164      FA4-1d      10.290      75.000       1.560       2.050
   165     PC25-2b      13.780      82.000       0.790       1.430
```

```
MYSTAT Editor
  Case       TEST$      HEATIN       PCTPC        SR1         SR2
   166     PC25-2c      12.720      80.000       0.860       1.490
   167      FA4-4b      10.800      76.000       0.750       1.450
   168     PC25-2d      13.250      81.000       0.830       1.495
   169     PC25-3a      16.160      84.500       0.660       1.290
   170      FA3-6b       8.680      82.000       1.120       1.810
   171      FA3-6c       8.680      82.000       1.120       1.810
   172     EPA1-5b       9.500      40.000       1.200       1.830
   173     EPA2-1b      10.050       0.000       1.100       1.250
   174     EPA2-1c       9.950       0.000       1.120       1.750
   175         FA1      12.940       0.000       1.010       1.150
   176         FA2      10.940       0.000       1.180       1.180
   177       FA6-1      10.830      87.000       1.180       1.490
   178       FA6-2      10.830      87.000       1.200       1.520
   179       FA6-3      10.830      87.000       1.200       1.520
   180       FA6-4      10.830      87.000       1.170       1.480
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IYSTAT Editor
  Case        TEST$       HEATIN        PCTPC          SR1          SR2
   181         FA6-5       10.830       87.000        1.120        1.430
   182         FA6-6       10.830       87.000        1.120        1.430
   183        IT1-1a        8.970       59.000        1.000        1.400
   184        IT1-1b        8.970       59.000        1.000        1.700
   185        IT1-1c        8.970       59.000        1.000        1.700
   186        IT1-1d        8.970       59.000        1.140        1.840
   187        IT1-1e        8.970       59.000        1.195        1.890
   188       PC26-1a       14.410       93.500        0.750        1.250
   189       PC26-1b       14.410       93.500        0.770        1.260
   190       PC26-1c       14.410       93.500        0.770        1.260
   191       PC26-1d       14.410       93.000        0.780        1.290
   192       PC26-1e       14.410       93.000        0.790        1.300
   193       PC26-2a        9.060       77.000        1.100        2.320
   194       PC26-2b        9.060       77.000        1.100        2.320
   195       PC26-2c        9.060       77.000        1.100        2.320
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MYSTAT Editor
  Case        TEST$       HEATIN        PCTPC          SR1          SR2
   196       PC26-2d        9.060       77.000        1.100        2.320
   197       PC26-2e        9.060       77.000        1.040        2.270
   198       PC26-2f       10.820       81.000        0.860        1.890
   199       PC26-2g       10.820       81.000        0.890        1.920
   200       PC26-2h       10.820       81.000        0.890        1.920
   201       PC26-3a       13.510       89.000        0.740        1.460
   202       PC26-3b       13.510       89.000        0.750        1.470
   203       PC26-3c       13.630       89.000        0.810        1.530
   204       PC26-3d       12.370       83.000        0.830        1.630
   205       PC26-3e       12.370       83.000        0.860        1.650
   206       PC26-4a        9.900       85.000        0.960        1.490
   207       PC26-4b        9.690       84.000        1.090        1.640
   208
   209
   210
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U.S. DOE-CLEAN COAL PROGRAM

"THE DEMONSTRATION OF AN ADVANCED CYCLONE COAL COMBUSTOR, WITH INTERNAL SULFUR, NITROGEN, AND ASH CONTROL FOR THE CONVERSION OF A 23 MMBTU/HOUR OIL FIRED BOILER TO PULVERIZED COAL"

FINAL TECHNICAL REPORT

APPENDIX II:STATISTICAL ANALYSIS OF OPERATING DATA FOR THE COAL TECH COMBUSTOR

REPORTING PERIOD - March 9, 1987 to February 28, 1991
DOE Cooperative Agreement No. DE-FC22-87PC79799

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TABLE OF CONTENTS

1. INTRODUCTION

In an attempt to unravel the complex interactions of combustor operating conditions on test observables, the Clean Coal data base, supplemented by the DOE and EPA ash conversion data, was subjected to statistical analysis. The extensive data base consisted of a matrix sized 207 X 45, i.e. there were 207 separate test conditions, each having up to 45 different observations or measurements. Thus the matrix potentially consisted of over 9000 entries. However, in many cases certain measurements were not always taken so that the actual data base consisted of about 6500 entries. It should be noted that the Clean Coal data base did not include tests with the initial liner since most of that data was obtained in preliminary testing, where combustion efficiency and slagging were very poor and, in any case, the recorded data were not as comprehensive as with the new liner. Thus, all results are for the new liner only.

2. DEPENDENT & INDEPENDENT VARIABLES

The initial step in the analysis was to divide the 45 variables into dependent and independent variables. The dependent variables were the test observables of interest such as NOx and SO2 levels in the boiler outlet, the liner temperature, combustion efficiency, etc. The nominally independent variables included first and second stage stoichiometries, fuel type, heat input, calcium/sulfur ratio and so forth. The nominally independent variables were then correlated and plotted against each other to determine the degree of mutual interaction. If the interaction between two variables was high, then only one was selected for subsequent use in modeling. Otherwise, one could obtain results which are contradictory or unintelligible from a physical model point of view. It should be noted that high levels of positive or negative correlation between variables in any given data base are a mathematical result and do not necessarily suggest a cause-and-effect relationship. Quite often, however, this kind of coupling does occur. For example, analysis showed a high degree of positive correlation between the coal firing rate in PPH (PPHPC) and the percent contribution of the coal to the total fuel heat input (PCTPC). From test experience, it is known that as the coal firing rate went up, the coal's percentage of the total fuel also went up..

Winnowing of the independent variables was followed by linear regression modeling of the dependent variables against various combinations of the remaining independent variables. However, for the sake of simplicity, no "X*Y" terms were included. Retention of an independent variable in any given model was based on its having a low probability (two-tailed significance) of zero coefficient and possessing a high tolerance or orthogonality, i.e. one independent variable cannot be easily modeled by the other independent variables in the model. In cases where two or more models, having different but non-orthogonal independent variables, could be constructed for a given dependent variable, the one that covered the most cases, while providing a "good fit" or high R-squared, was chosen.

A unique situation arose in evaluating the nominally independent slag T-250 temperature (oxidizing conditions) or OXIDT250. Even though OXIDT250 is operationally independent, efforts to include it in models also having total fuel heat input (HEATIN) as an independent variable were unsuccessful, owing to the very low mutual tolerance of these two variables. The probable explanation is that at high coal firing rates, coinciding with high HEATIN, the slag T-250 generally increased due to physical limits on the maximum flow of fluxing agent. In any case, one of these variables had to be eliminated. Since OXIDT250 occurred in the data base only 66 times vs. 207 times for HEATIN, it was deselected. Attempts to build models with OXIDT250 while excluding HEATIN were inconclusive.

Finally, the effects of second stage or boiler sorbent injection, as well as the effects of fly ash injection, on key process observables could not be evaluated statistically since the number of non-zero cases was very low. In the case of sorbent boiler injection, there was really no need for this approach since experimental results clearly show a cause-and-effect relationship between injection of calcium hydrate into the boiler and reduction of SO2 in the boiler outlet. In addition, testing also showed that limestone was much less effective than hydrate for this application. These results are presented in section 3.6.5. In the case of fly ash injection, modeling occasionally revealed some low level of influence on various measurables. However, more experimental data would be needed to clarify this.

3. EFFECTS OF OPERATING CONDITIONS ON PERFORMANCE

After evaluating hundreds of models, it was determined that all key process observables could be adequately accounted for by models having four independent variables, namely, first stage inverse equivalence ratio (SR1), combustion swirl air pressure (SWIRLPR in "WC), total fuel heat input (HEATIN in MMBtu/hr), and percent contribution of coal to the total heat input (PCTPC). In addition, models of the sulfur related independent variables included the Ca/S mole ratio (CASRAT).

To determine the relative effects of the above four (or five) independent variables on test observables, model predicted values for these observables or dependent variables were calculated. These calculations were performed by varying one independent variable at a time over its normal range while the remaining independent variables were held at their average values. The ranges and average values, respectively, for each independent variable were: SR1, 0.6 to 1.3, 1.03; SWIRLPR, 10 to 40, 17.8; HEATIN, 8 to 20, 12.35; PCTPC, 0 to 100, 71.5; CASRAT, 0 to 3, 1.33. Independent variable effects on a given dependent variable were then gauged by comparing the spreads in the calculated independent variable resulting from each independent parameter's normal variation. The spreads in the calculated dependent variables were quantified by expressing the minimum calculated value as a percent change from the maximum calculated value. A positive percent change was chosen to indicate that the dependent variable increased as the independent variable increased, while a negative change meant that the dependent variable decreased as the independent variable increased. This method was chosen so that the strength of a given independent variable's effects could be evaluated for different dependent variables, having different engineering units, on a normalized basis.

It should be emphasized that the above comparison method, while useful in gauging relative effects at average conditions, is less useful, and may even be misleading, in predicting the true or actually measured range of values for the various dependent variables. This resides in the fact that model predicted values used in this analysis are based on the full range of one independent variable plus the average values for the other independent variables in the model. In actual operation, the negative effects of one of the process variables on good operation were ordinarily compensated for by varying other parameters, usually away from their average values.

One other point is that linear models of experimental observables yield only a general dependency on the independent variables over their range of values. This simple approach, while appropriate for dealing with a large and complex database, cannot describe detailed variable relationships associated with non-linear or "bell shaped" curves. In these cases, physical modeling, based on empirical relations and/or theoretical principles, is preferred to statistical modeling provided that the physical concepts are fairly well defined. The results of the above analysis on process observables or independent variables of interest are discussed below by category.

3.1. Combustion Efficiency

There were three independent methods to assess the degree of fuel utilization or combustion efficiency as a percent of total combustibles: slag carbon content (SLAGCEFF), measured air and fuel flows vs. stack oxygen (GASCEFF), and carbon content of the solids discharged by the scrubber (TSSCEFF). These values are expressed as percent conversion of fuel combustibles to final products. SLAGCEFF relates directly to the combustor's operation, which includes fuel rich conditions, while the other two relate to overall efficiency, including second stage combustion with excess air. In percent units, the average measured value, standard deviation, plus high and low values for each of these variables is: SLAGCEFF: 99.8, 0.7, 100.0, 95.0; GASCEFF: 107.0, 9.0, 135.0, 81.0; TSSCEFF: 94.4, 3.8, 99.8, 80.8. Models based on the four independent variables were constructed. Evaluations of the effects of the individual independent variables on each of the three combustion efficiency variables are presented below.

3.1.1. Combustor Stoichiometry

For the three combustion efficiency variables SLAGCEFF, GASCEFF, and TSSCEFF, the effects of SR1, as maximum percent variation in the calculated dependent variable, were +22%, +26%, and +25%, respectively. The positive signs indicate that all combustion efficiencies increased as SR1 increased, which is expected on the basis of improved combustion at stoichiometric and low excess air conditions. The effect of SR1 is nearly equal for all three combustion efficiency variables. It should be reiterated that the above percentages refer to the effects of SR1 on each of the independent variables when the other independent variables are at their average values. Thus the percentages do not add to 100%. This convention is used throughout unless indicated otherwise.

3.1.2. Combustion Air Swirl Pressure

Combustion air swirl pressure (SWIRLPR) effects on SLAGCEFF, GASCEFF, and TSSCEFF, as maximum percent variation in the calculated dependent variable, were -7%, -13%, and -10%, respectively. The negative signs indicate that all combustion efficiencies decreased as air swirl pressure increased. This effect is likely due to increased liner surface cooling at higher swirl pressure. This phenomenon had been observed on several occasions. This cooling probably results in partial quenching of the wall coal burning reactions, especially at low SR1 where endothermic char gasification reactions must proceed to completion to obtain good fuel utilization and/or combustion efficiencies. As with SR1, the small effect of SWIRLPR is about the same for all three combustion efficiency variables.

3.1.3. Fuel Heat Input

Fuel heat input (HEATIN) effects on SLAGCEFF, GASCEFF, and TSSCEFF, as maximum percent variation in the calculated dependent variable, were +35%, +39%, and +39%, respectively. The positive signs indicate that all combustion efficiencies increased as fuel heat input increased. This effect is probably attributable to increased combustion intensity at higher firing rates, resulting in improved fuel utilization. As with SR1 and SWIRLPR, the effect of HEATIN is about the same for all three combustion efficiency variables.

3.1.4. Percent Coal Firing

The percent of fuel heat input due to coal (PCTPC) effects on SLAGCEFF, GASCEFF, and TSSCEFF, as maximum percent variation in the calculated dependent variable, were +29%, +16%, and +15%, respectively. The positive signs indicate that all combustion efficiencies increased as the percent of coal firing increased. At first glance, this appears to be unexpected since coal is more difficult to burn than natural gas or light oil, the auxiliary fuels used in the tests. However, as PCTPC increases, the percent of auxiliary fuel decreases and there is, therefore, less competition for oxygen from the premium fuels, and coal combustion can proceed to a greater extent. In addition, and probably more importantly, coal char combustion/gasification takes place to some extent in the combustor wall slag layer. As PCTPC goes up, there is relatively more coal ash/slag in which the char particles can be embedded for subsequent reaction via gas scrubbing. This interpretation is supported by testing in early Phase III, which showed that the presence of a liquid combustor wall slag layer was necessary to ensure good coal combustion.

Unlike SR1, SWIRLPR, and HEATIN, the effect of PCTPC on the three combustion efficiency variables is not the same. This is illustrated in figure A. PCTPC appears to affect SLAGCEFF about twice as much as GASCEFF or TSSCEFF. This is not unexpected inasmuch as the latter two variables are measures of overall combustion efficiency and thus include the effects of second stage burnout, which always takes place under excess air conditions. SLAGCEFF, however, includes fuel rich combustion and would therefore be more susceptible to the oxygen competition and wall burning effects of PCTPC than the other variables.

3.1.5. Combustion Efficiency Review

Although each of the combustion efficiency variables depends on several operating parameters, the relative effects vary. The following is the strength ordering of these effects.

SLAGCEFF: HEATIN > PCTPC > SR1 >> SWIRLPR

GASCEFF: HEATIN > SR1 > PCTPC > SWIRLPR

TSSCEFF: HEATIN > SR1 > PCTPC > SWIRLPR

These effects are depicted graphically in figures B, C, and D, where the parameter effects are normalized to 100 % absolute. As noted previously, positive percent contributions mean that combustion efficiency increases as the numerical value of the operating parameter or independent variable increases, while negative percent contributions mean that combustion efficiency decreases as the value of the parameter increases.

3.2. Process Temperature

Three experimental observables are related to process temperature. The calculated liner surface temperature (LINERTEM), degrees F, is an indicator of the combustor wall temperature. The combustor cooling air tube-hot-side temperature (THSTEMP), degrees F, is a directly measured variable which relates to the amount of heat being generated in and extracted from the combustor. Finally, the wall heat flux in Btu/hr/ft2, as calculated from the cooling air flow and delta-T (AIRFLUX), is an overall measure of the thermal interaction between the hot combustion gases and the combustor wall. The average measured value, standard deviation, plus high and low values for each of these variables, were used in the analysis. The specific terms analyzed were LINERTEM, THSTEMP, and AIRFLUX. Models based on the four independent variables were constructed. Evaluations of the effects of the individual independent variables on each of the three process temperature variables are presented below.

3.2.1. Combustor Stoichiometry

For the three process temperature variables LINERTEM, THSTEMP, and AIRFLUX, the effects of SR1, as maximum percent variation in the calculated dependent variable, were +22%, +21%, and +9%, respectively. The positive signs indicate that all process temperature indicators increased as SR1 increased, which is expected on the basis of improved combustion efficiency and/or heat release at stoichiometric and low excess air conditions. This effect is naturally coupled to the effect of SR1 on combustion efficiency discussed above. The effect of SR1 is nearly equal for LINERTEM and THSTEMP but considerably less for AIRFLUX. This difference is probably due to the fact that AIRFLUX is a measurement integrated over the entire combustor wall surface, including both the relatively cool mixing zone as well as the main flame or combustion zone. The other two measurements are localized to the downstream side of the combustor where the main flame zone is located. Peak flame temperatures strongly depend on SR1 so that flame zone wall temperature measurements are expected to be highly influenced. Alternatively, integrated or averaged wall thermal effects would tend to smooth out this SR1 effect due to combustor geometry effects on radiative heat transfer.

Analysis of combustor circumferential and axial wall thermocouple (TC) temperature measurements, made in early Phase III testing (March, 1988), showed that combustor heat release was essentially radially uniform but axially non-uniform. Excluding the exit nozzle, approximately the first one-third of the combustor served as an air/fuel/sorbent mixing zone and had a relatively low temperature, which was anticipated as this was the air-fuel mizing zone, while the rest of the combustor had higher temperature and heat release. It should be emphasized that these measurements reflect the smoothing effect of radiative heat transfer, so that the actual differences in combustor zone gas temperatures are probably much greater than those suggested by the wall TC measurements.

3.2.2. Combustion Air Swirl Pressure

Combustion swirl air pressure (SWIRLPR) effects on LINERTEM, THSTEMP, and AIRFLUX, as maximum percent variation in the calculated dependent variable, were -8%, +7%, and +1%, respectively. The negative sign for LINERTEM is in line with the wall cooling effect discussed in the preceding section on combustion efficiency. The positive sign for THSTEMP is undoubtedly an artifact of combustor operation. On numerous occasions, it has been observed that increases in swirl air pressure, brought about by closing the swirl dampers, resulted in diminished cooling air flow via a backpressuring effect, which also resulted in an increase in tube-hot-side temperature. The effect of SWIRLPR on AIRFLUX is negligible.

3.2.3. Fuel Heat Input

Fuel heat input (HEATIN) effects on LINERTEM, THSTEMP, and AIRFLUX, as maximum percent variation in the calculated dependent variable, were +37%, +35%, and +40%, respectively. The positive signs indicate that all process temperature indicators increased as fuel heat input increased. This effect is attributable to increased combustion intensity at higher firing rates, resulting in higher heat release. The effect of HEATIN is about the same for all three process temperature variables.

3.2.4. Percent Coal Firing

The percent of fuel heat input due to coal (PCTPC) effects on LINERTEM, THSTEMP, and AIRFLUX, as maximum percent variation in the calculated dependent variable, were +27%, +23%, and +37%, respectively. The positive signs indicate that all process temperature indicators increased as the percent of coal firing increased. This effect is no doubt coupled to improved combustion efficiency at higher PCTPC as already noted. However, the relative effect is larger for process temperature than for combustion efficiency. This is probably attributable to enhanced wall heat transfer as PCTPC increases, owing to its higher flame emissivity vs. oil & NG, and the effects of wall burning. The effect of PCTPC on the process temperature variables is essentially the same for LINERTEM and THSTEMP, but is somewhat higher for AIRFLUX. This is illustrated in fig.E.

3.2.5. Process Temperature Review

The following is the strength ordering of the effects of the independent variables on the various process temperature variables.

LINERTEM: HEATIN > PCTPC > SR1 >> SWIRLPR

THSTEMP: HEATIN > PCTPC = or > SR1 >> SWIRLPR

AIRFLUX: HEATIN = or > PCTPC > SR1

These effects are shown graphically in figures F, G, and H.

Basically, process temperature variables are affected by the same independent variables, and to the same degree, as the combustion efficiency variables. This is to be expected, since good combustion is associated with high heat release.

3.3. Solids Distribution

Of the total solids injected into the combustor, which include coal, sorbent, and, on occasion, fly ash, various percentages of the non-combustible and/or non-volatile solids report as slag rejected by the combustor (SLAGREJ), as boiler deposits (BOILREJ), as scrubber solids (SCRUBREJ), and as atmospheric emissions. In a separate DOE SBIR project, aimed at evaluating the feasibility of converting utility fly ash to an environmentally inert slag, using the Coal Tech combustor, non-isokinetic particulate sampling of the atmospheric discharge, downstream of the scrubber, was performed. Results of these preliminary measurements showed that with coal firing (HEATIN = 10.6 MMBtu/hr, PCTPC = 75%), plus combustor sorbent and fly ash injection (0 to 150 PPH), the solids discharged to atmosphere accounted for about 0.5 to 3% of the total solids input. This relatively small amount was neglected in the present bulk solids distribution analysis.

SLAGREJ is actually a lower limit on combustor slag retention since the measurement only occasionally included slag inventoried in the combustor and exit nozzle and basically was only the slag rejected through the tap. In our assessment, the slag depositing in the exit nozzle, and flowing onto the boiler front wall and hearth, should be considered as part of the combustor slag. This is especially important at high coal fire, when there can be large slag deposits in the exit nozzle, since this material can rarely backflow into the combustor and be rejected through the tap. However, in practice, this material was seldom included in the SLAGREJ measurement since retrieval of this slag required considerable effort and downtime. Thus, in the present analysis, this slag ended up as BOILREJ by default.

In addition, the lower SLAGREJ measurements were obtained for unoptimized parametric operation. This kind of operation was necessary for scoping the effects of operating conditions on SLAGREJ, but does not reflect optimum performance. SCRUBREJ was determined from the scrubber water discharge solids content and flow. BOILREJ was obtained by difference, namely, BOILREJ = 100 - SCRUBREJ - SLAGREJ, and is therefore an upper limit. As percents of total permanent solids, the average measured value, standard deviation, plus high and low values for each of these variables is: SLAGREJ: 45, 13, 80, 18; BOILREJ:

19, 14, 50, 0; SCRUBREJ: 36, 16, 66, 1. Models based on the four independent variables were constructed. Evaluations of the effects of the individual independent variables on each of the three bulk solids distribution variables are presented below.

3.3.1. Combustor Stoichiometry

For the three bulk solids distribution variables SLAGREJ, BOILREJ, and SCRUBREJ, the effects of SR1, as maximum percent variation in the calculated dependent variable, were +50%, +45%, and -8%, respectively. The signs indicate that SLAGREJ and BOILREJ increased as SR1 increased, while SCRUBREJ decreased. The considerable positive effect of high SR1 on SLAGREJ is probably related to the already discussed enhancement of combustion efficiency and process temperature, which is expected to result in better solids melting and slagging. In a similar way, high BOILREJ is also associated with high SR1. As noted above, a substantial fraction of BOILREJ could be conceptually considered as part of SLAGREJ. Thus, it is reasonable that SR1 should produce the same qualitative effect on both variables. In addition, it is possible that with improved combustor melting, the material carried out of the combustor is partly melted and thus sticks easier to boiler surfaces than dry ash. The effect of increasing SR1 on SCRUBREJ is negative. This is expected due to mass balance considerations, i.e. if more solids are retained by the combustor/boiler at high SR1 then less will be in the scrubber. These effects are shown in figure I.

3.3.2. Combustion Air Swirl Pressure

Combustion swirl air pressure (SWIRLPR) effects on SLAGREJ, BOILREJ, and SCRUBREJ, as maximum percent variation in the calculated dependent variable, were +7%, -17%, and -35%, respectively. The signs indicate that SLAGREJ increased, but BOILREJ and SCRUBREJ decreased, as SWIRLPR increased. Improved slag rejection at higher SWIRLPR is likely due to enhanced cyclonic action of the swirl air. Although the modeled strength of this effect on SLAGREJ is relatively small, the large negative influence it has on BOILREJ and SCRUBREJ can only be attributable to enhanced combustor slag retention at high swirl pressure. The relatively small strength of SWIRLPR in the SLAGREJ model may reflect a non-linear threshold effect. In any case, the effect of SWIRLPR on total combustor slag retention is believed to be of more significance than indicated by the SLAGREJ modeling results.

3.3.3. Fuel Heat Input

Fuel heat input (HEATIN) effects on SLAGREJ, BOILREJ, and SCRUBREJ, as maximum percent variation in the calculated dependent variable, were +12%, +53%, and +48%, respectively. The positive signs indicate that all solid stream contents, as a percent of total solids, increased as fuel heat input increased. There appears to be a relatively small improvement in SLAGREJ as HEATIN increases, conceptually in line with improved combustion intensity and melting as discussed previously. However, both BOILREJ and SCRUBREJ are also increased as the total fuel heat input goes up. Here we have a contradiction since mass balance considerations require that the sign dependencies of the dependent variables cannot all be the same.

Even though combustion efficiency/process temperature increase as HEATIN increases, and you might therefore expect better ash melting and slag rejection, visual observations of the combustor exit nozzle have indicated that at higher HEATIN a significant portion of the combustion takes place in the exit nozzle, particularly with staged combustion. In this situation the flame is not entirely confined within the combustor proper. Thus experimental observations suggest that the rate of combustor slag rejection increases at higher firing rates, but that slag retention, as percent of total solids input, probably has a negative dependence on HEATIN when PCTPC is large, i.e. total solids loading to the combustor is high. This interpretation is at odds with the present statistical result but is justified to some extent by the huge positive effects of HEATIN on BOILREJ and SCRUBREJ, and by the PCTPC effects discussed below.

3.3.4. Percent Coal Firing

The percent of fuel heat input due to coal (PCTPC) effects on SLAGREJ, BOILREJ, and SCRUBREJ, as maximum percent variation in the calculated dependent variable, were -12%, -48%, and +73%, respectively. The signs indicate that both SLAGREJ and BOILREJ are reduced, while SCRUBREJ is increased, as the percent of coal firing increased. This result is in line with the discussion in the preceding section, where it was generally concluded that higher solids loading lead to decreased SLAGREJ in spite of better combustion efficiency and higher process temperatures. As PCTPC increases, we have higher solids input, with the associated negative effect on SLAGREJ. One interesting difference is that BOILREJ has a negative dependence on PCTPC but had a positive dependence on HEATIN. This may be related to one of the experimental results of the DOE SBIR ash melting project, in which it was discovered that ash melting was enhanced as the ratio of heat input to solids went up. In any case, it is quite clear that increases in coal firing, either in absolute terms or as a percent of fuel input, dramatically increased the scrubber solids loading. The effects of PCTPC on solids distribution are shown in figure J.

It is important to emphasize that the positive effect of increased PCTPC on SCRUBREJ is due to increased scrubber solids loading as ash, not as unburned coal. In section 3.1.4 it was determined that increased PCTPC lead to improved combustion efficiencies, having a +15% maximum spread influence on TSSCEFF, the combustion efficiency based on scrubber carbon. Thus, the positive effect of increased PCTPC on scrubber solids cannot be due to poorer combustion efficiency and, hence, more unburned coal carryover to the scrubber. Instead, it must be due to more ash and other non-combustibles carryover.

3.3.5. Solids Distribution Review

The following is the strength ordering of the effects of the independent variables on the various bulk solids distribution variables.

SLAGREJ: SR1 >> [HEATIN ? =] PCTPC > SWIRLPR

BOILREJ: HEATIN = or > PCTPC = or > SR1 >> SWIRLPR

SCRUBREJ: PCTPC > HEATIN > SWIRLPR >> SR1

These effects are illustrated in figures K, L, and M.

SLAGREJ appears to be positively influenced by variables (e.g. SR1) which enhance ash melting via improvements in combustion efficiency/process temperature, but is negatively influenced by variables (e.g. PCTPC) which increase total mass or solids input. The impact of variables (e.g. HEATIN) which have a dual effect is unclear. As solids input increases, the rate of slag rejection also increases but SLAGREJ, as a percent of total solids, goes down while the amount of solids in both the boiler and scrubber goes up. Part of this result is due to the narrow definition of SLAGREJ imposed by the experimental method. In addition, solids not captured in the combustor tend to end up in the scrubber rather than layout in the boiler as the total solids input increases. As SWIRLPR increases there is better SLAGREJ and less boiler and scrubber solids. In general, these results, plus test observations, support the view that the present combustor volume is underutilized, or that the combustor is too short to adequately retain and reject slag at high mass/thermal input.

Although not part of the statistical analysis, an examination of factors leading to exit nozzle slag buildup is relevant to this section. Exit nozzle slagging can occur either as an upset in operation or as a normal adjunct to operation at moderate to high fire. This latter phenomenon has already been mentioned in section 3.3. Upset exit nozzle slag buildup/blockage has two requirements: (1) poor slagging in the combustor; and (2) a hot exit nozzle. The former requirement is usually accompanied by poor combustion as evidenced by "char balls" in the rejected slag. Poor slagging/combustion occurs when the ash/slag is not tacky or sticky so that injected solids tend not to be trapped on the combustor wall but are carried out to the exit nozzle. Since the exit nozzle is almost always hotter than the combustor, due to heavier insulation and the lack of active cooling, slagging occurs here with buildup and potential blockage, or with slag flow into the boiler. The presence of a hot exit nozzle was especially evident during consecutive day firing with overnight heating.

Conditions in the combustor itself, which are not conducive to good slagging/combustion can arise if (1) the combustor is too cold; (2) the flame temperature is too low; or (3) the slag T-250 is too high. The first case occurs when the combustor is cooled too much or if the switch-over from oil to coal is premature. The second condition can occur if SR1 is too low (< 0.6) or too high (>1.5 as per test FA4 of the DOE SBIR project), in which cases there is poor heat release to the combustor due to incomplete combustion or excessive flame cooling, respectively. Thus the interplay of these three factors can account for poor slagging/combustion as well as exit nozzle slag buildup. As noted above, there is almost always some nozzle slagging at moderate to high fire owing to direct flame impingement.

3.4. Refractory Liner Wear

The combustor liner consisted of several metal oxide compounds. By focussing on the quantity of one of these oxides whose concentration exceeded that in the slag it is possible to estimate liner material loss. The oxide selected for this purpose was chrome oxide. The presence of chrome (XSCHROM, as percent of slag sample weight) in the coal ash slag is an indication of liner loss. Models based on the four independent variables were constructed. Evaluations of the effects of the individual independent variables on XSCHROM are presented below. Efforts were made to include variables relating to combustor sorbent injection rates in the models. However, they were excluded on the basis of high probability of zero coefficient.

3.4.1. Combustor Stoichiometry

The effect of SR1 on XSCHROM, as maximum percent variation in the calculated dependent variable, was -24%. This means that as SR1 increased there was less liner degradation. From the preceding discussions, we have determined that high SR1 yields high heat release and process temperature, which are generally known to be unfavorable to refractory life (Reference A). However, SR1 also affects the nature of the gaseous environment in terms of oxidizing vs. reducing conditions. Articles in the literature (e.g. Reference B) indicate that reducing atmospheres usually promote refractory corrosion by slags. Thus, it appears in the present case that the negative effects of reducing atmosphere on refractory life outweigh the benefits of reduced gas temperature. Put another way, the positive effects of an oxidizing atmosphere on refractory life at high SR1 outweigh the negative effects of higher temperature.

3.4.2. Combustion Air Swirl Pressure

Combustion swirl air pressure (SWIRLPR) effects on XSCHROM, as maximum percent variation in the calculated dependent variable, was -26%. The sign indicates that XSCHROM decreased as SWIRLPR increased. As in several of the above discussions, this effect may be attributed to increased liner/slag cooling at high SWIRLPR, which results in a kinetic rate reduction of slag/liner chemical interaction.

3.4.3. Fuel Heat Input

The fuel heat input (HEATIN) effects on XSCHROM, as maximum percent variation in the calculated dependent variable, was +49%. The positive sign indicates that liner degradation, as measured by XSCHROM, increased significantly as HEATIN increased. This effect is likely due to increased process temperature at higher heat input, which accelerates the kinetics of slag corrosion of the liner.

3.4.4. Percent Coal Firing

The percent of fuel heat input due to coal (PCTPC) effect on XSCHROM, as maximum percent variation in the calculated dependent variable, was +88%. The sign indicates that XSCHROM is greatly increased as the percent of coal firing is increased. As with HEATIN, increases in PCTPC lead to increased process temperature, with its associated negative effect on liner life. In addition, as PCTPC is raised, the amount of coal ash slag also increases, thereby providing greater potential for corrosive interaction between the slag and the liner.

3.4.5. Refractory Liner Wear Review

The following is the strength ordering of the effects of the independent variables on the liner degradation variable, XSCHROM.

XSCHROM: PCTPC > HEATIN > SWIRLPR = or > SR1

These effects are illustrated in figure N.

Degradation of the combustor refractory liner, as indicated by chrome in the rejected slag, is primarily caused by the presence of coal ash slag. This may be caused by chemical corrosion which increases kinetically as process temperature increases (HEATIN effect). Although this coal ash effect is largely immune to effects of ash composition, analysis indicated that higher iron content slags somewhat accelerated the negative effect of coal ash on liner wear. Alternatively, the presence of basic sorbent material had no discernable impact on liner loss. Increased SWIRLPR partially offsets slag corrosion by cooling the liner/slag surface. In addition, liner wear appears to be more severe under reducing vs. oxidizing conditions (SR1 effect), in line with the literature.

3.5. NO_x Control

One of the main goals of the Clean Coal project was to reduce the atmospheric emissions of oxides of nitrogen (NO_x) to 100 ppm or less. The technique used to achieve this was staged combustion, with a fuel rich first stage to convert fuel-bound-nitrogen (FBN) to molecular nitrogen, followed by a fuel lean second stage to complete fuel burnout, but without generating excessive thermal NOx. In the present project, the combustor itself was the first stage, while second stage or tertiary air was injected into the boiler firebox surrounding the combustor gas exit nozzle. The effects of this control strategy were determined by measuring NOx (ppmv, dry basis) at the boiler outlet. For comparison, the measured NO_x levels were converted to equivalent values at 3% oxygen or 15% excess air (NORMNOX). In addition, a small further reduction in NO_x was obtained due to the action of the wet particulate scrubber. This effect contributed an additional 5 to 10% reduction in NO_x emitted to atmosphere. As ppmv, dry basis, and normalized to 3% O2, the average measured value, standard deviation, plus high and low values for NORMNOX are: 355, 148, 769, 81. It should be noted that the lowest value corresponds to oil-only firing and that the minimum with coal firing was 184 ppm. The minimum coal fired NO_x level in the scrubber stack was 160 ppm. Models based on the four independent variables were constructed. Evaluations of the effects of the individual independent variables on NORMNOX are presented below.

3.5.1. Combustor Stoichiometry

The effect of SR1 on NORMNOX, as maximum percent variation in the calculated dependent variable, was +48%. This means that as SR1 increased the level of NO_x in the boiler outlet increased. This relationship has been demonstrated many times by various groups, and is due to increased oxidation of FBN to NO_x at higher SR1. For high coal firing as percent of total heat input, namely PCTPC > 70%, the degree of control of NOx at the boiler outlet, obtained by staged combustion, is shown in figure O. As can be seen, a minimum in NO_x occurs at SR1 around 0.75. Globally, NOx levels have been reduced from an unstaged value of about 800 ppm to below 200 ppm, a reduction of more than 75%.

3.5.2. Combustion Air Swirl Pressure

Combustion swirl air pressure (SWIRLPR) effects on NORMNOX, as maximum percent variation in the calculated dependent variable, was +21%. The sign indicates that NORMNOX increased as SWIRLPR increased. As SWIRLPR increases, we have seen that slag combustion efficiency and process temperature decrease while combustor slag rejection increases. The former effect is due to higher liner/slag surface cooling, while the latter result is caused by higher cyclonic action. With regard to NOx control via staging, it is important to release the FBN in the fuel rich first stage. Otherwise, FBN carried over to the fuel lean second stage will be easily converted to NO_x. In the present instance, the twin effects of increasing SWIRLPR on FBN release are at cross-purposes. Decreased combustion efficiency and process temperature are expected to result in lower FBN release, while higher combustor solids retention is expected to improve FBN release. Since the overall effect of increased SWIRLPR is to increase NO_x emissions, the solids retention effect must be subordinate to the combustion efficiency and temperature effects, i.e. there is less FBN release in the combustor, resulting in more NO_x formation in the second stage.

3.5.3. Fuel Heat Input

The fuel heat input (HEATIN) effect on NORMNOX, as maximum percent variation in the calculated dependent variable, was -32%. The negative sign indicates that NORMNOX decreased as HEATIN increased. This effect is likely due to increased slag combustion efficiency and process temperature at higher heat input, which accelerated the release of FBN in the combustor.

3.5.4. Percent Coal Firing

The percent of fuel heat input due to coal (PCTPC) effect on NORMNOX, as maximum percent variation in the calculated dependent variable, was +42%. The sign indicates that NORMNOX increased as the percent of coal firing increased. As PCTPC increases the total amount of FBN increases. It is generally agreed that fuel-NOx is highly dependent on the amount of fuel nitrogen or FBN present in the system. For the eight coals tested, fuel nitrogen averaged 1.27% by weight, with a range of 1.12 to 1.83%. This narrow range of FBN content was tested in models of NORMNOX but had a relatively low tolerance of PCTPC, which was a more important variable.

3.5.5. NO_x Control Review

The following is the strength ordering of the effects of the independent variables on measured NOx levels in the boiler outlet.

NORMNOX: SR1 > PCTPC > HEATIN > SWIRLPR

These effects are illustrated in figure P.

As SR1 and PCTPC increase, NOx increases as expected. As HEATIN increases, NOx decreases due to better FBN release on the first stage, owing to higher combustion efficiency and process temperature. This results in lower overall NOx with staged combustion. As SWIRLPR increases, NOx increases due to the liner/slag cooling effect quenching FBN release.

3.6. Sulfur Control

During combustion the coal sulfur was partitioned among four streams: sulfur retained and rejected with the slag (ACTSLGS), sulfur deposited in the boiler (BOILSULF), sulfur found in the scrubber discharge (PCTSSCRB), in solution and/or as part of the suspended solids, and sulfur emitted to atmosphere (ATMSULF). In practice, BOILSULF was not measured directly but was determined by subtracting ACTSLGS from the measured reduction in SO_2 (as percent of total sulfur) in the boiler outlet or SREDBO. In a similar way ATMSULF was taken to be (100 - SREDFS), where SREDFS is the measured reduction in SO_2 in the scrubber fan stack. As percent of total sulfur, the average measured value, standard deviation, plus high and low values for each of the directly measured variables is: ACTSLGS: 1.90, 2.54, 11.15, 0.16; SREDBO: 15, 17, 82, 0; PCTSSCRB: 25, 18, 100, 1; SREDFS: 35, 12, 57, 9. It should be noted that the SREDBO maximum value of 82% was obtained with boiler sorbent injection. The maximum obtained with combustor sorbent injection was 52%. Models based on the four independent variables were constructed. Evaluations of the effects of the individual independent variables on each of the four sulfur partitioning variables are presented below.

3.6.1. Combustor Stoichiometry

For the four sulfur variables ACTSLGS, BOILSULF, PCTSSCRB, and ATMSULF, the effects of SR1, as maximum percent variation in the calculated dependent variable, were -87%, -9%, -23%, and +2% respectively. The signs indicate that overall system sulfur retention decreased as SR1 increased, while emission to atmosphere increased. It is likely that these effects, taken as a whole, are due to increased sorbent deadburning at high SR1, which has been shown to raise combustor temperature. On an individual basis, however, the different degrees of dependency of the sulfur variables suggest that other changes in operating conditions, due to variation in SR1, must be at work.

The slag sulfur content is the sulfur variable most susceptible to SR1 variation, as shown in figure Q. This profound dependency suggests that at low SR1 (around 0.6 to 0.7) local conditions of temperature and gas composition are optimized for in-situ sulfur capture by sorbent with subsequent rejection in the slag. This aspect had been studied in detail by Coal Tech in previous work (Reference C) where it was found that first stage stoichiometry was a critical parameter in the sulfur capture process. For comparison, data obtained from Reference C are presented in figure R, showing a remarkable qualitative similarity to figure Q.

It should be noted that good slag sulfur retention/rejection is also associated with rapid slag removal from the combustor, in order to minimize slag desulfurization. As discussed in section 3.3, good slag rejection depends most significantly upon high SR1. This result contrasts with the slag sulfur results, which show maximum slag sulfur at low SR1. This implies that local combustor thermal/chemical environment is more important than bulk slag removal in achieving good slag sulfur retention. In any case, it is probably necessary to optimize both ACTSLGS and SLAGREJ by manipulation of operating parameters other than SR1 and/or by incorporating combustor design changes as discussed in section 4.2.

Figure S* illustrates the relative effects of SR1 on BOILSULF, PCTSSCRB, and ATMSULF. Both boiler and scrubber sulfur contents decrease as SR1 increases. This is partly due to sorbent deadburning, as noted above. In the case of PCTSSCRB, however, the reduction at higher SR1 is undoubtedly coupled to the fact that total scrubber solids (SCRUBREJ) also decrease as SR1 increases, as discussed in section 3.3.1. In addition, it was shown in section 3.1.1 that increasing SR1 lead to improved combustion efficiency and, thus, less unburned fuel. Since PCTSSCRB increased as SR1 decreased, it is fair to attribute part of the increase in scrubber sulfur to the presence of some unburned coal. More will be said on this in section 3.6.4. Finally, more sulfur is emitted to atmosphere as the sorbent becomes less effective in capturing sulfur due to the deadburning effect of high SR1. However, the correspondence is not proportional since the scrubber can remove some sulfur with or without sorbent.

3.6.2. Combustion Air Swirl Pressure

Combustion air swirl pressure (SWIRLPR) effects on ACTSLGS, BOILSULF, PCTSSCRB, and ATMSULF, as maximum percent variation in the calculated dependent variable, were +76%, +5%, -1%, and +8%, respectively. The positive sign for ACTSLGS indicates that slag sulfur content greatly increased as air swirl pressure increased. The high positive effect of increasing SWIRLPR on slag sulfur content may be due to a number of factors. First, it has been shown that high SWIRLPR leads to increased liner/slag surface cooling. This could be important for slag sulfur retention by (a) helping to reduce sorbent deadburning, and (b) minimizing temperature dependent slag desulfurization. Secondly, it has also been shown that high swirl air pressure improves slag rejection. This would result in more of the sulfated sorbent being thrown to the wall and embedded in the slag. The other sulfur variables show only a weak dependence

(*)-Added information is contained in the Proprietary Report"

on SWIRLPR. These effects are believed to be indirect and coupled to the SWIRLPR effects on combustion efficiency and process temperature, with their attendant impact on fuel sulfur release, and on bulk solids distribution.

3.6.3. Fuel Heat Input

The fuel heat input (HEATIN) effects on ACTSLGS, BOILSULF, PCTSSCRB, and ATMSULF, as maximum percent variation in the calculated dependent variable, were +41%, -11%, +60%, and -29%, respectively. The signs indicate that ACTSLGS and PCTSSCRB increased when HEATIN increased, while BOILSULF and ATMSULF decreased as HEATIN increased. The positive effect of higher fuel heat input on slag sulfur retention/rejection may be due to enhanced combustion efficiency/process temperature resulting in better coal sulfur release. Alternatively, the higher combustion intensity may promote more vigorous mixing of the air/fuel/sorbent. In addition, the rate of slag rejection (but probably not SLAGREJ as percent of total solids) also increases as HEATIN increases, thus minimizing slag residence time and desulfurization in the combustor.

As HEATIN increases there is a slight decrease in boiler sulfur. This may be due to unfavorably high flame temperatures and/or more sorbent deadburning in the second stage, which generally burns more intensely at higher HEATIN. The significant increase in scrubber sulfur with increasing heat input is no doubt largely related to increased bulk solids in the scrubber as discussed previously. In addition, higher fuel rates may provide a higher and more favorable sulfur/sorbent reaction temperature in the boiler, downstream of the second stage flame zone, and in the boiler outlet. For example, the boiler outlet stack temperature was found to increase most at higher fuel heat inputs. Finally, as HEATIN increases, there is a fair decrease in atmospheric SO2. This drop is mainly due to improved scrubber sulfur retention at high HEATIN. The effects of HEATIN on slag, boiler, and scrubber sulfur retentions are shown in figure S-2*.

3.6.4. Percent Coal Firing

The percent coal firing (PCTPC) effects on ACTSLGS, BOILSULF, PCTSSCRB, and ATMSULF; as maximum percent variation in the calculated dependent variable.

(*)-Added information is contained in the Proprietary Report"

were +100, +100%, +61%, and -18%, respectively. The extremely large positive effects of higher PCTPC on slag, boiler, and scrubber sulfur contents are shown in figure T*. This situation arises since higher coal contributions to total heat input are expected to kinetically increase the sulfur/sorbent reaction rate by increasing the partial pressure of SO2. It has been variously shown (e.g. Reference D) that the overall reaction rate of sorbent and SO2 is proportional to the concentration of SO2, usually expressed in atmospheres. In the present analysis, this effect is believed to be mainly important for improved slag and boiler sulfur retention, while the enhancement of scrubber sulfur is mainly attributable to increased scrubber solids at high PCTPC. A possible corollary effect is that at higher PCTPC there may be more condensation of SO2 vapors on particles going to the scrubber. As with fuel-nitrogen, efforts to explicitly include coal-sulfur content in the models were not successful owing to high correlation with PCTPC. With increasing PCTPC, there is a moderate decrease in atmospheric sulfur, as expected from an overall sulfur balance.

It is important to note that the positive effects of increased PCTPC on slag and boiler sulfur retention are not due to lack of complete release of sulfur from the coal. That is, the sulfur measured in the slag and boiler solids is chemically associated with the presence of sorbent, and is not associated with the presence of unburned coal. With no combustor sorbent injection, slag and boiler solids sulfur contents are always below the level of detectability.

Scrubber sulfur content may be slightly associated with the presence of unburned coal. With no sorbent injection and TSSCEFF > 95%, PCTSSCRB averaged 14% of total sulfur. Of this, the vast majority is due to the washing out of SO_2 (+ 0.5 O_2 + H_2O = H_2SO_4), as indicated by the high dissolved sulfur content, accounting for 94% of PCTSSCRB, and the low pH of 4. Thus, with about 6% of PCTSSCRB in the scrubber solids, presumably as unburned coal, less than 1% of the total sulfur can be associated with unburned coal under these conditions. In the relatively few cases where TSSCEFF < 95%, again with no sorbent injection, PCTSSCRB averaged 26%, of which 77% is dissolved and 23% is in suspended solids. Thus for these cases of low TSSCEFF, only about 6% of the total sulfur can be associated with unburned coal. This would be the worst case.

(*)-Added information is contained in the Proprietary Report"

With combustor sorbent injection, PCTSSCRB averaged 24% while TSSCEFF averaged 94%. Here, around 58% of PCTSSCRB is dissolved while 42% is in the solids. Based on the above analysis with no sorbent injection, the bulk of the sulfur solids cannot be coal since TSSCEFF is relatively high. This is confirmed by chemical analysis of the scrubber solids, showing high sulfur content only in the presence of sorbent calcium. In addition, the associated pH averages 9.5, showing the neutralization effect of hydrolyzed sorbent on the originally acidic scrubber water. Nearly all of the dissolved sulfur is present as sulfate, with measured dissolved calcium and sulfate concentrations corresponding to the solubility limit of CaSO4. In this situation, "excess" CaSO4 would remain as a solid, since the ionic solubility product cannot be exceeded.

3.6.5. Calcium/Sulfur Mole Ratio

The effects of the calcium/sulfur mole ratio (CASRAT) on ACTSLGS, BOILSULF, PCTSSCRB, and ATMSULF, as maximum percent variation in the calculated dependent variable, were +44, +27%, -22%, and -13%, respectively. As anticipated, both slag and boiler sulfur contents increased significantly as the Ca/S ratio increased due to enhancement of the sulfur/sorbent reaction rate via increased sorbent availability. Since more sulfur is retained in the slag and boiler at higher CASRAT, the amounts retained in the scrubber and emitted to atmosphere correspondingly decreased. These effects of CASRAT are illustrated in figure U* for the slag, boiler, and scrubber sulfur variables.

The data show little or no dependence of the sulfur variables on combustor sorbent type. It is possible that calcium hydrate performed slightly better than limestone but only marginally so. In addition, injection of calcium acetate could not be fully evaluated due to feeding problems associated with combustion of the organics at the injection point, resulting in heavy ash buildup.

Although there was limited data on boiler sorbent injection, it is clear that this technique was most efficacious in reducing SO2. At a Ca/S ratio of 3, an 82% reduction in measured stack SO2, using hydrate, was obtained. With limestone injection at Ca/S > 3, the reduction in SO2 was less than 20%. Improved SO2 reduction in the boiler outlet with hydrate vs. limestone was

(*)-Added information is contained in the Proprietary Report"

probably related to the lower calcination temperature of hydrate, which, in the present application, gave rise to more internal surface exposure, i.e. a higher porosity, for reaction with the SO2 than did the limestone. Besides sorbent type and Ca/S ratio, analysis of the limited data indicates that the temperature in the boiler sorbent injection area is also critical.

3.6.6. Sulfur Control Review

The following is the strength ordering of the effects of the independent variables on the sulfur distribution variables.

ACTSLGS: PCTPC > SR1 > SWIRLPR > CASRAT = or > HEATIN

BOILSULF: PCTPC >> CASRAT > HEATIN > SR1 > SWIRLPR

PCTSSCRB: PCTPC = or > HEATIN > SR1 = or > CASRAT >> SWIRLPR

ATMSULF: HEATIN > PCTPC > CASRAT > SWIRLPR > SR1

These effects are illustrated in figures V, W, X, and Y.

Even though the global phenomena are complex and not yet fully understood, several conclusions are possible. Slag sulfur retention and rejection is clearly a delicate process, having very narrow parametric windows in which to be optimized. Every independent variable in the ACTSLGS model exercised great influence. Aside from the obvious requirements of sufficient sorbent (CASRAT effect) and high sulfur concentration (PCTPC effect), maximum slag sulfur strongly depends on the local thermal/chemical environment as indicated by its sharp dependence on SR1, which is believed to have a major impact on sorbent deadburning as well as sorbent/sulfur reaction kinetics and the stability of the sulfated sorbent product. Other variable enhancement factors seem to include minimum sorbent deadburning, minimum slag desulfurization, and good slag rejection (SWIRLPR effect); good coal- sulfur release and good air/fuel/ sorbent mixing (HEATIN effect).

Except for HEATIN, boiler sulfur retention (BOILSULF) is qualitatively affected by the independent variables in much the same way as ACTSLGS. Since the boiler observables implicitly include the exit nozzle and the surrounding boiler refractory face, it is not unreasonable to consider at least some portion of this zone as an extension of the combustor. Thus it is expected that parameters affecting combustor slag sulfur rejection also affect BOILSULF. The negative dependence of BOILSULF on increasing HEATIN may be attributed to second stage sorbent deadburning.

PCTSSCRB appears to totally depend on the amount of bulk solids reporting to the scrubber since its dependence on the four major independent variables practically mirrors the SCRUBREJ dependence. The negative dependence of PCTSSCRB on increasing CASRAT simply states that sulfur not retained in the combustor/boiler, due to sorbent capture, will end up in the scrubber or go to atmosphere. ATMSULF essentially increases when operating conditions tend to deadburn the sorbent (high SR1) or tend to reduce PCTSSCRB (low HEATIN and/or PCTPC), which is in turn coupled to reduced SCRUBREJ.

It should be noted that post-test chemical analysis of boiler solids, obtained late in the Phase III testing, yielded up to 30% of the total sulfur in the presence of CaO. Experimental evidence indicates that almost all observed reductions in boiler outlet SO2 were due to carried over sorbent. What is unclear is whether the actual SO2 capture took place within the combustor, with the sulfated sorbent being carried out, or whether the sorbent was first carried out, then reacted with the sulfur in the second stage. The overall impression, however, is that significant sulfur capture may be taking place in the combustor but that there is insufficient reactive residence time to accomplish fuel burnout/ash melting at the higher coal firing rates needed to maximize slag rejection. Consequently, most of the reactive solids, at high fire, are blown out of the combustor, with some settling in the boiler and some getting carried to the scrubber.

4. STATISTICAL MODELING SUMMARY

The four major independent variables used in dependent variable modeling were discovered to produce one or more general effects on the overall process. These effects, for increasing values of the variables, are as follows:

SR1: - better fuel combustion, burnout, heat release.
- better ash melting.
- a more oxidizing atmosphere.
- higher flame temperature.

SWIRLPR: - cooler liner/slag surface.
- more cyclonic action, better combustor solids retention.

HEATIN: - higher air/fuel/sorbent mixing, combustion intensity, and heat release.
- better ash melting.
- higher mass throughput, less combustor gas and/or solids residence time.

PCTPC: - more ash/slag system loading.
- more coal wall burning, different combustor heat release pattern.
- increased sulfur and fuel-nitrogen to the system.

Based on maximum effect on the modeled dependent variables, PCTPC was found to have the greatest impact on operation, followed closely by SR1 and HEATIN. SWIRLPR proved to have the least global influence although its contribution to slag sulfur retention was very high. For models containing CASRAT, its influence was about midway between SR1 (or HEATIN) and SWIRLPR. This relatively modest effect of Ca/S mole ratio may be due to some type of threshold effect and/or the fact that the scrubber can remove some sulfur even with no sorbent.

In the preceding sections, we have discussed how operating parameters have impacted the individual dependent variables. In actual operation, however, the picture is more complex since efforts to optimize one dependent variable, by manipulating one or more independent variables, invariably lead to performance changes in other areas of operation. In the remainder of this section, the effects of varying individual parameters will be assessed in terms of group impact on important process observables. This information is useful for two reasons: (1) it allows model simulation of condition combinations which may not have been actually run; and (2) it provides guidance in evaluating combustor operating or design modifications needed to upgrade performance. In regard to statistical modeling, it should be emphasized that predicted results are generally valid provided that the input values of the independent variables are within the normal range of those in the database. In other words, statistical models are good for interpolating but poor for extrapolating.

4.1. Independent Variable Effects

The average global impact of varying SR1 over its normal range of values is illustrated in figure Z. In the figure, the total effect of SR1 is broken down on a percent basis. Thus, any change in first stage stoichiometry will affect slag sulfur content the most and atmospheric SO2 the least. The signs, as has been the convention, indicate whether the variable will increase (+) or decrease (-) as the independent variable increases.

From figure Z, it can be seen that efforts to improve slag sulfur retention by lowering SR1 will also result in a fairly strong decrease in NOx, which is desirable, and a fairly strong decrease in slag rejection, which is not desirable. Other effects include a moderate decrease in combustion efficiency and process temperature, a moderate increase in liner loss, and a small decrease in atmospheric SO2 emissions. Thus, fine-tuning the operation based on stoichiometry would involve significant trade-offs.

Following the same convention as with SR1, the average impact of varying SWIRLPR is shown in figure A-1. From the figure it is evident that slag sulfur content is the variable most affected by changes in SWIRLPR, with sulfur content increasing with increasing SWIRLPR. In addition, as SWIRLPR increases, we have a moderate improvement in liner life as well as a modest increase in NOx. The other dependent variables are only weakly affected.

With changes in HEATIN, the various dependent variables are all moderately affected as shown in figure B-1. However, except for liner wear, all dependent variables are nudged into more favorable values as HEATIN is raised.

Increasing PCTPC (Figure C-1) markedly improves slag sulfur content but also has a significant negative effect on liner life, while NOx is also moderately increased. The remaining variables are only weakly affected.

Raising the Ca/S mole ratio positively influences slag and boiler sulfur retention more than it negatively influences scrubber sulfur retention and atmospheric sulfur emissions, as can be seen in figure D-1. If the presence of sorbent was the only or, at least, the major factor in sulfur capture, one might expect nearly equal positive and negative effects on the sulfur distribution. Part of this imbalance is likely due to the sorbent deadburning effect which impacts slag and boiler capture the most. As noted, the scrubber can retain sulfur even without sorbent. The fact that atmospheric SO2 emissions are little affected by combustor CASRAT indicates that overall conditions have not been optimized, principally in the area of sorbent deadburning.

4.2. Optimized Model Simulation Results

Key process variables were model simulated to provide optimized values based on varying the independent variables. Since the dependent variables often exhibit different sign dependencies on the independent variables, appropriate independent variable values were chosen to individually optimize each dependent variable. SR1 was therefore chosen to be 0.6 or 1.3, HEATIN was 6 or 20 (MMBtu/hr), and SWIRLPR was 10 or 40 (" WC). In order to avoid trivial cases, PCTPC was held at 100 (%) while CASRAT was always 3. It should be noted that optimized values of some variables (e.g. NORMNOX) are a minimum, while for other variables (e.g. TSSCEFF) they are a maximum. The results are presented in Table A.

Table A. Model Simulation for Individually Optimized Process Observables

	Optimized Variables (a)							
	ACTSLGS	BOILSULF	PCTSSCRB	ATMSULF	SLAGREJ	NORMNOX	XSCHROM	TSSCEFF
ACTSLGS	6.5	5.6	4.2	4.2	4.0	4.2	3.1	1.7
BOILSULF	22	24	21	21	21	21	23	20
PCTSSCRB	47	19	48	48	40	48	12	41
ATMSULF	48	74	43	43	49	43	75	44
SLAGREJ	27	21	24	24	50	24	44	47
NORMNOX	258	409	168	168	467	168	620	379
XSCHROM	1.5	0.8	1.7	1.7	1.2	1.7	0.6	1.5
TSSCEFF	107	49	116	116	133	116	75	142

Optimum Conditions

SR1	0.6	0.6	0.6	0.6	1.3	0.6	1.3	1.3
SWIRLPR	40	40	10	10	40	10	40	10
HEATIN	20	6	20	20	20	20	6	20

(a) Optimized variables are in the horizontal row. Optimized values for each variable are found along the diagonal. The columns contain the values of the other variables when the row variable is optimized. The optimum conditions for the row variables are at the bottom. PCTPC = 100 and CASRAT = 3 in all cases.

As can be seen from table A, BOILSULF is essentially unaffected by varying operating conditions when PCTPC = 100 and CASRAT = 3. The only variable optimized at low fire (HEATIN = 6 MMBTU/hr) is XSCHROM, which is little affected by changes in SR1 and SWIRLPR. However, in this case, low fire results in 75% of the total sulfur being emitted to atmosphere, NOx at 620 ppm, and combustion efficiency = 75%. Clearly, low heat input has a tremendously adverse impact on combustion and environmental control, which is hardly offset by the corresponding increase in liner life. This is an important result since operating the combustor at a maximum firing rate is desirable from a process efficiency and economic point of view. Ordinarily, this situation would dictate frequent liner replacement, with resultant high cost due not only to labor and materials for repair but also due to down time. However, toward the end of the Phase III testing, an operating technique was developed to replenish the combustor walls. This technique requires careful monitoring of process temperature as well as timely application in order to be effective. Thus, the adverse effects of high firing rate on liner life can be neutralized without derating the combustor. Development of this technique was a major accomplishment of the present project.

Although the above technique was developed under manual combustor operation, it is believed that its full potential can only be achieved with computer process control. In addition, economic factors related to the degree of required operator supervision in a commercial application, dictate automatic control of this strategy.

At high firing rate, the overall combustion efficiency, as given by TSSCEFF, is little affected by changes in SWIRLPR. At low SR1, efficiency is somewhat lower, but still predicted to be generally acceptable, even if predicted efficiencies greater than 100% are taken with a grain of salt. In any case, satisfactory combustion efficiency can no doubt be attained by the implementation of standard techniques such as external air preheat and/or modified tertiary air injection geometry, if necessary. The implementation of this kind of technology should not be considered novel or developmental, but is more of the "off-the-shelf" variety. Slag combustion efficiency (not shown) closely follows overall efficiency in terms of magnitude and degree of independent variable dependence.

At high firing rate, both NO_x reduction and slag sulfur content are optimized at low SR1 while slag rejection is decreased from the excess air value. In addition, NOx levels are significantly decreased at low air swirl pressure, but slag sulfur content is reduced. Slag rejection is little affected by changes in SWIRLPR. These results indicate that the above three variables cannot be simultaneously optimized in the present system by manipulation of operating parameters alone. Instead, some compromise or trade-off would be required, all other factors remaining the same.

Also at high firing rate, the scrubber sulfur retention (PCTSSCRB) and the sulfur emitted to atmosphere (ATMSULF) are little influenced by SR1 and SWIRLPR. The latter result is important since it basically says that atmospheric SO2 emissions cannot be reduced below about 43% of total sulfur with combustor sorbent injection, using the present combustor operational and design configuration. The fact that boiler sorbent injection resulted in atmospheric SO2 of less than 18% of total sulfur clearly shows that thermal/chemical regimes of high sulfur capture potential do exist in the current system configuration, but were not achieved by combustor sorbent injection. This is seen In table A where even the optimized value of ACTSLGS is disappointingly low.

Regarding overall system sulfur retention, the upshot seems to be that sulfur capture and rejection in the combustor have not been optimized due to underutilization of the combustor volume, i.e. the air/fuel/sorbent mixing zone is too extensive (with the injection configuration used in the Clean Coal tests), or the combustor is in fact too short to allow complete reaction to occur, including fuel burnout, sorbent sulfur capture, and ash melting, within the combustor proper. With the first stage reactions continuing in the exit nozzle and/or near the boiler front wall, especially with staged operation, it is not surprising that relatively little sulfur is captured and rejected with the slag, and that the amount of rejected slag is reduced. It is also not surprising that carried over sorbent/sulfur reactions in the boiler do not approach the efficiency of direct boiler sorbent injection since the sulfur capture reactions are either thermodynamically reversed, or the sorbent deadburned, as the first stage gases encounter the hot second stage flame front.

4.3. Impact on Combustor Design & Operation

Consideration of the above modeling results, as well as other experimental observations, yielded several conclusions and/or hypotheses applicable to operation and design of a commercial coal fired, air cooled combustor. One clear result was that best overall combustor performance was obtained at high fuel heat input. This is important from an operational and economic point of view. Extrapolation from the database, setting HEATIN to 30 MMBtu/hr, predicts improvement in all key process variables except XSCHROM and BOILSULF. The maximum heat input during the tests was around 20 MMBtu/hr, even though the combustor was designed for 30 MMBtu/hr and the boiler was thermally rated at around 23 MMBtu/hr. This was due to facility limits on water availability for the boiler and for cooling the combustor. In fact, even 20 MMBtu/hr was borderline, so that most of the testing was conducted at lower rates.

Attempts to optimize process variables via independent parameter changes showed that there were two difficulties in this approach. The first was that changes in operating parameters to enhance one dependent variable often resulted in degradation of other process variables. For example, both NO_x reduction (NORMNOX) and slag sulfur content (ACTSLGS) were optimized at low SR1 while slag rejection (SLAGREJ) was decreased from the excess air value. In addition, NO_x levels were significantly decreased at low air swirl pressure, but slag sulfur content was reduced. These results indicate that these variables cannot be simultaneously optimized in the present system by manipulation of operating parameters alone. This situation is largely inherent to the process physics and chemistry and cannot be disregarded. Here, one must either compromise and choose operating conditions which involve a trade-off in performance among the affected variables, or introduce changes in operating technique and/or combustor design which will offset the negative effects of certain operating conditions for one or more process variables.

The latter approach had been successfully implemented for XSCHROM where liner life, at operating conditions associated with good overall performance but higher liner wear, was extended by wall replenishment. In a similar way, the addition of external air preheat was suggested to upgrade combustion efficiency, if necessary, at low SR1. It is possible that high air preheat at low SR1 may also be helpful in improving the combustion efficiency/process temperature needs associated with good slag rejection, while at the same time retaining the stoichiometry/chemistry needed for good NO_x and SO_2 control. Here, the key parameter for slag sulfur retention and NO_x control, SR1, could be maintained while the combustion intensity necessary for good fuel utilization, heat release, and ash melting would be improved. Implementation of this external air preheat modification would require an auxiliary air preheater, electrical or gas fired, plus new piping including insulation.

Of perhaps more importance is the second difficulty, namely that the performance level of certain process variables could not be brought to acceptable levels for any practical combination of operating parameters. Even under optimum conditions; the best values for ACTSLGS, ATMSULF, and SLAGREJ are considerably less than desired. It is observed in table A that predicted SLAGREJ does not exceed 50% even under optimized conditions. Part of this result is due to the narrow operational definition of SLAGREJ as discussed previously. It should be noted that the values in table A are from the statistical model and that during actual combustor operation the measured values sometimes surpassed these in performance. However, these "high water" marks were not typical and were probably due to a combination of operating conditions, likely including unobserved transitory or non-steady-state phenomena, which were not routinely accessible, and therefore were not easily repeatable.

This second difficulty then suggests that optimization of the affected process variables is limited by some sort of barrier inherent to the present combustor operating technique and/or design. This in turn suggests that improvement can only be obtained by radically altering operating conditions. As already mentioned in the preceding sections, experimental evidence strongly suggests that the combustor volume is underutilized, i.e. the air/fuel/sorbent mixing zone is too extensive, or the combustor is in fact too short, to allow complete reaction to occur, including fuel burnout, sorbent sulfur capture, and ash melting. Thus corrective operation or design modifications would include changes in the air/fuel/sorbent mixing via injection modification, or by making the combustor longer, i.e. increasing the length to diameter (L/D) ratio. With the present injection geometry, a modest length increase would probably result in substantial improvement. Alternatively, modified air/fuel/sorbent injection geometry could have a positive effect if it reduces the size of the mixing zone. In fact, injection modifications have recently been implemented under another project and have yielded significant improvement in SLAGREJ. Additional testing of this new injection geometry for improving slag rejection and slag sulfur retention with coal firing would be extremely useful since up till now both parameters could not be simultaneously optimized.

One of the chief goals of the Clean Coal project was to capture the coal sulfur in the combustor and reject it with the slag. Although this concept was clearly validated, the quantitative levels of slag sulfur content were generally low. Part of the problem was that two key process requirements, low SR1 operation for maximum combustor sulfur capture, and high slag rejection, could not be simultaneously optimized in the present unit. Regarding atmospheric SO_2 emissions, if combustor sulfur capture and rejection with the slag cannot be raised to acceptable levels by combustor operation or design changes, then direct boiler sorbent injection would be the preferred sulfur control technique. In this situation, combustor sorbent injection would mainly be for slag viscosity control, and only secondarily for sulfur capture. Another possibility is multi-point sorbent injection.

In conclusion, it is to be mephasized that the above discussion is based on an analysis that is suitable for interpolation, but not for extrapolation of the combustor data base. With the operating experience and continuous improvements made in the combustor operation in the past three years, the operating data base is being extended outside the regime considered in the above analysis. Therefore, the conclusions presented here, especially in areas such as sulfur capture and and slag retention will most probably be modified as a result of continued operation under the more accurate computer control now installed in the combustor and improved solids injection and improved slag removal from the combustor.

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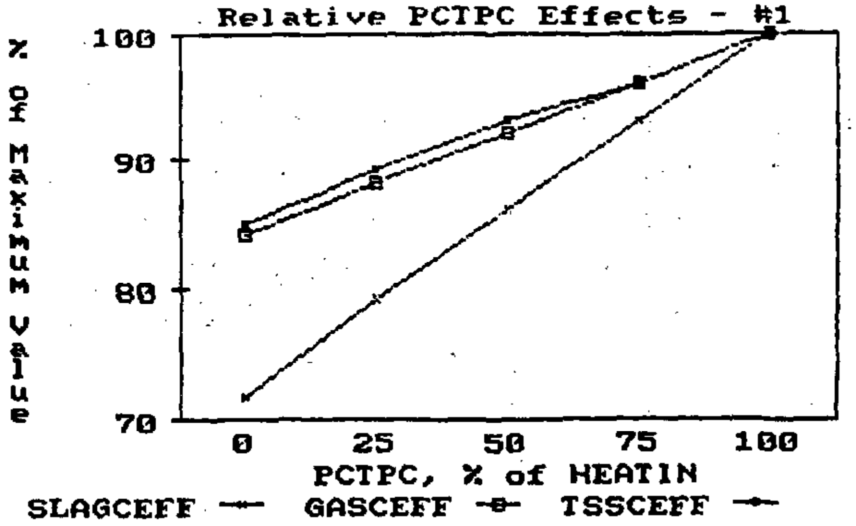

FIG. A: Effects of Coal Firing on Combustor Efficiency

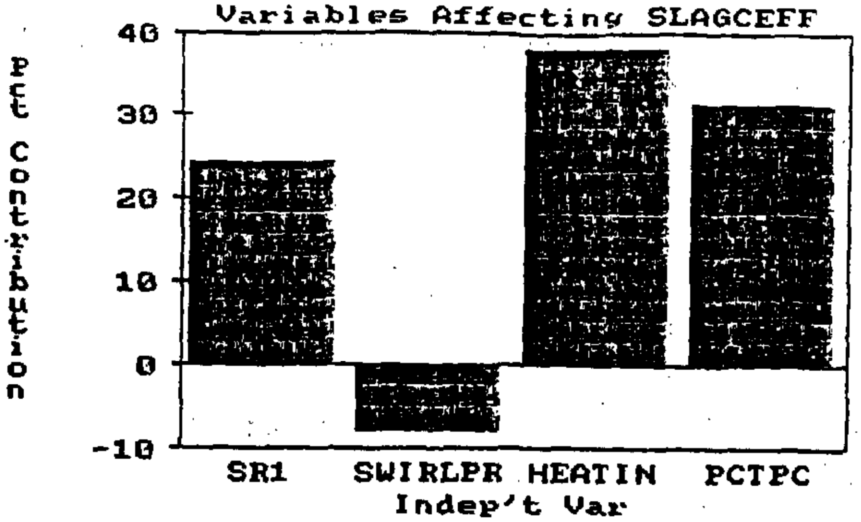

FIG. B: Operation Variable Effects on Slag Combustion Efficiency

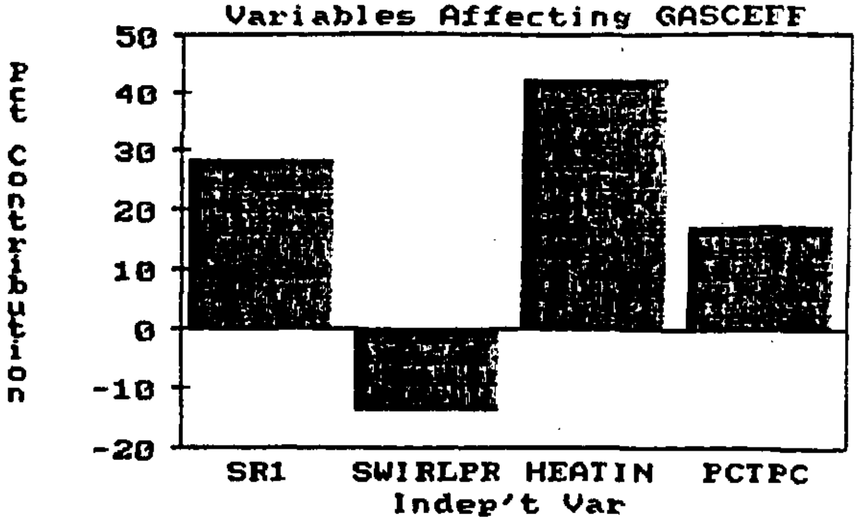

FIG C: Operating Variable Effects on Gas Combustion Efficiency

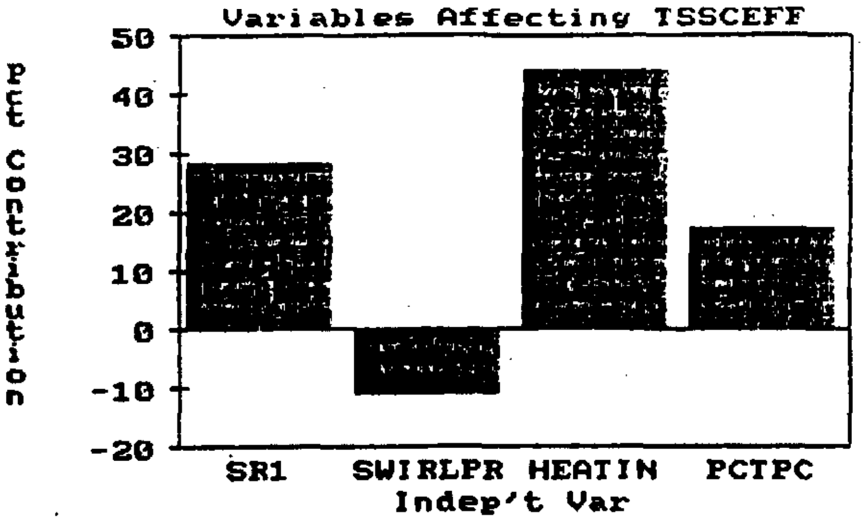

FIG D: Operating Variable Effects on Total Suspended Solids Combustion Efficiency

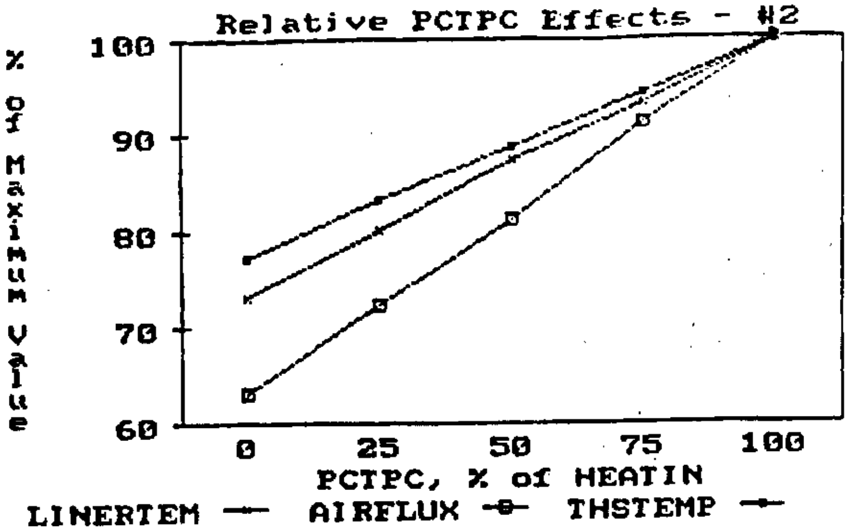

FIG E: Effects of Coal Firing on Combustor Temperature Variables

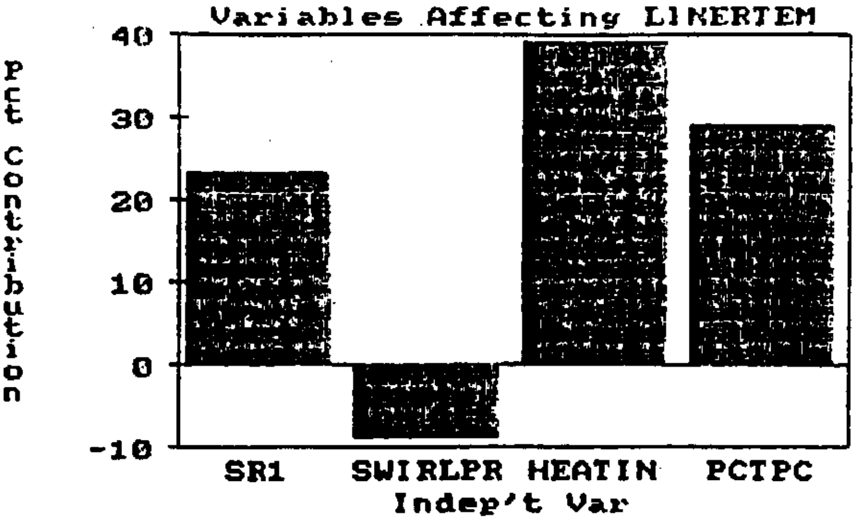

FIG F: Operating Variable Effects on Liner Temperature

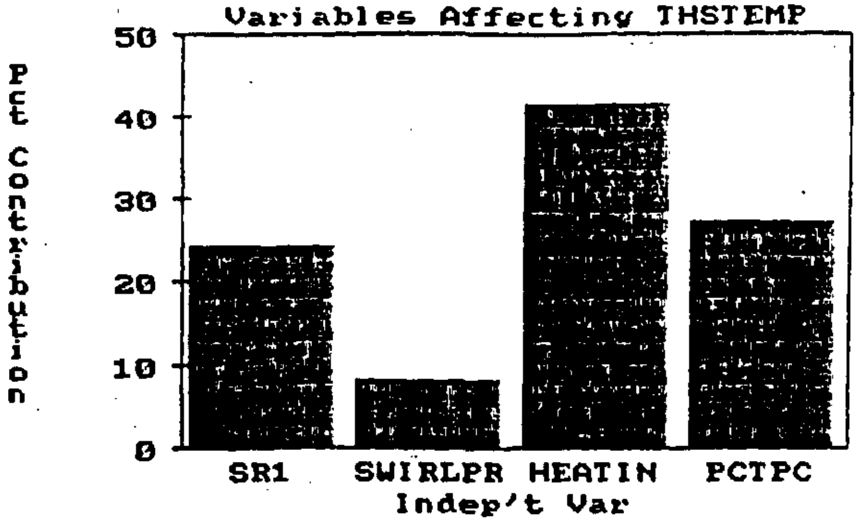

FIG G: Operating Variable Effects on Cooling Tube Temperature

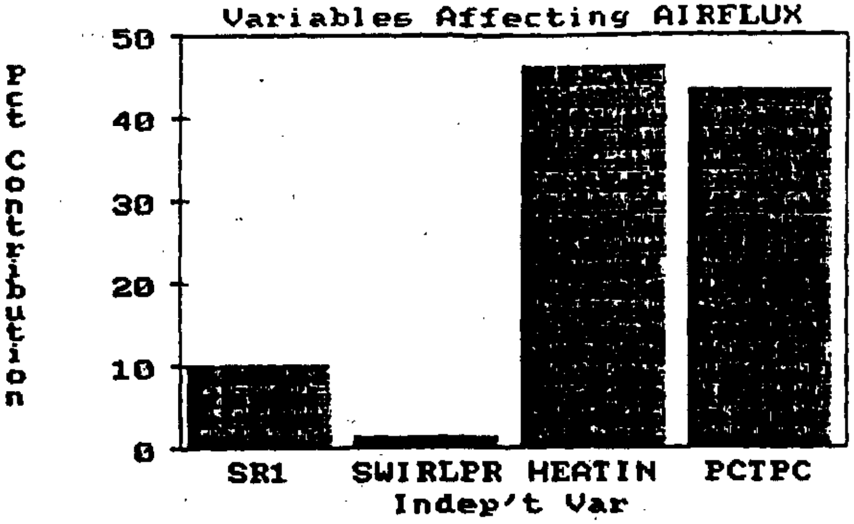

FIG H: Operating Variable Effects on Wall Flux

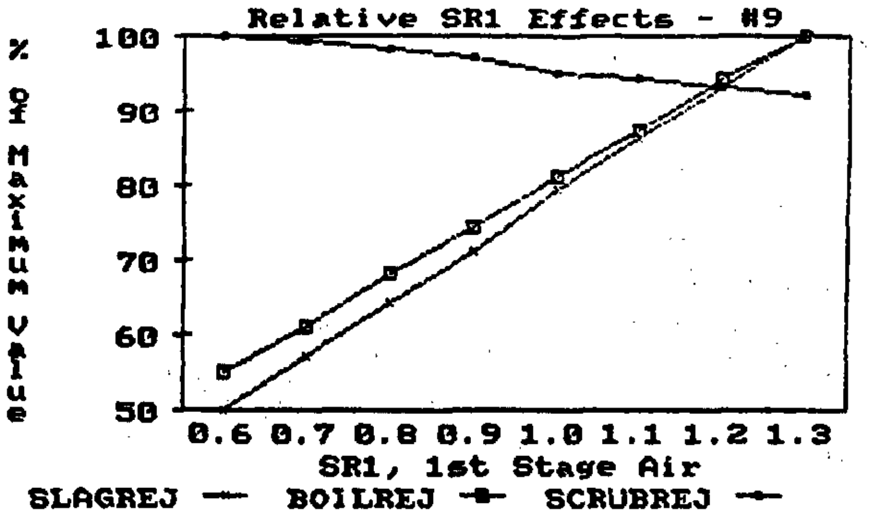

FIG I: Effects of First Stage Stoichiometry on Solids Partioning

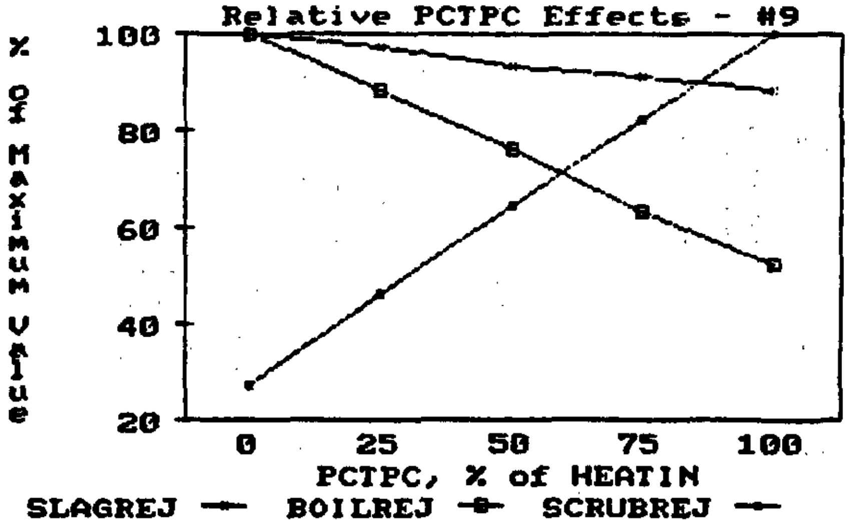

FIG J: Effects of Coal Firing on Solids Partioning

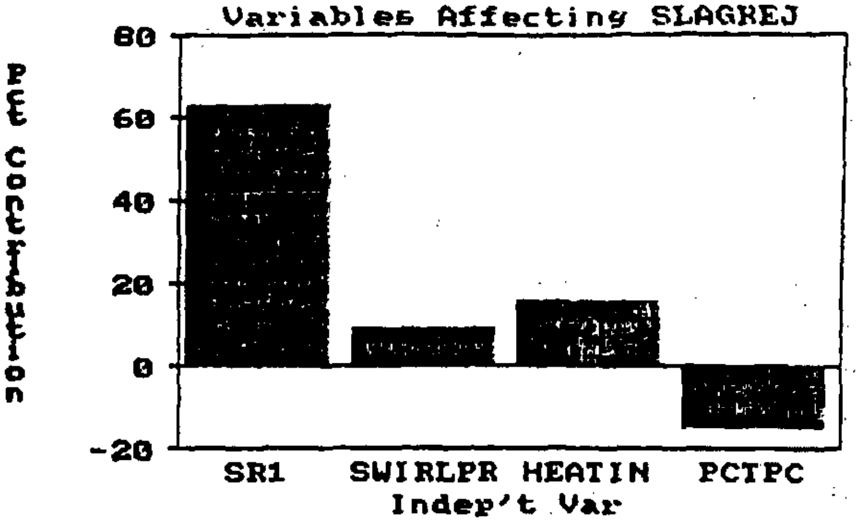

FIG K: Operating Variable Effects on Combustor Slag Rejection

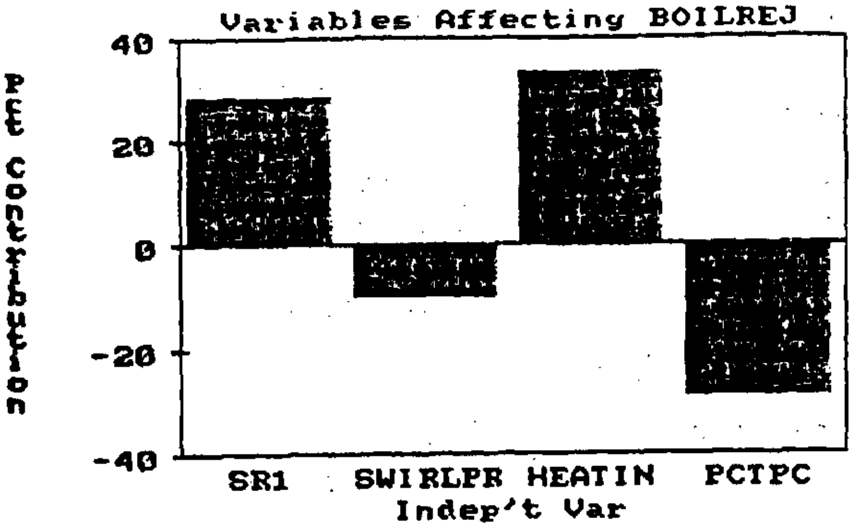

FIG L: Operating Variable Effects on Boiler Solids

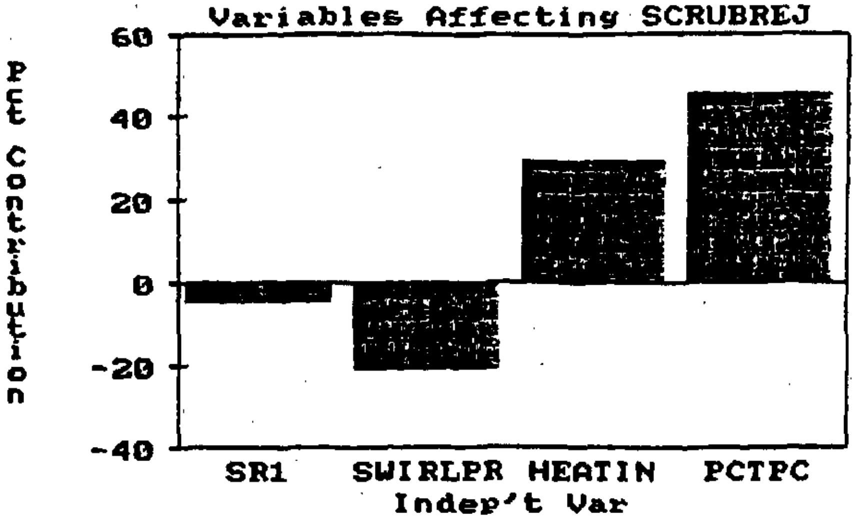

FIG M: Operating Variable Effects on Scrubber Solids

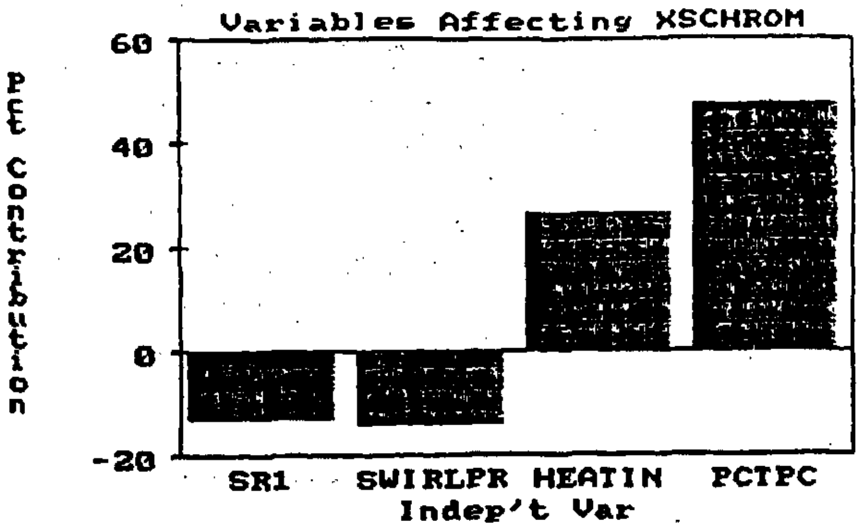

FIG N: Operating Variable Effects on Slag Chrome Content

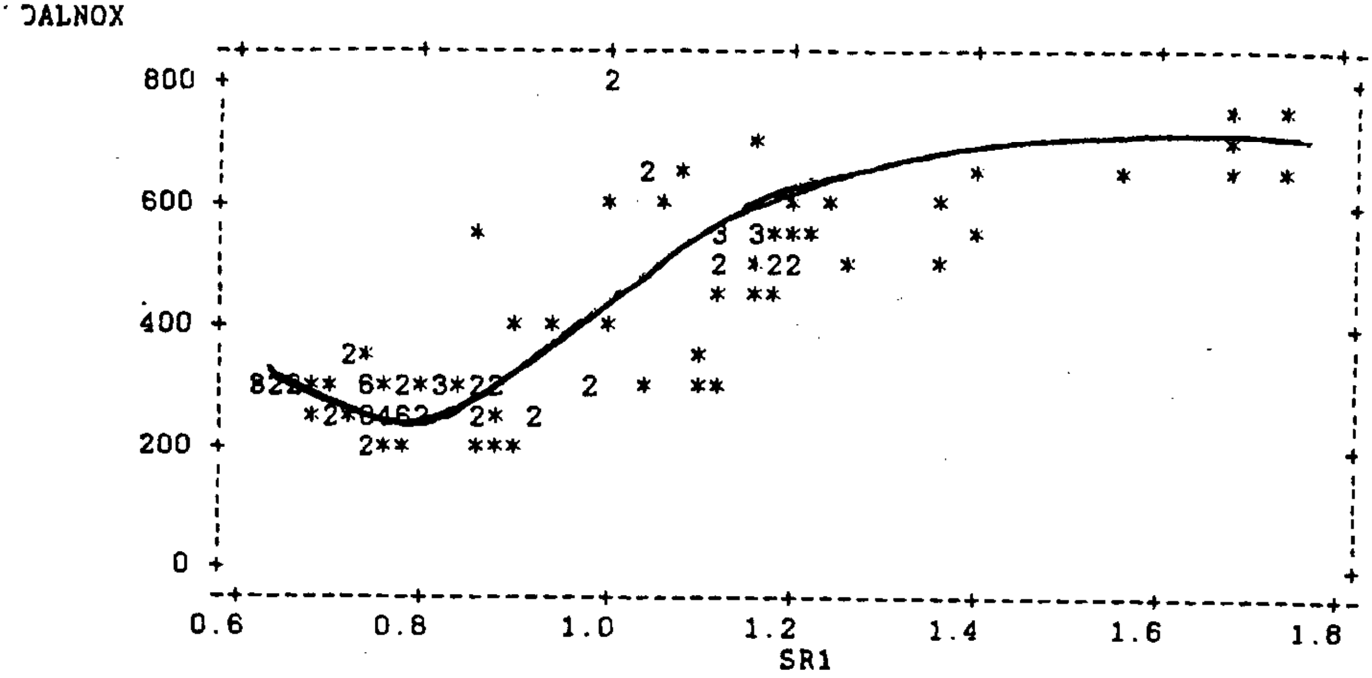

FIG O: Measured Stack NOx (Normalized to 3% O2) vs First Stage Stoichiometry (PCTPC > 70)

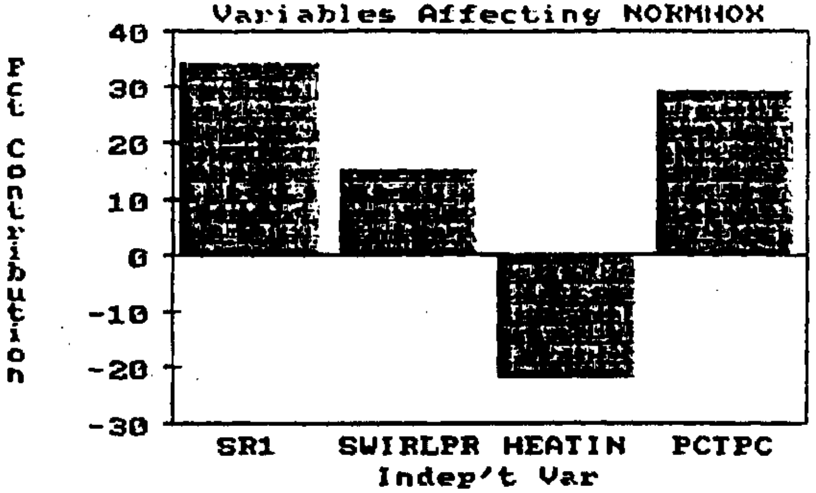

FIG P: Operating Variable Effects on NOx Emissions

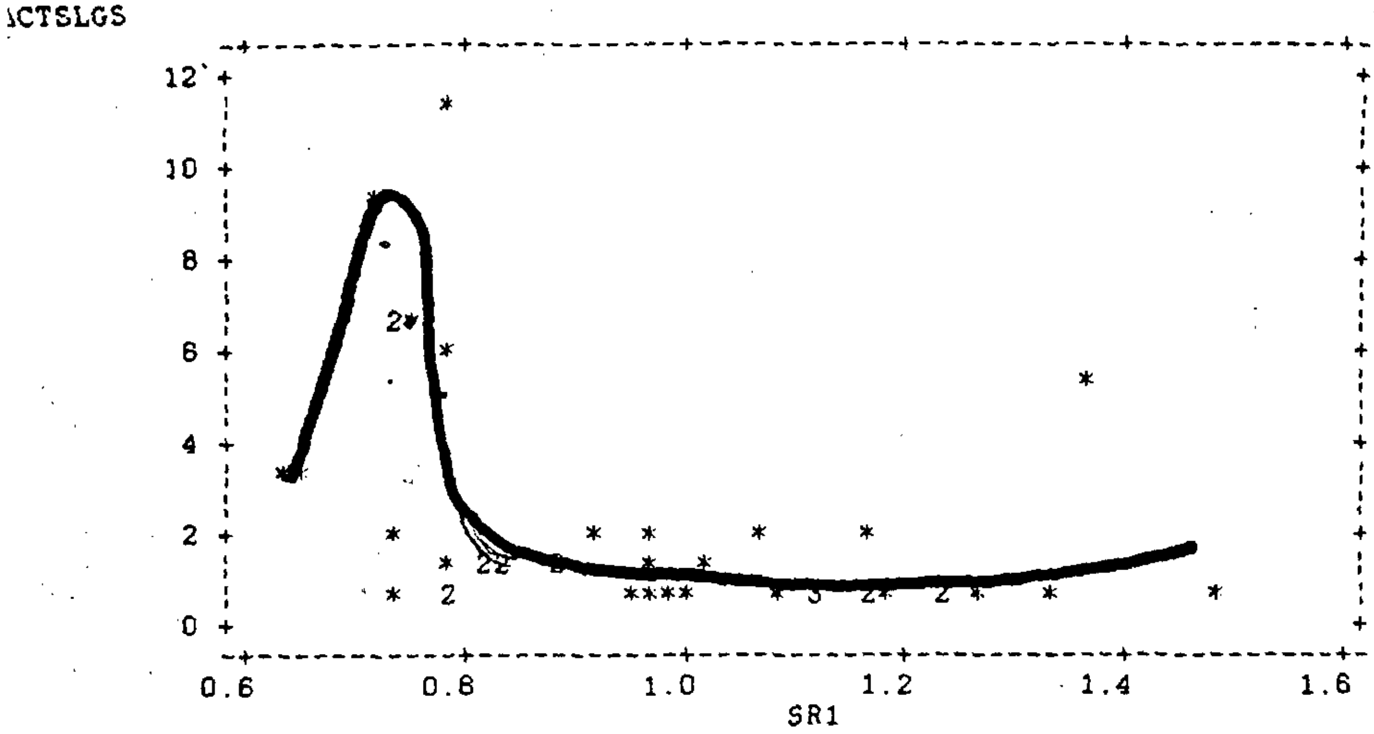

FIG Q: Measured Slag Sulfur Content with Sorbent Injection vs First Stage Stoichiometry

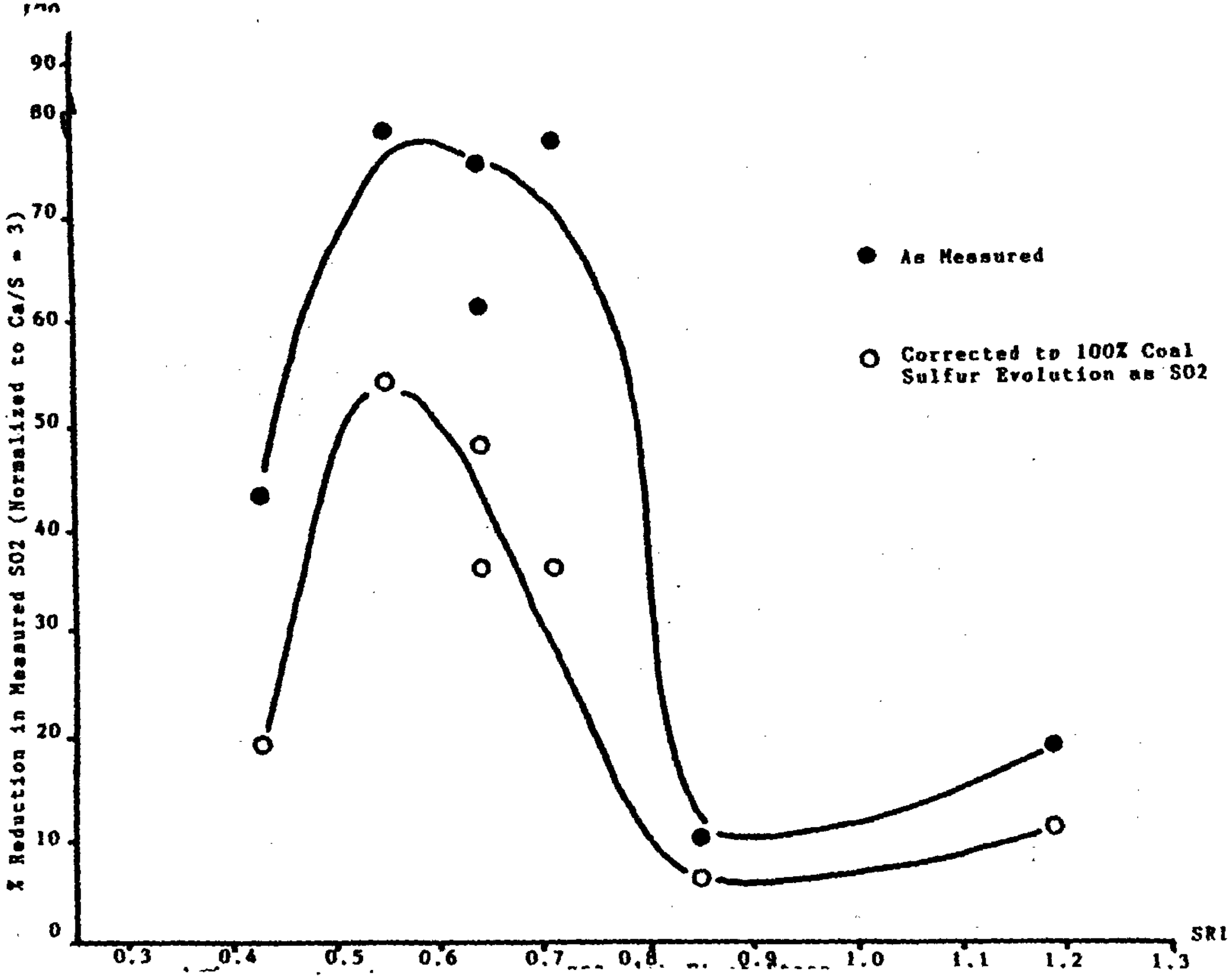

FIG R: Reduction in First Stage SO2 with Sorbent Injection vs First Stage Stoichiometry (from Ref. 25)

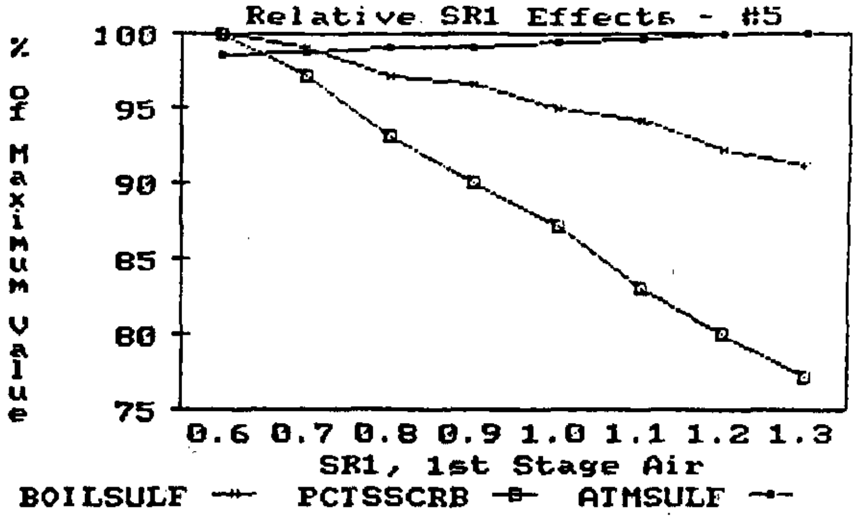

FIG S: Effects of First Stage Stoichiometry on Sulfur Partitioning

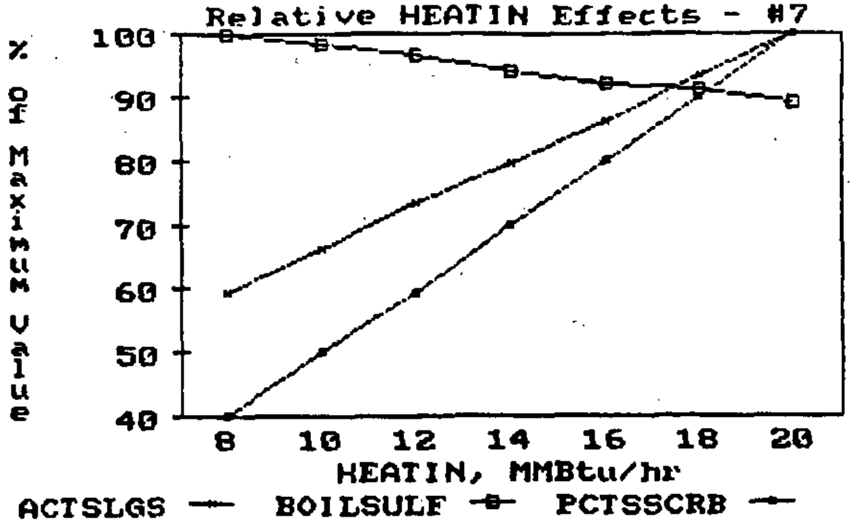

FIG S-2: Effects of Fuel Heat Imput on Sulfur Partitioning

"additional data is contained in the Proprietary Document"

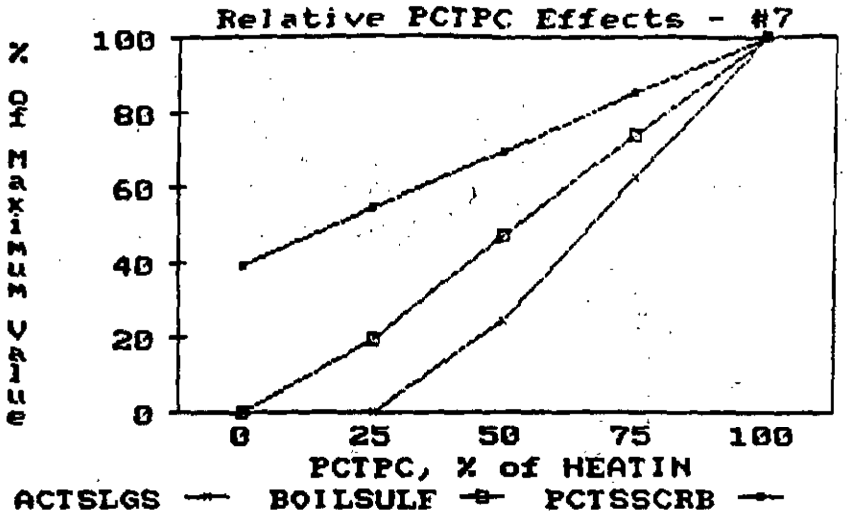

FIG T: Effects of Coal Firing on Sulfur Partitioning

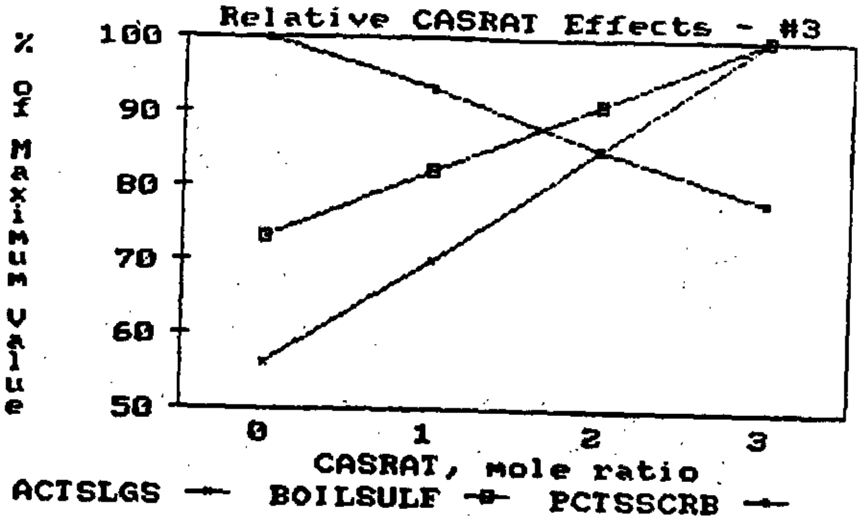

FIG U: Effects of Calcium/Sulfur Ratio on Sulfur Partitioning

"Additional data is contained in the Proprietary Document"

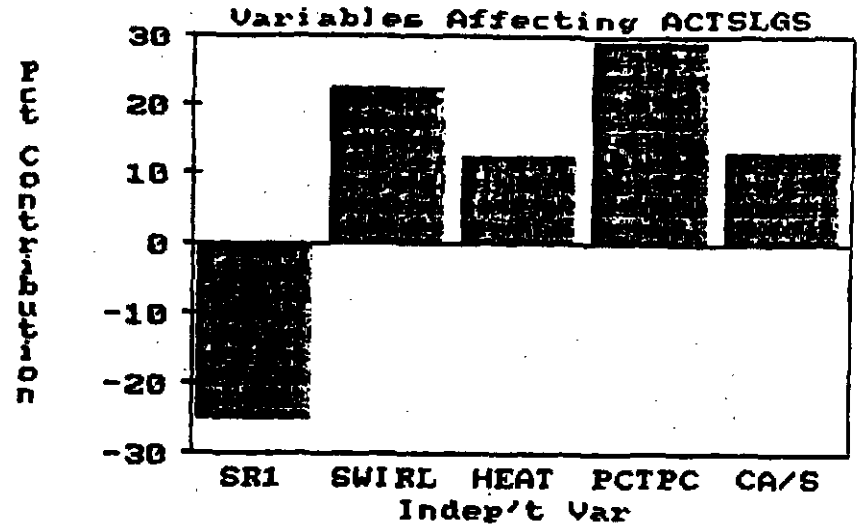

FIG V: Operating Variable Effects on Slag Sulfur Content

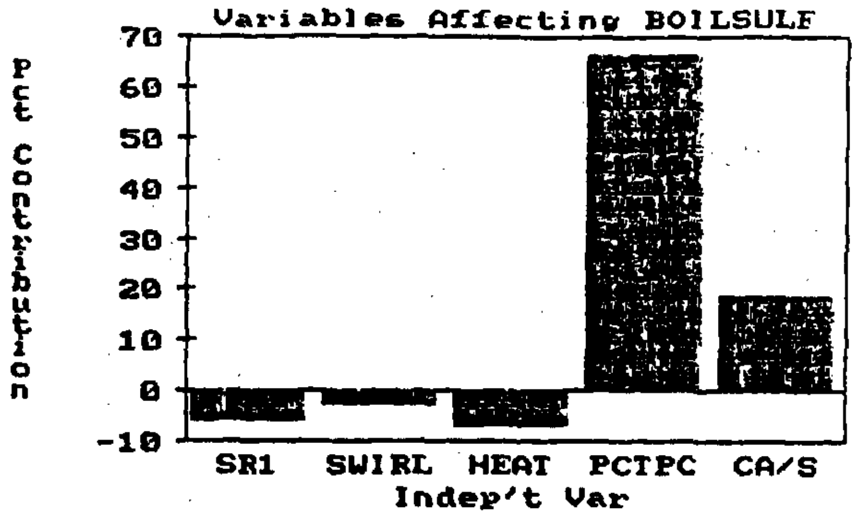

FIG W: Operating Variable Effects on Boiler Sulfur Deposits

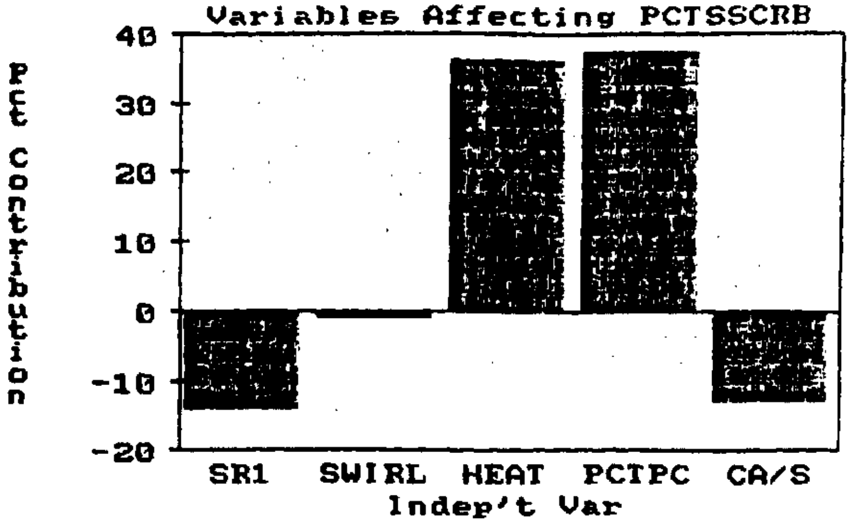

FIG X: Operating Variable Effects on Scrubber Sulfur Content

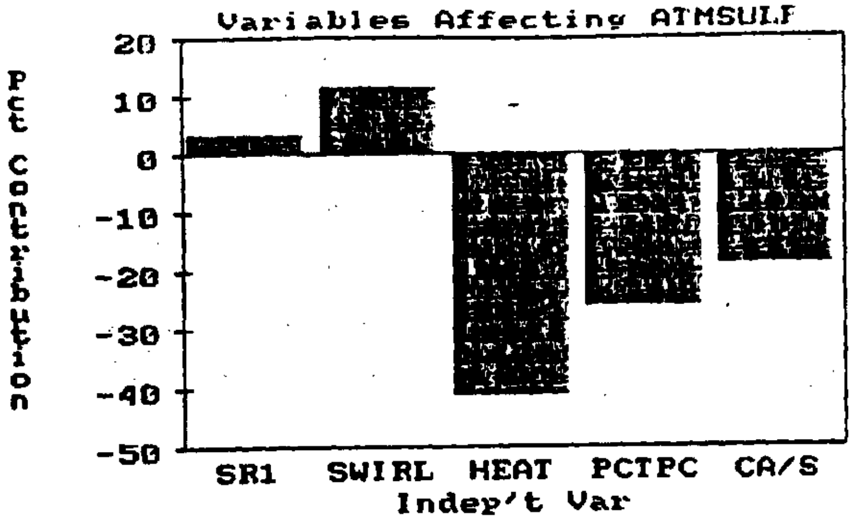

FIG Y: Operating Variable Effects on Atmospheric Sulfur Emissions

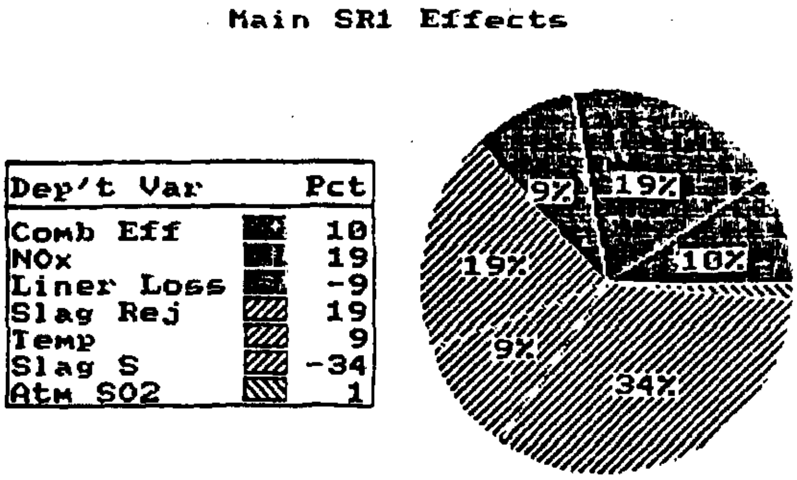

FIG Z: Effects of First Stage Stoichiometric Ratio on Process Observables

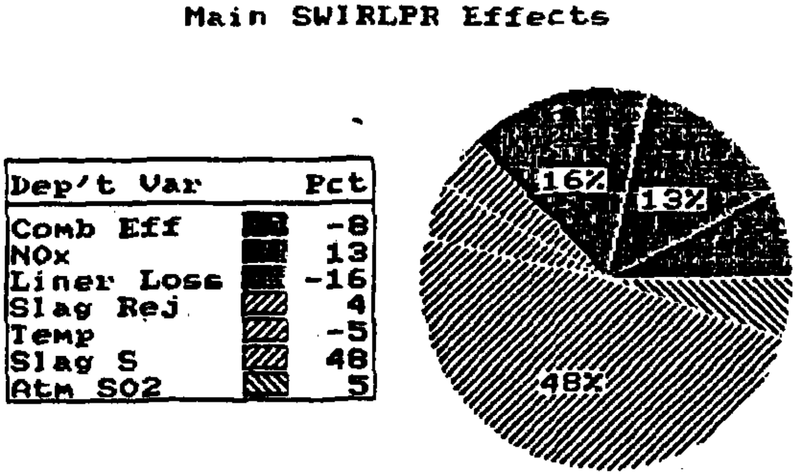

FIG A-1: Effects of Swirl Air Pressure on Process Observables

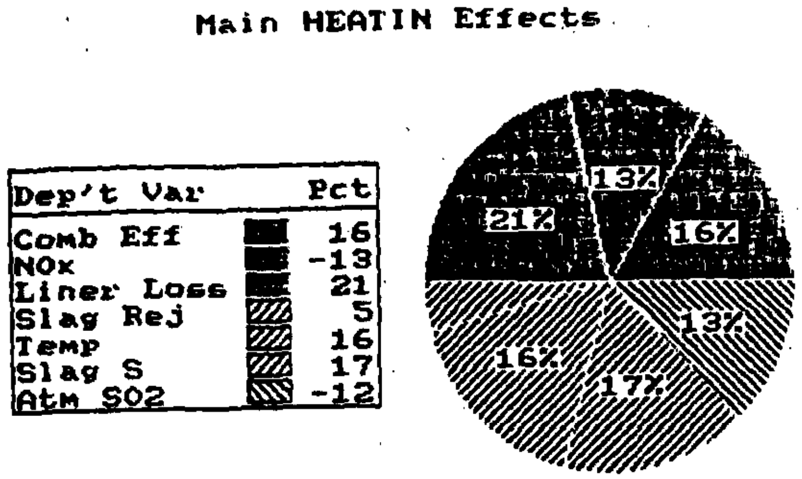

FIG B-1: Effects of Fuel Heat Imput on Process Variables

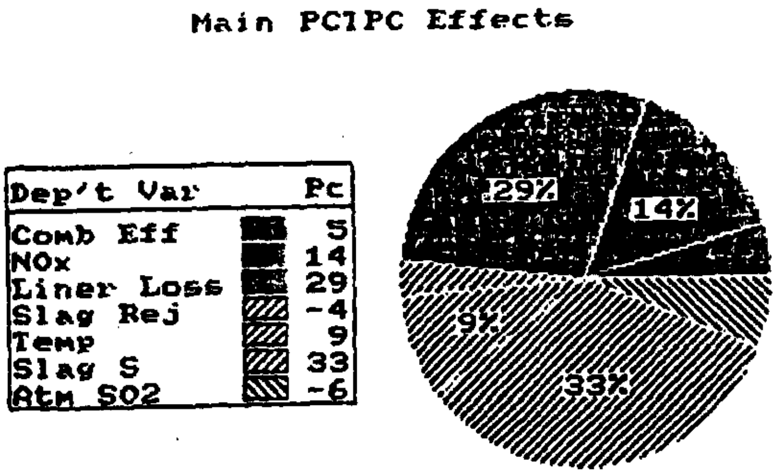

FIG C-1: Effects of Coal Firing on Process Variables

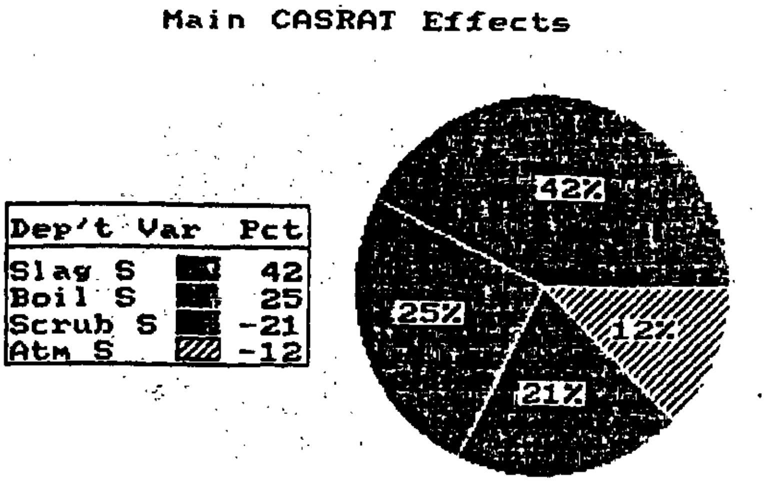

FIG D-1: Effects of Calcium/Sulfur Ratio on Sulfur Variables

U.S. DOE-CLEAN COAL PROGRAM

"THE DEMONSTRATION OF AN ADVANCED CYCLONE COAL COMBUSTOR, WITH INTERNAL SULFUR, NITROGEN, AND ASH CONTROL FOR THE CONVERSION OF A 23 MMBTU/HOUR OIL FIRED BOILER TO PULVERIZED COAL"

FINAL TECHNICAL REPORT

APPENDIX III.Photographic History of the Project

REPORTING PERIOD - March 9, 1987 to February 28, 1991
DOE Cooperative Agreement No. DE-FC22-87PC79799

August 30,1991

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TABLE OF CONTENTS

1. Introduction

Since the 30 MMBtu/hr combustor's fabrication in 1985, Coal Tech has taken a series of photographs at varying intervals to chart the progress of the various steps in its development. These photographs focussed on what appeared to be an important issue at that time. For that reason, a relatively large fraction of the photographs focus on problems that were encountered at the time the photographs were taken. In addition, to protect Coal Tech's proprietary position the photographs included in this portfolio do not include detailed design features. Nevertheless, there is sufficient detail to enable the viewer to visually the progress and problems experienced. As there was no prearranged plan to record the entire progress of the project, there are gaps in the photographic record. As much as possible these gaps are filled in the written record of the project that is contained in this report.

The photographs were divided according to the topics contained in the Table of Contents of this Appendix. These topics generally reflect the most significant problems and accomplishments encountered in the project. The photographs only contain brief captions. For further details, the reader is referred to the chronological record of the project in Appendix I and the body of the Final Report.

1. Change or Installation

Figure A-III-1: The gas fired burner and combustion air system on the 17 500 lb/hr oil designed Kewanee package boiler installed at the Keeler boilerhouse in Williamsport, PA. This entire section was removed and replaced with the air cooled combustor.

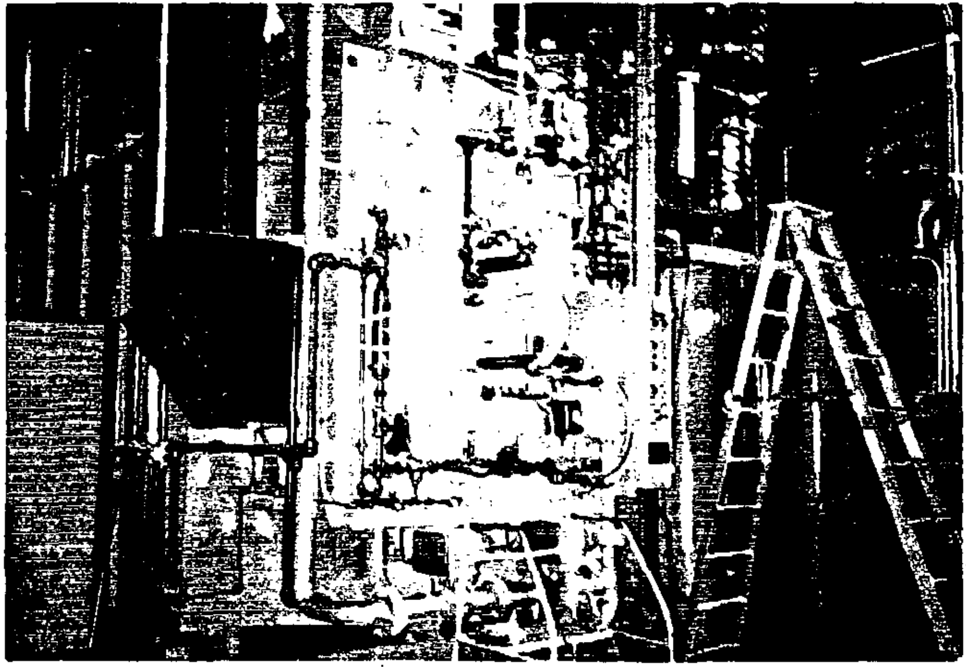


Figure A-III-2: The 4 ton pulverized coal bin and air filter on the parking lot in front of the boilerhouse. The particulate stack scrubber vessel is shown on the right in the background. This photograph was taken in 1982

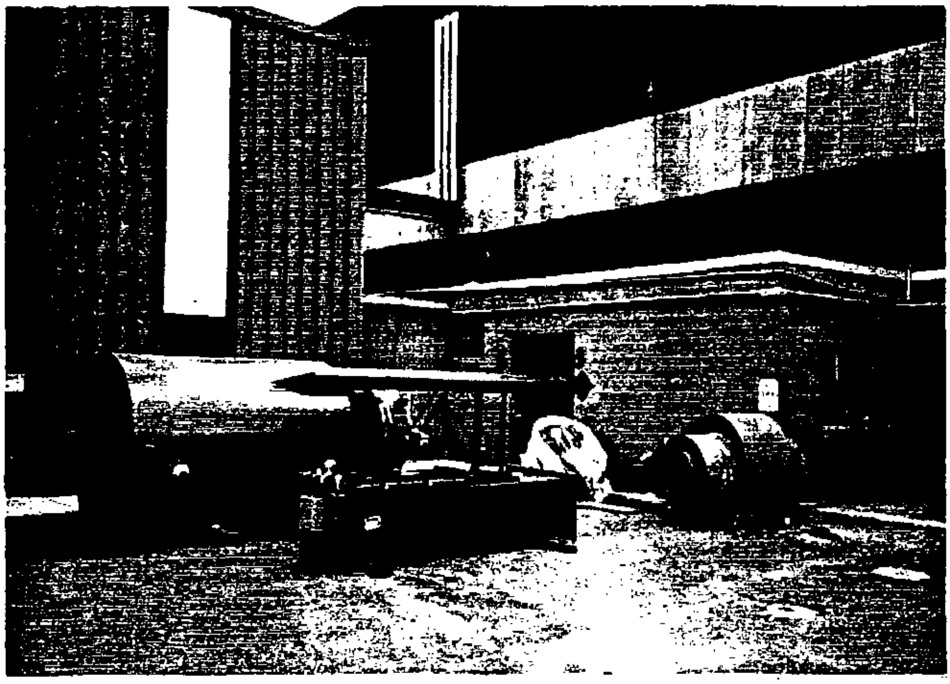


Figure A-III-3: The boiler control panel (left foreground), the back of the of the combustor manual control panel (right foreground). The front end of the combustor is visible in between the two panels.

Figure A-III-4: The air cooled combustor shell and air plenum chamber standing on its end in the fabricating shop in March 1986

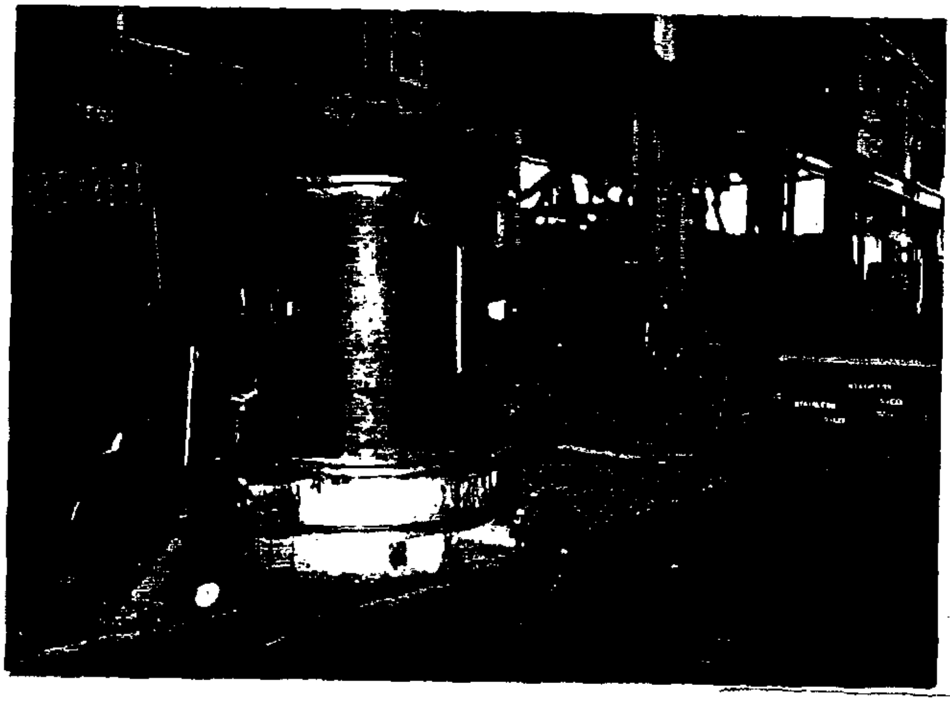


Figure A-III-5: The combustor installed on the boiler, with the front section removed. The air plenum ducts are in the foreground. The refractory liner is installed in the combustor, as is the exit nozzle refractory is in the background. November 1986.

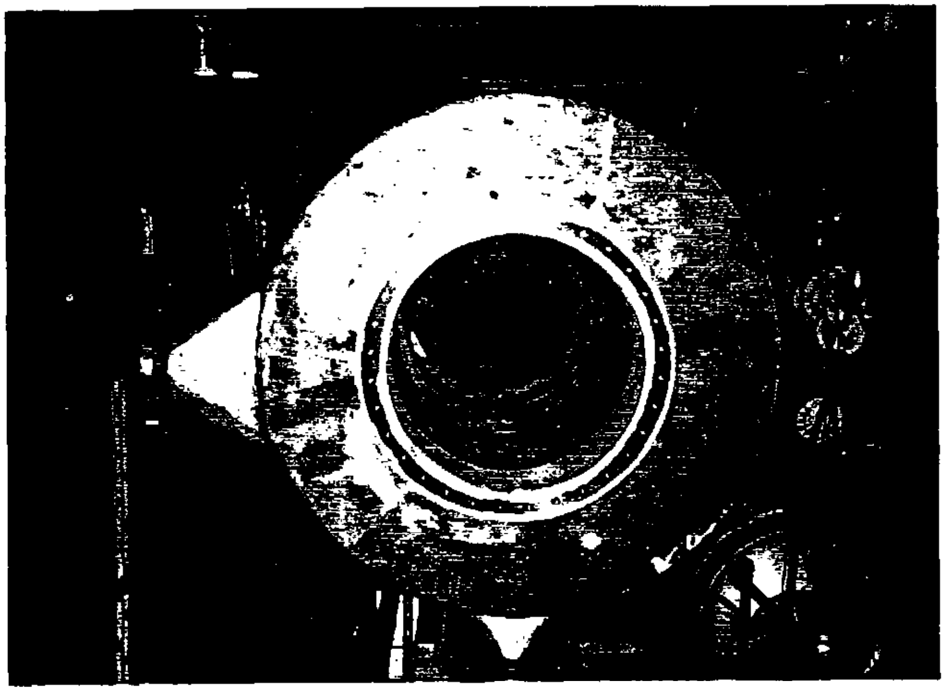


Figure A-III-6: The combustor installed on the boiler with the primary and secondary air pipes connected, and the front section which contains the burners and primary and secondary air inlets, and fuel inlets. Winter 1986-7.

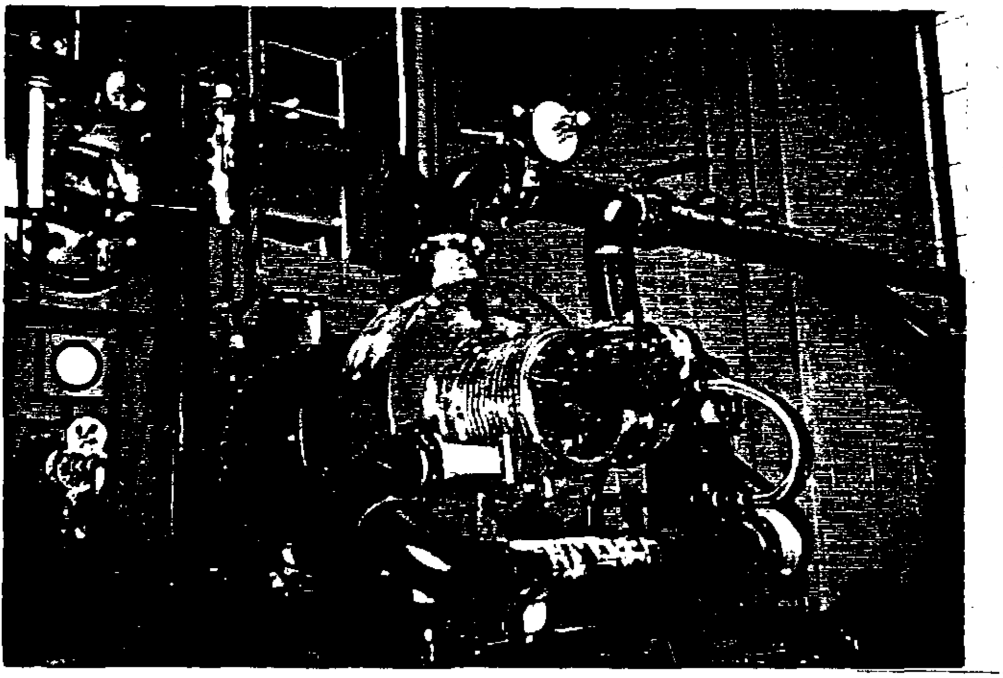


Figure A-III-7: The combustor with most of the electrical and plumbing connections attached. February 1987.

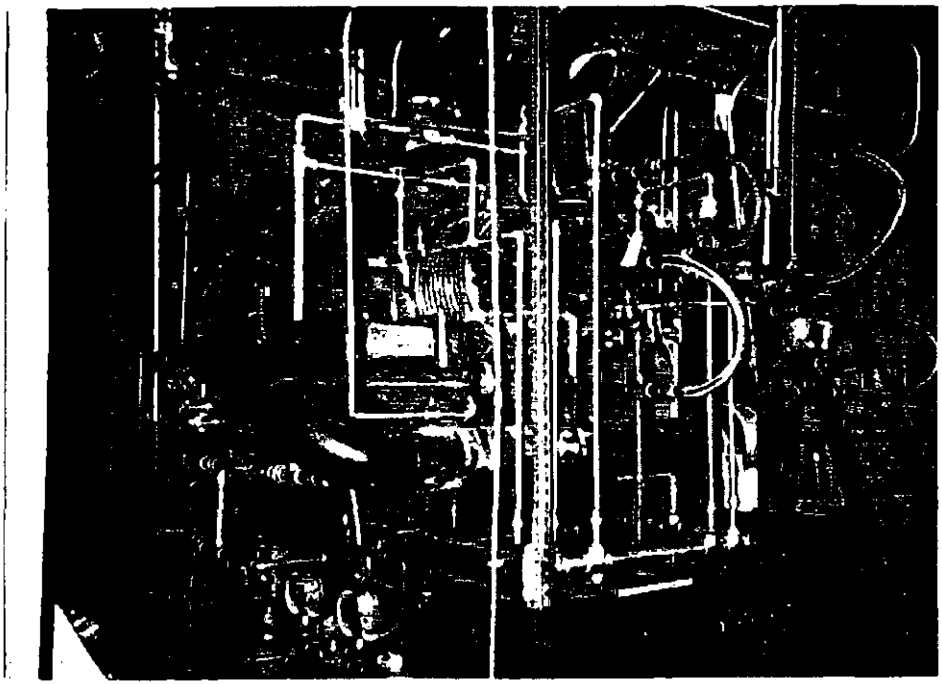
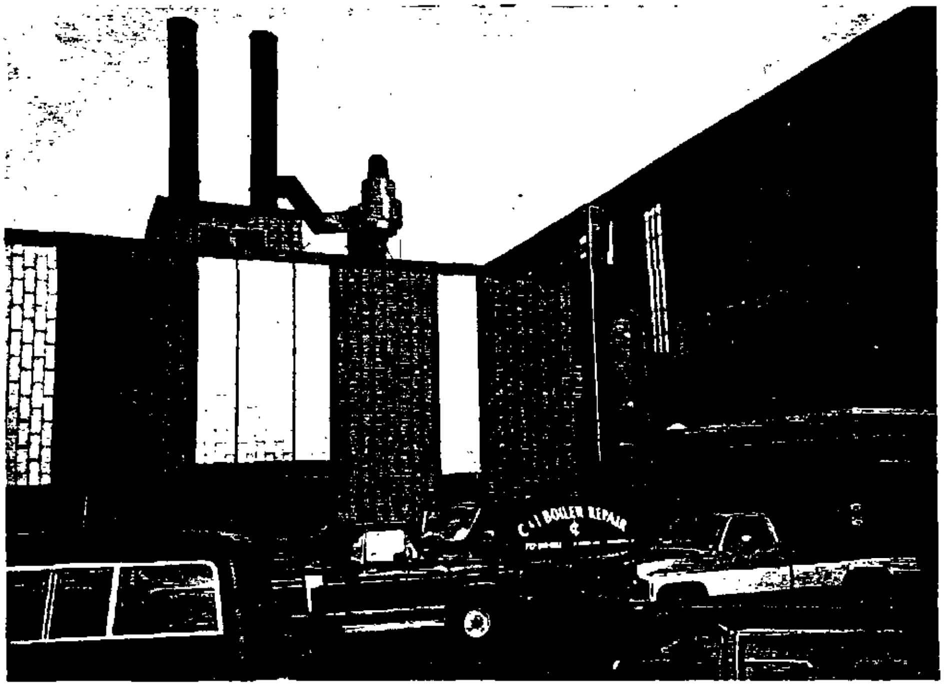


Figure A-III-8: The primary and secondary air fans installed outside the boilerhouse. Due to noise problems with the secondary air fan a sound insulated shack had to be installed around the fans to allow combustor operation. It was necessary to rebuild the fan in 1988. The 2000 gallon coal-water slurry tank is shown in the background. Winter 1986/7.

Figure A-III-9: The completed combustor installation showing the 4 ton coal bin alongside the boilerhouse on the right and the stack scrubber attached to the right side stack which is connected to the retrofitted boiler. 1987



3. Coal Water Slurry Test

Figure A-III-10: The first test in test in Phase 2 of the Clean Coal project was performed with a coal-water slurry. The figure shows the 2000 gallon tank used to store the slurry. November 1987

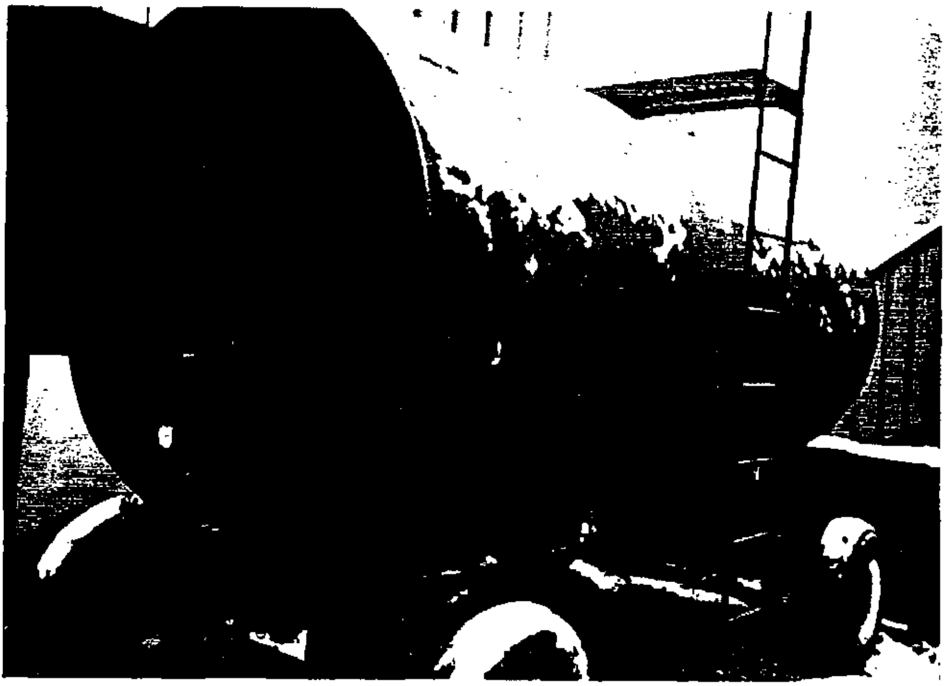
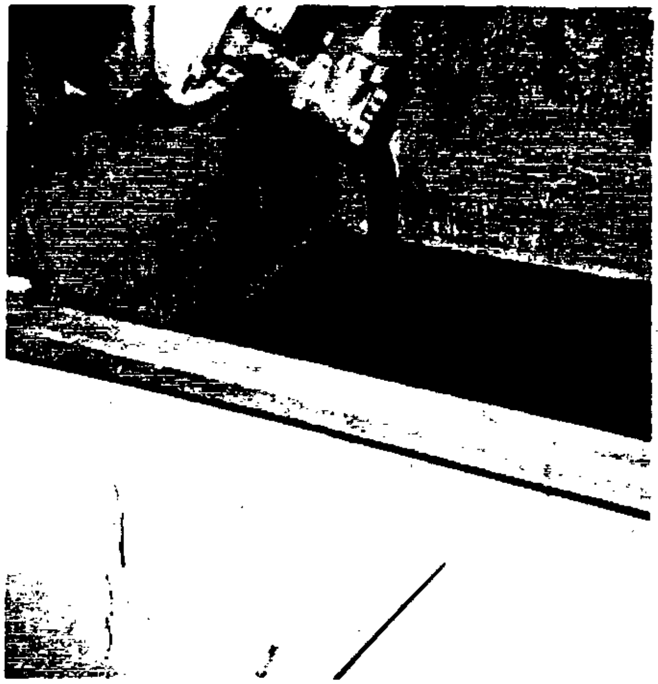


Figure A-III-11: The coal water slurry was transferred to the small holding tank shown in the figure, prior to pumping to the slurry burner in the combustor. The photo shows filling of this tank from a 55 gallon drum, rather than from the 2000 gallon tank. November 1987.



4. The Air Cooled Combustor Liner

Figure A-III-12: The inner refractory wall of the air cooled combustor liner. The slag tap block is shown in the bottom background, and part of the exit nozzle inner wall in the background. Photo taken in November 1986 during the combustor's installation.

Figure A-III-13: Photograph of the combustor liner wall and front of the exit nozzle taken inside the combustor after the first slurry tests in 1987. A thin, smooth, slag layer covers the liner wall, and some refractory erosion is visible on the exit nozzle front which was due to spalling caused by too rapid heatup of the combustor, 1987.

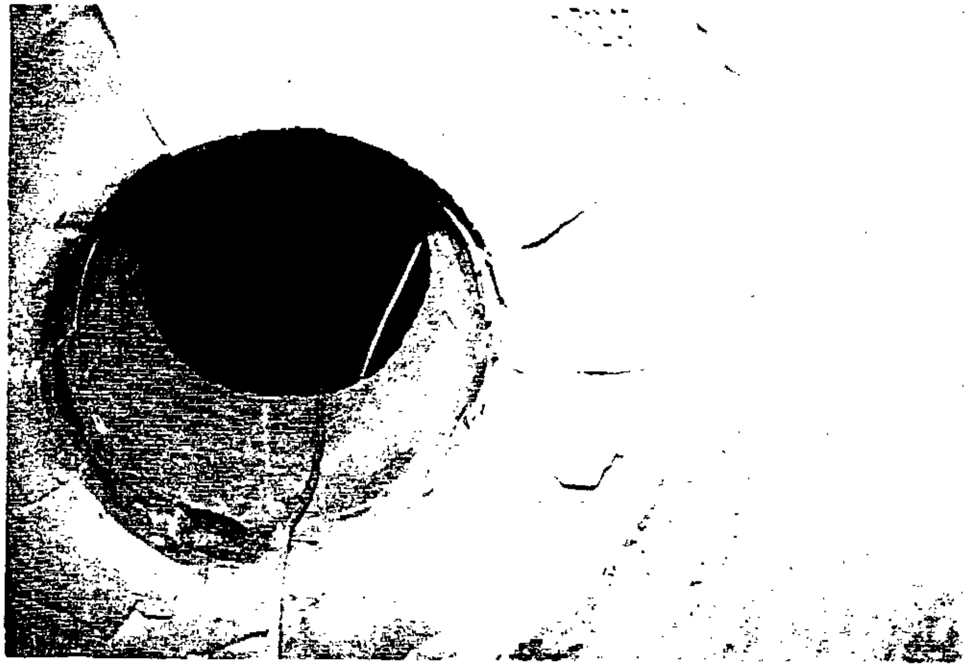


Figure A-III-14: Photo of the <u>2nd liner</u> taken from the downstream end, showing slag tap in the foreground, and the inlet section in the background. Note the smooth slag covered liner wall. Taken in November 1988. The second liner had been installed in March 1988.

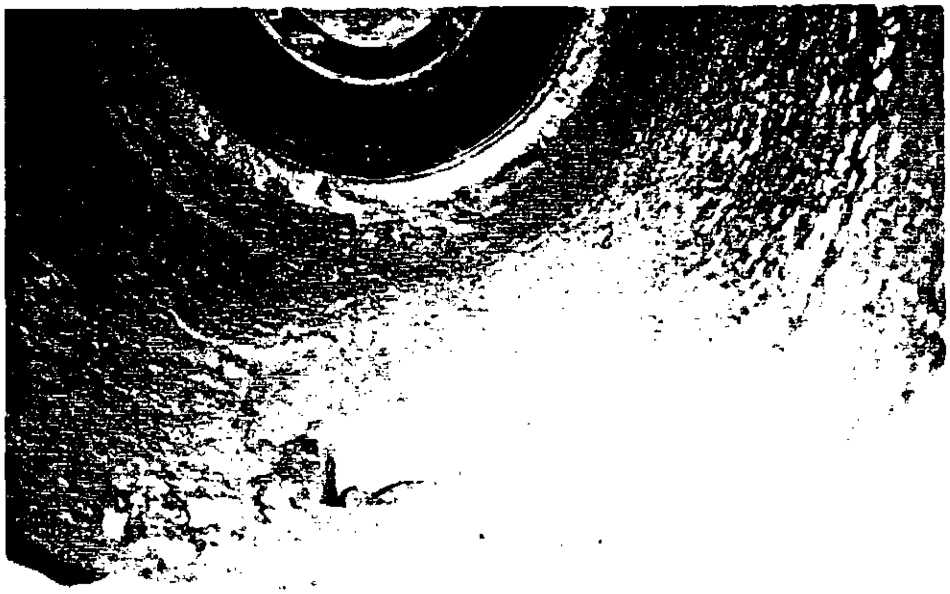


Figure A-III-15: Photo of the roof of the <u>1st combustor liner</u> taken in February 1988 after the test prior to the one that resulted in refractory failure of part of the liner. Note the smooth slag covered wall, with several circumferential and axial hairline cracks which were caused by thermal stresses during heatup and [illegible]

Figure A-III-16: Photo of the <u>2nd liner</u> taken from the downstream end, showing part of the bottom and side of the liner with the slag tap just visible in the foreground, and the inlet section in the background. Note the smooth slag covered liner wall. The exit nozzle wall is in the foreground. The photo was taken in November 1988 at the same time as figure A-III-14. The second liner had been installed in March 1988

Figure A-III-17: Close-up photo of the 2nd liner side wall, with the exit nozzle slag covered wall in foreground-(slightly out of focus). Note the smooth slag covered wall. April 1989.

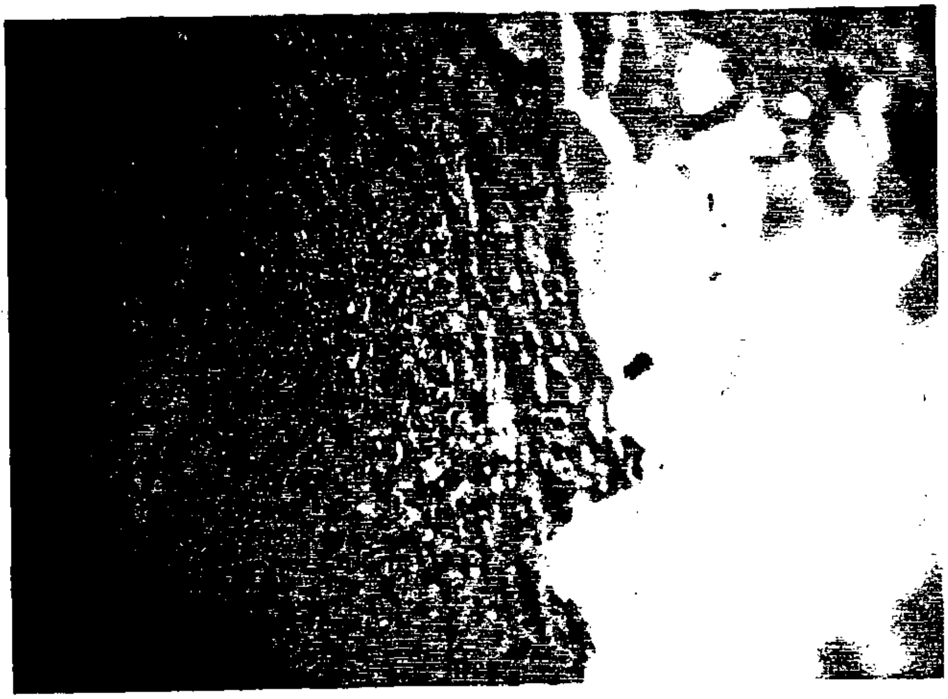


Figure A-III-18. Very near close-up of the 2nd liner wall. In this case a slight ripple structure is visible on the wall. The section in the lower lest is part of the exit nozzle wall. Taken November 1988.

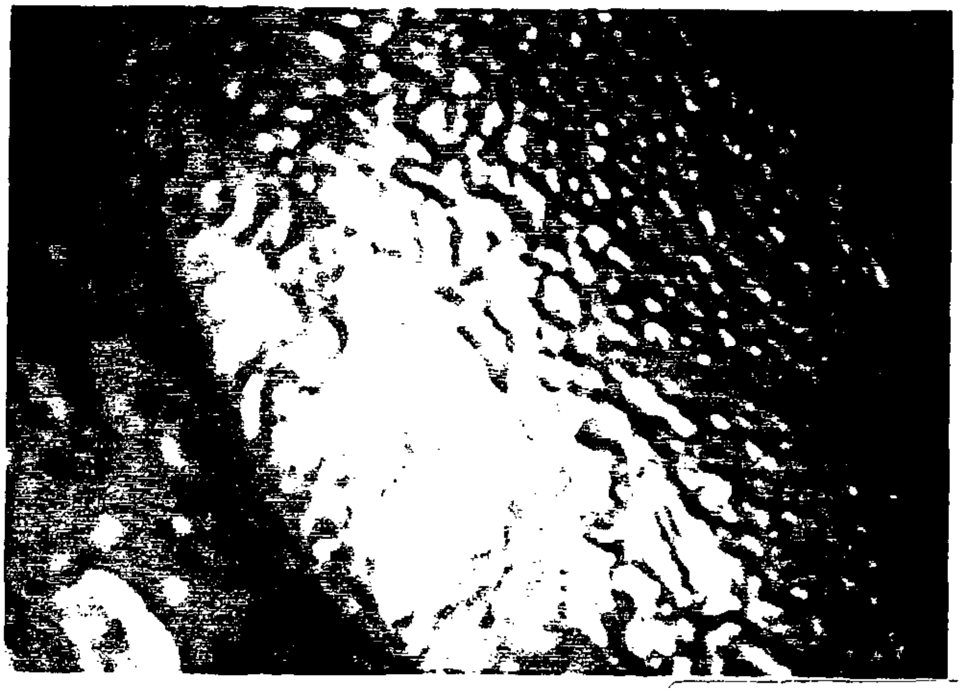


Figure A-III-19: Photo of section of 1st combustor liner that was damaged in test of late February 1988. The refractory from the air cooled panels have been removed and pitted metal sections of the wall are visible. The metal wall was repaired and relined with the 2nd refractory liner without replacing the entire wall.

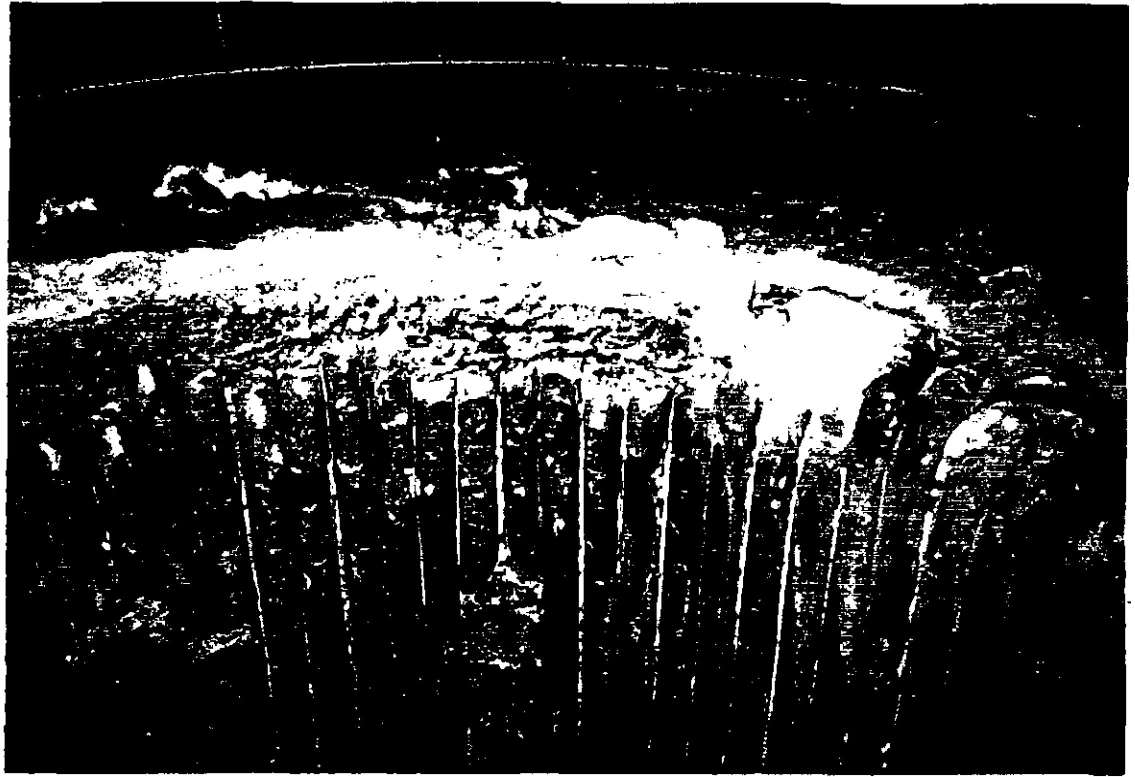
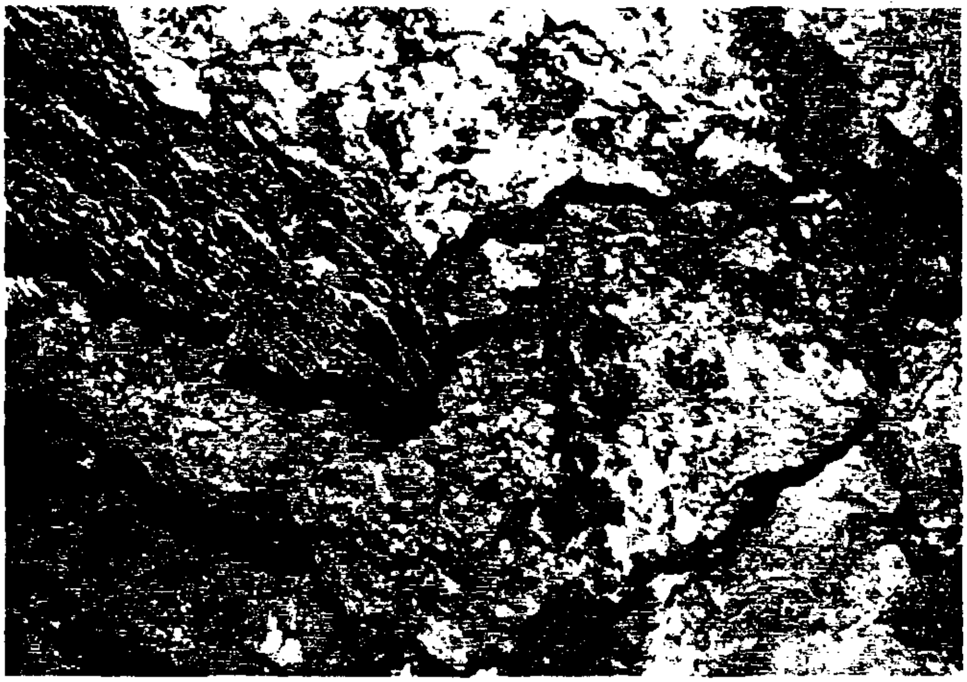


Figure A-III-20: Photo of 2nd combustor liner and front injection section after a test in which a high level of fly ash was injected. This test was not part of the Clean Coal project. It is included to show that the combustor can operate with thick 9several inches) ash/slag coatings. This can either melted by subsequent firing, or it can be easily removed manually. Both approaches were used in the project. The white portion in the foreground is the exit nozzle wall. November 1988.

Figure A-III-21: Photo of slag deposits on 1st combustor liner taken prior to dis-assembly of combustor for repair of the liner. The several layers of slag were the result of accumulation from several days of test firings with heatup and cooldown. March 1988.



5. Combustor Operation

Figure A-III-22: Photo of exit nozzle taken from boiler observation port at the rear of the boiler with the combustor at steady state operation. February 1988.

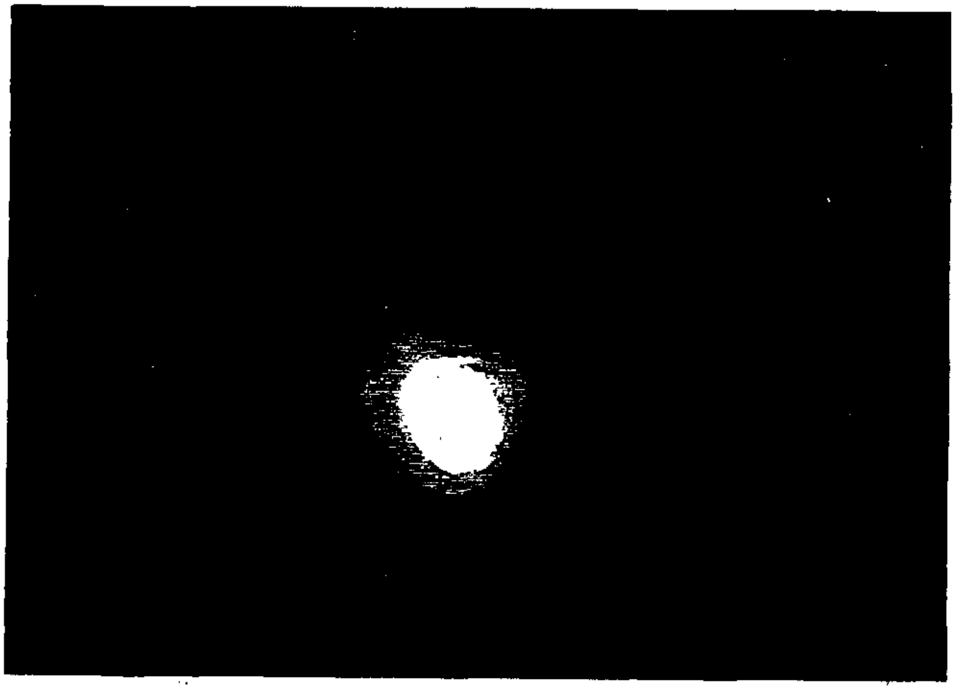
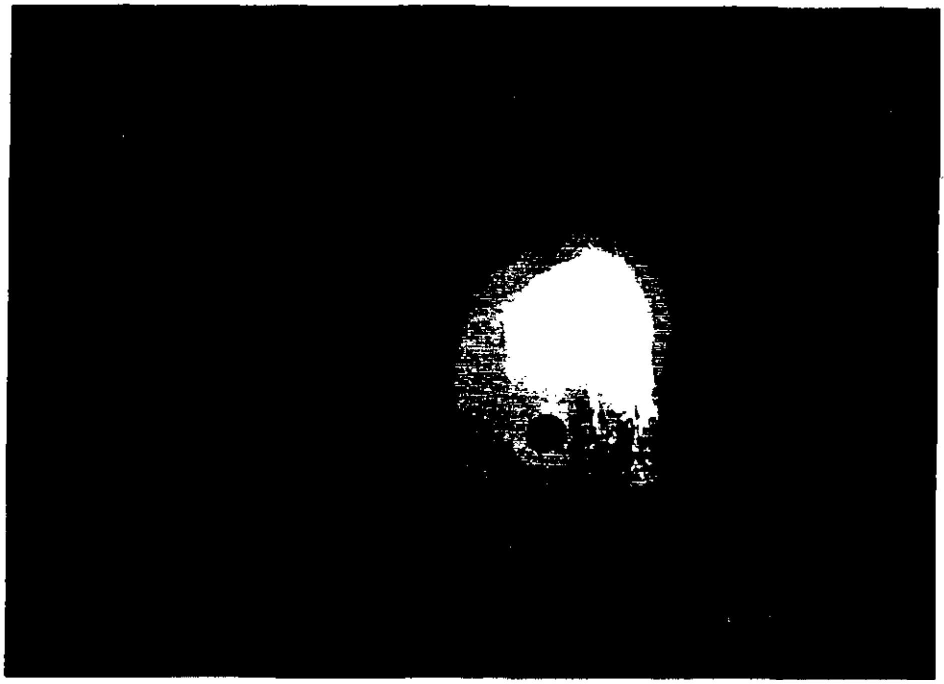


Figure A-III-23: Front of exit nozzle taken from boiler observation port at the rear of the boiler with the combustor at steady state operation. February 1988. Note the frozen slag on the front boiler wall that drained out of the exit nozzle. This slag is [illegible] formed from coal ash resulting from coal particle combustion inside the [illegible]. February 1988.



6. The Combustor's Exit Nozzle

NOTE: The part of the exit nozzle passing through the boiler front wall was reconstructed after it failed in the summer of 1988.

Figure A-III-24: Photo of exit nozzle viewed from inside the combustor after initial coal-water slurry tests. There is very little slag deposits on the nozzle wall, which was expected due to the low ash (2%) concentration and high ash fusion temperature in the [illegible]. The [illegible] front surface of the exit nozzle is due to spalling caused [illegible] thermal [illegible]. Fall 1987.

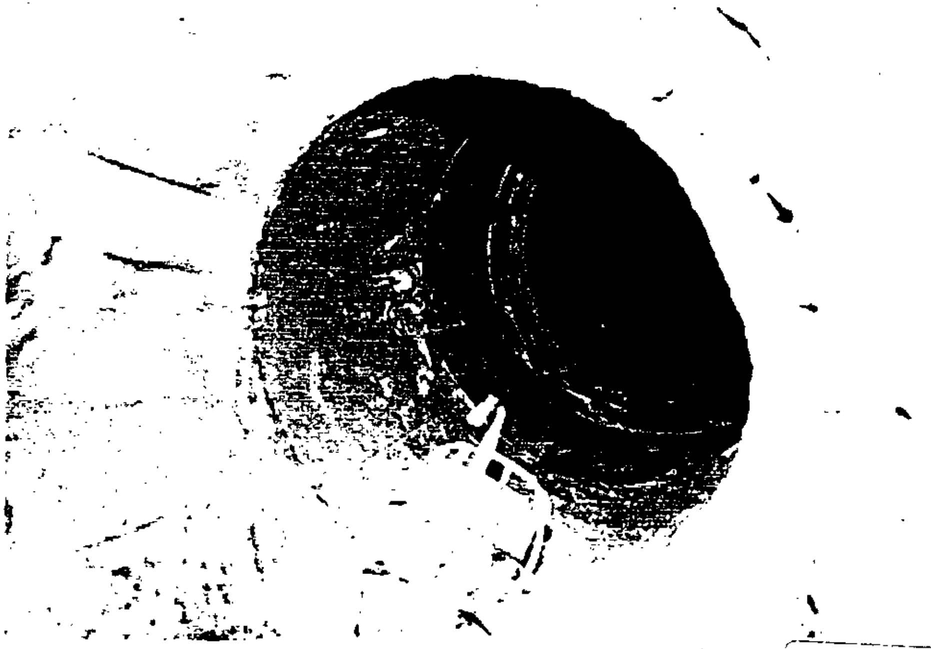


Figure A-III-25: Photo of front wall of the boiler, taken inside the boiler, showing the downstream end of the exit nozzle. The frozen slag flow on the front wall is visible, as are slag deposits on the boiler floor. The quantity of slag deposited was a function of the operating conditions. This slag flow was practically eliminated by either installing a slag dam on the floor of the exit nozzle, or operating the combustor in a manner that formed a slag dam. February 1988.

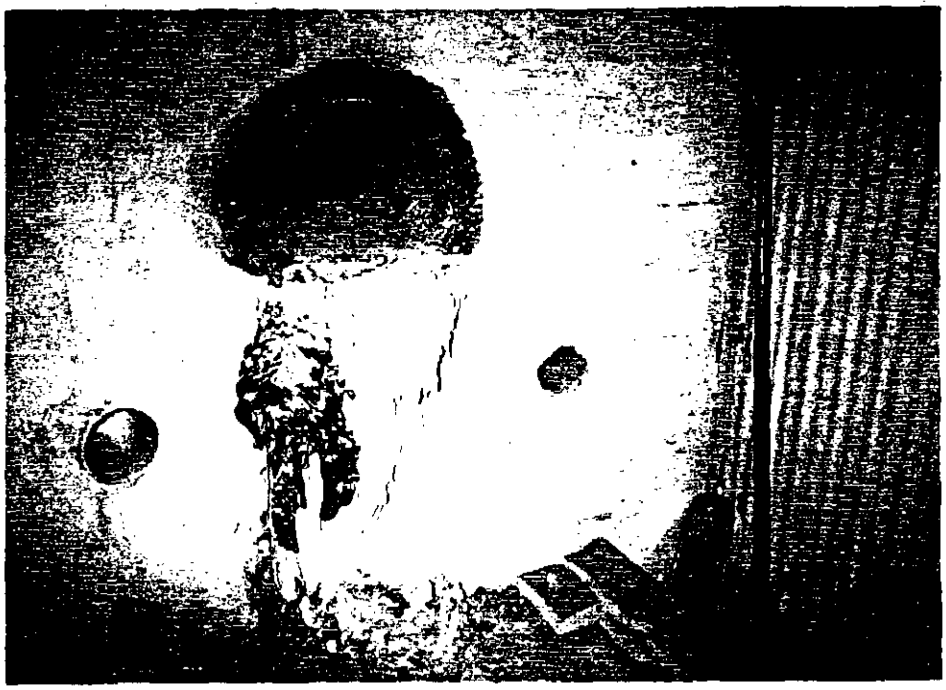


Figure A-III-26: Photo of the front wall of the boiler, showing the exit nozzle exit. In this case there is no slag flow into the boiler. Instead a slag barrier has been formed on the bottom and left side of the exit nozzle. As noted in the previous caption, the form of slag flow in the exit nozzle is a function of operating conditions. [illegible] Feb 1988

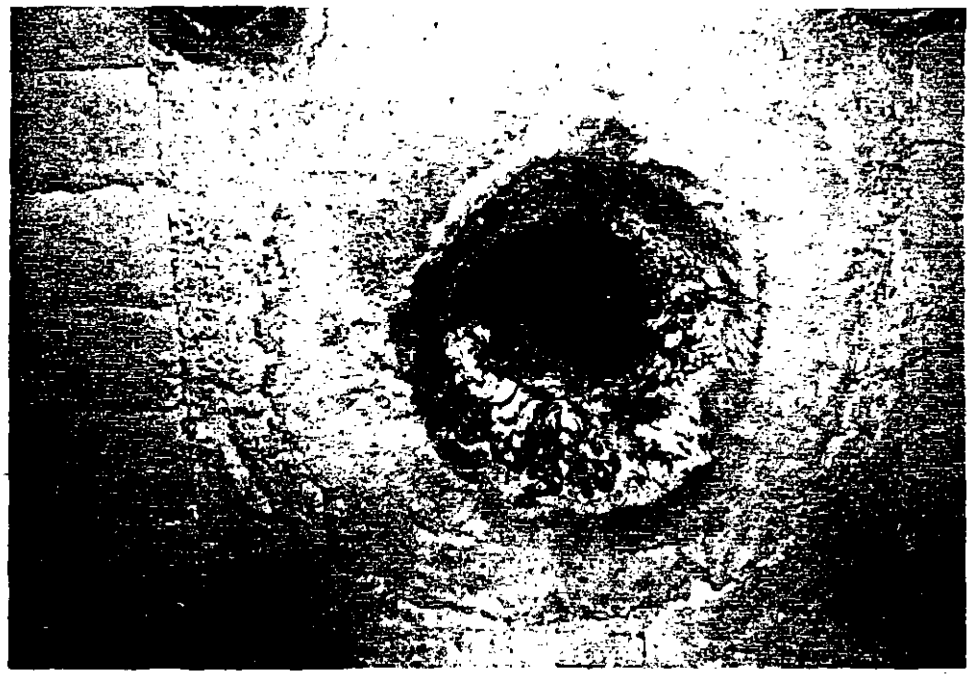


Figure A-III-27: Photo of the front wall of the boiler, showing the exit nozzle exit. In this case there is no slag flow into the boiler nor is there any slag dam inside the exit nozzle. December 1988. Note the front part of the nozzle is part of the combustor front wall, while the rear part, (the darker rear section) is part of the exit nozzle. December 1988.

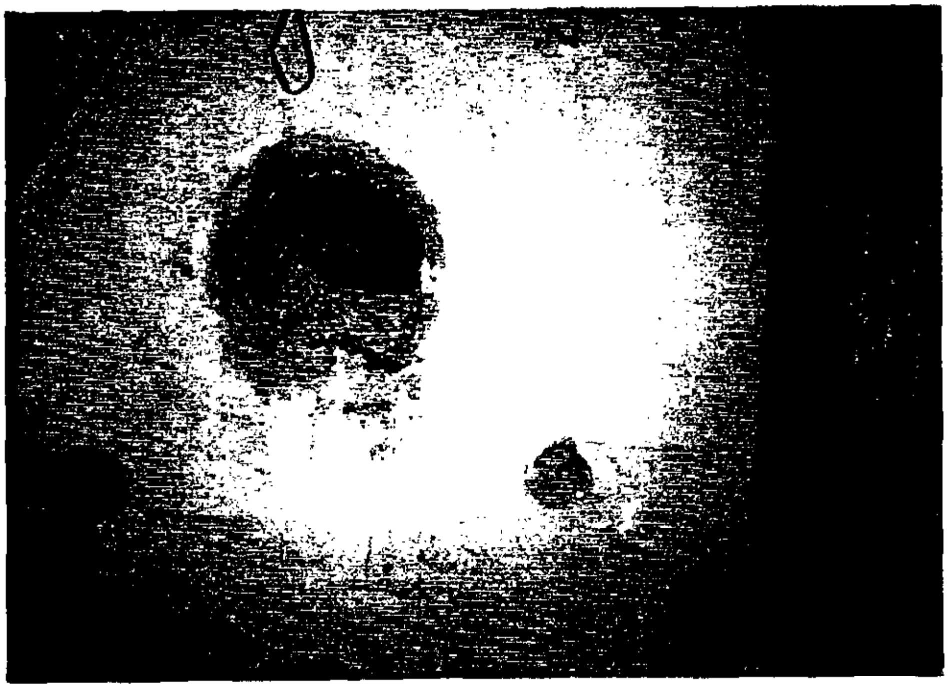


Figure A-III-28: Photo of the exit nozzle and and its penetration through the boiler front wall taken after the front wall refractory had failed in the summer of 1988. Note that the exit nozzle material in the background was relatively unaffected except for some spalling. In fact that part of the nozzle remained in place throughout the 3 years of the Clean Coal project. The bottom front section is a natural slag dam. The top of this section had materials lose where the combustion gases removed material. This refractory wall did not contain slag resistant material. Thes photo was taken after refractory has been manually removed to asses the damage. July 1988.

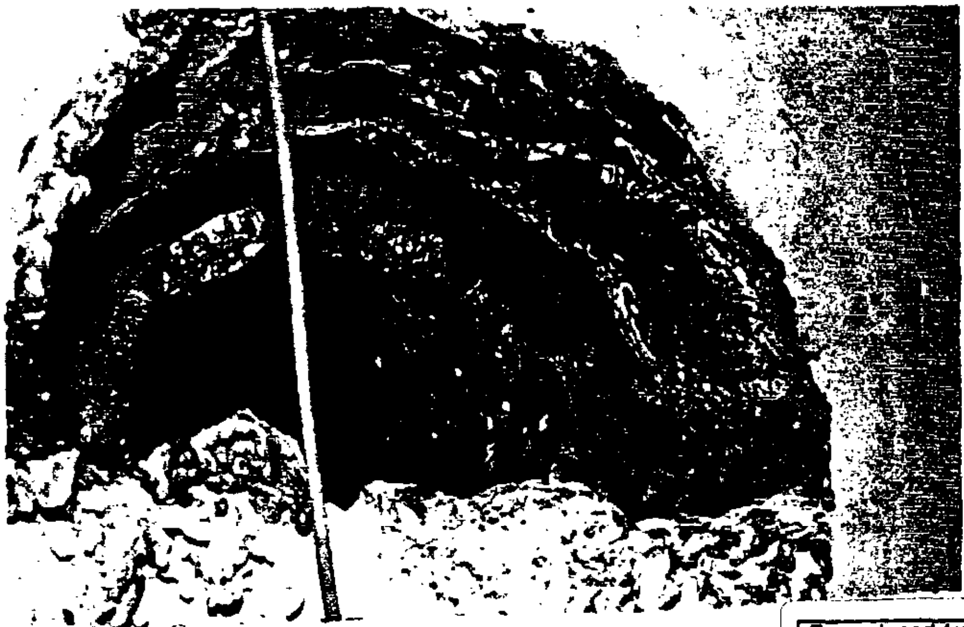
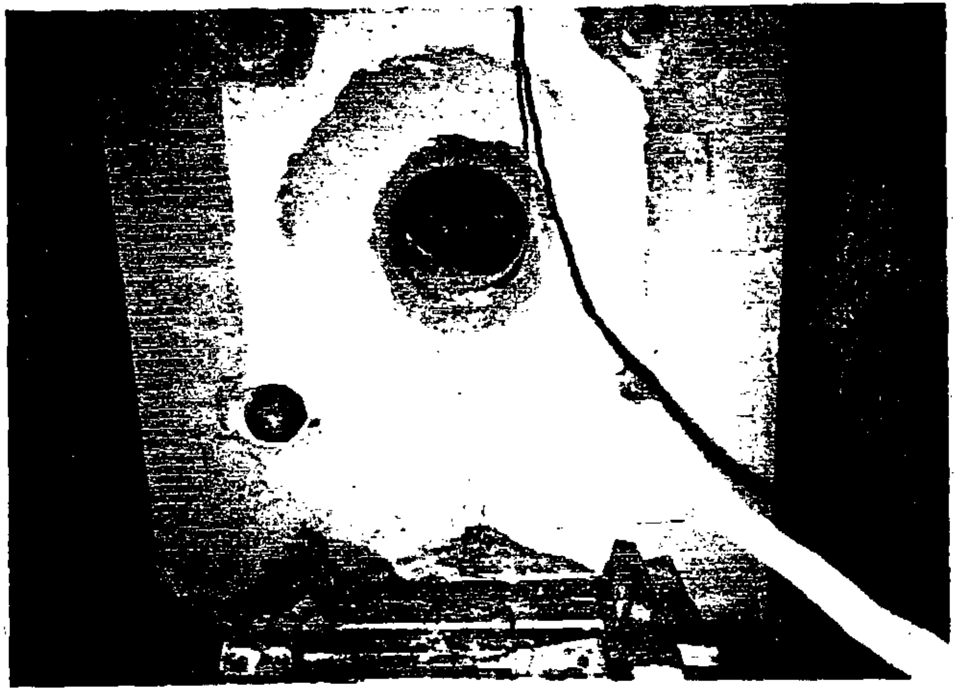


Figure A-III-29: Photo of the exit nozzle and front wall of the boiler taken inside the boiler after the front wall section enclosing the exit nozzle had been completely re-build October 1988. Compare this photo with those taken after that date shown above. Also shown are the fire bricks placed on the refractory floor of the furnace [illegible] any slag flowing out of exit nozzle.



7. The Oil Designed Package Boiler

The following photos show the effect [illegible] on the boiler.

Figure A-III-30: Photo of floor of boiler furnace taken inside the boiler looking toward the front refractory boiler wall. Note ash deposits on floor as well as small slag pieces. These deposits were formed after a poor coal combustion tests. The bricks near the front wall were placed to protect the furnace floor. June 1988. Note black coal char ash deposits on the boiler tubes.

Figure A-III-31: Photo of floor of boiler furnace taken inside the boiler looking toward the front refractory boiler wall. Note in this case the ash deposits on floor are fairly limited compared to the previous test. In this case combustion was very [illegible]

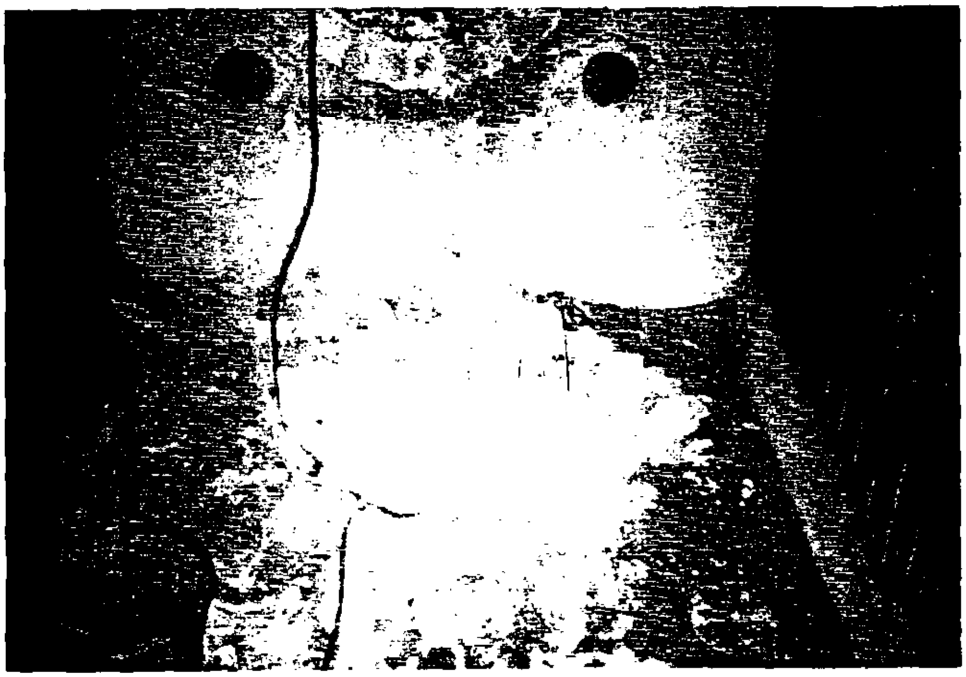


Figure A-III-32: Photo of rear boiler floor and lower boiler tubes taken at the same time as figure A-III-30. Note the high ash/char deposits in right rear corner of boiler. June 1988.

Figure A-III-33. Photo of rear boiler floor and lower boiler tubes taken at the same time as figure A-III-31. Note the lower level of ash deposits in right rear corner of boiler in this run with good combustion in combustor. Mid-1988.

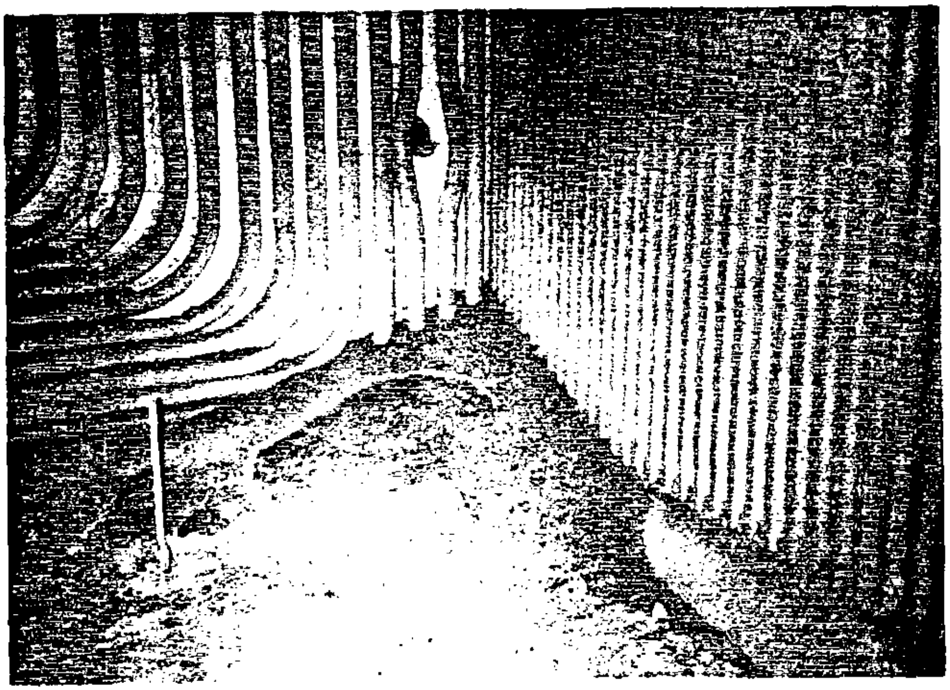


Figure A-III-34: Photo of rear boiler floor and lower boiler tubes. Note that the refractory tile floor is visible and the near absence of ash deposits in rear corners of the boiler in this run with very good combustion in combustor. Late 1988.

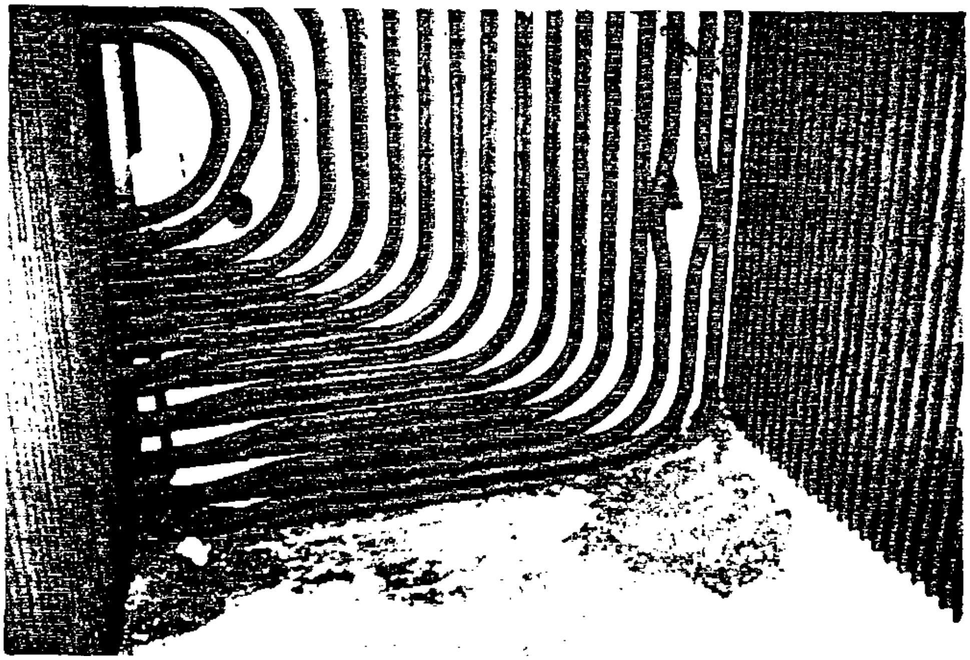


Figure A-III-35: Photo of deposits on the boiler tubes in furnace section of boiler showing the ash deposits. The lighter colored sections where brushed off manually to show that the deposits are easily removed. Note that the refractory bricks in rear of the tubes shows no evidence of ash deposits. 1989.

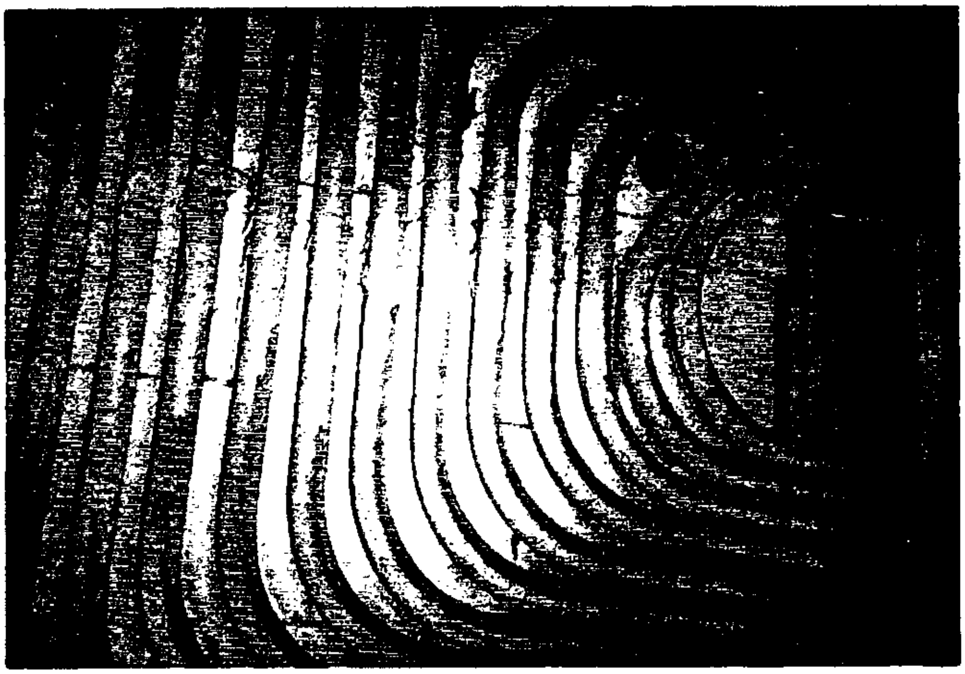
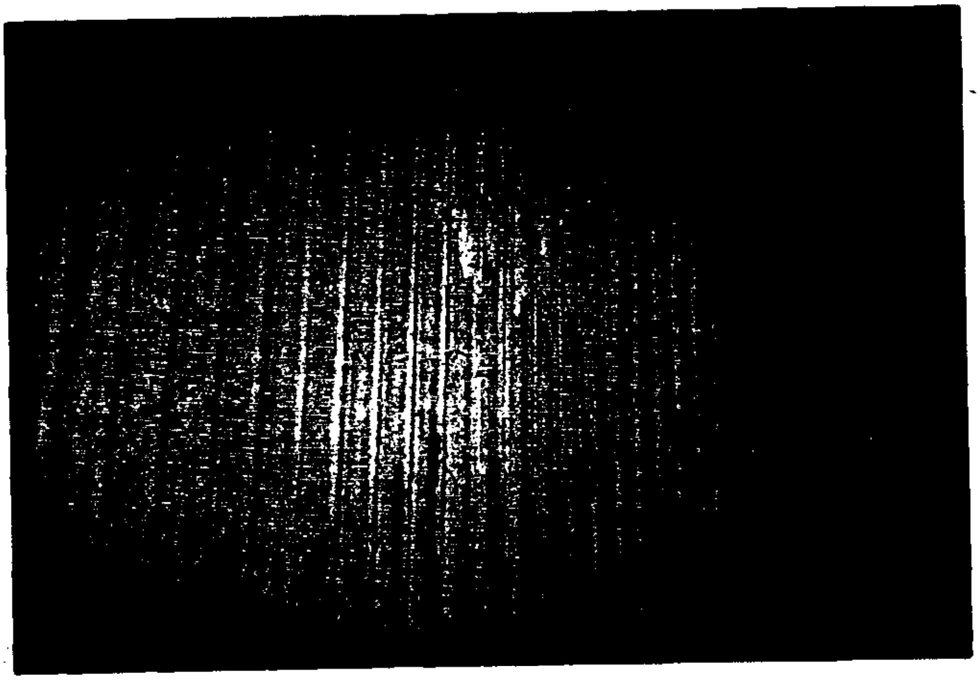


Figure A-III-36: Photo of one wall in the furnace section of the boiler showing the ash deposits on the wall, as well as several small sections where the ash had been brushed off. 1989.



6. Slag Rejection from the Combustor

Figure A-III-37: Installation of the slag conveyor into the slag tank. 1989.

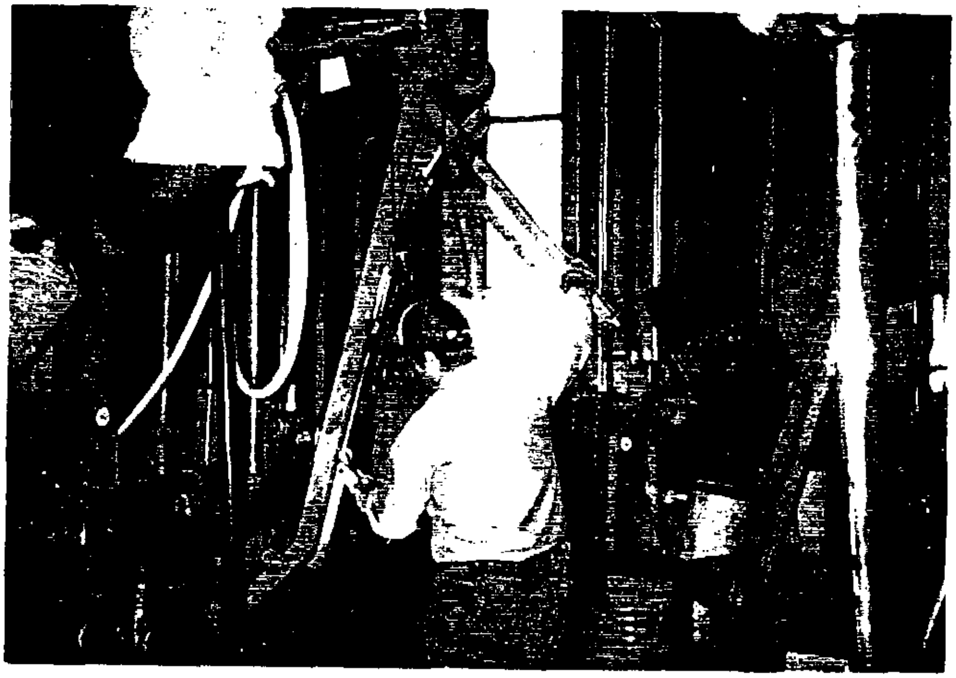


Figure A-III-38: Slag granules being transported by the conveyor from the bottom of the slag chute to a collection barrel. 1989.

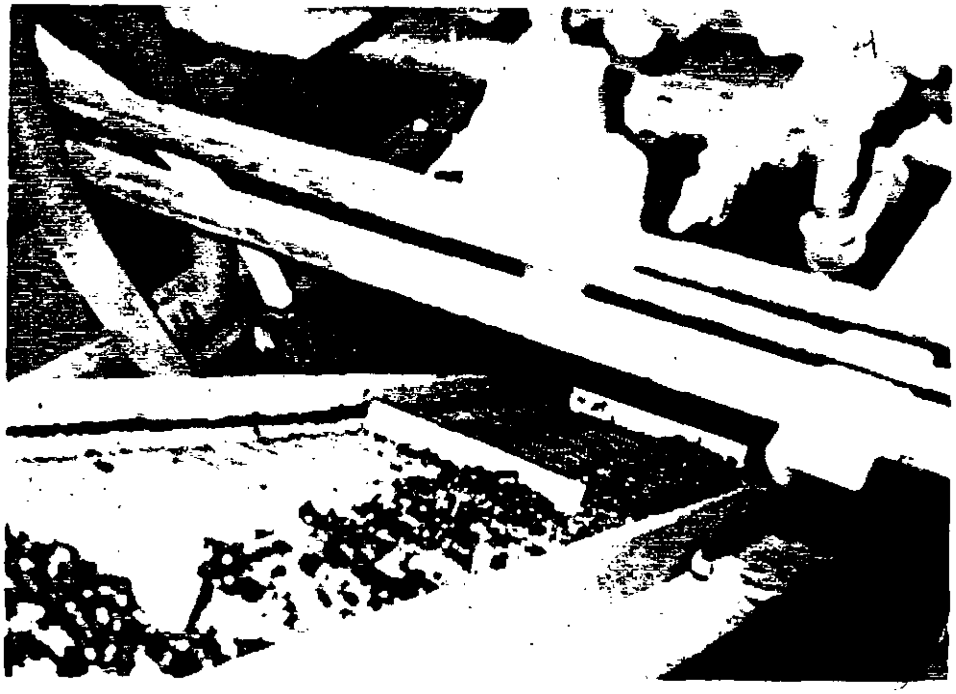


Figure A-III-39: Top of slag conveyor discharging slag granules into collection barrels. The two drums represent the slag collection from one day's operation.

Figure A-III-40: Large slag sections manually cleared from slag tap after the slag tap blocked. February 1989.

Figure A-III-41: Slag pieces cleared from the slag tap by means of periodic application of the slag breaker which was first installed in June 1989. The left piece is about 1 ft long and weighs about 20 lbs. These, and similar size, slag pieces were cleared after June 1989, while the combustor was at steady state coal fired operation.

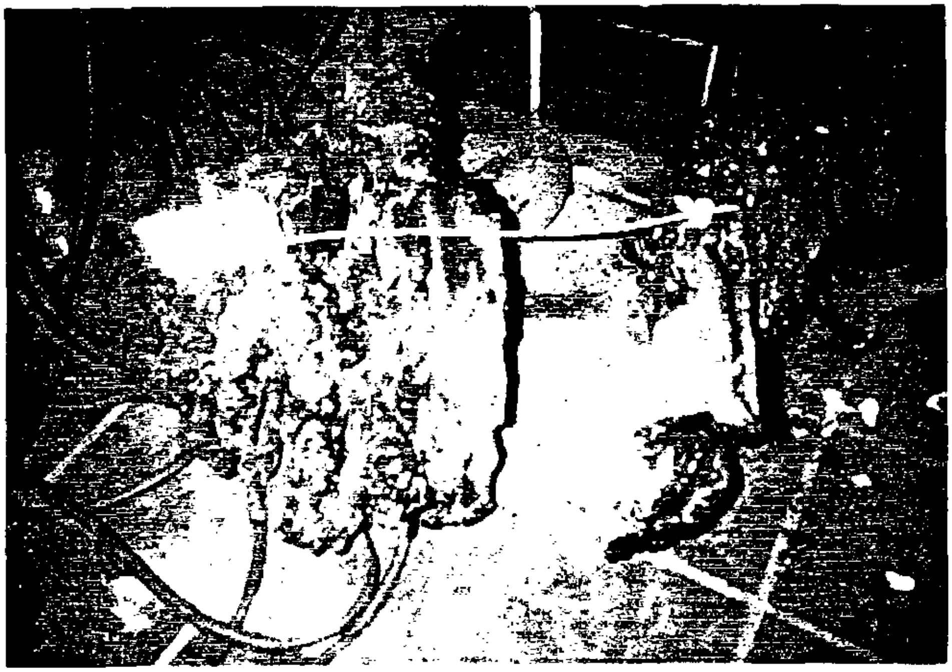


Figure A-III-42: View of the bottom of the slag tap and slag tank, showing a piece of hot slag dropping from the tap into the tank. December 1988.

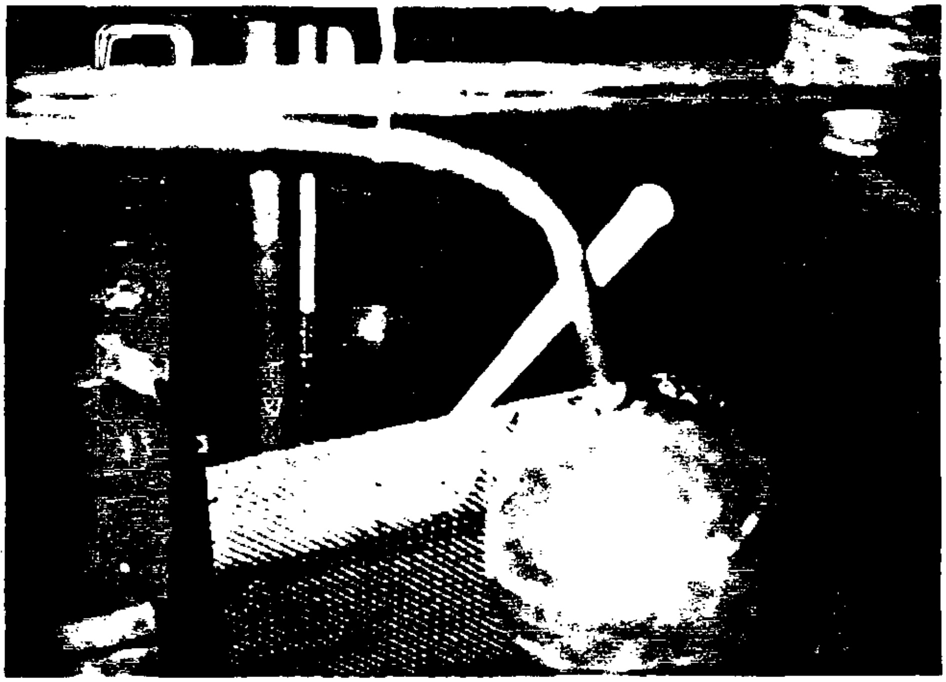


Figure A-III-43: Reflection of the slag tap in the water of the slag tank. The luminous spots are pieces of hot slag. February 1989.

Figure A-III-44: Photo of slag top completely blocked by frozen slag. The view is from the bottom of the tap. Reopening of the tap required chiselling of the slag. Prior to introduction of the mechanical breaker slag in June 1989, tap blockage was the most frequent reason for test termination. After that, very few tests were terminated due to tap blockage. June 1988.

9. Scrubber Operation

Figure A-III-45: Scrubber vessels installed on the roof of the boilerhouse-Summer 1987.

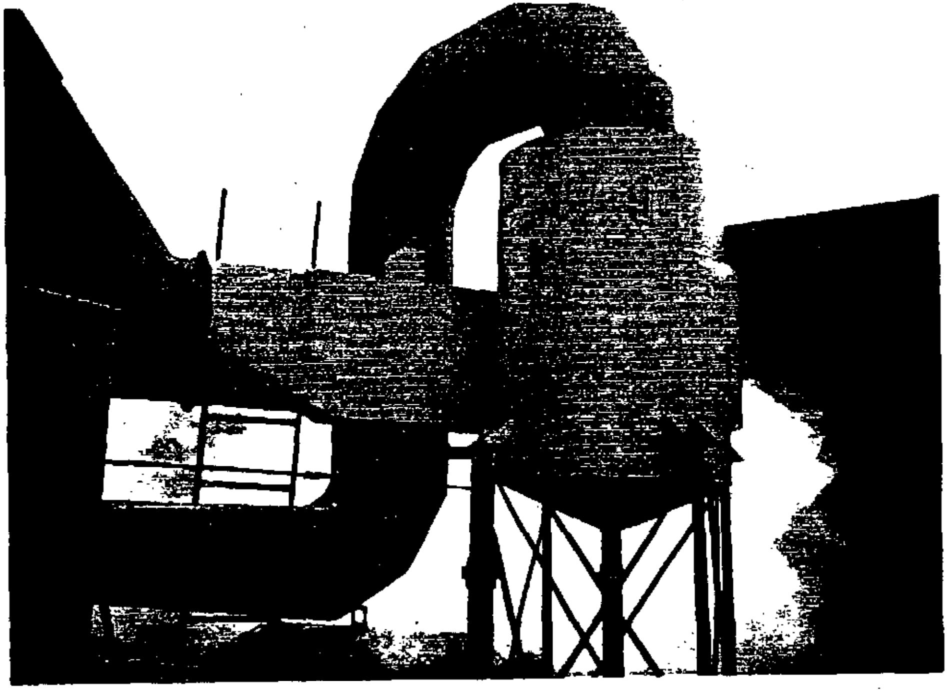


Figure A-III-46: Scrubber fan with its stack, as well as connecting duct from scrubber vessel to fan installed on roof of boilerhouse. The steam blow-off silencer is at lower right. Summer 1987.

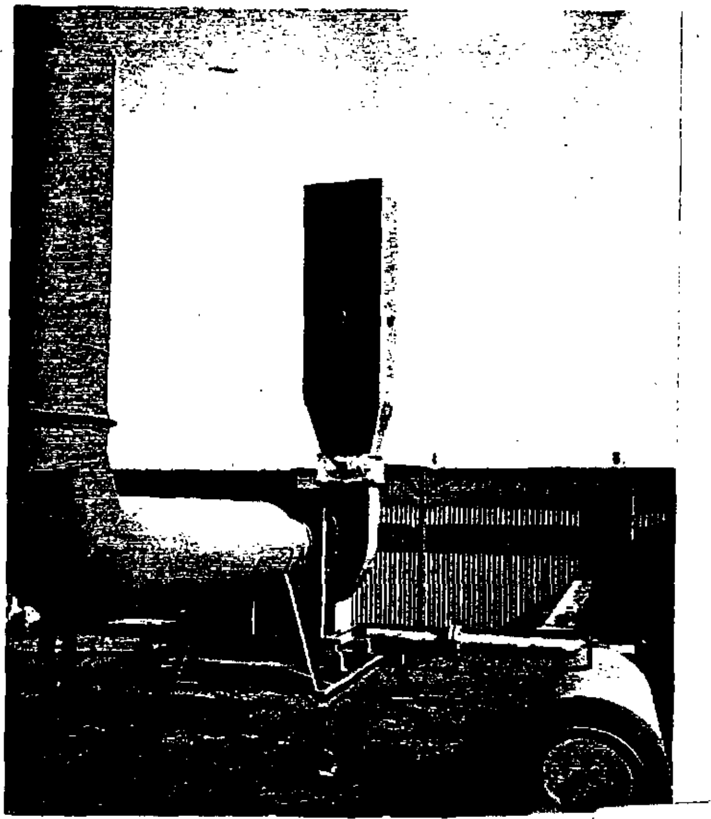
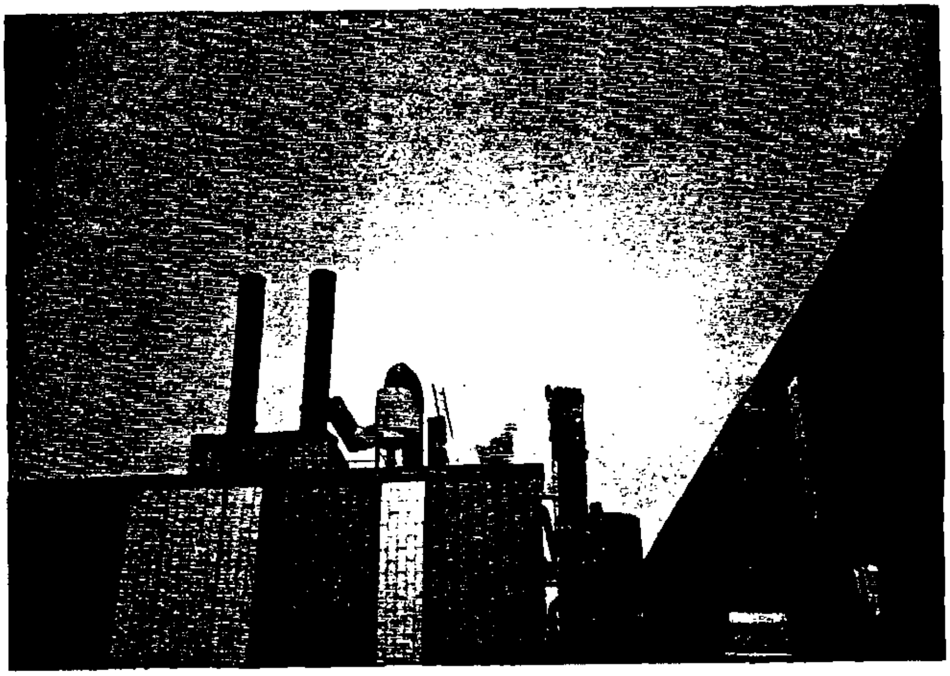


Figure A-III-47: Operation of scrubber vessel showing clear stack exhaust (near ladder on roof) and steam blown off from boiler.



10. Combustor Operation & Automation

Figure A-III-48. Manually operated control panel which was used for the entire Clean Coal project.

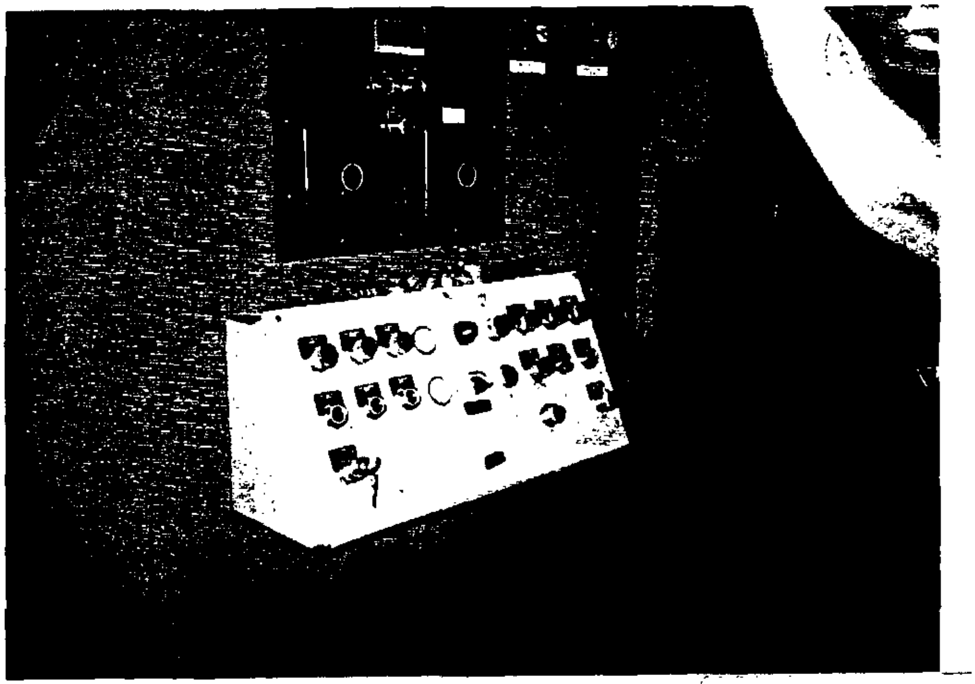
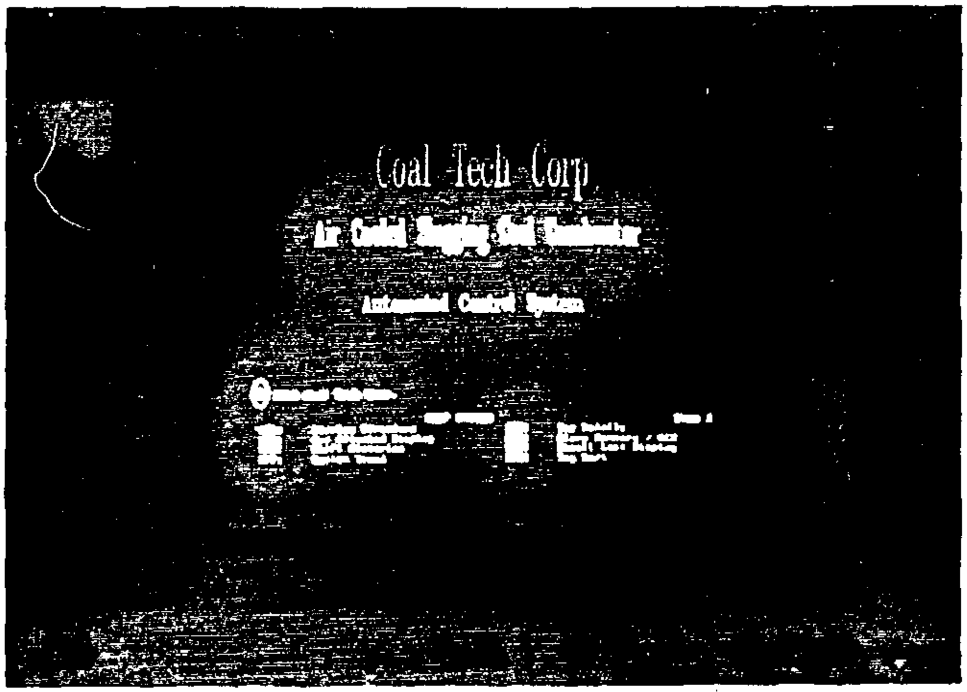


Figure A-III-49: Photo of logo of computerized computer control system as recorded on the computer screen, May 1990.



Coal Tech Corp

Air Cooled Slagging Coal Combustor

Automated Control System

Figure A-III-50: Computer control diagram showing the various process streams. May 1990.

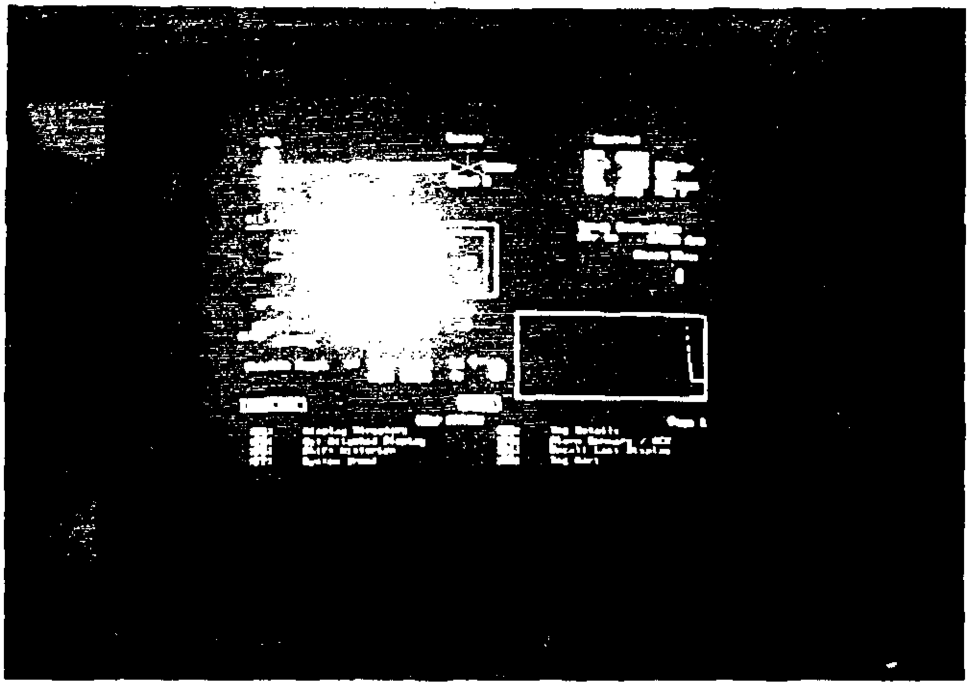


Figure A-III-51: Sample data output from computer control of [illegible] May 1990.

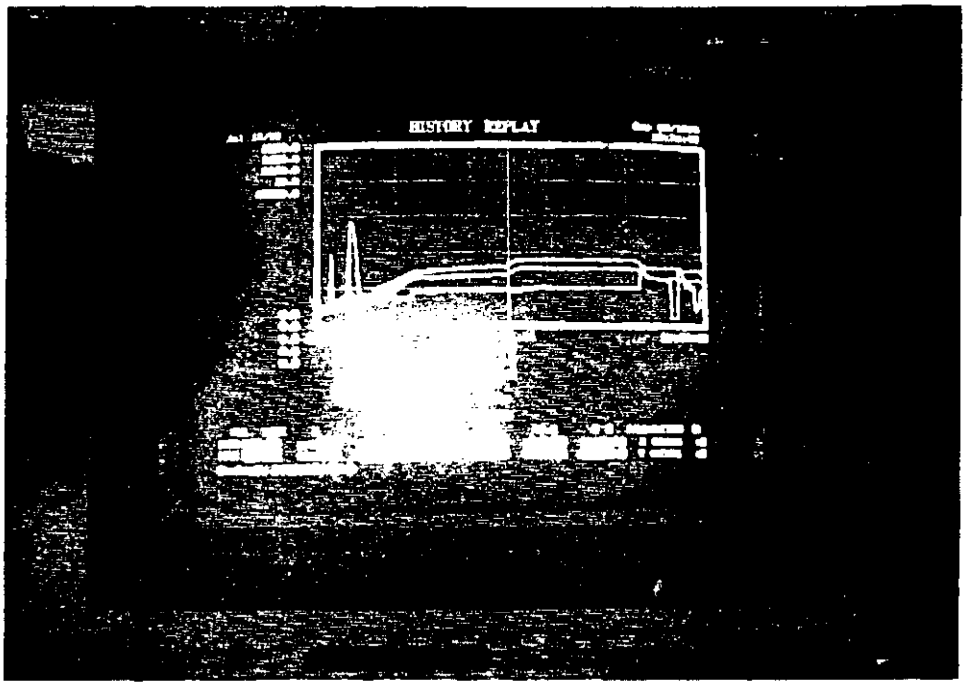
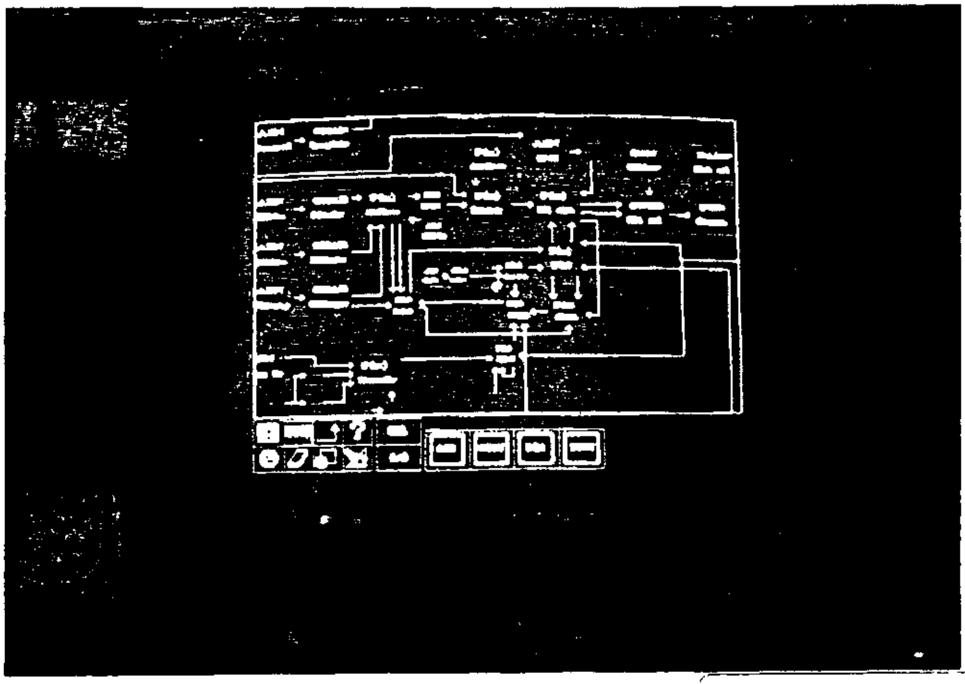


Figure A-III-52: Computer control strategy diagram. May 1990.



U.S. DOE-CLEAN COAL PROGRAM

"THE DEMONSTRATION OF AN ADVANCED CYCLONE COAL COMBUSTOR, WITH INTERNAL SULFUR, NITROGEN, AND ASH CONTROL FOR THE CONVERSION OF A 23 MMBTU/HOUR OIL FIRED BOILER TO PULVERIZED COAL"

FINAL TECHNICAL REPORT

APPENDIX IV. Results of Slag Analysis by PA DER Module 1 Procedure

REPORTING PERIOD - March 9, 1987 to February 28, 1991
DOE Cooperative Agreement No. DE-FC22-87PC79799

August 30,1991

By: Bert Zauderer, Project Manager,
Edward S.Fleming
COAL TECH CORP.
P.O. BOX 154
MERION, PA 19066

prepared for
U.S. DEPARTMENT OF ENERGY
PITTSBURGH ENERGY TECHNOLOGY CENTER
P.O. BOX 10940
PITTSBURGH, PA 15236

SSM
SPOTTS, STEVENS and McCOY, INC
ENGINEERS • PLANNERS • SCIENTISTS

APPENDIX IV: ANALYSIS OF SLAG PRODUCED BY THE COAL TECH COMBUSTOR, AS PER PA DER MODULE 1 PROCEDURE

CERTIFICATE OF ANALYSIS

CLIENT: COAL TECH CORP.
P. O. BOX 154
MERION, PA. 19066-0154

DATE REPORTED: 8/19/88
REPORT NO: 8818610
DATE SAMPLED:
DATE RECEIVED: 8/2/88
PURCHASE NO.: DOE-CC-70
ORDER NO.:

SAMPLE TYPE: SOLID WASTE
SAMPLED BY: CLIENT
SAMPLE IDENTIFICATION: COMBINED SAMPLE

<u>DER MODULE ONE ANALYSIS:</u>

		DRY BASIS	AS RECEIVED BASIS
1. Total Analysis of Solid			
Total Residue	%		96.8
Volatile Residue	%	2.31	2.23
pH			10.0
Cyanide	mg/Kg	< 0.01	< 0.01
Oil & Grease	mg/Kg	<52	< 50
Total Metals			
Arsenic	mg/Kg	66.7	64.6
Barium	mg/Kg	218	211
Cadmium	mg/Kg	< 2.27	< 2.20
Chromium	mg/Kg	3660	3540
Lead	mg/Kg	<15.2	< 14.7
Mercury	mg/Kg	< 0.26	< 0.25
Nickel	mg/Kg	22.0	21.3
Selenium	mg/Kg	4.56	4.41
Silver	mg/Kg	< 4.56	< 4.41
Copper	mg/Kg	12.2	11.8
Molybdenum	mg/Kg	<37.9	< 36.7
Zinc	mg/Kg	15.9	15.4
Total Halogens	mg/Kg	62	60
Total Sulfur	mg/Kg	83	80
Heating Value	BTU/lb		< 50
Corrosivity	by pH		10.0

The pH was determined on a mixture of 150 Grams of sample with 3 Liters of Reagent Water.

Metals Method SW-846

REPLY TO:

☐ HOME OFFICE
345 N. Wyomissing Blvd.
P.O. Box 6307
Reading PA 19610-0307
(215) 376-6581
Fax # (215) 376-6950

☐ ANALYTICAL LABORATORIES
30 Noble Street
P.O. Box 6257
Reading PA 19611-0327
(215) 376-6581
Fax # (215) 376-6950

☐ LEHIGH VALLEY OFFICE
MacArthur Office Plaza Suite 401
3722 Lehigh Street
Allentown PA 18052-3439
(215) 433-4186

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ENGINEERS • PLANNERS • SCIENTISTS

COAL TECH CORP.
REPORT #8818610
8/19/88

PAGE 2

<u>Leaching Tests</u>:

pH	mg/L	5.0
Oil & Grease	mg/L	< 4
Ammonia Nitrogen	mg/L	0.17
Phenolics	ug/L	< 1
Cyanide	mg/L	< 0.01

Total Metals

Antimony	mg/L	< 0.5
Arsenic	mg/L	< 0.002
Barium	mg/L	< 0.3
Cadmium	mg/L	< 0.03
Chromium	mg/L	< 0.1
Chromium, Hexavalent	mg/L	< 0.01
Lead	mg/L	< 0.2
Mercury	mg/L	< 0.0005
Nickel	mg/L	< 0.1
Selenium	mg/L	< 0.002
Silver	mg/L	< 0.06
Copper	mg/L	< 0.09
Molybdenum	mg/L	< 0.5
Zinc	mg/L	0.08
Total Organic Halides	ug/L	< 5
Chemical Oxygen Demand	mg/L	348
Total Organic Carbon	mg/L	141.2
Total Volatile Residue (550 oC)	mg/L	192
Total Residue (105 °C)	mg/L	1730

Respectfully submitted,

James S. Maurer

J. S. MAURER - GROUP LEADER
LABORATORY SERVICES

cc: Dr. Zauderer

SSM
SPOTTS, STEVENS and McCOY, INC
ENGINEERS • PLANNERS • SCIENTISTS

CERTIFICATE OF ANALYSIS

CLIENT:
COAL TECH CORPORATION
P O BOX 154
MERION PA 19066-0154

DATE REPORTED: 12/07/88

REPORT NO: 8818610

DATE SAMPLED:

DATE RECEIVED: 8/02/88

PURCHASE NO.: DOE-CC-70

ORDER NO.:

SAMPLE TYPE: SOLID WASTE

SAMPLED BY: CLIENT

SAMPLE IDENTIFICATION: COMBINED SAMPLE

This report is an Addendum to our previous report issued August 19, 1988.

At the request of Dr. Zauderer the sample was extracted with Hexane by sonication according to EPA SW-846 Method 3550, and the extract was subsequently analyzed for Total Organic Halides using EPA Method 9020. The sample was found to contain Less Than 1 mg/Kg TOX.

Respectfully submitted,

James S. Maurer

JAMES S. MAURER - GROUP LEADER
LABORATORY SERVICES

cc: Dr. Zauderer

Form No. L11a Rev. 1/87

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U.S. DOE-CLEAN COAL PROGRAM

"THE DEMONSTRATION OF AN ADVANCED CYCLONE COAL COMBUSTOR, WITH INTERNAL SULFUR, NITROGEN, AND ASH CONTROL FOR THE CONVERSION OF A 23 MMBTU/HOUR OIL FIRED BOILER TO PULVERIZED COAL"

FINAL TECHNICAL REPORT

APPENDIX V. Properties of the Coals & Limestone Used in the Test Effort

REPORTING PERIOD - March 9, 1987 to February 28, 1991
DOE Cooperative Agreement No. DE-FC22-87PC79799

August 30,1991

By: Bert Zauderer, Project Manager,
Edward S.Fleming
COAL TECH CORP.
P.O. BOX 154
MERION, PA 19066

prepared for
U.S. DEPARTMENT OF ENERGY
PITTSBURGH ENERGY TECHNOLOGY CENTER
P.O. BOX 10940
PITTSBURGH, PA 15236

INTRODUCTION

The following tables provide the Higher Heating Value, Proximate, Ultimate, and ash chemical analysis of all the test coals used in this project. In addition, a sieve analysis is presented for several of the coals. This size distribution was used throughout the test effort. The test coals can be correlated with the chronological test effort described in Appendix I by noting that the date of the analysis, as given in each table, corresponds to the dates at which a specific coal was used in the test effort, which is described in Appendix I. As the coals was delivered to the off-site pulverization company in 20 ton trucks, each coal delivery was used for several tests runs until the supply was exhausted. In one case, test PC25 February 1990, due to a mix-up, the supplier pulverized delivered 3.26% sulfur coal for part of the test and 1.06% sulfur coal for the balance of the test. This error was uncovered during the data analysis, and the results have been corrected for the proper coal. All the coals were PA bituminous coals, that were supplied by the PA Power & Light Company's coal suppliers. This was PP&L's cost share to the present project. The HHV was in the 12,000-13,000 BTU/lb range, the ash content was in the 10% range, the volatile matter was in the 20-30% range, and the sulfur content was in the 1 to 3% range.

A major problem was the T250 temperature of the coals, and this matter is discussed at length in the Final Report. We also include in this Appendix a brief memo on this subject from Penn State's Fuels Research Center.

The limestone properties and size distribution are listed after the coal tables. This material, as well as the hydrated lime, which was used in several very brief tests near the end of the project, were commercial, pulverized material sold for agricultural purposes by Agway Company, Williamsport, PA, a farm supply distributor. They obtain the material from PA suppliers. No attempt was made to perform a pore size analysis of the sorbent.

Finally, several brief tests were performed with food grade, calcium acetate, which was obtained from Niacet Chemical Company, Niagara Falls, NY. While the initial test showed that this material was considerably more effective as a sulfur sorbent than limestone, subsequent attempts to increase the injection rate into the combustor caused the formation of major deposits in the injection zone, and the tests were terminated. These tests are briefly noted in Appendix I. Due to the injection difficulties, we cannot draw any conclusions on the effectiveness of this sorbent.

Finally, numerous slag and scrubber samples were taken and analyzed. The conclusions drawn from these analyses are given in the body of the final report, and in Appendix II. Due to the numerous data sheets of these data, they are not included in the Final Report. However, they are available for future inspection or analysis, if the need arises.

PROPERTIES OF THE TEST LIMESTONE, AS SUPPLIED BY AGWAY COMPANY

COMPOSITION

CaCO3 (%weight)	MgO (%weight)	OTHER INSOLUBLE (%wt)
87	10	3

SIZE DISTRIBUTION

Mesh Size	30	50	60	100	200	325
Percent Passing Mesh	100%	97%	90%	85%	65%	40%

PENNSTATE

(814) 865-6543
(814) 865-6545

Energy and Fuels Research Center

513 Deike Building
The Pennsylvania State University
University Park, PA 16802

July 21, 1988

Mr. Ed Fleming
1109 Wassergass
Hellertown, PA 18055

Dear Mr. Fleming:

Enclosed is the information you requested (7/21/88) pertaining to the ash fusion properties of coal seams that may be used by Pennsylvania Power and Light. Table 1 provides a listing of coal seams by county that have ash fusion (reducing softening) temperatures below 2200°F. Total sulfur also is included to provide some indirect information on raw coal quality. The information provided in Table 1 was extracted from the Pennsylvania Coal Data Base and Market Analysis System which is a remote access coal data base funded, in part, by PEDA.

In an earlier conversation with David Glick, you expressed interest in correlations between ash fusion (reducing softening) temperatures and the forms of sulfur. The following is a listing for whole seam samples from the Appalachian region as a whole (174 samples) and for Pennsylvania coal seams alone (97 samples). This information was obtained from a preliminary statistical analysis of the Penn State Coal Data Base.

Correlation Coefficients
Ash Fusion vs. Sulfur Forms

	Total	Pyritic	Organic
Appalachian Coals	-0.72	-0.69	-0.52
Pennsylvania Coals	-0.71	-0.71	-0.42

Thank you for your inquiry.

Sincerely,

Gary Mitchell

Gareth Mitchell

GM:plm

Enclosure

TABLE 1

Township	Seam	Ash Fusion, Reducing Softening Temp.	Total Sulfur
Cambria County			
Blacklick	Lower Freeport	2193	2.59
Barr	Lower Freeport	2175	2.44
Barr	Lower Freeport	2130	2.58
Barr	Lower Freeport	2045	3.25
Barr	Lower Freeport	2080	2.82
Barr	Lower Freeport	2025	2.98
Barr	Lower Freeport	2020	2.54
Barr	Lower Freeport	2070	3.76
Barr	Lower Freeport	2065	3.17
Barr	Lower Freeport	2120	4.83
Barr	Lower Freeport	2170	2.93
	Lower Freeport	2180	2.58
Dean	Upper Freeport	2040	3.56
	Upper Kittanning	2140	2.83
Centre County			
Rush	Brookville	2190	5.20
Rush	Brookville	2130	3.50
Rush	Lower Kittanning	1900	3.90

TABLE 1 continued

Township	Seam	Ash Fusion, Reducing Softening Temp,	Total Sulfur
Indiana County			
Cherryhill	Clarion	2170	.40
Canoe	Lower Freeport	2130	2.50
Canoe	Lower Freeport	2130	3.10
	Lower Kittanning	2190	3.79
East Wheatfield	Lower Kittanning	2000	4.45
Burrell	Upper Freeport	2130	2.40
West Wheatfield	Upper Freeport	2169	.86
Banks	Upper Freeport	2080	2.10
Canoe	Upper Freeport	2170	2.40
Pine	Upper Freeport	2185	3.54
Canoe	Upper Freeport	2100	3.50
Canoe	Upper Freeport	2140	1.90
Banks	Upper Freeport	2090	2.80
West Wheatfield	Upper Kittanning	2127	3.30
Somerset County			
	Lower Bakerstown	2180	4.14
	Lower Bakerstown	2130	2.10
Stony Creek	Lower Freeport	2130	2.90
	Middle Kittanning	2195	3.12
	Upper Freeport	2190	3.99
Milford	Upper Freeport	2035	3.20
Paint	Upper Kittanning	2145	2.00

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CERTIFICATE OF ANALYSIS

CLIENT: Coal Tech Corporation
P.O. Box 154
Merion Station, PA 19066-0154

DATE REPORTED: 11/30/87

REPORT NO: 8712504-001

DATE SAMPLED: Unknown

SAMPLE TYPE: Ash and Deposits

DATE RECEIVED: 11/23/87

SAMPLED BY: Client

PURCHASE NO.: DOE-CC-26

SAMPLE IDENTIFICATION: Coal #1

ORDER NO.:

- - - - - - -

		AS RECEIVED	DRY BASIS
Total Moisture	%	0.65	
Volatile Matter	%	19.8	19.9
Fixed Carbon	%	68.3	68.7
Ash	%	11.2	11.3
Heating Value	Btu/lb	12140	12220
Sulfur	% S	1.13	1.14
Carbon	% C	78.4	78.9
Hydrogen (Excluding H in moisture)	% H	4.17	4.2
Hydrogen (Including H in moisture)	% H	4.24	
Nitrogen	% N	1.21	1.22
Oxygen (Excluding O in moisture)	% O	3.21	3.23
Oxygen (Including O in moisture)	% O	3.79	

Respectfully submitted,

C. J. Wummer

C. J. Wummer, Program Supervisor
Laboratory Services

APR

cc: Dr. Bert Zauderer

Form No. L11a Rev. 1/87

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CERTIFICATE OF ANALYSIS

CLIENT: Coal Tech Corporation
P.O. Box 154
Merion Station, PA 19066-0154

DATE REPORTED: 12/01/87

REPORT NO: 8712504-001

DATE SAMPLED: Unknown

DATE RECEIVED: 11/23/87

PURCHASE NO.: DOE-CC-26

ORDER NO.:

SAMPLE TYPE: Ash and Deposits

SAMPLED BY: Client

SAMPLE IDENTIFICATION: Coal #1

- - - - - - - - -

ASH ANALYSIS

		%
Silica	SiO_2	52.2
Iron Oxide	Fe_2O_3	7.37
Aluminum Oxide	Al_2O_3	29.7
Calcium Oxide	CaO	1.04
Magnesium Oxide	MgO	0.47
Sodium Oxide	Na_2O	0.24
Potassium Oxide	K_2O	2.68

Respectfully submitted,

John M. Meholick

John M. Meholick, Chemist
Laboratory Services

APR

cc: Dr. Bert Zauderer

Form No. L11a Rev. 1/87

A-V-8

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CERTIFICATE OF ANALYSIS

CLIENT: COAL TECH CORP.
P. O. BOX 154
MERION, PA. 19066-0154

DATE REPORTED: 2/5/88
REPORT NO: 8813725-001
DATE SAMPLED: Unknown
DATE RECEIVED: 1/22/88
PURCHASE NO.: DOE-CC-41
ORDER NO.:

SAMPLE TYPE: Coal #2
SAMPLFD BY: Client
SAMPLE IDENTIFICATION: Pulverized Coal - Sample A

		AS RECEIVED	DRY BASIS
Total Moisture	%	0.66	
Volatile Matter	%	22.8	22.9
Fixed Carbon	%	63.6	64.0
Ash	%	12.9	13.0
Heating Value	Btu/lb	13,420	13,510
Sulfur	%	1.25	1.26
Carbon	%	76.8	77.3
Hydrogen (Excluding H in moisture)	%	4.23	4.18
Hydrogen (Including H in moisture)	%	4.16	
Nitrogen	%	1.30	1.30
Oxygen (Excluding O in moisture)	%	3.54	2.97
Oxygen (Including O in moisture)	%	2.95	

Respectfully submitted,

Carl J. Wummer

CARL J. WUMMER - GROUP LEADER
LABORATORY SERVICES

Form No. L11b Rev. 8/86

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SPOTTS, STEVENS and McCOY, INC
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CERTIFICATE OF ANALYSIS

CLIENT: COAL TECH. CORP.
P. O. BOX 154
MERION, PA. 19066-0154

DATE REPORTED: 2/5/88
REPORT NO: 8813726N
DATE SAMPLED: Unknown
DATE RECEIVED: 1/22/88
PURCHASE NO.: DOE-CC-41
ORDER NO.:

SAMPLE TYPE: Coal Ash #2
SAMPLED BY: Client
SAMPLE IDENTIFICATION: 001: Sample A Ash FROM COAL SAMPLE

ANALYSIS		001
Aluminum Oxide as Al_2O_3	%	23.8
Calcium Oxide as CaO	%	1.25
Iron Oxide as Fe_2O_3	%	10.7
Potassium Oxide as K_2O	%	2.72
Sodium Oxide as Na_2O	%	0.37
Silica as SiO_2	%	53.2

Respectfully submitted,

Carl J. Wummer
CARL J. WUMMER - GROUP LEADER
LABORATORY SERVICES

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CERTIFICATE OF ANALYSIS

CLIENT: Coal Tech Corporation
P. O. Box 154
Merion Station, PA 19066-0154

DATE REPORTED: 12/16/87

REPORT NO: 8712838-002

DATE SAMPLED: Unknown

SAMPLE TYPE: Coal #1

DATE RECEIVED: 12/11/87

SAMPLED BY: Client

PURCHASE NO.:

SAMPLE IDENTIFICATION: Sample B: 2nd Load

ORDER NO.:

- - - - - - - - -

SIEVE ANALYSIS (WET)

% Retained on 60 Mesh	0.0
% Retained on 100 Mesh	0.2
% Retained on 200 Mesh	2.5
% Retained on 325 Mesh	4.2
% Passing on 325 Mesh	93.1

Air Dry Loss	%	0.13

Respectfully submitted,

J. K. Kieffer

J. K. Kieffer, Technical Director
Laboratory Services

APR
cc: Ed Fleming

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CERTIFICATE OF ANALYSIS

CLIENT: Coal Tech Corporation
P. O. Box 154
Merion Station, PA 19066-0154

DATE REPORTED: 12/16/87

REPORT NO: 8712838-001

DATE SAMPLED: Unknown

DATE RECEIVED: 12/11/87

PURCHASE NO.:

ORDER NO.:

SAMPLE TYPE: Coal #1

SAMPLED BY: Client

SAMPLE IDENTIFICATION: Sample A: Bottom of Bin

- - - - - - - -

SIEVE ANALYSIS (WET)

% Retained on 60 Mesh		0.7
% Retained on 100 Mesh		3.1
% Retained on 200 Mesh		7.6
% Retained on 325 Mesh		5.0
% Passing on 325 Mesh		83.6
Air Dry Loss	%	0.18

Respectfully submitted,

J. K. Kieffer

J. K. Kieffer, Technical Director
Laboratory Services

APR
cc: Ed Fleming

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CERTIFICATE OF ANALYSIS

CLIENT: COAL TECH CORP.
P. O. BOX 154
MERION, PA. 19066-0154

DATE REPORTED: 3/14/88

REPORT NO: 8814603

DATE SAMPLED:

SAMPLE TYPE: COAL

DATE RECEIVED: 3/1/88

SAMPLED BY: CLIENT

PURCHASE NO.: DOE-CC-44

SAMPLE IDENTIFICATION: #8814603-001
SAMPLE "A"

ORDER NO.:

		AS RECEIVED	DRY BASIS
Total Moisture	%	1.03	
Volatile Matter	%	22.4	22.6
Fixed Carbon	%	63.0	63.6
Ash	%	13.6	13.7
Heating Value	Btu/lb	13280	13420
Sulfur	%	1.34	1.35
Carbon	%	75.7	76.4
Hydrogen (Excluding H in moisture)	%	4.18	4.11
Hydrogen (Including H in moisture)	%	4.07	
Nitrogen	%	1.33	1.34
Oxygen (Excluding O in moisture)	%	3.85	2.97
Oxygen (Including O in moisture)	%	2.94	

Respectfully submitted,

Carl J. Wummer

CARL J. WUMMER - GROUP LEADER
LABORATORY SERVICES

cc: Dr. B. Zauderer

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CLIENT: COAL TECH CORP.
P. O. BOX 154
MERION, PA. 19066-0154

DATE REPORTED: 6/17/88

REPORT NO: 8816719

DATE SAMPLED:

DATE RECEIVED: 6/2/88

PURCHASE NO.: DOE-CC-62

ORDER NO.:

SAMPLE TYPE: COAL

SAMPLED BY: CLIENT

SAMPLE IDENTIFICATION: #8816719-001
SAMPLE "A"

		AS RECEIVED	DRY BASIS
Total Moisture	%	1.15	
Volatile Matter	%	28.3	28.6
Fixed Carbon	%	58.2	58.9
Ash	%	12.4	12.5
Heating Value	Btu/lb	13280	13430
Sulfur	%	1.54	1.56
Carbon	%	73.8	74.7
Hydrogen (Excluding H in moisture)	%	4.18	4.22
Hydrogen (Including H in moisture)	%	4.30	
Nitrogen	%	1.14	1.16
Oxygen (Excluding O in moisture)	%	5.77	5.84
Oxygen (Including O in moisture)	%	6.79	

Respectfully submitted,

J. M. MEHOLICK - GROUP LEADER
LABORATORY SERVICES

cc: Dr. Zauderer

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CERTIFICATE OF ANALYSIS

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P. O. BOX 154
MERION, PA. 19066-0154

DATE REPORTED: 6/17/88
REPORT NO: 8816719
DATE SAMPLED:
DATE RECEIVED: 6/2/88
PURCHASE NO.: DOE-CC-62
ORDER NO.:

SAMPLE TYPE: ASH
SAMPLED BY: CLIENT
SAMPLE IDENTIFICATION: #8816719:001
SAMPLE "A"

ANALYSIS		001
Aluminum Oxide	% Al_2O_3	24.2
Calcium Oxide	% CaO	0.47
Iron Oxide	% Fe_2O_3	12.4
Magnesium Oxide	% MgO	0.63
Silica	% SiO_2	49.5
Chromium Oxide	% Cr_2O_3	0.02

Respectfully submitted,

J. M. MEHOLICK - GROUP LEADER
LABORATORY SERVICES

cc: Dr. Zauderer

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CERTIFICATE OF ANALYSIS

CLIENT: COAL TECH CORP.
P. O. BOX 154
MERION, PA. 19066-0154

DATE REPORTED: 9/6/88
REPORT NO: 8819251
DATE SAMPLED:
DATE RECEIVED: 8/22/88
PURCHASE NO.: DOE-CC-71
ORDER NO.:

SAMPLE TYPE: COAL
SAMPLED BY: CLIENT
SAMPLE IDENTIFICATION: #8819251-001
SAMPLE "B" COAL

ANALYSIS		001
Aluminum Oxide	% Al_2O_3	22.3
Calcium Oxide	% CaO	0.62
Chromium Oxide	% % CrO_2	0.03
Iron Oxide	% Fe_2O_3	16.4
Magnesium Oxide	% MgO	0.50
Silica	% SiO_2	49.7

Respectfully submitted,

JOHN M. MEHOLICK - GROUP LEADER
LABORATORY SERVICES

cc: Dr. Zauderer

A-V-16

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ENGINEERS • PLANNERS • SCIENTISTS

CERTIFICATE OF ANALYSIS

CLIENT: COAL TECH CORP.
P. O. BOX 154
MERION, PA. 19066-0154

DATE REPORTED: 9/6/88
REPORT NO: 8819251
DATE SAMPLED:
DATE RECEIVED: 8/22/88
PURCHASE NO.: DOE-CC-71
ORDER NO.:

SAMPLE TYPE: COAL

SAMPLED BY: CLIENT

SAMPLE IDENTIFICATION: #8819251-001
SAMPLE "B" COAL

		AS RECEIVED	DRY BASIS
Total Moisture	%	2.65	
Volatile Matter	%	34.3	35.2
Fixed Carbon	%	50.0	51.4
Ash	%	13.0	13.4
Heating Value	Btu/lb	12590	12930
Sulfur	%	2.48	2.55
Carbon	%	68.0	69.9
Hydrogen (Excluding H in moisture)	%	4.43	4.55
Hydrogen (Including H in moisture)	%	4.73	
Nitrogen	%	1.14	1.17
Oxygen (Excluding O in moissture)	%	8.21	8.43
Oxygen (Including O in moisture)	%	10.6	

Respectfully submitted,

JOHN M. MEHOLICK - GROUP LEADER
LABORATORY SERVICES

cc: Dr. Zauderer

Form No. L11a Rev. 1/87

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698 Fairmount Avenue
Suite 105
Baltimore MD 21204-2819
(301) 494-0500

SSM
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ENGINEERS • PLANNERS • SCIENTISTS

DEC 88 Run

CERTIFICATE OF ANALYSIS

CLIENT: COAL TECH CORP
P O BOX 154
MERION PA 19066-0154

SAMPLE TYPE: COAL

SAMPLED BY: CLIENT

SAMPLE IDENTIFICATION: #8822262-001
FUEL SAMPLE

DATE REPORTED: 12/26/88

REPORT NO: 8822262

DATE SAMPLED:

DATE RECEIVED: 12/20/88

PURCHASE NO.: DOE-CC-78A

ORDER NO.:

		AS RECEIVED	DRY BASIS
Total Moisture	%	2.04	
Volatile Matter	%	32.2	32.9
Fixed Carbon	%	53.0	54.1
Ash	%	12.8	13.1
Heating Value	Btu/lb	12750	13020
Sulfur	%	2.08	2.12
Carbon	%	72.5	74.0
Hydrogen (Excluding H in moisture)	%	4.42	4.51
Hydrogen (Including H in moisture)	%	4.65	
Nitrogen	%	1.16	1.18
Oxygen (Excluding O in moisture)	%	5.02	5.12
Oxygen (Including O in moisture)	%	6.83	

SIEVE ANALYSIS

% Retained on 50 Mesh	0.2
% Retained on 100 Mesh	0.4
% Retained on 200 Mesh	22.9
% Passing 200 Mesh	76.5

Respectfully submitted,

J. M. MEHOLICK - GROUP LEADER
LABORATORY SERVICES

cc: Dr. B. Zauderer

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CERTIFICATE OF ANALYSIS

CLIENT: COAL TECH CORP
P O BOX 154
MERION PA 19066-0154

DATE REPORTED: 12/26/88
REPORT NO: 8822262
DATE SAMPLED:
DATE RECEIVED: 12/20/88
PURCHASE NO.: DOE-CC-78A
ORDER NO.:

SAMPLE TYPE: COAL
SAMPLED BY: CLIENT
SAMPLE IDENTIFICATION: #8822262-001
FUEL SAMPLE

			001
Silica	%	SiO_2	48.4
Aluminum Oxide	%	Al_2O_3	21.6
Calcium Oxide	%	CaO	0.95
Iron Oxide	%	Fe_2O_3	14.3
Potassium Oxide	%	K_2O	1.62
Sodium Oxide	%	Na_2O	0.02

Respectfully submitted,

J. M. MEHOLICK - GROUP LEADER
LABORATORY SERVICES

cc: Dr. B. Zauderer

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A-V-19

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CERTIFICATE OF ANALYSIS

CLIENT:	COAL TECH CORP P O BOX 154 MERION PA 19066	**REPORT NO:**	8927802
		P.O. NO.:	DOE-CC-100
		DATE REPORTED:	July 14, 1989
		DATE RECEIVED:	July 01, 1989
		WORK ORDER NO.:	

SAMPLING DATE: **BY:** CLIENT

SAMPLE DESCRIPTION: COAL

SAMPLE IDENTIFICATION: #8927802-001
COAL SAMPLE

		AS RECEIVED	DRY BASIS
Total Moisture	%	2.27	
Volatile Matter	%	33.7	34.5
Fixed Carbon	%	53.5	54.7
Ash	%	10.5	10.7
Heating Value	Btu/lb	13010	13310
Sulfur	%	2.26	2.31
Carbon	%	71.8	73.5
Hydrogen (Excluding H in moisture)	%	4.69	4.54
Hydrogen (Including H in moisture)	%	4.44	
Nitrogen	%	1.19	1.22
Oxygen (Excluding O in moisture)	%	9.53	7.69
Oxygen (Including O in moisture)	%	7.51	

		COAL SAMPLE - 001
Silica	% SiO_2	44.8
Aluminum Oxide	% Al_2O_3	21.8
Calcium Oxide	% CaO	3.57
Iron Oxide	% Fe_2O_3	19.0
Magnesium Oxide	% MgO	1.43

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CERTIFICATE OF ANALYSIS

COAL TECH CORP
REPORT #8927802

JULY 14, 1989
PAGE 2

PARTICLE SIZE (BAHCO)

LAB. NO. 8927802-1

TERMINAL VELOCITY (IN/MIN)	PARTICLE SIZE (MICRONS)	CUMULATIVE WEIGHT (%) (LESS THAN)
285	45	77.4

% Larger Than 100 Mesh (150 Microns)	0.0
% Smaller Than 100 Mesh (150 Microns)	10.0 – 100?
Specific Gravity	1.28

Respectfully submitted,

Carl J. Wummer

CARL J. WUMMER – GROUP LEADER
LABORATORY SERVICES

cc: Dr. B. Zauderer

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CERTIFICATE OF ANALYSIS

CLIENT:	COAL TECH CORP P O BOX 154 MERION PA 19066	REPORT NO:	8931465
		P.O. NO.:	DOE-CC-108
		DATE REPORTED:	October 16, 1989
		DATE RECEIVED:	October 05, 1989
		WORK ORDER NO.:	

SAMPLING DATE: BY: CLIENT

SAMPLE DESCRIPTION: COAL

SAMPLE IDENTIFICATION: 9/28/89 RUN

		AS RECEIVED	DRY BASIS
Total Moisture	%	1.18	
Volatile Matter	%	24.8	25.1
Fixed Carbon	%	62.5	63.2
Ash	%	11.5	11.6
Heating Value	Btu/lb	13250	13410
Sulfur	%	1.47	1.49
Carbon	%	73.4	74.3
Hydrogen (Excluding H in moisture)	%	4.11	4.16
Hydrogen (Including H in moisture)	%	4.25	
Nitrogen	%	1.12	1.13
Oxygen (Excluding O in moisture)	%	7.20	7.28
Oxygen (Including O in moisture)	%	8.25	

SIZE ANALYSIS

	% MATERIAL
> 100 MESH	0.0
> 52 MICRONS	21.4
< 52 MICRONS	78.6

ASH ANALYSIS

			DRY BASIS
Silica	%	SiO_2	47.6
Iron Oxide	%	Fe_2O_3	12.0
Aluminum Oxide	%	Al_2O_3	26.5
Calcium Oxide	%	CaO	2.17
Magnesium Oxide	%	MgO	0.81

Respectfully submitted,

J. M. Meholick / J. A. Maurer

J. M. MEHOLICK - GROUP LEADER
LABORATORY SERVICES

cc: Dr. B. Zauderer

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CERTIFICATE OF ANALYSIS

CLIENT: COAL TECH CORP
P O BOX 154
MERION PA 19066

REPORT NO: 9034079
P.O. NO.:
DATE REPORTED: January 12, 1990
DATE RECEIVED: January 02, 1990
WORK ORDER NO.: DOE-ASH-11

SAMPLING DATE: **BY:** CLIENT

SAMPLE DESCRIPTION: COAL

SAMPLE IDENTIFICATION: #903407-001
COAL SAMPLE

		AS RECEIVED	DRY BASIS
Total Moisture	%	1.17	
Volatile Matter	%	37.1	37.5
Fixed Carbon	%	50.8	51.4
Ash	%	10.9	11.0
Heating Value	Btu/lb	13450	13610
Sulfur	%	3.29	3.33
Carbon	%	74.4	75.3
Hydrogen (Excluding H in moisture)	%	5.01	5.07
Hydrogen (Including H in moisture)	%	5.14	
Nitrogen	%	1.53	1.54
Oxygen (Excluding O in moisture)	%	3.73	3.77
Oxygen (Including O in moisture)	%	4.77	

Respectfully submitted,

John M Meholick

J. M. MEHOLICK - GROUP LEADER
LABORATORY SERVICES

cc: Dr. B. Zauderer

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CERTIFICATE OF ANALYSIS

CLIENT: COAL TECH CORP
P O BOX 154
MERION PA 19066

REPORT NO: 9034079
P.O. NO.:
DATE REPORTED: January 12, 1990
DATE RECEIVED: January 02, 1990
WORK ORDER NO.:

DOE-ASH-11

SAMPLING DATE: **BY:** CLIENT

SAMPLE DESCRIPTION: COAL

SAMPLE IDENTIFICATION: #9034079-001
COAL SAMPLE

			001
Silica	%	SiO_2	46.2
Calcium Oxide	%	CaO	1.44
Magnesium Oxide	%	MgO	0.6
Sulfur Trioxide	%	SO_3	1.7
Aluminum Oxide	%	Al_2O_3	19.6
Iron Oxide	%	Fe_2O_3	26.8
Barium	mg/kg	Ba	< 1190
Strontium	mg/kg	Sr	1190
Lead	mg/kg	Pb	< 79
Cadmium	mg/kg	Cd	< 119
Chromium	mg/kg	Cr	< 396
Arsenic	mg/kg	As	80
Copper	mg/kg	Cu	364

Respectfully submitted,

J. M. MEHOLICK - GROUP LEADER
LABORATORY SERVICES

cc: Dr. B. Zauderer

SSM /Laboratories
SPOTTS, STEVENS and McCOY, INC
ENGINEERS • PLANNERS • SCIENTISTS

CLIENT:	COAL TECH CORP P O BOX 154 MERION PA 19066-0154	**REPORT NO:**	9035936
		P.O. NO.:	DOE-CC-112 B
		DATE REPORTED:	March 6, 1990
		DATE RECEIVED:	February 21, 1990
		WORK ORDER NO.:	DOE-CC-112 B

SAMPLING DATE: **BY:** CLIENT

SAMPLE DESCRIPTION: COAL

SAMPLE IDENTIFICATION: #9035936-001
SAMPLE 2/13/90

		AS RECEIVED	DRY BASIS
Total Moisture	%	1.28	
Volatile Matter	%	21.0	21.3
Fixed Carbon	%	66.7	67.6
Ash	%	11.0	11.1
Heating Value	Btu/lb	13500	13680
Sulfur	%	1.06	1.07
Carbon	%	79.5	80.5
Hydrogen (Excluding H in moisture)	%	4.04	4.09
Hydrogen (Including H in moisture)	%	4.18	
Nitrogen	%	1.24	1.25
Oxygen (Excluding O in moisture)	%	2.98	3.01
Oxygen (Including O in moisture)	%	4.11	

Respectfully submitted,

Carl J. Wummer

CARL J. WUMMER - GROUP LEADER
LABORATORY SERVICES

cc: Dr. B. Zauderer

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CLIENT: COAL TECH CORP
P O BOX 154
MERION PA 19066-0154

REPORT NO: 9035936
P.O. NO.: DOE-CC-112
DATE REPORTED: March 6, 1990
DATE RECEIVED: February 21, 1990
WORK ORDER NO.:

SAMPLING DATE: **BY:** CLIENT

SAMPLE DESCRIPTION: COAL

SAMPLE IDENTIFICATION: #9035936-001
SAMPLE 2/13/90

Aluminum Oxide	%	Al_2O_3	42.4
Silica	%	SiO_2	29.7
Iron Oxide	%	Fe_2O_3	7.72
Calcium Oxide	%	CaO	1.25

Respectfully submitted,

Carl J. Wummer

CARL J. WUMMER - GROUP LEADER
LABORATORY SERVICES

cc: Dr. B. Zauderer

SSM /Laboratories
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CERTIFICATE OF ANALYSIS

CLIENT: COAL TECH CORP
P O BOX 154
MERION PA 19066-0154

REPORT NO: 9038951
P.O. NO.: DOE-CC-124
DATE REPORTED: June 26, 1990
DATE RECEIVED: June 05, 1990
WORK ORDER NO.:

SAMPLING DATE: **BY:** CLIENT

SAMPLE DESCRIPTION: COAL

SAMPLE IDENTIFICATION: #9038951-001
COAL SAMPLE

		AS RECEIVED	DRY BASIS
Total Moisture	%	1.67	
Volatile Matter	%	31.9	32.4
Fixed Carbon	%	53.8	54.7
Ash	%	12.6	12.8
Heating Vaue	Btu/lb	12,830	13,050
Sulfur	%	1.75	1.78
Carbon	%	74.1	75.4
Hydrogen (Excluding H in moisture)	%	4.74	4.82
Hydrogen (Including H in moisture)	%	4.92	
Nitrogen	%	1.27	1.29
Oxygen (Excluding O in moisture)	%	3.84	3.90
Oxygen (Including O in moisture)	%	5.32	

RESPECTFULLY SUBMTITED,

J.L. Paris

J. L. PARIS - CHEMIST
LABORATORY SERVICES

cc: Dr. B. Zauderer

SSM /Laboratories
SPOTTS, STEVENS and McCOY, INC
ENGINEERS • PLANNERS • SCIENTISTS

CERTIFICATE OF ANALYSIS

CLIENT:	COAL TECH CORP P O BOX 154 MERION PA 19066-0154	**REPORT NO:**	9038951-2
		P.O. NO.:	DOE-CC-124
		DATE REPORTED:	June 26, 1990
		DATE RECEIVED:	June 05, 1990
		WORK ORDER NO.:	

SAMPLING DATE: **BY:** CLIENT

SAMPLE DESCRIPTION: COAL

PARTICLE SIZE (BAHCO ANALYSIS)

LAB NO. 9038951 - 1 COAL

TERMINAL VELOCITY (IN/MIN)	PARTICLE SIZE (MICRONS)	CUMULATIVE WEIGHT (%) (LESS THAN)
0.34	2.0	10.6
1.18	3.6	18.4
5.70	8.0	37.3
45.0	23.0	78.8
141	40.0	85.6
285	48.0	88.9

Specific Gravity	1.26
% Retained on 100 Mesh	0.0
% Passing 100 Mesh	100

Respectfully submitted,

J. L. Paris

J. L. PARIS - CHEMIST
LABORATORY SERVICES

cc: Dr. B. Zauderer

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CERTIFICATE OF ANALYSIS

CLIENT: COAL TECH CORP
P O BOX 154
MERION PA 19066-0154

REPORT NO: 9038951-3
P.O. NO.: DOE-CC-124
DATE REPORTED: June 26, 1990
DATE RECEIVED: June 05, 1990
WORK ORDER NO.:

SAMPLING DATE: **BY:** CLIENT

SAMPLE DESCRIPTION: COAL

			001
Moisture	%		0.33
Loss On Ignition	%		84.5
Silica	%	SiO_2	7.27
Aluminum Oxide	%	Al_2O_3	3.30
Iron Oxide	%	Fe_2O_3	2.73
Calcium Oxide	%	CaO	0.332
Magnesium Oxide	%	MgO	0.09
Potassium Oxide	%	K_2O	0.29
Zinc	mg/kg		120
Cadmium	mg/kg		< 14.7
Barium	mg/kg		< 147
Copper	mg/kg		< 44.2
Mercury	mg/kg		0.103
Strontium	mg/kg		90.5
Arsenic	mg/kg		9.70
Lead	mg/kg		< 98.2
Chloride	mg/kg		120

NOTE: All results reported on the Dry Basis, except the Moisture analysis.

< Indicates a Less Than value.

Respectfully submitted,

J. L. Paris

J. L. PARIS - CHEMIST
LABORATORY SERVICES

U.S. DOE-CLEAN COAL PROGRAM

"THE DEMONSTRATION OF AN ADVANCED CYCLONE COAL COMBUSTOR, WITH INTERNAL SULFUR, NITROGEN, AND ASH CONTROL FOR THE CONVERSION OF A 23 MMBTU/HOUR OIL FIRED BOILER TO PULVERIZED COAL"

FINAL TECHNICAL REPORT

APPENDIX VI. Results of the Solid Waste Sampling Performed on the Coal Tech Combustor by an Independent Contractor During the February 1990 Tests

REPORTING PERIOD - March 9, 1987 to February 28, 1991
DOE Cooperative Agreement No. DE-FC22-87PC79799

August 30,1991

By: Bert Zauderer, Project Manager,
Edward S.Fleming
COAL TECH CORP.
P.O. BOX 154
MERION, PA 19066

prepared for
U.S. DEPARTMENT OF ENERGY
PITTSBURGH ENERGY TECHNOLOGY CENTER
P.O. BOX 10940
PITTSBURGH, PA 15236

INTRODUCTION

The DOE Clean Coal Program Office selected an independent contractor, Energy & Environmental Research, to sample the various solid waste streams produced by several of the Clean Coal Projects. In 1989, Coal Tech agreed to participate in this effort. A sampling team was to take slag, scrubber solid, slag tank water, and scrubber water samples during the course of one of the air cooled combustor tests. To avoid any conflict of interest, and to protect Coal Tech's proprietary position, the Environmental Resources Management Company was selected by DOE and EER to perform the actual sampling at Coal Tech. The sampling took place during the four day combustor test in February 1990. The samples were analyzed in part by the technical staff of the University of North Dakota Environmental Research Center.

An initial report of the sampling was prepared in the Spring of 1990. A second report contained a summary of the sampling analysis results. A third report was prepared in mid-1991 which also summarized the findings and also presented a series of conclusions. In addition to conclusions concerning the results of the sampling, this final report also contained conclusions on the overall combustion process in the air cooled combustor. In Coal Tech's opinion, the latter conclusions extended beyond the mandate agreed upon between Coal Tech and DOE for this sampling effort. In addition, some of the conclusions concerning the combustor were speculative as the sampling team had no access to the complete combustor test data base. After discussing this matter with DOE, Coal Tech agreed to include in its Final Final Report the results contained in the first two reports. These two reports contain all the sampling test results and summaries. As such all the information obtained during sampling is presented, and it is included in this Appendix.

This Appendix consists of several parts. Parts 1, beginning on page VI-1, summarizes the objectives of the sampling effort and describes the test procedures. Part 2, beginning on page VI-11, describes ERM's test procedure. Part 3, provides the results of the sampling analysis, and the reader is referred to this part for a summary of the sampling results.

SOLID WASTE SAMPLING AND DISTRIBUTION PROJECT

SAMPLING REPORT #1

May 1990

Work Performed Under Contract No. DE-AC21-88MC25185

for

U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

by

Energy and Environmental Research Corporation
Irvine, California

INTRODUCTION

The United States Department of Energy (DOE) has established a Waste Management Program within the Office of Fossil Energy. A key goal of this is to ensure that waste management issues do not become roadblocks to the commercialization of advanced coal utilization technologies. In achieving this goal, the Waste Management Program identifies various emerging coal utilization technologies and performs comprehensive characterizations of the waste streams and products. The characterizations include engineering assessments to define waste streams of interest/potential concern, field studies to collect samples of the waste, and complete chemical analysis of collected samples.

In a previous effort under the above mentioned program, DOE obtained waste stream samples from approximately 20 different facilities utilizing advanced coal technologies. These facilities were mainly small pilot scale facilities. DOE now is extending their characterization program to include a number of new facilities, particularly larger pilot- and commercial-scale units. Energy and Environmental Research Corporation (EER) was selected to perform the site selection and the sampling aspects of this project.

The current EER contract consists of two interrelated efforts: site selection and waste sampling. Detailed sample analysis is being conducted under another DOE contract. The primary objectives of the site selection and sampling effort are listed below.

- Survey sites at which advanced fossil energy combustion technologies are being operated, and identify five sites for sampling. Priority should be given to DOE Clean Coal Technology Program Sites.
- Identify candidate solid waste streams in advanced coal utilization processes likely to present disposal problems and prioritize them for sampling at selected sites.
- Contact site personnel for site access, sample the streams representatively and document them according to established methodology and known process conditions.
- Distribute the samples to DOE's Morgantown Energy Technology Center or their representatives for analysis and report on the site visit.

Several advanced coal utilization technologies have been tentatively selected for comprehensive waste characterization. One of those technologies is the advanced slagging cyclone combustor being developed by Coal Tech Corporation of Williamsport, PA. Coal Tech agreed to inclusion of their technology in the current waste characterization project. On February 13 and 14, 1990 samples were collected to characterize both solid and liquid waste streams. This document provides background information on the site and describes sampling activities performed at this facility.

SITE SELECTION

EER established criteria for selecting the candidate sites. These included:

- The demonstration has been selected as part of DOE's Clean Coal Technology (CCT) Program,
- There is a lack of data regarding the waste products from this technology,
- Facility operators will cooperate,
- There is a possibility that the waste contains regulated compounds,
- The demonstration is being conducted in a pilot scale facility or larger with the availability of 50 lbs of waste, and
- The demonstration will be operational before August 1990.

Coal Tech Corporation is demonstrating the operation of a pilot scale advanced cyclone slagging combustor. This is a new technology which has not been demonstrated at full scale yet and thus minimal data are available regarding the characteristics of the waste products. The demonstration has been selected as one of the projects funded in Round 1 of DOE's CCT Program, the Facility operators were willing for this sampling program to be conducted at their facility. having met all of the criteria listed above, the slagging combustor being developed by Coal Tech in Williamsport, PA was selected for inclusion in the current sampling program.

STREAM SELECTION

A process flow diagram for Coal Tech's slagging cyclone combustor is shown in Figure 1. Both liquid and solid phase wastes are produced by this facility. The major solid waste stream consists of slag from the combustor and residue from the wet scrubber, while liquid wastes consist of scrubber water and slag quench water streams.

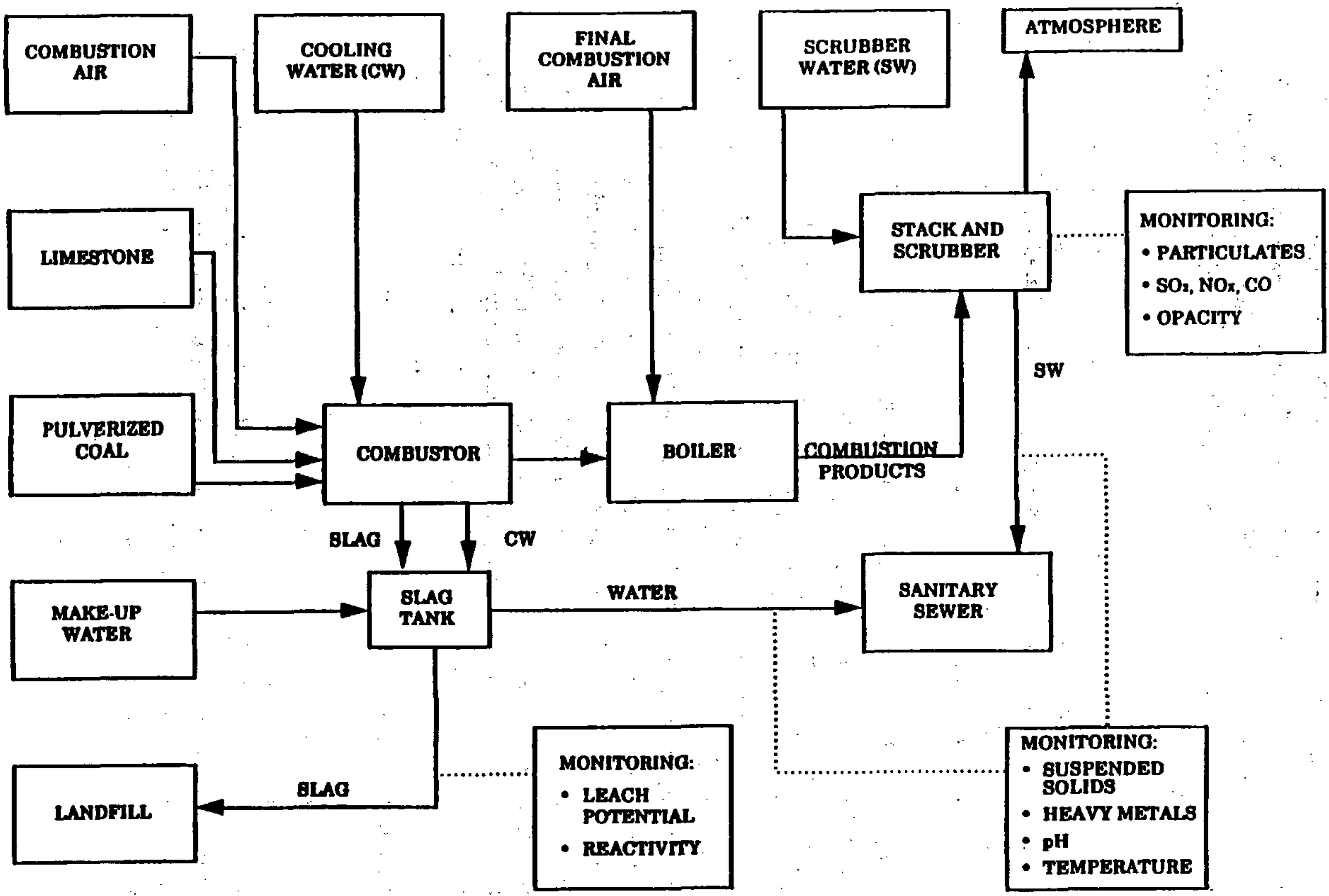


FIGURE 1. PROCESS FLOW DIAGRAM FOR SLAGGING CYCLONE COMBUSTOR

The slag is a glassy dark material rejected in a molten form as small nodules (approximately 1/4-inch in diameter), or as "stalagtite" formation, depending on viscosity and other operating parameters. It is collected from the bottom of the furnace and flows into a water quench where it is cooled. The slag then is transported by a submerged conveyor to drums for landfill disposal.

A venturi wet scrubber is used for particulate collection in the flue gas. The scrubber water *normally consists of fly ash suspended in water. However, when limestone is injected into the* combustor with coal, unreacted limestone and lime also are suspended in the scrubber water. The scrubber water and solids are directly discharged into a sanitary sewer according to a permit issued by the Williamsport Sanitary Authority.

Streams selected for sampling include the slag, the slag quench water, the scrubber water, and samples of the inlet water supply and coal supply. The slag was selected because it will be disposed in a landfill, and permitting problems may arise if the waste has not been fully characterized. The slag quench water was selected to determine the concentration of substances which may leach into the water while the slag is being cooled. There is one in-line sampling tee for extracting water samples prior to sewer disposal. This scrubber water was separated into two streams by filtering the scrubber water to obtain the scrubber solids and the filtered water. Finally, inlet water and coal samples were taken for comparison purposes. The inlet water must be characterized to determine the extent to which constituents in the slag quench water and the scrubber water can be attributed to the combustion process and which were already present in the inlet water. This same procedure was used for the solids by collecting and analyzing the coal being burned and comparing those properties to the measured characteristics of the slag and fly ash.

SAMPLING PROCEDURES

Environmental Resources Management, Inc. (ERM) of Exton, Pennsylvania was subcontracted to conduct the sampling effort. The sampling team was on-site for a two-day period during the second week in February when Coal Tech was conducting operational tests. ERM prepared a sampling plan which is provided in Appendix A. The following subsections provide a description of the sampling methods, the operational data collected and the packing and shipping procedures for delivering samples to the analytical laboratory.

Streams Sampled

As described above, there are six streams from which samples were taken: 1) unburned coal, 2) inlet water, 3) slag, 4) slag quench water, 5) scrubber solids, and 6) scrubber water. During the test run, ERM collected samples from each of these streams for later laboratory analysis. All samples were collected in 500 ml Teflon® bottles and purged with nitrogen to maintain sample integrity. Bulk samples also were taken of the slag and coal. Details of sample collection for each waste stream are provided below.

Inlet water samples were collected from a facility water supply line located upstream of the advanced coal utilization processes. Two water samples were collected each day in 500 ml Teflon® bottles. The bottles were purged with nitrogen to prepare for shipment. Each sample was collected, 100 ml at a time, in 15-minute intervals.

Solid slag samples were collected in both small analytical samples and a large bulk sample of 175 pounds (79.5 kg). For the analytical samples, approximately 3 pounds (1.4 kg) of slag was collected, thoroughly mixed, and then equally divided into two 500 ml Teflon® bottles. Two analytical samples were collected each day of the sampling effort. The bulk sample was collected over a two-day period in triple layered trash bags inside two large 80-quart (75.7 l) coolers.

Samples of the water from the slag quench tank were collected with a stainless steel ladle. Ladle samples of about 100 ml were taken at 15-minute intervals and transferred into two 500 ml bottles. Sampling continued until both bottles were filled. The bottles were then capped, purged with nitrogen, and labeled for shipping. A second set of two 500 ml bottles was collected the second day of sampling.

Waste from the scrubber, which is typically fly ash suspended in water, was separated into two sample streams. Coarse (20 mm) filter paper was used, and one 500 ml bottle of solids was collected each sampling day. Two 500 ml bottles of filtrate were collected each day. All of the jars were purged with nitrogen and labeled appropriately.

A coal sample was collected the first day of sampling. A five gallon (18.9 l) bucket was filled with coal by the coal supplier and sealed by ERM personnel. The coal is supplied to Coal Tech in a pre-pulverized form.

Operation Data

Operating data for key parameters also were collected during the test program. The parameters measured included slag flow rate, scrubber water flow rate, boiler load, boiler steam pressure, boiler steam temperature, and oxygen and carbon monoxide levels in the exhaust gas. Data were collected hourly throughout the sampling process. Appendix B provides the table of data collected during sampling. Some of the other parameters listed on the table could not be completed due to the confidential nature of the demonstration.

Sample Shipment

Samples were shipped via Federal Express to the University of North Dakota Energy Research Center for analysis. The analytical samples comprising 18 500 ml Teflon® bottles were packed into a large 80 quart (75.7 l) cooler. The samples were surrounded with ice packs and vermiculite to maintain the temperature at 4°C. Two other 80-quart (75.7 l) coolers were used to ship the slag samples which were also shipped on ice. The coal was sent in a 5-gallon (18.9 l) bucket. The chain of custody reports and shipping reports (traffic reports) are provided in Appendix C.

SAMPLE ANALYSIS

The samples obtained from the Coal Tech slagging cyclone combustor are being analyzed at University of North Dakota Energy Research Center. A comprehensive set of physical and chemical tests are being conducted on these samples. These are presented in the form of flow charts in Figures 2 and 3, respectively. Figure 4 provides more details of the ASTM Water Extraction method listed in Figure 3 as one of the chemical characterization test to be conducted. In addition, testing will include the standard RCRA hazardous classification tests and qualitative tests for organics.

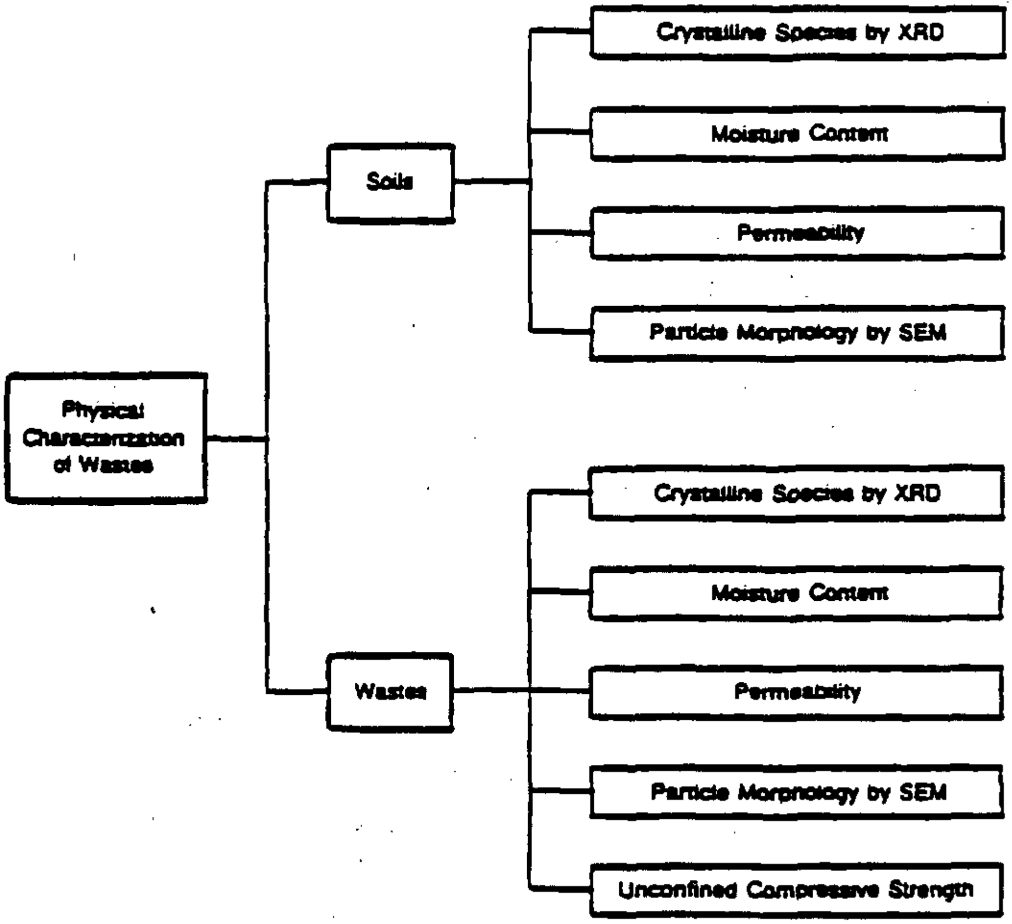
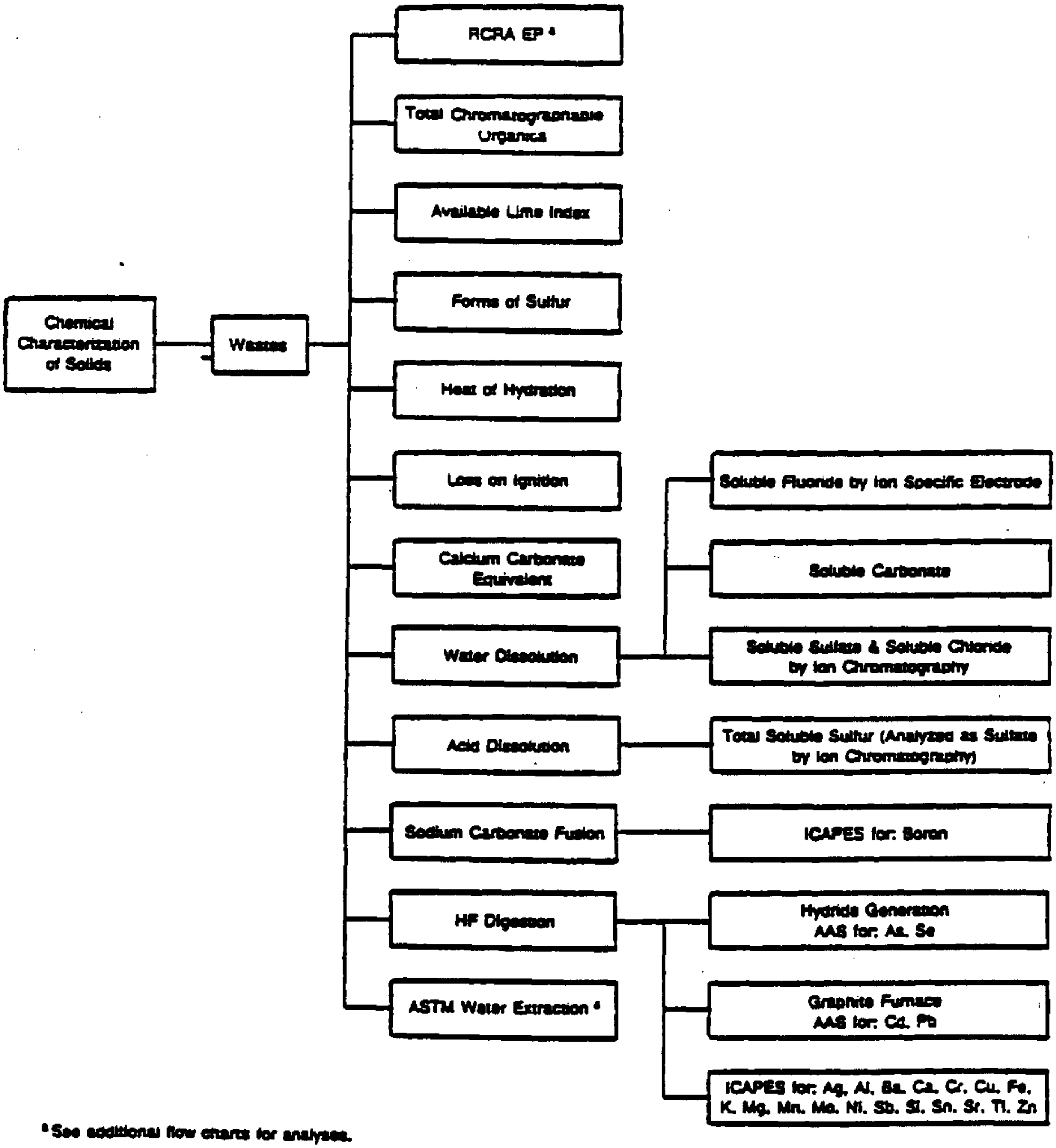
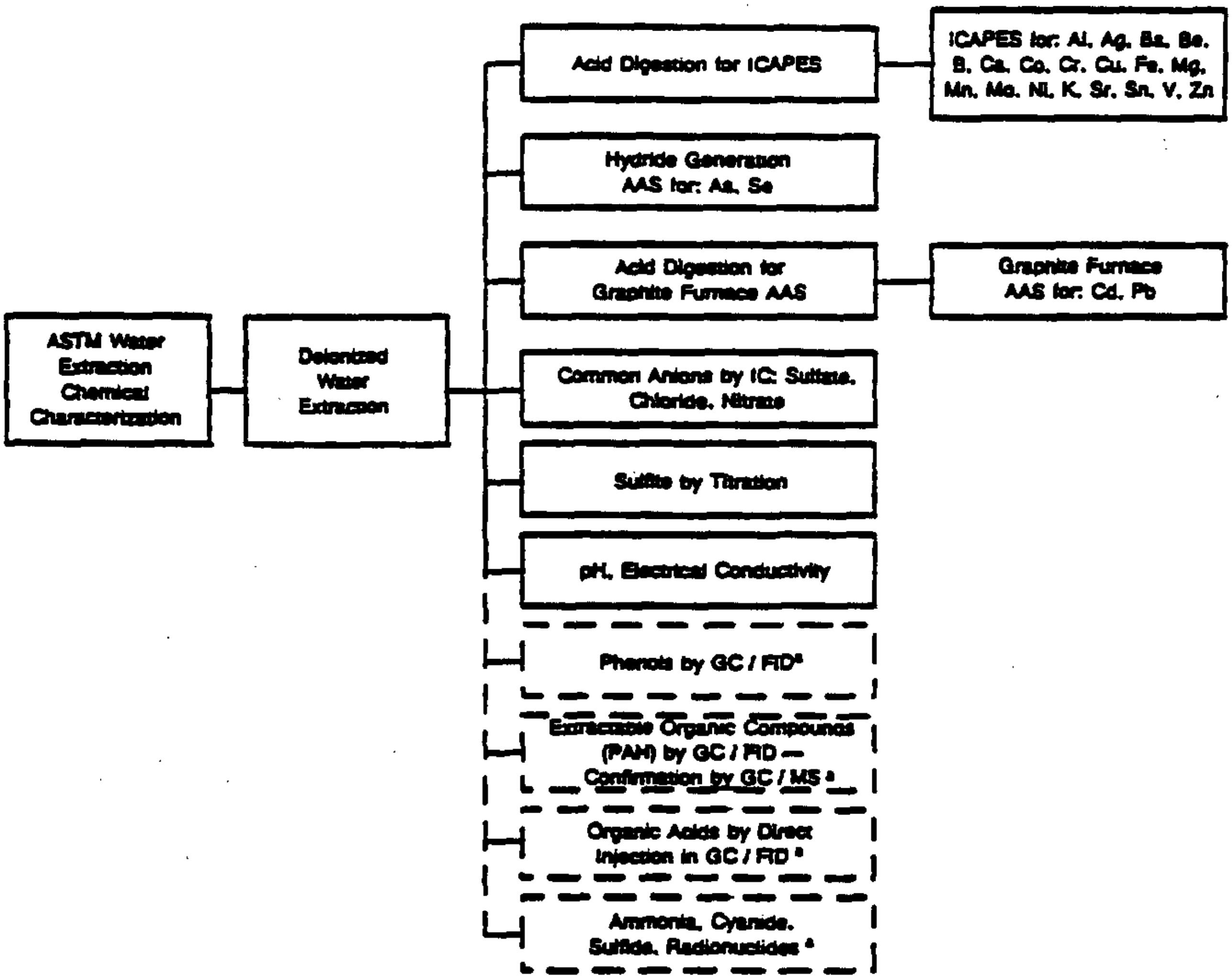


Figure 2. Flow Chart for Physical Characterization



[a] See additional flow charts for analyses.

Figure 3. Flow Chart for Chemical Characterization



[a] Only the initial waste leachate will be analyzed for these parameters. Subsequent analyses will include only those parameters determined to be present in the waste.

Figure 4. Flow Chart for ASTM Water Extraction Chemical Characterization

APPENDIX A

EER - COAL TECH CORP.
COAL SLAG & WASTE WATER SAMPLING
W.O.# 972.01.00.01

FEBRUARY 1990

Background

The U.S. Department Of Energy (DOE) is conducting a survey/evaluation of alternative coal burning technologies around the country. As part of that program, the DOE contracted The Energy and Environmental Research Corporation (EER) to sample the waste products from five of the most promising alternative coal technology systems. EER has sub-contracted Environmental Resources Management, Inc. (ERM) to do this sampling at the one site in Williamsport, PA. The coal burning pilot plant is being run by Coal Tech Corp., on the plant property of the Keeler/Dorr-Oliver company. The technology being demonstrated is called a Slagging Cyclone Combustor.

Coal Tech Corp. will be conducting a test run for one week - probably the second full week in February. During this test run, ERM will take analytical samples from the coal slag, the 'raw' inlet water, the quench water, and the fly ash scrubber water, and send them to the University Of North Dakota Environmental Research Center (UNDERC) for analysis. ERM will also collect a bulk sample of the slag, and of the fly ash water for further testing at the UNDERC. ERM must also record many operating condition data during the sampling event, and report them to EER. A brief final report of the field work will also be completed and sent to EER.

Directions

It takes approximately three hours to get to the Coal Tech site from the ERM warehouse. From the warehouse, take Rt. 202 N. to Rt. 100 N. to the PA Turnpike, heading West. Get off the Turnpike at Exit 19 - "Harrisburg East". Follow the signs for Rts. 322 & 22 West - toward "State College". Follow 22 & 322 across the Susquehanna River. Within a mile after crossing the river, get onto Rts. 11 & 15, headed North – toward Sellinsgrove. A few miles North of Sellinsgrove, Rts. 11 & 15 split. Continue following Rt. 15 North, all the way into Williamsport. **Note: Do not take the "Downtown Williamsport" exit off of Rt. 15. - <u>Stay on Rt. 15</u>. As you cross the river into Williamsport, you will see the Keeler/Dorr-Oliver plant from the bridge on the left. Follow Rt. 15 to Hepburn Street - now the plant will be on the right. Go to the left side of the front of the plant, that is where the pilot plant is located. Look for a smallish building with three small stacks on top of it.

Pre-Sampling

Call Dr. Bert Zauderer at (717) 326 - 3361 ext. 5156 at the Williamstown site the day before the sampling is scheduled to begin. Make certain that the process is up and running, and that Dr. Zauderer is aware that we will be there to sample. You must have a signed copy of the Nondisclosure Agreement before Dr. Zauderer will answer any questions, or give you any help.

Call Frank Beaver at (701) 777 - 2869 at the Univ. Of North Dakota. He is our lab contact, and needs to be notified when the sampling is taking place, so that he can be prepared to receive the samples.

Sampling

There are four locations at the plant, from which samples will be taken. The 'solid' slag sample will be taken off the conveyor belt that brings it out from under the coal furnace, through the quench water. The quench water will be sampled directly from the pool into which the hot slag falls, under the coal furnace. The fly ash scrubber sample will be taken from a tap located outside the furnace building, next to the main plant building right next door. A 'solid' flyash sample will also be collected from that sampling location. The last sample will be a raw water sample taken from somewhere in the plant, before the water enters any of the coal processes.

Each of the four locations will be sampled for the analytical parameters at two different times during the day, when the operating data are all about the same. Each sample will be collected in duplicate 500 ml. volumes. One bulk slag sample will be composited over a six hour period, for a total of 100 pounds. A bulk sample of the fly ash will be collected by periodically be taking and filtering the fly ash water over a six hour period, and the resulting flyash filtered out of the water will be composited, for a total of 500 ml. of solid sample.

Equipment

Reserve the necessary equipment, listed below, with Dieter at the warehouse as early before the sampling event as possible.

Coolers/ Ice packs
S/S ladle w/ extension handle & spoons
Paper towels
Bottle labels & pens
Nitrile gloves
Hardhats
Ear plugs
Liquid soap & other decon solutions
First Aid kit
Scale - to weigh samples
Tools - Knife
Traffic Reports & COC's
Flash light
Vermiculite & other packing supplies
Cooler custody seals
Stainless steel spatulas

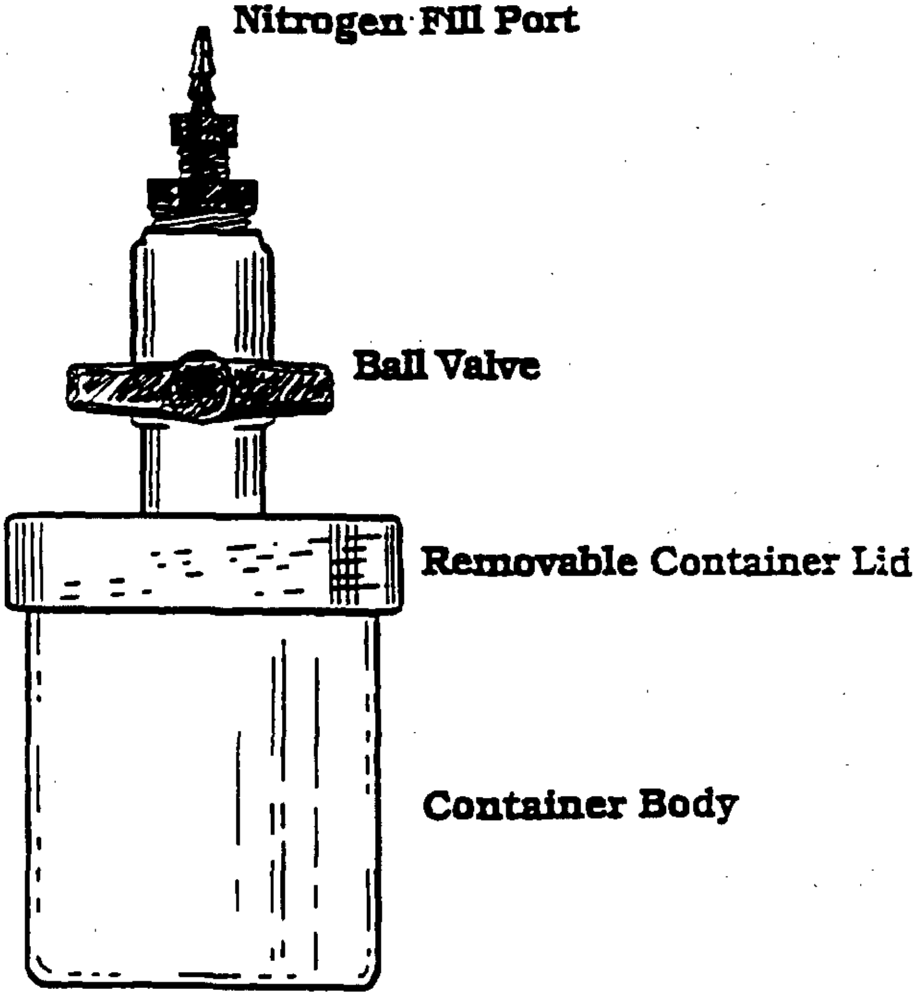
Special sample jars (Teflon®)
Plastic sheeting
Trash bags
Surgical gloves
Cloth gloves
Safety glasses
Scrub bucket & brush
Distilled water
Fire extinguisher
Nitrogen tank - for samples
Field book
Sampling and H&S Plans
Bottle overpacks
Fed-X forms
Zip-lock bags
Millipore® filter unit & filters

Bottle List

18 - 500 ml. Teflon® bottles have been specially prepared by Dieter for this project

1 - Large Coleman® cooler will be needed for the bulk sample of the slag, as well as three large trash bags

500 ml Teflon® Sample Container



Sampling Instructions

Operating Condition Data: The information in Table One must be completed each hour during which samples are collected. Ask Dr. Zauderer for help in where to obtain all the necessary information.

Solid Slag: Analytical Sample: Grab four or five ounces every five minutes from the slag conveyor with a stainless steel spoon or scoop. Thereby, approximately three pounds should be collected in about fifty minutes. Place the three pounds of slag onto a new, clean plastic sheet. Fold over the corners of the sheet, and roll the slag back and forth until it is thoroughly mixed. Next, equally divide the slag sample into two 500 ml. Teflon® jars. Follow the attached instructions to purge the jars with Nitrogen, label them, and pack them for shipment to UNDERC. At another time, at least three hours later in the day, when the operating data are similar to those during the first sample, collect a second sample in exactly the same manner as the first.

Solid Slag: Bulk Sample: The rate at which the furnace generates slag will directly determine the rate at which it will be collected for the bulk sample. It may take six, or more, hours to get 100 pounds, even if all of it is collected for the sample. Collect the sample directly off the conveyor belt, into triple layered trash bags inside a large Coleman® cooler. If the flow of slag is higher than anticipated, simply divert the slag into another collection basin, so that you collect between fifteen and twenty pounds of slag per hour. Make certain that the rate at which you collect the sample, and the way you collect it, remain fairly constant throughout the six hour period. Therefore the slag flow rate should be checked and recorded hourly, as should all the other operating condition data.

Having collected the 100 pounds of slag, securely close the plastic bags, use vermiculite, if necessary, seal the cooler with appropriate Chain Of Custody and Traffic Report forms included, and label the cooler for shipment to UNDERC.

Raw Water: Analytical Sample: The raw water will be collected for the analytical samples only. The general protocol for this sample will apply to all the water samples. Wearing surgical gloves, collect 100 milliliters of the water in each 500 ml. bottle from the raw water tap. Do this every fifteen minutes, until the bottles are filled, which will take one hour. Having filled the two 500 ml. Teflon® jars, Follow the attached instructions to purge them with Nitrogen, label them, and pack them for shipment to UNDERC. At another time, at least three hours later in the day, when the operating data are similar to those during the first sample, collect a second sample in exactly the same manner as the first.

Flyash Residue From Filtered Scrubber Water: Bulk Sample: Over a six hour period, we need to collect approximately 500 ml. of filtered flyash. It must be determined in the field how often, and how much of the flyash discharge water needs to be collected and filtered in order to collect the required amount. Using the course (20 µm) filter paper, throughout the collection of the composite water, filter enough water through the Millipore® filtration apparatus to collect at least 500 ml. of solids, over the six hour period. Carefully remove the filtered solids from the filter paper, scraping them into one of the specially made 500 ml. sample containers, being careful not to include any of the filter paper in the sample. After filling one jar with flyash, follow the attached instructions to purge it with Nitrogen, label it and pack it for shipment to UNDERC.

Flyash Scrubber Water: Analytical Sample: For the flyash water analytical sample, split volumes between two 500 ml. Teflon® jars. Collect and filter 200 ml.of the flyash water every fifteen minutes, and split the filtered volume between the two Teflon® jars. Having filled the jars in approximately one hour, follow the attached instructions to purge the jars with Nitrogen, label them, and pack them for shipment to UNDERC. At least three hours later, under similar operating conditions as the first sample, collect a second sample in exactly the same manner as the first.

Quench Water: Analytical Sample: The quench water, through which the slag travels in order to cool, will be collected only for the analytical samples. Using a stainless steel ladle, with a five foot extension handle, carefully collect 200 milliliters of the water every fifteen minutes. Placing 100 ml. into each container will fill the two 500 ml. Teflon® jars in one hour. Having filled the jars, follow the attached instructions to purge them with Nitrogen, and then label and pack them for shipment to UNDERC. At another time, at least three hours later in the day, when the operating data are similar to those during the first sample, collect a second sample in exactly the same manner as the first. If you cannot get a direct reading of the quench water flow rate, approximate it from the discharge port, or in some other way. Record that flow rate, as well as all the other operating condition data, once an hour

Nitrogen Purging, Labelling And Packing Instructions

All samples collected into the specially made 500 ml. Teflon® jars must be purged with Nitrogen as soon after sample collection is completed as possible. This is done by attaching the hose from the Nitrogen tank to the specially fitted port on top of the sample container. With the lid loosely held on the jar, and the ball valve below the gas fill port open, start a light flow of gas into the jar, holding the lid so that the air in the jar can escape, and be replaced by the Nitrogen. After letting gas flow over the sample for several seconds, begin screwing the lid onto the jar, and <u>simultaneously</u> turn off the gas flow. Be very careful not to overfill or damage the jar with excessive gas pressure. Close the ball valve below the gas fill port, and then remove the Nitrogen fill line from the top of the jar.

Next, label the jar with the project name and number, the sample location, ERM Traffic Report number, date and time of sample location, initials of the samplers, and be sure to note whether it is an analytical or bulk sample.

Place the jar inside a ziplock bag, and then that inside the protective four inch PVC sleeve. Place the entire unit into the cooler, and keep it cool with ice packs until all the samples are collected, and the whole cooler is ready to be packed for shipment to UNDERC.

When packing the cooler, remove the ice packs, and place enough vermiculite around the bottles to make certain that they are unable to shift or move during transport. Pack vermiculite across the top of the containers, leaving enough room to replace one layer of ice packs. After including the ice packs, pack any remaining space with vermiculite, and make sure that nothing can shift during shipment. Seal the Traffic Report and Chain Of Custody forms inside the cooler, with the corresponding samples. Sign at least two ERM Custody Seals and use them and clear packing tape to seal the cooler. Attach the Federal Express forms and a mailing label to the top of the cooler, along with 'Fragile' and 'Handle With Care' stickers. The cooler should then be ready to be taken to the Federal Express office.

QA/QC

For each analytical sample and bulk sample, an ERM Traffic Report must be filled out, in order to help in the tracking of the samples. List the analytical samples as "Analytical Samples", and list the others as "Bulk Samples". Chain Of Custody must also be maintained and filled out for the samples. List the bulk samples on separate COC forms, but you may put all the analytical samples on the same COC form.

There are no travel blanks, nor any other QA samples to be submitted with these samples. There is also no data package to request.

Shipping

All samples will be shipped, appropriately packed (see attached instructions) in Coleman® coolers, via Federal Express to the following shipping address:

University Of North Dakota

Energy And Environmental Research Center

15 North 23rd St.

Grand Forks, ND 58201

Attn: ~~Frank Beaver~~ (701) 777-2869

The nearest Federal Express office is located at:

415 Airport Rd., Montoursville, PA

You will have to drop off the samples at that Federal Express location. Directions:

Take I-180 South or East to the Montoursville exit. Follow the signs to Airport Rd. Fed-X is supposed to be 1/4 mile down Airport Rd.

ERM's Fed-X account #: 1288-9719-4 ERM Warehouse 208 Carter Dr., Unit 17A, West Chester, PA 19382 . (215) 430 - 0632.

Decontamination

Because most samples are being collected directly into the sample containers, there is very little equipment that needs to be deconned. In fact, the only item needing cleaned before sampling, and between the two sets of samples will be the ladle for the quench water analytical sample. Thoroughly decon the ladle with a soap scrub, tap water rinse, 10% nitric acid rinse, DI water rinse, methanol rinse, DI rinse, acetone rinse, DI rinse, and then let it air dry. Rinse it once more with DI water before beginning any sampling.

Special Considerations

Because we are sampling during a test run at a pilot plant, please try not to interfere or bother the site personnel too much. Also, since this is a test run, various hazardous situations may arise. Keep alert, and always be ready to get out of way of the site personnel, whenever necessary.

There is quite a bit of noise inside the boiler building, so it is recommended that hearing protection be worn. Be careful of hot slag and quench water as you are sampling, or working near it. Safety glasses and hard hats are required to be worn whenever you are inside the boiler building. Use clear glasses; it is fairly dark inside the building.

Contact Personnel

Frank Holmes - ERM - (215) 524 - 3523

Chris S. Goss - ERM - (215) 430 - 6219

Al Funk - ERM - (215) 524 - 3514

Dr. Zauderer - Coal Tech - (215) 667 - 0442
Williamsport Site - (717) 326 - 3361 Ext. 5156

Sue Agrawal - EER - (919) 489 - 1726

Jerry Harness - DOE - (304) 291 - 4835

Frank Beaver - Lab contact - (701) 777 - 2869

TABLE ONE

OPERATING CONDITION DATA

This table must be completed hourly, during sample collection

PARAMETER TIME									
Coal flow rate									
Limestone flow rate									
Slag flow rate									
Scrubber water flow rate - in									
Scrubber water flow rate - out									
Boiler load									
Boiler temperature									
Boiler pressure									
Excess air									
Flue gas flow rate									
Inlet temperature of scrubber									
Exit temperature of scrubber									
Quench water flow rate									
Slag description									

APPENDIX B

TABLE ONE

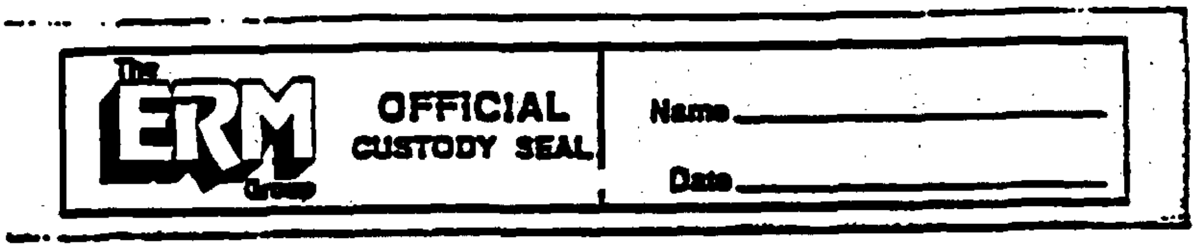
OPERATING CONDITION DATA

2/14/90

This table must be completed hourly, during sample collection 2/13/90

PARAMETER TIME	1130	1225	1335	1430	1530	1630	1215	1300	1315
Coal flow rate - later									
Limestone flow rate									
Slag flow rate	~1/2 lb/mn	~1/2 lb/mn	~1/2 lb/mn	~1/2 lb/mn	~1/3 lb/mn	~1/4 lb/mn	minimal	~1/2 lb/min	~1/4 lb/min
Scrubber water flow rate - in ✓	~28 gpm	~27 gpm	~27 1/2 gpm	~28 gpm	~28 gpm	~27.5 gpm	N/D	27 1/2 gpm	~27 gpm
Scrubber water flow rate - out									
Boiler load (Steam Flow) ✓	12,000 ~~545~~ PPH	12,000	13,500 PPH	13,250	13,000 PPH	13,750 PPH	13000 PPH	15,000 PPH	15,000 PPH
Boiler temperature Sat T									
Steam Boiler pressure ✓	60 psig	60	61	61	60	60	60	60	60
Excess air	✓ CO-2585 Oxy-5.3%	Oxy-7.6%	STemp: 512F Oxy-7.8%	STemp: 512°F Oxy-6.2%	STemp: 509 Oxy-9.3%	STemp: 508 Oxy: 9.2%	CO: 34 ppm Oxy: 5.2%	CO: 169 ppm Oxy: 3.4%	STemp: 545°F Oxy: 7.9%
Flue gas flow rate									
Inlet temperature of scrubber									
Exit temperature of scrubber									
Quench water flow rate									
Slag description									

ERM CUSTODY SEAL



The ERM Group

OFFICIAL
CUSTODY SEAL

Name ____________________

Date ____________________

ERM TRAFFIC REPORT FORM

ERM

Traffic Report

1 Project W.O.

Project Name/Location

2 Sample Concentration

☐ Low Concentration

☐ Medium Concentration

5425

3 Ship to:

+ Attn:

4 Sample Matrix

☐ Liquid ☐ Solid

☐ Other

5 Sampling Personnel Contact

Sampler

Project Manager

Phone No. (215) 524-3500

6 Shipping Information

(Name of Carrier)

(Date Shipped)

(Airbill Number)

7 Specify Type of Analyses, Number of Containers, Approx. Volume

Analyses / Method Requested	No. of Bottles	Total Volume

8 Sample Location

Date:

Time:

9 Sample Description

☐ Surface Water ☐ Soil

☐ Ground Water ☐ Solid

☐ Leachate ☐ Other:

☐ Sediment

10 Special Handling (e.g. Safety Procedures/Hazardous)

Additional comments: (Specify [illegible])

11 Condition of Samples Received (to be completed by Laboratory Log-in.)

☐ Samples received intact

☐ Samples at 4 degrees (C)

☐ Samples not leaking

☐ Container numbers match as specified in item 7

☐ Container tags match Chain of Custody

Log-in Person's Signature

ERM

ERM CHAIN OF CUSTODY RECORD

ERM

Sample Chain of Custody

O No:

Project Name:

mple:

ERM ample umber	Date	Time	COMP	GRAB	Station Location	Number of Containers							Remarks

ample Relinquished by:	Date	Time	Sample Received by:	Date	Time	Reason for Transfer

ERM

US White & Yellow [illegible]

APPENDIX C

Sample Chain of Custody

W.O.No.: —	Project Name: EERI / Coal Tech
Sampler: Chris B. Cross & Charlie B. Salerno	

ERM Sample Number	Date	Time	COMP	GRAB	Station Location	Number of Containers	[illegible]						Remarks
136416	2/13/90	1230	X		Filtered Scrubber Water #1	2	2						Purged w/ Nitrogen / Field Filtered w/ 20 µ filter
21130		1310	X		Raw Water #1	2	2						
21131		1320	X		Quench Water #1	2	2						
21132		1330	X		Coal Slag #1	2	2						
136415	↓	1400	X		Flyash #1	1	1						Field Filtered w/ 20 µ filter
24858	2/14/90	1310	X		Filtered Scrubber Water #2	2	2						" "
24859		1320	X		Raw Water #2	2	2						
24860		1320	X		Quench Water #2	2	2						
24861		1330	X		Coal Slag #2	2	2						
24862	↓	1315	X		Flyash #2	1	1						↓ Field Filtered w/ 20 µ filter

Sample Relinquished by:	Date	Time	Sample Received by:	Date	Time	Reason for Transfer
Chris B. Cross	2/14/90	1600				Shipped To Lab via Federal Express

COPIES: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for files. Pink copy retained by sampler. Gold copy extra copy as needed (warehouse).

The ERM Group

Sample Chain of Custody

W.O.No.:

Project Name: [illegible] Coal Tech

Sampler: Chris [illegible] & Charlie B. [illegible]

ERM Sample Number	Date	Time	COMP	GRAB	Station Location	Number of Containers	[illegible]	[illegible]					Remarks
21133	2/13/90	1500		X	Bulk Raw Coal	1	1						
21134	2/13-14/90	1700	X		Bulk Slag	2		2					

Sample Relinquished by:	Date	Time	Sample Received by:	Date	Time	Reason for Transfer
[illegible] & [illegible]	2/14/90	1500				Shipped To Lab Via Fed Ex

COPIES: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for files. Pink copy retained by sampler. Gold copy extra copy as needed (warehouse).

The ERM Group

Traffic Report

21133

1 Project W.O. —

Project Name/Location

EEC / Coal [illegible]

Williamsport, PA

2 Sample Concentration

☒ Low Concentration

☐ Medium Concentration

3 Ship to:

University of North Dakota

Energy and Environmental Research

Center

Attn: Dr. David [illegible]

4 Sample Matrix

☐ Liquid ☒ Solid

☐ Other

5 Sampling Personnel Contact

Sampler: [illegible]

Project Manager: Frank [illegible]

Phone No. (215) 524-3500

6 Shipping Information

(Name of Carrier) Federal Express

(Date Shipped) 2/14/90

(Airbill Number) —

7 Specify Type of Analyses, Number of Containers, Approx. Volume

Analyses / Method Requested	No. of Bottles	Total Volume
Bulk Sample	1	4 kgs

8 Sample Location

Bulk Raw Coal

Date: 2/13/90 ~~[illegible]~~

Time: 1500

9 Sample Description

☐ Surface Water ☐ Soil

☐ Ground Water ☐ Solid

☐ Leachate ☒ Other: Coal

☐ Sediment (Pulverized)

10 Special Handling (e.g. Safety Procedures/Hazardous)

Additional comments: (Specify data package, rush work, special detection limits, etc.)

11 Condition of Samples Received (to be completed by Laboratory Log-in.)

☐ Samples received intact

☐ Samples at 4 degrees (C)

☐ Samples not leaking

☐ Container numbers match as specified in item 7

☐ Container tags match Chain of Custody

☐ Cooler received with Custody Seals Intact

☐ Samples contained within plastic bags

Log-in Person's Signature

Copies: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for file. Pink copy retained by sampler. Gold copy extra copy as needed (warehouse).

The ERM Group

Traffic Report

21134

1 Project W.O. —

Project Name/Location

EERl Coal Tech

Williamsport, PA

2 Sample Concentration

☒ Low Concentration

☐ Medium Concentration

3 Ship to:

University of North Dakota

Environmental Research

Center Dr. David

Attn: [illegible]

4 Sample Matrix

☐ Liquid ☒ Solid

☐ Other

5 Sampling Personnel Contact

Sampler: [illegible]

Project Manager: Frank Holmes

Phone No. (215) 524-3500

6 Shipping Information

(Name of Carrier) Federal Express

(Date Shipped) 2/14/90

(Airbill Number)

7 Specify Type of Analyses, Number of Containers, Approx. Volume

Analyses / Method Requested	No. of Bottles	Total Volume
Bulk Sample	2 crates	~150 lbs

8 Sample Location

Bulk Slag

Date: 2/14/90-2/15/90

Time: 1700

9 Sample Description

☐ Surface Water ☐ Soil

☐ Ground Water ☐ Solid

☐ Leachate ☒ Other: Coal slag

☐ Sediment

10 Special Handling (e.g. Safety Procedures/Hazardous)

Additional comments: (Specify data package, rush work, special detection limits, etc.)

~~Composited over two days~~

Coal [illegible] - not [illegible]

11 Condition of Samples Received (to be completed by Laboratory Log-In.)

☐ Samples received intact

☐ Samples at 4 degrees (C)

☐ Samples not leaking

☐ Container numbers match as specified in item 7

☐ Container tags match Chain of Custody

☐ Cooler received with Custody Seals intact

☐ Samples contained within plastic bags

Log-In Person's Signature

Copies: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for files. Pink copy retained by sampler. Gold copy extra copy as needed (warehouse).

The ERM Group

Traffic Report

13546

1 Project W.O. —

Project Name/Location

[illegible] Tech

[illegible] PA

2 Sample Concentration

☒ Low Concentration

☐ Medium Concentration

3 Ship to:

[illegible]

Environmental Research

Center

Attn: Dr. David [illegible]

4 Sample Matrix

☒ Liquid ☐ Solid

☐ Other

5 Sampling Personnel Contact

Sampler: [illegible]

Project Manager Frank [illegible]

Phone No. (215) 524-3500

6 Shipping Information

(Name of Carrier) Federal Express

(Date Shipped) [illegible]

(Airbill Number)

7 Specify Type of Analyses, Number of Containers, Approx. Volume

Analyses / Method Requested	No. of Bottles	Total Volume
Analytical Sample	2	1000 ml

8 Sample Location

[illegible]

[illegible] #1

Date: [illegible]

Time: [illegible]

9 Sample Description

☐ Surface Water ☐ Soil

☐ Ground Water ☐ Solid

☐ Leachate ☒ Other: Filtered

☐ Sediment Process Water

10 Special Handling (e.g. Safety Procedures/Hazardous)

Additional comments: (Specify data package, rush work, special detection limits, etc.)

Field filtered w/ 20μ filter.

11 Condition of Samples Received (to be completed by Laboratory Log-in.)

☐ Samples received intact

☐ Samples at 4 degrees (C)

☐ Samples not leaking

☐ Container numbers match as specified in item 7

Log-in Person's Signature

☐ Container tags match Chain of Custody

☐ Cooler received with Custody Seals intact ☐ Samples contained within plastic bags

Copies: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for file. Pink copy retained by sampler. Gold copy extra copy as needed (warehouse).

The ERM Group

Traffic Report

21130

1 Project W.O. —

Project Name/Location
EERI Coal Tech
Williamsport, PA

2 Sample Concentration
☒ Low Concentration
☐ Medium Concentration

3 Ship to:
University OF North Dakota
Environmental Research
Center
Attn: Dr. David Hassett

4 Sample Matrix
☒ Liquid ☐ Solid
☐ Other

5 Sampling Personnel Contact
Sampler: C H Gross, E R Salomon
Project Manager: Frank Holmes
Phone No. (215) 524-3500

6 Shipping Information
(Name of Carrier) Federal Express
(Date Shipped) 2/14/90
(Airbill Number)

7 Specify Type of Analyses, Number of Containers, Approx. Volume

Analyses / Method Requested	No. of Bottles	Total Volume
Analytical Sample	2	1000 ml

8 Sample Location
Raw Water #1

Date: 2/13/90
Time: 1710

9 Sample Description
☐ Surface Water ☐ Soil
☐ Ground Water ☐ Solid
☐ Leachate ☒ Other: City Water
☐ Sediment

10 Special Handling (e.g. Safety Procedures/Hazardous)

Additional comments: (Specify data package, rush work, special detection limits, etc.)

11 Condition of Samples Received (to be completed by Laboratory Log-In.)
☐ Samples received intact
☐ Samples at 4 degrees (C)
☐ Samples not leaking
☐ Container numbers match as specified in item 7
☐ Container tags match Chain of Custody
☐ Cooler received with Custody Seals Intact
☐ Samples contained within plastic bags

Log-in Person's Signature

Copies: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for
retained by sampler. Gold copy extra copy as needed (warehouse).

The ERM Group

Traffic Report

21131

1 Project W.O. —

Project Name/Location

EERI Coal Tech

Williamsport PA

2 Sample Concentration

☒ Low Concentration

☐ Medium Concentration

3 Ship to:

University Of North Dakota
Environmental Research
Center

Attn: Dr. David Hassett

4 Sample Matrix

☒ Liquid ☐ Solid

☐ Other

5 Sampling Personnel Contact

Sampler: CBGoss CBSolomon

Project Manager: Frank Holmes

Phone No. (215) 524-3500

6 Shipping Information

(Name of Carrier) Federal Express

(Date Shipped) 2/14/90

(Airbill Number)

7 Specify Type of Analyses, Number of Containers, Approx. Volume

Analyses / Method Requested	No. of Bottles	Total Volume
Analytical Sample	2	1000 ml

8 Sample Location

Quench Water #1

Date: 2/13/90

Time: 1320

9 Sample Description

☐ Surface Water ☐ Soil

☐ Ground Water ☐ Solid

☐ Leachate ☒ Other:

☐ Sediment Process Water

10 Special Handling (e.g. Safety Procedures/Hazardous)

Additional comments: (Specify data package, rush work, special detection limits, etc.)

11 Condition of Samples Received (to be completed by Laboratory Log-in.)

☐ Samples received intact

☐ Samples at 4 degrees (C)

☐ Samples not leaking

☐ Container numbers match as specified in item 7

Log-in Person's Signature

☐ Container tags match Chain of Custody

☐ Cooler received with Custody Seals Intact

☐ Samples contained within plastic bags

Copies: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for
Pink copy retained by sampler. Gold copy extra copy as needed (warehouse).

The ERM Group

Traffic Report

21132

1 Project W.O. —

Project Name/Location

EER/ Coal Tech

Williamsport, PA

2 Sample Concentration

☒ Low Concentration

☐ Medium Concentration

3 Ship to:

University of North Dakota

Environmental Research Center

Attn: Dr. David Hassett

4 Sample Matrix

☐ Liquid ☒ Solid

☐ Other

5 Sampling Personnel Contact

Sampler: C&Goss CBSolomon

Project Manager: Frank Holmes

Phone No. (215) 524-3500

6 Shipping Information

(Name of Carrier) Federal Express

(Date Shipped) 2/14/90

(Airbill Number)

7 Specify Type of Analyses, Number of Containers, Approx. Volume

Analyses / Method Requested	No. of Bottles	Total Volume
Analytical Sample	2	1000 ml

8 Sample Location

Coal Slag

Date: 2/13/90

Time: 1330

9 Sample Description

☐ Surface Water	☐ Soil
☐ Ground Water	☐ Solid
☐ Leachate	☒ Other: Slag
☐ Sediment	

10 Special Handling (e.g. Safety Procedures/Hazardous)

Additional comments: (Specify data package, rush work, special detection limits, etc.)

11 Condition of Samples Received (to be completed by Laboratory Log-In.)

☐ Samples received intact

☐ Samples at 4 degrees (C)

☐ Samples not leaking

☐ Container numbers match as specified in item 7

☐ Container tags match Chain of Custody

☐ Cooler received with Custody Seals Intact

☐ Samples contained within plastic bags

Log-In Person's Signature

Copies: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for file. Pink copy retained by sampler. Gold copy extra copy as needed (warehouse).

Traffic Report

13645

1 **Project W.O.**

Project Name/Location

EER/Coal Tech

Williamsport, PA

2 **Sample Concentration**

☒ Low Concentration

☐ Medium Concentration

3 **Ship to:**

University of North Dakota

Environmental Research

Center

Attn: Dr. David Hassett

4 **Sample Matrix**

☐ Liquid ☒ Solid

☐ Other

5 **Sampling Personnel Contact**

Sampler: C$Goss + CBielemen

Project Manager: Frank Holmes

Phone No. (215) 524-3500

6 **Shipping Information**

(Name of Carrier) Federal Express

(Date Shipped) 2/14/90

(Airbill Number)

7 **Specify Type of Analyses, Number of Containers, Approx. Volume**

Analyses / Method Requested	No. of Bottles	Total Volume
Analytical Sample	1	500mls.

8 **Sample Location**

Flyash #1

Date: 2/13/90

Time: 1400

9 **Sample Description**

☐ Surface Water ☐ Soil

☐ Ground Water ☐ Solid

☐ Leachate ☒ Other: Filtered Flyash

☐ Sediment

10 **Special Handling (e.g. Safety Procedures/Hazardous)**

Additional comments: (Specify data package, rush work, special detection limits, etc.)

Field filtered w/ 20um filter.

11 **Condition of Samples Received (to be completed by Laboratory Log-In.)**

☐ Samples received intact

☐ Samples at 4 degrees (C)

☐ Samples not leaking

☐ Container numbers match as specified in Item 7

☐ Container tags match Chain of Custody

☐ Cooler received with Custody Seals intact

☐ Samples contained within plastic bags

Log-in Person's Signature

Copies: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for files. Pink copy retained by sampler. Gold copy extra copy as needed (warehouse).

ERM Group

Traffic Report

24858

1 Project W.O.

Project Name/Location

EER / Coal Tech

Williamsport, PA

2 Sample Concentration

☒ Low Concentration

☐ Medium Concentration

3 Ship to:

University of North Dakota

Environmental Research

Center

Attn: Dr. David Hassett

4 Sample Matrix

☒ Liquid ☐ Solid

☐ Other

5 Sampling Personnel Contact

Sampler: CB Salomon, CS Goss

Project Manager: Frank Holmes

Phone No. (215) 524-3500

6 Shipping Information

(Name of Carrier) Federal Express

(Date Shipped) 2/14/90

(Airbill Number)

7 Specify Type of Analyses, Number of Containers, Approx. Volume

Analyses / Method Requested	No. of Bottles	Total Volume
Analytical Sample	2	1000 ml

8 Sample Location

Filtered ~~Flyash~~ CGG Water, #2

Scrubber

Date: 2/14/90

Time: 1310

9 Sample Description

☐ Surface Water ☐ Soil

☐ Ground Water ☐ Solid

☐ Leachate ☒ Other: Filtered

☐ Sediment Process Water

10 Special Handling (e.g. Safety Procedures/Hazardous)

Additional comments: (Specify data package, rush work, special detection limits, etc.)

Field filtered w/ 20μ filter

11 Condition of Samples Received (to be completed by Laboratory Log-In)

☐ Samples received intact

☐ Samples at 4 degrees (C)

☐ Samples not leaking

☐ Container numbers match as specified in item 7

☐ Container tags match Chain of Custody

☐ Cooler received with Custody Seals intact

☐ Samples contained within plastic bags

Log-In Person's Signature

Copies: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for files. Pink copy retained by sampler. Gold copy extra copy as needed (warehouse).

VT-37

ERM

Traffic Report

24860

1 Project W.O.

Project Name/Location

EERI Coal Tech

Williamsport, PA

2 Sample Concentration

☒ Low Concentration

☐ Medium Concentration

3 Ship to:

University of North Dakota

Environmental Research

Center

Attn: Dr. David Hassett

4 Sample Matrix

☑ Liquid ☐ Solid

☐ Other

5 Sampling Personnel Contact

Sampler: C A Goss, C B Solomon

Project Manager: Frank Holmes

Phone No. (215) 524-3500

6 Shipping Information

(Name of Carrier) Federal Express

(Date Shipped) 2/14/90

(Airbill Number)

7 Specify Type of Analyses, Number of Containers, Approx. Volume

Analyses / Method Requested	No. of Bottles	Total Volume
Analytical Sample	2	1000 ml

8 Sample Location

Quench Water #2

Date: 2/14/90

Time: 1320

9 Sample Description

☐ Surface Water ☐ Soil

☐ Ground Water ☐ Solid

☐ Leachate ☒ Other: Process Water

☐ Sediment

10 Special Handling (e.g. Safety Procedures/Hazardous)

Additional comments: (Specify data package, rush work, special detection limits, etc.)

11 Condition of Samples Received (to be completed by Laboratory Log-in.)

☐ Samples received intact

☐ Samples at 4 degrees (C)

☐ Samples not leaking

☐ Container numbers match as specified in item 7

☐ Container tags match Chain of Custody

☐ Cooler received with Custody Seals intact

☐ Samples contained within plastic bags

Log-in Person's Signature

Copies: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for files. Pink copy retained by sampler. Gold copy extra copy as needed (warehouse).

ERM Group

Traffic Report

24861

1 Project W.O.

Project Name/Location
EER/ Coal Tech

2 Sample Concentration
☒ Low Concentration
☐ Medium Concentration

3 Ship to:
University of North Dakota
Environmental Research
Center
Attn: Dr. David Hassett

4 Sample Matrix
☐ Liquid ☒ Solid
☐ Other

5 Sampling Personnel Contact
Sampler: C&Goss, CBSolomon
Project Manager: Frank Holmes
Phone No. (215) 524-3500

6 Shipping Information
(Name of Carrier) Federal Express
(Date Shipped) 2/14/90
(Airbill Number)

7 Specify Type of Analyses, Number of Containers, Approx. Volume

Analyses / Method Requested	No. of Bottles	Total Volume
Analytical Sample	2	1000 ml

8 Sample Location
Coal Slag #2

Date: 2/14/90
Time: 1330

9 Sample Description
☐ Surface Water ☐ Soil
☐ Ground Water ☒ Solid
☐ Leachate ☒ Other: Coal slag
☐ Sediment

10 Special Handling (e.g. Safety Procedures/Hazardous)

Additional comments: (Specify data package, rush work, special detection limits, etc.)

11 Condition of Samples Received (to be completed by Laboratory Log-in.)
☐ Samples received intact
☐ Samples at 4 degrees (C)
☐ Samples not leaking
☐ Container numbers match as specified in item 7
☐ Container tags match Chain of Custody
☐ Cooler received with Custody Seals Intact
☐ Samples contained within plastic bags

Log-In Person's Signature
____

Copies: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for files. Pink copy retained by sampler. Gold copy extra copy as needed (warehouse).

Traffic Report

24862

1 Project W.O.

Project Name/Location

EER/Coal Tech

Williamsport PA

2 Sample Concentration

☒ Low Concentration

☐ Medium Concentration

3 Ship to:

University of North Dakota
Environmental Research
Center

Attn: D. David Hassett

4 Sample Matrix

☐ Liquid ☒ Solid

☐ Other

5 Sampling Personnel Contact

Sampler: C&Goss CBSalomon

Project Manager: Frank Holmes

Phone No. (215) 524-3500

6 Shipping Information

(Name of Carrier) Federal Express

(Date Shipped) 2/14/90

(Airbill Number)

7 Specify Type of Analyses, Number of Containers, Approx. Volume

Analyses / Method Requested	No. of Bottles	Total Volume
Analytical Sample	1	500ml

8 Sample Location

Fly ash #2

Date: 2/14/90

Time: 1315

9 Sample Description

☐ Surface Water ☐ Soil

☐ Ground Water ☒ Solid

☐ Leachate ☒ Other:

☐ Sediment Flyash

10 Special Handling (e.g. Safety Procedures/Hazardous)

Additional comments: (Specify data package, rush work, special detection limits, etc.)

Filtered w/ 20μ Filter

11 Condition of Samples Received (to be completed by Laboratory Log-In.)

☐ Samples received intact

☐ Samples at 4 degrees (C)

☐ Samples not leaking

☐ Container numbers match as specified in item 7

☐ Container tags match Chain of Custody

☐ Cooler received with Custody Seals intact

☐ Samples contained within plastic bags

Log-In Person's Signature

Copies: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for files. Pink copy retained by sampler. Gold copy extra copy as needed (warehouse).

INORGANIC ANALYSES

Water Samples 9154-01, 9154-02, and 9154-03

Coal Slag 9255-01 and Fly Ash 9255-02

Clean Coal Technology Samples Received February 14, 1990

Samples were received packed with ice, in nitrogen purged teflon containers on February 14, 1990. This method of storage and shipping is acceptable for the inorganic parameters requested. A copy of the sample chain of custody received with this set of samples is attached (Attachment 1). The samples received are detailed on this attachment. Four containers of each water sample and two containers of each solid material were received. The materials were sampled on consecutive days with two containers of the water samples and one container of the solid materials taken each day. Before beginning the analyses on these samples, the appropriate samples were combined resulting in a set of five samples for organic and inorganic analyses. An aliquot of each of the original samples has been retained in our laboratory for future reference. The combined samples, two solid samples and three water samples, were analyzed for the requested parameters listed in Attachment 2. It should be noted that the solid materials appeared wet on initial observation, but although visually the liquid appeared to be a significant amount, no water could be separated physically from the solid by the technique described in the TCLP sample preparation procedure. The analytical results on the combined samples are listed on Attachment 3.

The leaching procedures used on the combined solid materials were the Toxic Characteristic Leaching Procedure (TCLP) which has recently become the official regulatory leaching procedure required for hazardousness characterization of solid materials, and the Synthetic Groundwater Leaching Procedure (SGLP), developed as a supplementary and comparable leaching procedure applicable to monofill disposal sites. The official protocol for the TCLP leaching was followed. The SGLP utilized the same general protocol as the TCLP with distilled water substituted for the acetate buffer used in the TCLP.

The important phenomena to note in the inorganic analytical data from leaching tests are the differences between the TCLP and the SGLP results. Arsenic, selenium, boron, barium, chromium, and lead were apparently present in the fly ash in acid soluble phases, thus producing higher solution concentrations in the TCLP test which utilizes acetic acid in the leaching solution. The coal slag leached greater amounts of barium and chromium in the TCLP test. The higher solution concentrations of select trace elements are not always the case with the acidic test in comparison with an alkaline leaching. The ultimate leaching solution concentrations depend on phase locations of trace elements and can differ greatly in different types of coal ash. These leaching data strongly indicate the need for the use of leaching tests appropriate for prediction of leachate quality. Although these data would tend to support the use of the TCLP as a worst case scenario this is not always the case.

None of the wastes contained concentrations of regulated elements high enough to be considered hazardous.

The wastes were also non-ignitable.

Leachage Analysis
EER/Coal Tech
TCLP and SGLP Leachates

Sample ID	Coal Slag SGLP Leachate	Coal Slag TCLP Leachate	Fly Ash SGLP Leachate	Fly Ash TCLP Leachate
Lab Number	39122	39122	39123	39123
Parameter				
Arsenic ug/l	<2	<2	4.5	172
Barium	<.02	.08	.43	.22
Cadmium	<.02	<.02	<.02	<.02
Chromium	<.02	.49	.04	.25
Lead ug/l	<10	<10	<10	<10
Mercury ug/l	<3	<3	<3	<3
Selenium ug/l	<2	<2	3.0	82
Silver ug/l	<1	<1	<1	<1
Molybdenum	.04	.03	.10	.06
Boron	<.05	<.05	<.05	1.2
Final pH	9.99	4.95	12.07	4.84

* all values are mg/L unless otherwise noted

Liquid Analysis
EER/Coal Tech

Sample ID	Quench H_2O	Raw H_2O	Filtered Scrubber H_2O
Lab Number	39119	39120	39121
Parameter			
Arsenic ug/l	<2	<2	2.2
Barium	0.03	0.03	0.10
Cadmium	<0.02	<0.02	<0.02
Chromium	<0.02	<0.02	<0.02
Lead ug/l	<10	<10	<21
Mercury ug/l	<3	<3	<3
Selenium ug/l	<2	<2	56
Silver ug/l	<1	<1	<1
Molybdenum	0.03	0.02	0.12
Boron	<0.5	<0.5	<0.5

* all values are mg/L unless otherwise noted

Solids Analysis
EER/Coal Tech
Analysis from $LiBO_2$ Fusion-All Values Reported as Moisture Free

Sample ID	Coal Slag	Fly Ash
Lab Number	39122	39123
Parameter		
% Moisture	10.40	58.38
% LOI	<.01	40.71
% SO_3	2.76	6.85
% SiO_2	27.7	19.7
% Al_2O_3	22.5	11.8
% Fe_2O_3	22.2	3.8
% CaO	23.9	13.3
% Mgo	1.4	0.5
% Na_2O	0.1	0.1
% K_2O	0.2	0.8
CN^- ppm/sec.	.0022	.00004
H_2S ppm/sec.	.072	.00057

* all values are mg/L unless otherwise noted

Solids Analysis
EER/Coal Tech
AR/HF Digestion-All Values Reported in ug/g

Sample ID	Coal Slag	Fly Ash
Lab Number	39122	39123
Parameter		
Arsenic	50.1	2.1
Barium	227	307
Cadmium	7.3	13.8
Chromium	147	10,720
Lead	47.3	<2
Mercury	<.6	<.6
Selenium	10.1	1.4
Silver	.24	<.2
Molybdenum	206	379
Boron	428	538

* all values are mg/L unless otherwise noted

ORGANIC ANALYSES, April, 1990

Water Samples 9154-01, 9154-02, and 9154-03

Coal Slag 9255-01 and Fly Ash 9255-02

Summary

The coal slag, fly ash, and each of the water samples were extracted and analyzed for the target compounds by a contract lab and by the GC/MS lab at EERC. None of the samples had significant concentrations of the target-list analytes (provided by Jerry Harness). Additionally, a broad-spectrum organic analysis also showed only trace concentrations of target list and non-target organics. Detection limits for the analyses were typically 0.1 to 10 ppb (ug/L or mg/kg) or less for the test compounds.

Approach

Each sample was analyzed according to the protocol described in the memorandum from Frank Beaver to Jerry Harness dated 4-11-90. Contract lab analyses were performed according to EPA methods SW-846 8240 (for the volatiles from liquids and solids), method 625 (for the semi- and non-volatiles from the water samples), and method 8270 (for the semi- and non-volatiles from the solids). In order to validate the contract lab results, and also to survey the samples for additional non-target analytes, extracts of the waters were prepared and analyzed at the GC/MS lab at EERC, and the solids extracts from the contract lab were analyzed at our GC/MS lab. Because of the lack of any significant target-list, or non-target species, no additional studies (e.g., leaching) were performed on these samples as outlined in the 4-11-90 memo.

Results

Water Samples:

The results of the contract lab analyses are shown in Attachments I and II. Note that the reported "less than" values are higher than the "Target Detection Limit" values for the semi- and non-volatiles. This was because the water samples that were provided to EERC were too small to achieve the desired detection limits. However, all three samples were essentially free of the target-list organics down to the detection limit concentrations (ca. 1 to 10 ug/L for most species) as shown in Attachment I.

The samples were also not collected and stored properly for volatiles analysis, which could have resulted in the loss of the volatile organics. Thus, the values in Attachment II may be artificially low. However, since all three samples were essentially free from the target list analytes, it is unlikely that they originally contained high concentrations of the volatiles. Only one sample (Raw Water) had significant concentrations of one target-list organic, 8.6 ug/L toluene.

GC/MS analyses of the water samples performed at EERC had detection limits similar to those shown in Attachments I and II. In general, detection limits for non-target analytes would be expected to be ca. 1-5 ug/L. Only a few non-target organics were identified in the samples, and none had concentrations over a few ug/L. Our GC/MS analyses did confirm the toluene found in the Raw Water, and also identified traces (ca. 1 ug/L) of C2-alkylbenzene isomers, as well as very low concentrations of C7 to C9 alkanes (ca. 1 to 3 ug/L). Additional species that might be expected to be present in such waters (e.g., pyridines and other N-heterocycles, thiophenes, furans, benzo- and dibenzofurans, phenols) were not detected.

Coal Slag and Fly Ash:

Both the coal and fly ash samples showed no significant concentrations of the target analytes except for low concentrations of bis (2-ethylhexyl) phthalate (Attachment III for volatiles and Attachment IV for semi- and non-volatiles). Since phthalates are ubiquitous plasticizers, the source of this phthalate ester is almost certainly not the coal slag or fly ash, and it is likely a contaminant. However, it was present at only very low concentrations (< 1 mg/kg), and should not be of concern. No target volatiles were detected (Attachment IV). GC/MS analyses of the extracts failed to detect any of the target-list or non-target species. Detection limits for the GC/MS analyses were estimated at ca. 1 mg/kg (ppb) for most species. As was the case for the water samples, no PAHs or additional species that might be expected to be present in coal waste solids (e.g., pyridines and other N-heterocycles, thiophenes, furans, benzo- and dibenzofurans, phenols) were detected.

interpoll

INTERPOLL LABORATORIES, INC.
4500 BALL ROAD N.E.
CIRCLE PINES, MINNESOTA 55014-1819
TEL: 612 786-6020
FAX: 612-786-7854

ATTACHMENT I

March 26, 1990

University of North Dakota
Energy & Environmental Research Center
P.O. Box 8213, University Station
Grand Forks, North Dakota 58202

Attention: Steven Hawthorne

LABORATORY REPORT: #9154
PURCHASE ORDER: #274259

SAMPLES RECEIVED: March 9, 1990

Sample Identification: Sample Type: Laboratory Log Number: Parameter	Units	Target Detection Limit[1]	Raw Water 9154-01	Quench Water 9154-02	Filtered Scrubber Water 9154-03
EPA Method 625:					
Bis(2-chloroethyl)ether	ug/L	0.40	< 0.80	< 0.80	< 0.80
Phenol	ug/L	4.2	< 8.4	< 8.4	< 8.4
2-Chlorophenol	ug/L	1.2	< 2.4	< 2.4	< 2.4
1,3-Dichlorobenzene	ug/L	1.8	< 3.6	< 3.6	< 3.6
1,4-Dichlorobenzene	ug/L	2.5	< 5.0	< 5.0	< 5.0
1,2-Dichlorobenzene	ug/L	2.1	< 4.2	< 4.2	< 4.2
Bis(2-chloroisopropyl)ether	ug/L	1.4	< 2.8	< 2.8	< 2.8
n-Nitroso-di-n-propylamine	ug/L	2.9	< 5.8	< 5.8	< 5.8
Hexachloroethane	ug/L	1.2	< 2.4	< 2.4	< 2.4
n-Nitroso-dimethylamine	ug/L	14	< 28	< 28	< 28
Nitrobenzene	ug/L	1.4	< 2.8	< 2.8	< 2.8
Isophorone	ug/L	1.1	< 2.2	< 2.2	< 2.2
2-Nitrophenol	ug/L	1.1	< 2.2	< 2.2	< 2.2
2,4-Dimethylphenol	ug/L	3.5	< 7.0	< 7.0	< 7.0
Bis(2-chloroethoxy)methane	ug/L	1.8	< 3.6	< 3.6	< 3.6
2,4-Dichlorophenol	ug/L	2.6	< 5.2	< 5.2	< 5.2
1,2,4-Trichlorobenzene	ug/L	2.4	< 4.8	< 4.8	< 4.8
Naphthalene	ug/L	1.5	< 3.0	< 3.0	< 3.0
Hexachlorobutadiene	ug/L	2.9	< 5.8	< 5.8	< 5.8
4-Chloro-3-methylphenol	ug/L	2.4	< 4.8	< 4.8	< 4.8
Hexachlorocyclopentadiene	ug/L	2.8	< 5.6	< 5.6	< 5.6

ATTACHMENT I (cont.)

Sample Identification:			Raw	Quench	Filtered Scrubber
Sample Type:			Water	Water	Water
Laboratory Log Number:			9154-01	9154-02	9154-03
Parameter	Units	Target Detection Limit[1]			
EPA Method 625 (continued):					
2,4,6-Trichlorophenol	ug/L	1.9	< 3.8	< 3.8	< 3.8
2-Chloronaphthalene	ug/L	0.51	< 1.0	< 1.0	< 1.0
Acenaphthylene	ug/L	0.87	< 1.7	< 1.7	< 1.7
Acenaphthene	ug/L	1.0	< 2.0	< 2.0	< 2.0
Dimethyl phthalate	ug/L	1.8	< 3.6	< 3.6	< 3.6
2,4-Dinitrotoluene	ug/L	2.6	< 5.2	< 5.2	< 5.2
2,4-Dinitrophenol	ug/L	2.3	< 4.6	< 4.6	< 4.6
4-Nitrophenol	ug/L	2.1	< 4.2	< 4.2	< 4.2
2,6-Dinitrotoluene	ug/L	1.8	< 3.6	< 3.6	< 3.6
Fluorene	ug/L	1.0	< 2.0	< 2.0	< 2.0
4-Chlorophenyl phenyl ether	ug/L	0.40	< 0.80	< 0.80	< 0.80
Diethyl phthalate	ug/L	0.57	< 1.1	< 1.1	< 1.1
1,2-Diphenylhydrazine	ug/L	2.4	< 4.8	< 4.8	< 4.8
4,6-Dinitro-2-methyl phenol	ug/L	2.8	< 5.6	< 5.6	< 5.6
n-Nitroso-diphenylamine	ug/L	0.78	< 1.6	< 1.6	< 1.6
4-Bromophenyl phenyl ether	ug/L	2.6	< 5.2	< 5.2	< 5.2
Hexachlorobenzene	ug/L	1.9	< 3.8	< 3.8	< 3.8
Pentachlorophenol	ug/L	2.8	< 5.6	< 5.6	< 5.6
Phenanthrene	ug/L	0.40	< 0.80	< 0.80	< 0.80
Anthracene	ug/L	0.20	< 0.40	< 0.40	< 0.40
Di-n-butyl phthalate	ug/L	1.4	< 2.8	< 2.8	< 2.8
Fluoranthene	ug/L	1.2	< 2.4	< 2.4	< 2.4
Benzidine	ug/L	14	< 28	< 28	< 28
Pyrene	ug/L	1.5	< 3.0	< 3.0	< 3.0
Butylbenzyl phthalate	ug/L	0.98	< 2.0	< 2.0	< 2.0
3,3'-Dichlorobenzidine	ug/L	6.2	< 12	< 12	< 12
Benzo(a)anthracene	ug/L	1.8	< 3.6	< 3.6	< 3.6
Chrysene	ug/L	0.33	< 0.66	< 0.66	< 0.66
Bis(2-ethylhexyl)phthalate	ug/L	2.5	< 5.0	< 5.0	< 5.0
Di-n-octyl phthalate	ug/L	2.8	< 5.6	< 5.6	< 5.6
Benzo(b)fluoranthene	ug/L	0.99	< 2.0	< 2.0	< 2.0
Benzo(k)fluoranthene	ug/L	1.7	< 3.4	< 3.4	< 3.4
Benzo(a)pyrene	ug/L	0.39	< 0.78	< 0.78	< 0.78
Indeno(1,2,3-cd)pyrene	ug/L	0.90	< 1.8	< 1.8	< 1.8
Dibenzo(a,h)anthracene	ug/L	0.88	< 1.8	< 1.8	< 1.8
Benzo(g,h,i)perylene	ug/L	1.2	< 2.4	< 2.4	< 2.4

ATTACHMENT I (cont.)

Sample Identification:			Raw	Quench	Filtered Scrubber
Sample Type:			Water	Water	Water
Laboratory Log Number:			9154-01	9154-02	9154-03
Parameter	Units	Target Detection Limit			
EPA Method SW-846, 8240:					
Chloromethane	ug/L	3.2	< 3.2	< 3.2	< 3.2
Bromomethane	ug/L	2.1	< 2.1	< 2.1	< 2.1
Vinyl chloride	ug/L	1.6	< 1.6	< 1.6	< 1.6
Chloroethane	ug/L	1.5	< 1.5	< 1.5	< 1.5
Acrolein	ug/L	13	< 13	< 13	< 13
Acrylonitrile	ug/L	4.8	< 4.8	< 4.8	< 4.8
Dichlorodifluoromethane	ug/L	3.2	< 3.2	< 3.2	< 3.2
Methylene chloride	ug/L	4.8	20	20	22
Acetone	ug/L	50	< 50	< 50	< 50
Carbon disulfide	ug/L	1.7	< 1.7	< 1.7	< 1.7
1,1-Dichloroethene	ug/L	1.6	< 1.6	< 1.6	< 1.6
1,1-Dichloroethane	ug/L	1.7	< 1.7	< 1.7	< 1.7
Iodomethane	ug/L	2.0	< 2.0	< 2.0	< 2.0
Dibromomethane	ug/L	1.0	< 1.0	< 1.0	< 1.0
1,4-Dichloro-2-butane	ug/L	1.6	< 1.6	< 1.6	< 1.6
trans-1,2-Dichloroethene	ug/L	1.3	< 1.3	< 1.3	< 1.3
Chloroform	ug/L	1.0	23	5.5	< 1.0
1,2-Dichloroethane	ug/L	1.3	< 1.3	< 1.3	< 1.3
2-Butanone	ug/L	2.4	< 2.4	< 2.4	< 2.4
1,1,1-Trichloroethane	ug/L	2.6	< 2.6	< 2.6	< 2.6
Carbon tetrachloride	ug/L	1.7	< 1.7	< 1.7	< 1.7
Vinyl acetate	ug/L	5.8	< 5.8	< 5.8	< 5.8
Bromodichloromethane	ug/L	1.6	4.2	< 1.6	< 1.6
1,1,2,2-Tetrachloroethane	ug/L	1.5	< 1.5	< 1.5	< 1.5
Ethylmethacrylate	ug/L	3.0	< 3.0	< 3.0	< 3.0
1,2-Dichloropropane	ug/L	1.3	< 1.3	< 1.3	< 1.3
trans-1,3-Dichloropropene	ug/L	1.2	< 1.2	< 1.2	< 1.2
Trichloroethene	ug/L	2.1	< 2.1	< 2.1	< 2.1
Dibromochloromethane	ug/L	7.5	< 7.5	< 7.5	< 7.5
1,1,2-Trichloroethane	ug/L	6.0	< 6.0	< 6.0	< 6.0
Trichlorofluoromethane	ug/L	1.2	< 1.2	< 1.2	< 1.2
1,2,3-Trichloropropane	ug/L	5.3	< 5.3	< 5.3	< 5.3
Benzene	ug/L	1.0	< 1.0	< 1.0	< 1.0
cis-1,3-Dichloropropene	ug/L	4.0	< 4.0	< 4.0	< 4.0
2-Chloroethylvinyl ether	ug/L	2.3	< 2.3	< 2.3	< 2.3
Bromoform	ug/L	2.4	< 2.4	< 2.4	< 2.4
2-Hexanone	ug/L	10	< 10	< 10	< 10

ATTACHMENT II

Sample Identification:			Raw	Quench	Filtered Scrubber
Sample Type:			Water	Water	Water
Laboratory Log Number:			9154-01	9154-02	9154-03
Parameter	Units	Target Detection Limit			
EPA Method SW-846, 8240 (continued):					
4-Methyl-2-pentanone	ug/L	9.1	< 9.1	< 9.1	< 9.1
Tetrachloroethene	ug/L	8.0	< 8.0	< 8.0	< 8.0
Toluene	ug/L	1.0	8.6	< 1.0	< 1.0
Chlorobenzene	ug/L	1.0	< 1.0	< 1.0	< 1.0
Ethylbenzene	ug/L	1.0	< 1.0	< 1.0	< 1.0
Styrene	ug/L	1.0	< 1.0	< 1.0	< 1.0
Total xylenes	ug/L	1.0	< 1.0	< 1.0	< 1.0

Respectfully submitted,

Wayne A. Olson

Wayne A. Olson,
Senior Scientist
Organic Chemistry Department

WAO/cg
Invoice Enclosed
< = less than

[1] The achieved detection limit is higher than the targeted detection limit because the volume of sample submitted for analysis was approximately half that normally analyzed.

All analyses were performed using EPA or other recognized methodologies.
All units are on an "as received" basis unless otherwise indicated.

interpoll

INTERPOLL LABORATORIES, INC.
4500 BALL ROAD N.E.
CIRCLE PINES, MINNESOTA 55014-1819
TEL: 612/786-6020
FAX: 612/786-7854

ATTACHMENT III

April 10, 1990

University of North Dakota
Energy & Environmental Research Center
P.O. Box 8213, University Station
Grand Forks, North Dakota 58202

Attention: David Miller

LABORATORY REPORT: #9255
PURCHASE ORDER: #275281

SAMPLES RECEIVED: March 30, 1990

Sample Type: Laboratory Log Number:			Coal Slag 9255-01	Fly Ash 9255-02
Parameter	Units	Target Detection Limit		
EPA Method SW-846, 8240:				
Acetone	mg/Kg	5.0	< 5.0	< 5.0
2-Butanone	mg/Kg	0.24	< 0.24	< 0.24
Benzene	mg/Kg	0.10	< 0.10	< 0.10
2-Hexanone	mg/Kg	1.0	< 1.0	< 1.0
4-Methyl-2-pentanone	mg/Kg	0.91	< 0.91	< 0.91
Toluene	mg/Kg	0.10	< 0.10	< 0.10
Chlorobenzene	mg/Kg	0.10	< 0.10	< 0.10
Ethylbenzene	mg/Kg	0.10	< 0.10	< 0.10
Styrene	mg/Kg	0.10	< 0.10	< 0.10
Total xylenes	mg/Kg	0.10	< 0.10	< 0.10

ATTACHMENT IV

Sample Type: Laboratory Log Number: Parameter	Units	Target Detection Limit	Coal Slag 9255-01	Fly Ash 9255-02
EPA Method SW-846, 8270:				
Naphthalene	mg/Kg	0.050	< 0.050	< 0.050
2-Chloronaphthalene	mg/Kg	0.017	< 0.017	< 0.017
Acenaphthylene	mg/Kg	0.029	< 0.029	< 0.029
Acenaphthene	mg/Kg	0.033	< 0.033	< 0.033
Fluorene	mg/Kg	0.033	< 0.033	< 0.033
Phenanthrene	mg/Kg	0.013	< 0.013	< 0.013
Anthracene	mg/Kg	0.0067	<0.0067	0.0070
Di-n-butyl phthalate	mg/Kg	0.047	< 0.047	< 0.047
Fluoranthene	mg/Kg	0.040	< 0.040	< 0.040
Pyrene	mg/Kg	0.050	< 0.050	< 0.050
Benzo(a)anthracene	mg/Kg	0.060	< 0.060	< 0.060
Chrysene	mg/Kg	0.011	< 0.011	< 0.011
Bis(2-ethylhexyl)phthalate	mg/Kg	0.083	0.31	0.26
Benzo(b)fluoranthene	mg/Kg	0.033	< 0.033	< 0.033
Benzo(k)fluoranthene	mg/Kg	0.057	< 0.057	< 0.057
Benzo(a)pyrene	mg/Kg	0.013	< 0.013	< 0.013
Indeno(1,2,3-cd)pyrene	mg/Kg	0.030	< 0.030	< 0.030
Dibenzo(a,h)anthracene	mg/Kg	0.029	< 0.029	< 0.029
Benzo(g,h,i)perylene	mg/Kg	0.040	< 0.040	< 0.040

Respectfully submitted,

Wayne Olson

Wayne A. Olson,
Senior Scientist
Organic Chemistry Department

WAO/cg
Invoice Enclosed
< = less than

All analyses were performed using EPA or other recognized methodologies.
All units are on an "as received" basis unless otherwise indicated.

The ERM Group

Sample Chain of Custody

W.O.No.: —					Project Name: EER/ Coal Tech								
Sampler: Chro & Goss + Charlie B. Salomon													
ERM Sample Number	Date	Time	COMP	GRAB	Station Location	Number of Containers	500ml Teflon jar						Remarks
13646	2/13/90	1230	X		Filtered Scrubber Water #1	2	2						Purged w/ Nitrogen \ Field Filtered w/ 20μ filter
21130		1310	X		Raw Water #1	2	2						
71131		1320	X		Quench Water #1	2	2						
71132		1330	x		Coal Slag #1	2	2						
13645		1400	X		Fly ash #1	1	1						Field Filtered w/ 20μ filter
24858	2/14/90	1310	X		Filtered Scrubber Water #2	2	2						" "
24859		1320	X		Raw Water #2	2	2						
24860		1320	X		Quench Water #2	2	2						
24861		1330	x		Coal Slag #2	2	2						
24862		1315	X		Fly ash #2	1	1						Field Filtered w/ 20μ filter

Sample Relinquished by:	Date	Time	Sample Received by:	Date	Time	Reason for Transfer
Chris B Goss	2/14/90	1600	D Harrell	2-15	11 AM	Shipped To Lab via Fed Ex

COPIES: White & Yellow copies accompany sample shipment to Laboratory. Yellow copy retained by Laboratory. White copy to be returned to ERM [illegible] copy retained by sampler. Gold copy extra copy as needed (warehouse)

The ERM Group

Traffic Report

24862

1 **Project W.O.**

Project Name/Location

EER/ Coal Tech

Williamsport, PA

2 **Sample Concentration**

☒ Low Concentration

☐ Medium Concentration

3 **Ship to:**

University of North Dakota
Environmental Research
Center
Attn: Dr. David Hassett

4 **Sample Matrix**

☐ Liquid ☒ Solid

☐ Other

5 **Sampling Personnel Contact**

Sampler: CB Goss, CB Salomon

Project Manager: Frank Holmes

Phone No. (215) 524-3500

6 **Shipping Information**

(Name of Carrier) Federal Express

(Date Shipped) 2/14/90

(Airbill Number)

7 **Specify Type of Analyses, Number of Containers, Approx. Volume**

Analyses / Method Requested	No. of Bottles	Total Volume
Analytical Sample	1	500ml

8 **Sample Location**

Fly ash #2

Date: 2/14/90

Time: 1315

9 **Sample Description**

☐ Surface Water	☐ Soil
☐ Ground Water	☒ Solid
☐ Leachate	☒ Other:
☐ Sediment	Flyash

10 **Special Handling (e.g. Safety Procedures/Hazardous)**

Additional comments: (Specify data package, rush work, special detection limits, etc.)

Filtered w/ 20µ filter

11 **Condition of Samples Received (to be completed by Laboratory Log-In.)**

☑ Samples received intact

☑ Samples at 4 degrees (C)

☑ Samples not leaking

☑ Container numbers match as specified in Item 7

☑ Container tags match Chain of Custody

☑ Cooler received with Custody Seals intact

☑ Samples contained within plastic bags

Log-In Person's Signature

D Hassett

Copies: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for files. Pink copy retained by sampler. Gold copy extra copy as needed (warehouse).

The ERM Group

Traffic Report

24361

1 Project W.O.

Project Name/Location

EER/ Coal Tech

2 Sample Concentration

☒ Low Concentration

☐ Medium Concentration

3 Ship to:

University Of North Dakota
Environmental Research
Center
Attn: Dr. David Hassett

4 Sample Matrix

☐ Liquid ☒ Solid

☐ Other

5 Sampling Personnel Contact

Sampler: CBGoss, CBSalomon

Project Manager: Frank Holmes

Phone No. (215) 524-3500

6 Shipping Information

(Name of Carrier) Federal Express

(Date Shipped) 2/14/90

(Airbill Number)

7 Specify Type of Analyses, Number of Containers, Approx. Volume

Analyses / Method Requested	No. of Bottles	Total Volume
Analytical Sample	2	1000 ml

8 Sample Location

Coal Slag #2

Date: 2/14/90

Time: 1330

9 Sample Description

☐ Surface Water	☐ Soil
☐ Ground Water	☒ Solid
☐ Leachate	☒ Other: Coal
☐ Sediment	slag

10 Special Handling (e.g. Safety Procedures/Hazardous)

Additional comments: (Specify data package, rush work, special detection limits, etc.)

11 Condition of Samples Received (to be completed by Laboratory Log-In.)

☑ Samples received intact

☑ Samples at 4 degrees (C)

☑ Samples not leaking

☑ Container numbers match as specified in Item 7

☑ Container tags match Chain of Custody

☑ Cooler received with Custody Seals intact

☑ Samples contained within plastic bags

Log-In Person's Signature

D Hassett

Copies: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for files. Pink copy retained by sampler. Gold copy extra copy as needed (warehouse).

The ERM Group

Traffic Report

24360

1 Project W.O.

Project Name/Location

EER Coal Tech

Williamsport, PA

2 Sample Concentration

☒ Low Concentration

☐ Medium Concentration

3 Ship to:

University of North Dakota

Environmental Research

Center

Attn: Dr. David Hassett

4 Sample Matrix

☒ Liquid ☐ Solid

☐ Other

5 Sampling Personnel Contact

Sampler: CS Goss, CB Solomon

Project Manager: Frank Holmes

Phone No. (215) 524-3500

6 Shipping Information

(Name of Carrier) Federal Express

(Date Shipped) 2/14/90

(Airbill Number)

7 Specify Type of Analyses, Number of Containers, Approx. Volume

Analyses / Method Requested	No. of Bottles	Total Volume
Analytical Sample	2	1000 ml

8 Sample Location

Quench Water #2

Date: 2/14/90

Time: 1320

9 Sample Description

☐ Surface Water ☐ Soil

☐ Ground Water ☐ Solid

☐ Leachate ☒ Other: Process Water

☐ Sediment

10 Special Handling (e.g. Safety Procedures/Hazardous)

Additional comments: (Specify data package, rush work, special detection limits, etc.)

11 Condition of Samples Received (to be completed by Laboratory Log-In.)

☑ Samples received intact

☑ Samples at 4 degrees (C)

☑ Samples not leaking

☑ Container numbers match as specified in Item 7

☑ Container tags match Chain of Custody

☑ Cooler received with Custody Seals intact

☑ Samples contained within plastic bags

Log-In Person's Signature

Copies: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for files. Pink copy retained by sampler. Gold copy extra copy as needed (warehouse).

The ERM Group

Traffic Report

24359

1 Project W.O.

Project Name/Location
EERI Coal Tech
Williamsport, PA

2 Sample Concentration
☒ Low Concentration
☐ Medium Concentration

3 Ship to:
University Of North Dakot
Environmental Research
Center
Attn: Dr. David Hassett

4 Sample Matrix
☒ Liquid ☐ Solid
☐ Other

5 Sampling Personnel Contact
Sampler: CB Goss, CB Solomon
Project Manager: Frank Holmes
Phone No. (215) 524-3500

6 Shipping Information
(Name of Carrier) Federal Express
(Date Shipped) 2/14/90
(Airbill Number)

7 Specify Type of Analyses, Number of Containers, Approx. Volume

Analyses / Method Requested	No. of Bottles	Total Volume
Analytical Sample	2	1000 ml

8 Sample Location
Raw Water #2
Date: 2/14/90
Time: 1320

9 Sample Description
☐ Surface Water ☐ Soil
☐ Ground Water ☐ Solid
☐ Leachate ☒ Other: City Water
☐ Sediment

10 Special Handling (e.g. Safety Procedures/Hazardous)

Additional comments: (Specify data package, rush work, special detection limits, etc.)

11 Condition of Samples Received (to be completed by Laboratory Log-In.)
☑ Samples received intact
☑ Samples at 4 degrees (C)
☑ Samples not leaking
☑ Container numbers match as specified in Item 7
☑ Container tags match Chain of Custody
☑ Cooler received with Custody Seals intact
☑ Samples contained within plastic bags

Log-In Person's Signature
D Hassett

Copies: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for files. Pink copy retained by sampler. Gold copy extra copy as needed (warehouse).

The ERM Group

Traffic Report

34858

1 Project W.O.

Project Name/Location
EER / Coal Tech
Williamsport, PA

2 Sample Concentration
☒ Low Concentration
☐ Medium Concentration

3 Ship to:
University of North Dakota
Environmental Research
Center
Attn: Dr. David Hassett

4 Sample Matrix
☒ Liquid ☐ Solid
☐ Other

5 Sampling Personnel Contact
Sampler: CBSalomon, C$Goss
Project Manager: Frank Holmes
Phone No. (215) 524-3500

6 Shipping Information
(Name of Carrier) Federal Express
(Date Shipped) 2/14/90
(Airbill Number)

7 Specify Type of Analyses, Number of Containers, Approx. Volume

Analyses / Method Requested	No. of Bottles	Total Volume
Analytical Sample	2	1000 ml

8 Sample Location
Filtered ~~Flyash~~ C&G Water #2
Scrubber

Date: 2/14/90
Time: 1310

9 Sample Description
☐ Surface Water ☐ Soil
☐ Ground Water ☐ Solid
☐ Leachate ☒ Other: Filtered
☐ Sediment Process Water

10 Special Handling (e.g. Safety Procedures/Hazardous)

Additional comments: (Specify data package, rush work, special detection limits, etc.)
Field filtered w/ 20μ filter

11 Condition of Samples Received (to be completed by Laboratory Log-In.)
☑ Samples received intact
☑ Samples at 4 degrees (C)
☑ Samples not leaking
☑ Container numbers match as specified in Item 7
☑ Container tags match Chain of Custody
☑ Cooler received with Custody Seals intact
☑ Samples contained within plastic bags

Log-In Person's Signature
D Hassett

Copies: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for files. Pink copy retained by sampler. Gold copy extra copy as needed (warehouse).

roup

Traffic Report

13645

1 Project W.O.

Project Name/Location

EER / Coal Tech

Williamsport, PA

2 Sample Concentration

☒ Low Concentration

☐ Medium Concentration

3 Ship to:

University Of North Dakota
Environmental Research
Center
Attn: Dr. David Hassett

4 Sample Matrix

☐ Liquid ☒ Solid

☐ Other

5 Sampling Personnel Contact

Sampler: CSGoss & CBSalomon

Project Manager: Frank Holmes

Phone No. (215) 524-3500

6 Shipping Information

(Name of Carrier) Federal Express

(Date Shipped) 2/14/90

(Airbill Number)

7 Specify Type of Analyses, Number of Containers, Approx. Volume

Analyses / Method Requested	No. of Bottles	Total Volume
Analytical Sample	1	500mls.

8 Sample Location

Flyash #1

Date: 2/13/90

Time: 1400

9 Sample Description

☐ Surface Water ☐ Soil

☐ Ground Water ☐ Solid

☐ Leachate ☒ Other: Filtered Flyash

☐ Sediment

10 Special Handling (e.g. Safety Procedures/Hazardous)

Additional comments: (Specify data package, rush work, special detection limits, etc.)

Field filtered w/ 20nm filter.

11 Condition of Samples Received (to be completed by Laboratory Log-In.)

☑ Samples received intact

☑ Samples at 4 degrees (C)

☑ Samples not leaking

☑ Container numbers match as specified in Item 7

☑ Container tags match Chain of Custody

☑ Cooler received with Custody Seals intact

☑ Samples contained within plastic bags

Log-In Person's Signature

D Hassett

Copies: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for files. Pink copy retained by sampler. Gold copy extra copy as needed (warehouse).

The ERM Group

Traffic Report

21132

1 Project W.O. —

Project Name/Location

EERI Coal Tech

Williamsport, PA

2 Sample Concentration

☒ Low Concentration

☐ Medium Concentration

3 Ship to:

University Of North Dakota

Environmental Research Center

Attn: Dr. David Hassett

4 Sample Matrix

☐ Liquid ☒ Solid

☐ Other

5 Sampling Personnel Contact

Sampler: CAGess, CBSalomen

Project Manager: Frank Holmes

Phone No. (215) 524-3500

6 Shipping Information

(Name of Carrier) Federal Express

(Date Shipped) 2/14/90

(Airbill Number)

7 Specify Type of Analyses, Number of Containers, Approx. Volume

Analyses / Method Requested	No. of Bottles	Total Volume
Analytical Sample	2	1000 ml

8 Sample Location

Coal Slag #1

Date: 2/13/90

Time: 1330

9 Sample Description

☐ Surface Water ☐ Soil

☐ Ground Water ☐ Solid

☐ Leachate ☒ Other: Slag

☐ Sediment

10 Special Handling (e.g. Safety Procedures/Hazardous)

Additional comments: (Specify data package, rush work, special detection limits, etc.)

11 Condition of Samples Received (to be completed by Laboratory Log-In.)

☑ Samples received intact

☑ Samples at 4 degrees (C)

☑ Samples not leaking

☑ Container numbers match as specified in Item 7

☑ Container tags match Chain of Custody

☑ Cooler received with Custody Seals intact

☑ Samples contained within plastic bags

Log-In Person's Signature D Hassett

Copies: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for files. Pink copy retained by sampler. Gold copy extra copy as needed (warehouse).

The ERM Group

Traffic Report

21131

1 Project W.O. —

Project Name/Location
EERI Coal Tech
Williamsport, PA

2 Sample Concentration
☒ Low Concentration
☐ Medium Concentration

3 Ship to:
University Of North Dakota
Environmental Research
Center
Attn: Dr. David Hassett

4 Sample Matrix
☒ Liquid ☐ Solid
☐ Other

5 Sampling Personnel Contact
Sampler: CBGoss, CBSalomon
Project Manager: Frank Holmes
Phone No. (215) 524-3500

6 Shipping Information
(Name of Carrier) Federal Express
(Date Shipped) 2/14/90
(Airbill Number)

7 Specify Type of Analyses, Number of Containers, Approx. Volume

Analyses / Method Requested	No. of Bottles	Total Volume
Analytical Sample	2	1000 ml

8 Sample Location
Quench Water #1
Date: 2/13/90
Time: 1320

9 Sample Description

☐ Surface Water	☐ Soil
☐ Ground Water	☐ Solid
☐ Leachate	☒ Other:
☐ Sediment	Process Water

10 Special Handling (e.g. Safety Procedures/Hazardous)

Additional comments: (Specify data package, rush work, special detection limits, etc.)

11 Condition of Samples Received (to be completed by Laboratory Log-In.)
☑ Samples received intact
☑ Samples at 4 degrees (C)
☑ Samples not leaking
☑ Container numbers match as specified in Item 7
☑ Container tags match Chain of Custody
☑ Cooler received with Custody Seals intact
☑ Samples contained within plastic bags

Log-In Person's Signature
D Hassett

Copies: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for files. Pink copy retained by sampler. Gold copy extra copy as needed (warehouse).

The ERM Group

Traffic Report

13646

1 Project W.O. —

Project Name/Location

EERI Coal Tech

Williamsport, PA

2 Sample Concentration

☒ Low Concentration

☐ Medium Concentration

3 Ship to:

University of North Dakota

Environmental Research

Center

Attn: Dr. David Hassett

4 Sample Matrix

☒ Liquid ☐ Solid

☐ Other

5 Sampling Personnel Contact

Sampler: CJGoss, CBSalomon

Project Manager: Frank Holmes

Phone No. (215) 524-3500

6 Shipping Information

(Name of Carrier) Federal Express

(Date Shipped) 2/14/90

(Airbill Number)

7 Specify Type of Analyses, Number of Containers, Approx. Volume

Analyses / Method Requested	No. of Bottles	Total Volume
Analytical Sample	2	1000 ml

8 Sample Location

Filtered Scrubber

Water #1

Date: 2/13/90

Time: 1230

9 Sample Description

☐ Surface Water ☐ Soil

☐ Ground Water ☐ Solid

☐ Leachate ☒ Other: Filtered

☐ Sediment Process Water

10 Special Handling (e.g. Safety Procedures/Hazardous)

Additional comments: (Specify data package, rush work, special detection limits, etc.)

Field filtered w/ 20μ filter.

11 Condition of Samples Received (to be completed by Laboratory Log-In.)

☑ Samples received intact

☑ Samples at 4 degrees (C)

☑ Samples not leaking

☑ Container numbers match as specified in item 7

☑ Container tags match Chain of Custody

☑ Cooler received with Custody Seals intact

☑ Samples contained within plastic bags

Log-In Person's Signature

D Hassett

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The ERM Group

Traffic Report

21130

1 Project W.O. —

Project Name/Location

EERC Coal Tech

Williamsport, PA

2 Sample Concentration

☒ Low Concentration

☐ Medium Concentration

3 Ship to:

University of North Dakota

Environmental Research

Center

Attn: Dr. David Hassett

4 Sample Matrix

☒ Liquid ☐ Solid

☐ Other

5 Sampling Personnel Contact

Sampler: CB Goss, CB Salemon

Project Manager: Frank Holmes

Phone No. (215) 524-3500

6 Shipping Information

(Name of Carrier) Federal Express

(Date Shipped) 2/14/90

(Airbill Number)

7 Specify Type of Analyses, Number of Containers, Approx. Volume

Analyses / Method Requested	No. of Bottles	Total Volume
Analytical Sample	2	1000ml

8 Sample Location

Raw Water #1

Date: 2/13/90

Time: 1310

9 Sample Description

☐ Surface Water ☐ Soil

☐ Ground Water ☐ Solid

☐ Leachate ☒ Other: City Water

☐ Sediment

10 Special Handling (e.g. Safety Procedures/Hazardous)

Additional comments: (Specify data package, rush work, special detection limits, etc.)

11 Condition of Samples Received (to be completed by Laboratory Log-In.)

☑ Samples received intact

☑ Samples at 4 degrees (C)

☑ Samples not leaking

☑ Container numbers match as specified in Item 7

☑ Container tags match Chain of Custody

☑ Cooler received with Custody Seals intact

☑ Samples contained within plastic bags

Log-In Person's Signature

D Hassett

Copies: White & Yellow copies accompany sample shipment to laboratory. Yellow copy retained by laboratory. White copy to be returned to ERM for files. Pink copy retained by sampler. Gold copy extra copy as needed (warehouse).