"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"

ANNUAL ENVIRONMENTAL REPORT

U.S. DOE-CLEAN COAL PROGRAM

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1. INTRODUCTION

Since Phase III testing extended only to May, 1990, it was decided to combine the 1989 and 1990 environmental reporting requirements into the present document.

As part of DOE's Waste Management Program, which aims at identifying emerging coal utilization technologies and performs comprehensive characterizations of the waste streams and products, Coal Tech consented to on-site waste steam sampling by an independent environmental sampling firm sub-contracted by DOE. Slag, scrubber discharge, slag quench water, as well as raw coal and inlet water samples were therefore obtained by this group during one of our multi-day test runs in February, 1990. The sampling protocols, analytical test results and evaluations have been presented in reference 1. Key conclusions noted in this reference are presented in this report.

1.1. Project Description

As part of the Department of Energy's Clean Coal Program, Coal Tech Corporation aimed at demonstrating the commercial readiness of an advanced cyclone, coal combustor for "new" and "retrofit" applications on industrial or utility boilers. This advanced combustor demonstrates control of SOx and NOx emissions to near New Source Performance Standards (NSPS) and at the same time retains and rejects ash, sorbent, and solid sulfur compounds as slag upstream of the boiler.

The Coal Tech project was conducted in three phases. Phase I consisted primarily of activities involving design and specification of equipment peripheral to the combustor and boiler, including pulverized coal (PC) and limestone dry feed systems, the stack particulate scrubber, several air blowers, as well as the various equipment required for flow stream measurement and control. In addition, an Environmental Monitoring Plan (EMP) was developed while efforts were initiated to acquire the necessary environmental regulatory operating permits.

During Phase II, Coal Tech installed the equipment designed and/or specified in Phase I and also conducted several one-day shakedown tests on the newly installed equipment to determine its operability. During Phase III the initial aim was to develop a data base associated with combustor operation and to identify and resolve materials and hardware issues related to actual retrofit. The ultimate aim of Phase III was to conduct multi-day tests demonstrating continuous operation. Both of these goals were accomplished and a detailed discussion of the technical results may be found in the Final Report.

It should be added that a considerable portion of the effort made during the project has been related to sampling, testing, and documentation for compliance with the various air, water, and solid waste stream regulations, which is discussed below.

1.2. Environmental Monitoring

The major objective of the EMP generated in Phase I was to provide a detailed description of Coal Tech's environmental compliance and supplemental monitoring tasks. These, in turn, served to provide operational and performance data aimed at ensuring that the demonstration project was not in violation of the applicable environmental standards and was otherwise not detrimental to human health or the environment. However, since one of the technical objectives of this project was to establish performance characteristics of the combustor, it was necessary to operate the combustor over a range of parametric test variables, some of which fell outside the range of acceptable environmental performance, if only for brief periods. With the exception of these short test periods, the combustor was operated within environmental standards, as is discussed in detail below.

As per the EMP, environmental data are divided into compliance and supplemental monitoring. The former refers to that environmental and health monitoring required by federal, state, and local regulatory agencies, while the latter is intended to provide environmental and health data for unregulated pollutants, if any, emitted from the demonstration project but not included in the compliance monitoring. Besides compliance and supplemental monitoring, additional monitoring of various combustion product gas streams, as well as boiler operating parameters, was performed. Owing to the limited environmental impact of this small project, all monitoring tasks fell into the area of Source Monitoring.

All monitored substance sampling procedures, locations, frequencies, and other protocols are as specified in the EMP unless noted otherwise. A brief process description and block flow diagram showing the various waste streams, monitored substances, and monitoring locations is presented in Appendix A.

In practice, once operating conditions were stabilized, time resolved boiler outlet and stack gas, scrubber discharge water, and rejected slag samples were obtained at varying intervals. The boiler outlet gas samples were analyzed on site via continuous sampling to a bank of instruments giving direct readings on oxygen, carbon dioxide, carbon monoxide, nitrogen oxides, unburned hydrocarbons, and sulfur dioxide. Periodically, this system was switched over to monitor the scrubber stack emissions to atmosphere. It should be noted, however, that since one of the main goals of the project was to evaluate combustor environmental performance, the bulk of the gas sampling focused on the boiler outlet upstream of the scrubber. In addition, combustion conditions were routinely checked by oxygen and combustible measurements in the boiler outlet provided by a Teledyne (and later an Enerac) portable analyzer.

Although the combustor is mostly air cooled, some internal members are water cooled. With coal firing, this cooling water was then used as the slag quench water and the scrubber water. The slag quench tank (SQT) and scrubber water streams were then discharged to the sanitary drains at the test site. The scrubber water discharge was routinely sampled and analyzed for compliance with the thermal, suspended solids, and heavy metal trace elements standards and regulations of the

Williamsport Sanitary Authority. Scrubber water samples, taken in plastic bottles, and slag samples were collected at definite time intervals, nominally every half hour. Selected water and slag samples were subsequently sent to a commercial laboratory for chemical analysis.

The following sectional divisions of the report conform to the topical organization of the EMP, i.e. the monitoring data are presented in the order: Air Emission Monitoring, Waste Water Effluent Monitoring, and Solid Waste Monitoring.

2. AIR EMISSION MONITORING

2.1. Compliance Monitoring

Compliance monitoring requirements were specified by the Pennsylvania Department of Environmental Resources (PA DER), Bureau of Air Quality Control, viz. SO2 limit of 4 lb/MMBtu, particulate limit of 0.4 lb/MMBtu, and opacity limit of 20%. Details of this monitoring are presented below.

2.1.1. Sulfur Dioxide

A major advantage of the Coal Tech cyclone combustor is its ability to control sulfur emissions. This is achieved by means of limestone (LS) or other sorbent injection, adjacent to the coal ports. With this technique, measured reductions in boiler outlet SO2 emissions in 1989/90 were as high as 58%, depending on the Ca/S ratio and combustor operating conditions. With sorbent injection downstream of the combustor, up to 82% SO2 reduction was achieved. The results of Phase III testing clarified these results and identified the conditions giving rise to maximum reduction in SO2 emitted to the atmosphere. This subject is discussed in detail in the Final Report.

With regard to environmental monitoring, calculations show that for 100% coal firing and 100% conversion of coal sulfur to SO2 the 4 lb/MMBtu limit on SO2 emissions would be exceeded only if the coal sulfur content were higher than 2.5%. In 1989 the combustor was operated with coals having sulfur contents ranging from about 2.1 to 2.3%, while in 1990 the range was around 1.1 to 3.3%. In practice, however, co-firing with oil & NG yielded an effective fuel sulfur content that was lower, such that emission requirements were almost always met even with no environmental control. The only exception was baseline operation with the 3.3% sulfur coal. In any case, the bulk of operating time was with sorbent injection so that the above "worst case" SO2 emission rate was only for a brief period. Thus, measured boiler outlet and stack SO2 levels were virtually always below the regulatory limit.

In 1989, boiler outlet SO2 levels averaged 2.30 lb/MMBtu, while in 1990, the figure was 3.58 lb/MMBtu. It should be emphasized that the increase in SO2 emissions for 1990 was due to the use of higher sulfur coals as well as an increase in the coal firing rate relative to the auxiliary fuels. These measured levels of SO2 in the boiler outlet, upstream of the scrubber, are given in Table 1 for 1989 and in Table 2 for 1990 along with various operating conditions. As noted above, the only excursion above the regulatory limit occurred during baseline operation with 3.3% sulfur coal. This condition is shown as test 25-2a in Table 2.

Since the tabularized data were obtained with the combustor operating over a wide range of parametric conditions, some of which were outside the envelope of maximum sulfur capture, the reported SO2 emission levels are not entirely indicative of optimum performance. It should also be emphasized that these emission rates are upper limits on actual atmospheric emissions since the wet scrubber itself has some sulfur capture capacity, partly independent of the level of sorbent injection, resulting, on average, in a further 20 to 25% reduction in the SO2 actually emitted.

2.1.2. Stack Particulates & Opacity

The use of a stack gas venturi wet scrubber resulted in compliance on particulate emissions and opacity, the latter diagnostic being, to some extent, an indirect particulate emissions measurement. As discussed in detail in the 1988 Annual Environmental Report, compliance on stack opacity was associated with operating the scrubber at the manufacturer's specified pressure drop of 15" WC or more. This operating criterion was maintained throughout 1989/90. Visual observation of the stack plume during operation indicated that scrubber performance had not deteriorated.

2.2. Supplemental Monitoring

No stack particulate mass loading rate (EPA Method 5) or size distribution (cup filter, 10 micron cutoff) measurements were performed under the Clean Coal I project in 1989/90 owing to limited resource allocation to other project goals. However, a measurement of particle mass (PMR) rate with coal firing via EPA Method 5 was made by a commercial testing firm under another project in July, 1990. In addition, non-isokinetic stack sampling was performed by Coal Tech, also under another project, in January of 1990.

The EPA Method 5 measurement of the particulate emission rate was conducted at a total fuel heat input of 9.0 MMBtu/hr with coal and oil co-firing, along with sorbent injection. The measurement was made in the boiler outlet stack, upstream of the scrubber. The resulting PMR is therefore an upper limit on the solids loading to the scrubber since it does not reflect solids layout in the ducting between the measuring point and the scrubber inlet. At 107% isokinetic, the boiler outlet solids emission was reported as 17 PPH or 1.89 lb/MMBtu. Analysis of scrubber discharge samples obtained in the same time interval yielded a scrubber solids rejection of 15 PPH or 1.67 lb/MMBtu. Discounting solids deposition losses, this places an upper limit of 0.22 lb/MMBtu on the particulate emissions to atmosphere.

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. These tests were conducted with coal and oil co-firing at a total fuel heat input of 10.6 MMBtu/hr, plus combustor sorbent and fly ash injection at various levels. With coal and oil co-firing, the atmospheric PMR was 0.20 lb/MMBtu. The addition of flyash yielded 0.09 lb/MMBtu, and for coal plus flyash plus sorbent the value was 0.30 lb/MMBtu. It should be emphasized that these figures are probably lower limits on the actual atmospheric emission rates due to sampling line losses. However, the values are in line with the one derived from the rigorous Method 5 measurement.

2.3. Additional Monitoring

Of the several process flow streams monitored during testing, the concentration levels of NOx, CO, and unburned hydrocarbons in the boiler outlet and stack are of some environmental importance.

To control nitrogen oxide emissions, the combustor was operated fuel rich. It was shown in the 1 MMBTU/hr pilot combustor (2) that over a factor of three NOx emission reduction could be obtained, i.e. less than 100 ppm in the stack, at a fuel rich stoichiometric air fraction of 0.7 in the combustor, with final excess air combustion in a second stage simulating the radiant section of a boiler. This NOx level is considerably lower than EPA's New Source Performance Standards (NSPS). In the Clean Coal project, boiler outlet NOx levels down to 184 ppm (normalized to 3% O2) have been measured under staged combustion operation, representing a reduction of >75% in the unstaged value, while additional NOx reductions of 5 to 10% have been obtained in the scrubber outlet discharging to atmosphere, resulting in atmospheric NOx emissions as low as 160 ppmv. Tables 1 and 2 present measured NOx levels in the boiler outlet as equivalent NO2 for 1989 and 1990 respectively.

As in 1988, with PC firing comprising >90% of the total fuel heat input, the balance being pilot natural gas, the measured boiler outlet CO averaged around 100 ppm at 5.0% oxygen. This level is comparable to that obtained in industrial boilers used for hazardous waste incineration with heavy fuel oil (3).

Again as in 1988, measured unburned hydrocarbons (HC's) in the boiler outlet were 0 ppm, with rare excursions up to 2 ppm. These low values indicate that the smoke number and/or opacity readings, to which unburned HC's would contribute, were mainly due to fly ash rather than smoke or soot from incompletely combusted fuel.

3. WASTE WATER EFFLUENT MONITORING

3.1. Compliance Monitoring

Compliance requirements are specified by the Williamsport Sanitary Authority, in concurrence with the PA DER, Bureau of Water Quality Control.

Water used for combustor cooling only, i.e. not in contact with any waste stream, was discharged to the storm sewer. With PC firing, the cooling water was recycled for slag quenching and scrubber operation. This resulted in two waste water streams, one generated in the scrubber and the other by contact with slag in the slag quench tank (SQT). These were eventually combined and discharged into a sanitary drain going to the Williamsport Sanitary Authority Central Treatment Plant. This facility is rated for a maximum flow of 10.5 million gallons per day (MGD). The daily average flow is typically 6 to 8 MGD or about 250,000 to 333,000 gallons per hour (GPH).

As per the Authority, the following parameters were monitored: total water discharged into the sanitary system; total suspended solids (TSS) in the discharged water; the heavy metals cadmium, copper, and selenium suspended in the water; the water discharge temperature and pH. The discharge limits are 0.5 lb of Cd/day, 1.0 lb of Cu/day, 0.1 lb of Se/day, maximum water temperature of 135 F, and 5 < pH < 9.

3.1.1. Total Water & Suspended Solids

Testing in 1989 consumed around 1,250,000 gallons of water for cooling the combustor, for quenching and solidifying the molten slag, and for operating the venturi scrubber. The consumption in 1990 was about 560,000 gallons. It should be noted that roughly one-third of the water usage occurred under projects other than the Clean Coal. Of the yearly totals about 25% was discharged to the sanitary sewer, the remaining 75% being discharged into the storm sewer system. Of the volume discharged into the sanitary drain, about 74% was scrubber discharge while the balance came from the slag quench tank (SQT). Sanitary sewer discharge occurred only during PC operation. Thus, most operating time was not on PC but on natural gas or light oil firing for combustor heat-up and cool-down procedures, for refractory curing, and for overnight idling of the system. In these latter instances the discharged water was used only for combustor cooling via indirect heat exchange and therefore contained no waste materials.

Water discharged from the SQT was filtered and therefore had a low total suspended solids (TSS), spot checked in 1988 to be 19 mg/l, the solids being unburned coal. Owing to this low solids loading of the SQT water, as well as the relatively low flow of around 10 gallons per minute (GPM), water quality testing focussed on the scrubber where water samples were usually obtained several times during each test run for subsequent commercial laboratory analysis.

Discharged scrubber water TSS averaged 5423 mg/l in 1989. This TSS level is higher than the average value of 3344 mg/l reported in 1988. The primary reason for the increase is the use of relatively higher coal firing rates in 1989. At the scrubber water use rate of 28 GPM the TSS discharge rate averaged 76 PPH. Variability in the TSS measurements is largely due to parametric operation which often resulted in less than maximum combustor solids retention. Table 3 shows measured scrubber water discharge properties as a function of operating conditions in 1989. The limited data for 1990 are shown in Table 4.

3.1.2. Heavy Metals

Under the Clean Coal I project, several of the scrubber water samples were tested for the presence of the trace metals cadmium and copper. Selenium was not included in the analysis since its 1988 level was extremely low, namely 0.014 mg/L. The average levels of cadmium and copper, in mg/l, were 0.042 and 0.513. Independent determinations of cadmium and selenium in filtered scrubber water, made under the Waste Management Program, yielded < 0.02 and 0.138 mg/l respectively. For an eight hour test day the highest measured levels translate into 0.0047, 0.0575, and 0.0155 lb/day of Cd, Cu, and Se. Thus, our measured discharge rates for these metals are well below the Authority's limits noted above.

3.1.3. Water Temperature & pH

Scrubber discharge water temperature has been uniformly between 100 and 120 F. Water pH in 1989 has been found to vary between a low of 4.5 and a high of 12.4. Because of the routine use of sorbent injection, the average value is 10.5, which somewhat above the Authority's limit. However, this waste water stream is diluted by the SQT water (pH normally 6 to 7) in about a 3 to 1 ratio upon entering the sanitary drain. In addition, based on the Central Treatment Plant's average daily influent rate noted above, our relatively low flow of 2280 GPH would be diluted at the plant by a factor of around 125, which is expected to result in little variation in total treated water pH. Measured pH values are shown in Table 3 for 1989 and in Table 4 for 1990.

3.2. Supplemental Monitoring

Analysis of the SQT and filtered scrubber water was performed under DOE's Waste Management Program. The samples were checked for 10 regulated trace metals and 24 target-list organics. As noted in reference 1, none of the samples had concentrations of analytes high enough to be considered hazardous.

In addition to the trace heavy metals, supplemental monitoring was to address the carbon, nitrogen, and sulfur content of the water discharged to the sanitary system. As noted above, the SQT water, which had low solids content and flow, had low levels of partially burned PC. As per the Waste Management Program testing, scrubber water TSS were comprised of around 41% unburned carbon, 43% ash, 3% sulfur, and 13% calcium oxide from the injected sorbent. It should be noted that this carbon content corresponds to >95% overall coal combustion efficiency.

4. SOLID WASTE MONITORING

4.1. Compliance Monitoring

As noted in the 1988 Annual Environmental Report, the EMP was developed on the basis of compliance monitoring requirements specified by the

Resource Conservation and Recovery Act (RCRA), and administered by the PA DER, Bureau of Solid Waste Management. The pertinent substances that fell under the RCRA are the slag nitrogen and sulfur reactivity to form gas phase cyanide and sulfide compounds, and the leaching potential of heavy metals and cyanide in the slag. The evaluation of compliance was to be determined by preparation of a Module 1 document in which the characteristics of the solid waste product are documented, using laboratory test results as a basis, to obtain the necessary landfill permits.

In 1988, the slag chemical analysis and other properties provided by the testing lab indicated that the material had none of the characteristics of a hazardous waste and could, therefore, be disposed of in a landfill for non-hazardous solid waste. However, it came to our attention that the slag generated by the combustor falls under the Pennsylvania Coal Waste Product Recycling Act and, as such, did not require extensive testing/analysis to obtain disposal permits. In view of this, we were able to quickly arrange for disposal of the slag, total amount around 2.5 tons, at the PP&L landfill. Much of the slag generated by PP&L is utilized in the construction industry.

In 1989/90, virtually all of the solid waste, approximately 10 tons, was also shipped to the PP&L landfill. A small amount of slag, around 1000 lbs, generated in the final Clean Coal test, could not be sent to PP&L owing to procedural difficulties involved in processing such a small shipment. instead, this material was sent to an Alabama landfill after they characterized some representative samples.

4.1.1. Reactivity & Metal Leaching

Under the Waste Management Program, slag and scrubber solids were subjected to the new, and more rigorous, TCLP (Toxic Characteristic Leaching Procedure) and the SGLP (Synthetic Groundwater Leaching Procedure) leach tests. In addition, cyanide and sulfide evolution rates were obtained. In all cases, none of the wastes contained concentrations of regulated elements high enough to be considered hazardous.

4.2. Supplemental Monitoring

Supplemental monitoring in the EMP involved slag sample analysis for carbon, nitrogen, and sulfur. The results were essentially identical to those reported in 1988, namely slag carbon <0.01%, sulfur between <0.01 to 0.05% with occasional values in excess of 1.0%. Slag nitrogen content remained uniformly low.

4.3. Additional Monitoring

Under the Waste Management Program, slag and scrubber solids were analyzed for 24 target-list organics. Both samples showed no significant concentrations of the target analytes.

5. SUMMARY

All environmental compliance monitoring data indicate that operation of the Coal Tech Combustor under the DOE Clean Coal I project was in compliance with regulatory limits prescribed by the relevant agencies in the areas of air, water, and solid waste. In addition, supplemental and additional monitoring tasks did not identify any substances or trends warranting corrective environmental or health action.

6. REFERENCES

1. "Solid Waste Sampling and Distribution Project", Sampling Report #1, prepared by EER for METC, Contract No. DE-AC21-88MC25185, May, 1990.

2. B. Zauderer et al.,"Experiments in NOx and SO2 Control in a Cyclone Combustor", Proc. 6th Intl. Workshop on Coal Liquid & Alter. Fuels Tech., Halifax, N.S., Oct., 1986.

3. R. A. Olexsey, "Air Emissions From Industrial Boilers Burning Hazardous Waste Materials", Incinerating Hazardous Wastes, H. M. Freeman, editor, Technomic Pub. Co., Lancaster, Pa., 1988.

Table 1. Measured Boiler Outlet Emissions of SO2 and NO2 in 1989 (b)

Test (a)	Stoichiometry SR1	SR2	Ca/S Ratio	Duration (hrs)	Heat In (MMBtu/hr)	Pct Btu from PC	lb/MMBtu(c) SO2	NO2
17-1	0.9	1.6	2.6	1.0	10.5	83	3.05	0.30
17-2	0.9	1.7	0	0.5	10.2	83	3.67	0.33
17-3	0.9	1.6	0	0.25	10.1	83	3.32	0.31
17-4	1.4	1.5	1.5	0.25	11.4	84	2.43	0.72
17-5	1.1	1.3	1.7	0.5	10.7	83	2.83	0.40
19-2	0.9	1.9	2.8	0.5	11.0	74	2.71	0.34
19-3	1.0	1.2	2.1	0.5	15.7	70	2.36	0.54
19-4a	1.0	1.1	0.6	0.75	15.4	70	1.89	0.47
20-1b	1.2	1.3	2.3	0.75	11.6	87	2.79	0.63
20-1c	1.2	1.3	2.3	0.75	11.9	87	2.67	0.58
20-2a	1.1	1.2	2.8	0.5	12.6	66	1.96	0.51
20-2b	1.1	1.2	2.6	1.5	12.4	65	2.41	0.49
20-3a	1.1	1.2	2.1	0.75	12.4	89	2.28	0.56
20-3b	1.2	1.2	1.9	0.5	13.4	89	2.58	0.60
20-3c	1.1.	1.2	2.0	1.0	12.9	89	2.58	0.62
20-4a	1.0	1.1	1.9	0.75	13.9	87	3.00	0.49
22-1	0.9	1.5	1.2	1.5	12.5	86	1.93	0.51
22-2a	1.3	1.8	1.3	0.5	11.7	86	2.38	0.67
22-2b	1.2	1.7	1.2	0.5	13.0	87	2.52	0.68
22-3	1.0	1.5	1.2	0.5	12.7	87	2.67	0.38
22-4	1.0	1.5	1.2	0.25	12.9	87	2.43	0.35
22-5	0.9	1.6	1.2	0.5	12.9	87	2.59	0.34
22-6	0.9	1.6	1.2	0.5	12.9	87	2.36	0.34
24-1a	0.9	1.7	2.1	0.75	11.7	64	1.84	0.36
24-1b	0.9	1.7	2.1	0.5	11.7	64	2.01	0.35
24-1c	0.9	1.7	1.6	0.75	11.8	64	1.79	0.36
24-1d	0.9	1.7	1.6	1.25	11.8	64	2.24	0.37
24-1e	0.9	1.7	1.6	0.5	11.8	64	1.71	0.37
24-2a	0.8	1.6	1.3	0.5	12.3	72	2.14	0.41
24-2b	0.8	1.6	1.3	0.5	12.6	73	2.21	0.41
24-2c	0.8	1.6	0	0.75	12.6	73	2.44	0.41
24-2d	0.8	1.5	0.5	0.5	13.3	74	2.30	0.41
24-2e	0.8	1.6	1.3	2.25	12.8	73	2.49	0.42
24-3a	0.8	1.5	1.0	1.0	15.9	73	2.42	0.47
24-3b	0.8	1.6	1.1	0.25	15.7	68	2.38	0.47
24-3c	0.8	1.5	1.7	0.55	15.9	68	2.23	0.44
24-3d	0.7	1.5	1.7	0.75	16.2	69	2.30	0.44
24-4a	0.7	1.5	1.6	0.75	16.5	73	1.60	0.43
24-4b	0.8	1.6	2.1	0.25	16.1	71	1.40	0.47
24-4c	0.7	1.6	2.1	1.25	16.2	71	1.33	0.46
24-4d	0.7	1.5	2.0	0.75	16.4	72	1.18	0.44
24-4e	0.7	1.5	2.0	0.5	16.4	72	1.22	0.45

TABLE 1 -CONTINUED

(a) Tests 17, 19, and 20 were conducted with coal having %S = 2.08. Tests 22 and 24 were conducted with coal having %S = 2.26.

(b) All SO2 and NOx measurements made as dry ppmv upstream of the scrubber. Reported values are average values for a given test/condition.

(c) (lb of SO2[NO2]/MMBtu) = (meas. ppm SO2[NOx]/106) X (SCF of Dry Product Gas at SR2/ 1 lb fuel) X (1 lb-mole/379 SCF) X (64[46] lbs/ lb-mole) X (1/ Btu per 1 lb fuel) X (106 Btu/ MMBtu). Both SCF Dry Product Gas at SR2, and Btu/ 1 lb fuel are determined from the weight percents of coal and oil fired at the test condition. Thus, the calculations are made on the basis of 1 lb of combined fuel.

Table 2. Measured Boiler Outlet Emissions of SO2 and NO2 in 1990 (b)

	Stoichiometry		Ca/S	Duration	Heat In	Pct Btu	lb/MMBtu(c)	
Test (a)	SR1	SR2	Ratio	(hrs)	(MMBtu/hr)	from PC	SO2	NO2
25-1a	0.8	1.4	0	1.0	13.3	81	2.72	0.31
25-1b	0.8	1.3	1.3	0.5	13.8	82	3.00	0.29
25-1c	0.8	1.3	1.3	0.5	13.8	82	3.21	0.32
25-1d	0.7	1.2	1.2	0.75	14.8	83	3.84	0.30
25-1e	0.7	1.2	1.2	0.75	15.4	84	3.55	0.31
25-1f	0.7	1.2	0.9	1.0	15.4	84	3.30	0.33
25-1g	0.7	1.2	0.9	0.5	15.4	84	3.55	0.31
25-2a	0.8	1.4	0	0.75	13.8	82	4.61	0.36
25-2b (d)	0.8	1.4	0	0.75	13.8	82	1.84	0.36
25-2c (d)	0.9	1.5	1.2	0.25	12.7	80	1.73	0.38
25-2d (d)	0.8	1.5	1.1	0.25	13.3	81	1.82	0.45
25-2e	0.8	1.3	1.0	0.5	14.0	82	3.26	0.35
25-2f	0.8	1.3	1.0	0.5	14.3	83	2.72	0.34
25-2g	0.8	1.3	1.0	0.5	14.8	83	2.28	0.34
25-2h	0.8	1.3	1.4	0.5	14.8	83	2.13	0.35
25-2i	0.7	1.3	1.4	0.5	14.6	83	1.90	0.37
25-2j	0.7.	1.3	1.4	0.5	14.6	83	2.07	0.34
25-2k	0.7	1.3	0.8	0.25	14.6	83	2.01	0.34
25-2l	0.8	1.3	0	0.25	14.0	82	2.39	0.30
25-2m	0.7	1.3	0.8	0.75	14.6	83	2.11	0.34
25-3a	0.7	1.2	0	0.25	16.4	85	1.89	0.36
25-3b (d)	0.7	1.4	0	0.25	15.4	84	0.35	0.48
25-3c	0.7	1.3	0	0.25	15.9	84	1.68	0.40
25-3d	0.7	1.2	1.8	0.25	16.7	85	1.30	0.39
25-3e	0.7	1.2	1.8	0.75	16.7	85	1.42	0.40
25-3f	0.6	1.2	1.8	1.0	17.0	85	1.72	0.41
25-3g	0.7	1.3	0	0.25	16.2	85	2.50	0.40
25-3h	0.6	1.2	0.9	1.5	16.7	85	2.52	0.40
25-3i	0.6	1.2	0	0.25	16.4	85	2.41	0.38

TABLE 2 CONTINUED

26-1a	0.8	1.3	2.1	0.75	14.4	94	2.70	0.30
26-1b	0.8	1.3	2.1	0.5	14.4	94	2.21	0.30
26-1c	0.8	1.3	2.7	0.25	14.4	94	2.21	0.30
26-1d	0.8	1.3	2.8	1.25	14.4	93	2.43	0.32
26-1e	0.8	1.3	3.4	0.5	14.4	93	2.43	0.32
26-2c	1.1	2.3	2.3	0.75	9.1	77	1.67	0.45
26-2d	1.1	2.3	2.3	0.5	9.1	77	1.78	0.46
26-2e	1.0	2.3	2.3	1.0	9.1	77	1.94	0.44
26-2f	0.9	1.9	2.4	1.0	10.8	81	1.98	0.39
26-2g	0.9	1.9	2.4	0.75	10.8	81	1.45	0.46
26-2h	0.9	1.9	2.4	0.25	10.8	81	1.65	0.44
26-3a	0.7	1.5	1.6	0.25	13.5	89	2.37	0.27
26-3b	0.8	1.5	1.6	1.25	13.5	89	2.45	0.43
26-3c	0.8	1.5	2.1	0.55	13.6	89	1.13	0.33
26-3d	0.8	1.6	2.5	0.25	12.4	83	1.11	0.35
26-3e	0.9	1.7	2.5	0.75	12.4	83	1.30	0.33

(a) Tests 25-1 and 25-2a through 2d were conducted with coal having %S = 3.29. Test 25-2e through 2m and 25-3 were conducted with coal having %S = 1.06. Test 26 was conducted with coal having %S = 1.75.

(b) All SO2 and NOx measurements made as dry ppmv upstream of the scrubber. Reported values are average values for a given test/condition.

(c) (lb of SO2[NO2]/MMBtu) = (meas. ppm SO2[NOx]/106) X (SCF of Dry Product Gas at SR2/ 1 lb fuel) X (1 lb-mole/379 SCF) X (64[46] lbs/ lb-mole) X (1/ Btu per 1 lb fuel) X (106 Btu/ MMBtu). Both SCF Dry Product Gas at SR2, and Btu/ 1 lb fuel are determined from the weight percents of coal and oil fired at the test condition. Thus, the calculations are made on the basis of 1 lb of combined fuel.

(d) Condition includes boiler sorbent injection.

Table 3. Scrubber Water Discharge Measurements for 1989 (a)

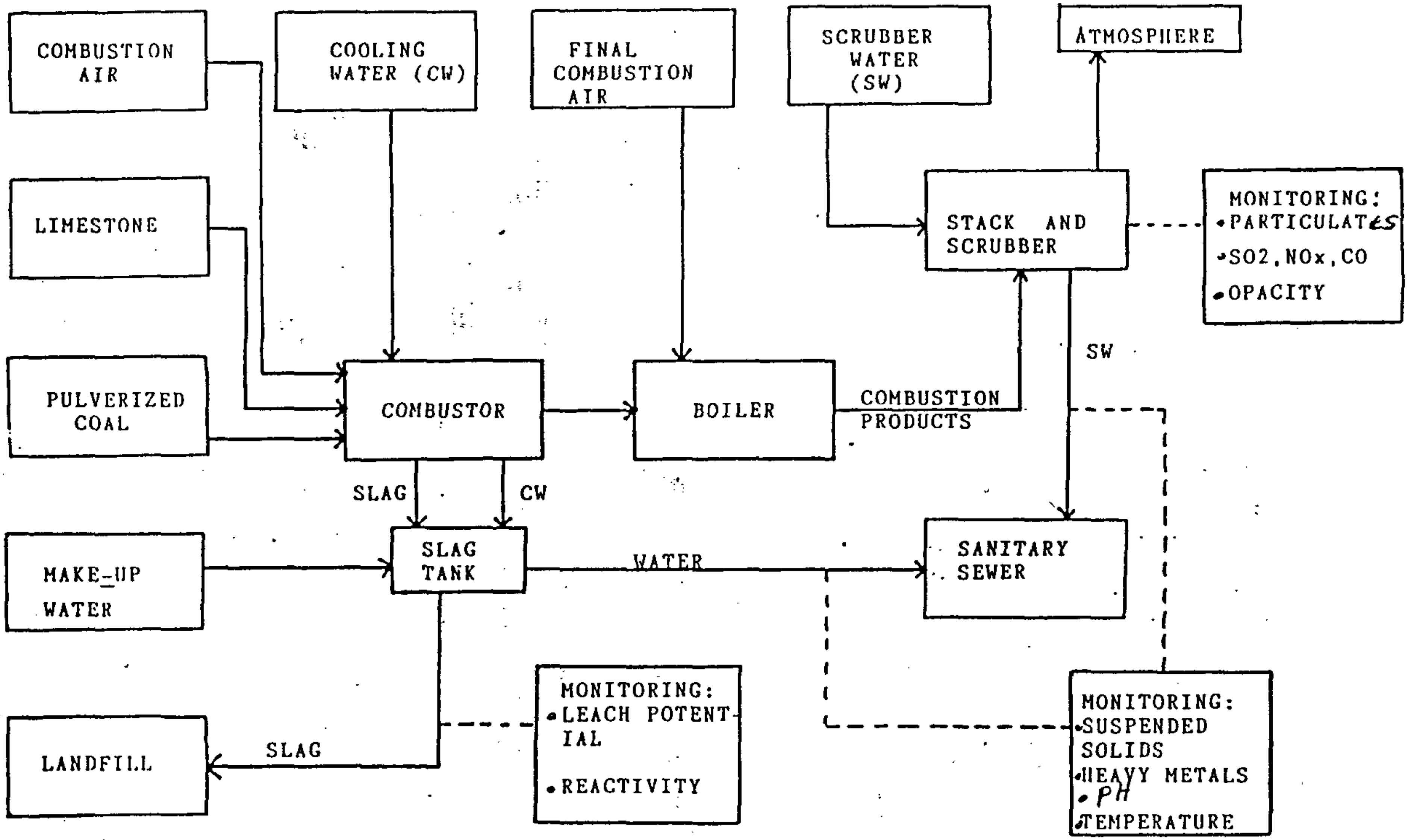
Test (a)	Stoichiometry SR1	SR2	Ca/S Ratio	Heat In (MMBtu/hr)	Pct Btu from PC	TSS (b) mg/L	pH (c)
17-1	0.9	1.6	2.6	10.5	83	9820	12.4
17-2	0.9	1.7	0	10.2	83	8740	4.5
17-5	1.1	1.3	1.7	10.7	83	4080	12.0
18-1b	1.2	1.7	2.4	11.3	85	4500	11.4
18-2b	1.2	1.7	0.5	11.1	85	3850	6.7
19-2	0.9	1.9	2.8	11.0	74	7830	12.3
19-3	1.0	1.2	2.1	15.7	70	4040	11.5
19-4	1.0	1.1	0.6	15.4	70	3320	9.0
20-2a	1.1	1.2	2.8	12.6	66	3230	8.1
20-3c	1.2	1.2	2.0	12.9	89	8330	12.1
22-1	0.9	1.5	1.2	12.5	86	3510	9.9
22-2a	1.3	1.8	1.3	11.7	86	3420	9.0
22-2b	1.2	1.7	1.2	13.0	87	275	8.7
22-5	0.9	1.6	1.2	12.9	87	8820	11.8
23-1a	1.3	1.8	1.2	12.8	87	3050	7.9
23-1c	1.3	1.8	1.2	12.8	87	4940	9.4
23-2b	1.3	1.8	1.5	12.6	88	4630	11.2
23-2c	1.3	1.8	1.5	12.6	88	4830	11.3
23-2f	1.2	1.7	1.5	13.1	87	5920	11.6
23-4b	0.8	1.8	1.7	13.2	88	12150	12.3
23-4d	0.7	1.6	1.5	14.6	61	7710	12.2
23-4f	0.7	1.6	1.5	14.6	61	6295	12.0
24-1e	0.9	1.7	1.6	11.8	64	2960	11.7
24-2a	0.8	1.6	1.3	12.3	72	5520	11.3
24-4d	0.7	1.5	2.0	16.4	72	11300	12.2

(a) Scrubber water discharge flow = 27 to 29 GPM.
(b) Variation in TSS (Total Suspended Solids) due to parametric changes in operation, especially coal firing rate.
(c) Variation in scrubber pH due to variation in sorbent injection rate and other operating conditions resulting in different levels of sorbent carryover to the scrubber. High carryover results in high pH due to hydrolysis of calcium oxide.

Table 4. Scrubber Water Discharge Measurements for 1990 (a)

Test (a)	Stoichiometry SR1	SR2	Ca/S Ratio	Heat In (MMBtu/hr)	Pct Btu from PC	TSS (b) mg/L	pH (c)
25-3d	0.7	1.2	1.8	16.7	85	12400	12.5
25-2h	0.8	1.3	1.4	14.8	83	9070	12.6
26-1d	0.8	1.3	2.8	14.4	93	21600	7.3
26-3c	0.8	1.5	2.1	13.6	89	12800	NM

(a) Scrubber water discharge flow = 27 to 29 GPM.
(b) Wide variation in TSS (Total Suspended Solids) due to parametric changes in operation, especially the injection of flyash.
(c) Variation in scrubber pH due to variation in sorbent injection rate and other operating conditions resulting in different levels of sorbent carryover to the scrubber. High carryover results in high pH due to hydrolysis of calcium oxide.



APPENDIX A PROCESS BLOCK FLOW DIAGRAM

APPENDIX A

OVERALL PROCESS DESCRIPTION OF THE COMBUSTOR OPERATION

Pulverized coal and combustion air are injected in the cyclone combustor at up to 23 MMBTU/hr thermal input. The combustor operates fuel rich for SO_2 and NO_x control, and final (tertiary) combustion air is injected directly into the boiler. In addition, various quantities of limestone are injected into the combustor for SO_2 control.

Coal slag and spent limestone sorbent are liquified in the combustor. Most (80-90%) of the slag mixture is drained into a water quenched tank for subsequent disposal at a landfill. It is anticipated that up to 100 hours of operation will be required before sufficient solid waste is generated for removal to the landfill. Samples from the slag will be subjected to analysis to determine compliance with solid waste disposal regulations. The balance of the slag/spent sorbent particles will be conveyed through the boiler to the stack, where they will pass through a venturi type wet scrubber which will remove sufficient particles to meet particulate emission regulations. The stack gas will also be sampled on a regular basis for compliance with air emissions regulations.

Various parts of the combustor are water cooled. This cooling water, as well as the slag quench water, and the water from the venturi scrubber will be discharged in the sanitary drains at the test site. The water discharge will be tested periodically for compliance with the thermal, suspended solids, and heavy metal trace elements standards and regulations of the Sanitary Authority.

Appendices II , III , IV , and V contain the Process Block Flow Diagram, the Test Site Plot Plan and Layout, the Site Plan, and the Local Area Site Plans, respectively.