DE-FG22-94PC94122

DOE/PC/94122--78

**COMBUSTION CHARACTERIZATION OF COAL FINES
RECOVERED FROM THE HANDLING PLANT**

Quarterly Technical Progress Report No. 7
Report Period: April 1, 1996 to June 30, 1996

RECEIVED

OCT 07 1996

OSTI

By:

Masudi, Houshang; Principal Investigator

Samudrala, Surender Rao; Graduate Research Assistant

Reid, Elna; Undergraduate Research Assistant

S. N. Dwivedi; Project Consultant

July 1996

Work Performed Under Contract No. DE-FG22-94PC94122

For

United States, Department of Energy

Pittsburgh Energy Technology Center

Pennsylvania

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

29

DISCLAIMER

This report was prepared as an account of work sponsored by United States Department of Energy. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

**Portions of this document may be illegible
in electronic image products. Images are
produced from the best available original
document.**

TABLE OF CONTENTS

	Page No
Abstract-----	4
Executive Summary -----	4
Introduction-----	5
Results and Discussion-----	6
Conclusion-----	7
Appendix A	
Appendix B	

ABSTRACT

The coal-water slurry fuel, plant coal, recovered coal fines and ash deposits are analyzed for elemental oxides. SiO_2 oxide was found to be the most dominating oxide element with more than 55 percent by weight in all cases. Additionally, the slurry fuel and its feedstocks were studied for particle size distribution. The maximum percentage of the particles by weight, was found to be in the size range of 36 to 88 microns, 3 to 27 microns and 9 to 77 microns for plant coal, recovered coal fines and coal-water slurry respectively.

EXECUTIVE SUMMARY

The coal blend is composed of 85 percent plant coal and 15 percent recovered coal fines. The coal-water slurry fuel CWSF is prepared at 53.3 percent solids with viscosity less than 500 centipoise and 80-90 percent of solid particles passing through 200 mesh. The CWSF, plant coal, recovered coal fines and ash deposits were analyzed for elemental oxides via x-ray fluorescence analysis. The most detrimental oxide elements were SiO_2 , Al_2O_3 , and Fe_2O_3 in which SiO_2 had the highest percentage by weight in all cases. Oxides such as P_2O_3 , CaO , MgO , Na_2O and K_2O had higher percentage in the recovered coal fines than in the plant coal. This is due to the fact that the waste coal fines contain mineral oxides.

The coal-water slurry fuel and its feed stocks were analyzed for particle size distribution via wet sieve and malvern laser diffraction. The maximum percentage of the particles by weight, was found to be in the size range of 36 to 88 microns, 3 to 27 microns and 9 to 77 microns for plant coal, recovered coal fines and coal-water slurry respectively.

Upon re-examining the gaseous emission data, it was found that the data as reported previously were not plotted correctly. Included in this report are the replots of gaseous emission data on O_2 , CO_2 , SO_2 and NO_x . The NO_x level was found to be just below 500 ppm for the three tests.

INTRODUCTION

During the reporting period (April 1 - June 30), research activities were focused on:

1. Particle size distribution of coal-water slurry fuel, plant coal and recovered coal fines.
2. Chemical constituents of ash deposits, coal-water slurry fuel, plant coal and recovered coal fines.
3. Re-examination of plots of gaseous emissions data on O₂, CO₂, SO₂ and NO_x as reported previously.

The work performed during this period is presented in appendix A, in which the paper entitled "Combustion Analysis of Coal-water Slurry Fuel Prepared from Plant Coal and Recovered Coal Fines" was prepared for First Joint Power & Fuel Systems Contractors Conference.

A summary of the work is given below starting with a brief discussion on coal-water slurry composition.

Coal-Water Slurry Fuel Composition

The coal blend used in preparation of the coal-water slurry fuel (CWSF) was composed of 85 percent plant coal and 15 percent recovered coal fines. The CWSF was prepared at 53.3 percent solids weight, with a viscosity less than 500 centipoise and 80-90 percent of solids passing through 200 mesh. The CWSF was fired at three firing rates(834,330 Btu/hr, 669,488 Btu/hr and 508,215 Btu/hr) and at three burner settings for each firing rate.

Particle Size Distribution

The data on particle size distribution via wet sieve and Malvern laser diffraction for coal-water slurry fuel, plant coal and recovered coal fines were analyzed. The

size distribution for plant coal, recovered coal fines and coal-water slurry fuel are shown in Figure 1, 2, and 3, appendix A, respectively.

Chemical Constituents

Elemental oxides for coal-water slurry fuel, plant coal, recovered coal fines and ash deposits as obtained by x-ray fluorescence analysis are shown in Figure 4 and 7, appendix A, respectively.

Gaseous Emissions

The data on O_2 , CO_2 , SO_2 and NO_x were examined, and it was found that the plots as reported in previous reports were not correct. The corrected plots along with their respective data are given in appendix B.

RESULTS AND DISCUSSION

Particle Size Distribution

The particle size distribution for the plant coal, recovered coal fines and CWF as shown in Figures 1, 2, and 3, appendix A, give the percentage of the total mass within a size range. The maximum percentage of the particles by weight, was found to be in the size range of 36 to 88 microns, 3 to 27 microns and 9 to 77 microns for plant coal, recovered coal fines and coal-water slurry respectively.

Chemical Constituents

Figure 4, appendix A, gives the elemental oxides for plant coal, recovered coal fines and coal-water slurry fuel. As seen from this figure the most detrimental oxides are SiO_2 , Al_2O_3 and Fe_2O_3 in which SiO_2 has the highest percentage in all the three samples. Some of the oxides such as P_2O_5 , CaO , MgO , Na_2O and K_2O have higher percentage in the recovered coal fines than in the plant coal. This is due to the fact that the waste coal fines contain mineral oxides.

The ash deposit data listed in Figure 7, appendix A, show similar compositions for all components during each test. The main difference between each deposit is the sodium content, which can be seen to decrease with decreasing temperature and firing rate. When available, sodium plays a major role in determining the fouling rate and strength of deposits formed. The available sodium will react with free silica to form the low melting point phases which are responsible for deposit growth and strength development.

Gaseous Emissions

NO_x and SO₂ emissions in PPM at firing rates of 834,330, 669,488 and 508,215 Btu/hr are shown in Figure 1, 2, and 3, appendix B, respectively. The NO_x for each of the three firing rates were found to be less than 500 ppm. Which is below the standards set by EPA. The SO₂ level for firing rate 669,488 and 508,215 Btu/hr were found to be about 2500 ppm, and between 2,500 and 3,000 ppm for the firing rate of 834,330 Btu/hr.

The percentage of O₂ and CO₂ by weight for the three firing rates are shown in Figure 4, 5, and 6, appendix B. As seen in these figures, the oxygen percentage is between 4 to 6 % by weight. The CO₂ percentage is between 13 to 16% by weight.

CONCLUSIONS

1. Particle size distribution on coal-water slurry fuel, plant coal, and recovered coal fines have been presented.
2. Elemental oxides for ash deposits, coal-water slurry and plant coal have been presented. The most detrimental oxides were found to be SiO₂, Al₂O₃ and Fe₂O₃ in which SiO₂ had the highest percentage of all the three samples.
3. Re-plots of gaseous emission data have been presented. The level of NO_x was found to be below the standards set by EPA, of 500 ppm.

APPENDIX A

COMBUSTION ANALYSIS OF COAL-WATER SLURRY FUEL PREPARED

FROM PLANT COAL AND RECOVERED COAL FINES

HOUSHANG MASUDI
MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY
PRAIRIE VIEW, TX 77446

SURENDER SAMUDRALA
MECHANICAL ENGINEERING DEPARTMENT
PRAIRIE VIEW A&M UNIVERSITY
PRAIRIE VIEW, TX 77446

ABSTRACT

In the process of coal cleaning operations, a significant amount of coal is washed away as waste into the ponds. Clearly, such a large quantity of dumped coal fines has a detrimental effect on the environment. This investigation presents an innovative approach to recover and utilize waste coal fines from the preparation plant effluent streams and tailing ponds. Due to the large moisture content of the recovered coal fines, this study is focused on the utilization of coal fines in the coal-water slurry fuel (CWSF). The CWSF consists of 53.3 percent weight solids with a viscosity of less than 500 centipoise and 80-90% of solids passing 200 mesh. The 53.3 percent weight solids constitute a blend of 15% effluent recovered coal fines and 85% clean coal. It is our premise that a blend of plant coal and recovered waste coal fines can be used to produce a coal-water slurry fuel with the desired combustion characteristics required by the industry. This paper includes the experimental data and analysis of plant coal, recovered coal fines and coal-water slurry as well as combustion characteristics of CWSF.

INTRODUCTION

Along with the mining and processing of coal there are substantial environmental problems. Recent studies have revealed that about 30 percent of the minerals from the underground coal mining operations are rejected on the surface as waste in the United States[1]. This accumulation of about 3 billion standard tons of fine and coarse coal refuse is mainly from coal cleaning processes. The coal fines that are rejected into the effluent ponds have a high percentage of pyrite sulfur, which causes a significant ground water pollution. Additionally, coal refuse disposal causes other environmental problems, such as acid formation, erosion and sediment control. Acres of land would be saved annually if the coal fines being rejected into the effluent ponds could be recovered by a cost effective process. An estimate by U. S. Bureau of Mines indicates 174,000 acres of coal refuse disposal remains unreclaimed [2].

Many methods have been developed to recover coal fines from effluent ponds. The recovered coal fines have a large moisture content. Even after a thorough dewatering process, the recovered fines can only achieve 22-25 percent moisture level. Because of this high moisture content, this investigation has lead to produce a coal-water slurry fuel that will have the combustion characteristics necessary to be utilized by industry. The recovered coal fines will have unique combustion characteristics due to its chemical composition, oxidation level, particle size distribution and moisture content. A slurry fuel produced from these fines will have unique combustion characteristics as well. To discover these characteristics, an analysis of the heating value, chemical composition, oxidation level, particle size distribution and moisture content for the slurry fuel and its feed stock is necessary. The production, application and utilization of coal-water slurry fuel will have a positive impact on the environment, while utilizing one of our most abundant natural resources.

EXPERIMENTAL PROCEDURE

Coal-Water Slurry Preparation

Approximately 1,850 lbs of 2" x 0" Peabody plant coal and 1,090 lbs of black water (pond) fines slurry were prepared into a coal-water fuel (CWF) for subsequent combustion tests. A 5-gallon composite as-received (AR)

plant coal sample was analyzed for proximate, ultimate, and heating values. The analyzed data are presented in Table 1. The AR plant coal was predominantly less than 1/4" but contained some large chunks up to 2". The AR plant coal, with a moisture content of 13.70 percent weight was visibly wet on surface. As a consequence, the plant coal was floor dried to remove surface moisture to facilitate proper functioning of comminution equipment. The plant coal was then stage crushed to 1/4" top size with a hammer-mill crusher, and then pulverized to a nominal 80% passing 200-mesh combustion grind using a hammer-mill pulverizer/mechanical separator system. The pulverized coal was analyzed for the moisture content, and particle size distribution via dry sieve and Malvern laser diffraction analysis as seen in Figure 1. The pond fines slurry, with an AR solids content of 21.63 percent weight, was thermally dewatered by using a steam coil to evaporate water. The concentrated slurry solids content was 41.95 percent weight. An attempt was initially made to mechanically dewater the pond fine slurry using a recessed plate frame filter press. However, the filters became quickly blinded, apparently by finely dispersed clay particles. The concentrated fines slurry was analyzed for particle size distribution via sieve and Malvern laser diffraction and then comminuted using a mechanically stirred ball mill and 1/8" stainless steel media. Wet milling was done to reduce the coarse coal particles, which would otherwise plug the CWF pumping and injection system. A composite sample of the milled fines slurry was analyzed for proximate, ultimate, heating values, which are presented in Table 1.

Table 1. Analysis of Bituminous CWF and Feedstocks			
	Plant Coal	Fines	Coal-Water Fuel
Proximate Analysis, wt%			
Moisture, as-recd	13.70	78.37	46.90
Volatile Matter, mf	40.46	22.88	37.91
Fixed Carbon, mf	46.83	20.40	42.34
Ash, mf	12.71	56.72	19.75
Ultimate Analysis, Wt%			
Hydrogen	4.65	1.83	7.40
Carbon	69.76	32.52	33.99
Nitrogen	1.24	0.68	0.57
Sulfur	3.50	2.82	1.84
Oxygen	8.14	5.42	45.71
Ash	12.71	56.72	10.49
Heating Value, Btu/lb. mf	12,130	5,440	10,985
Sulfur Input, lb./MMBtu	6.69	47.93	6.30
Ash Input, lb./MMBtu	10.48	104.26	17.98

The wet milled fines were also analyzed for particle size distribution via wet sieve and Malvern laser diffraction. The particle size distribution for recovered fines and wet milled fines are presented in Figure 2 and 3 respectively. Bench-scale rheological testing was performed using pulverized plant coal and wet milled pond fines blended in an 85/15 by weight ratio. The mass of CWF required for combustion testing was estimated from the ash-fouling furnace firing rate(s) and heating value of the CWF. The pulverized plant coal and wet milled fines slurry were then admixed with the required amount of deionized water in a 500-gallon stirred tank. The slurry was then pumped down to the barrels where minor adjustments of water content were made to achieve the desired viscosity. The final CWF, delivered to the combustion system, had a nominal solids content of 53.5 percent weight. A representative sample of the as-fired CWF was analyzed for proximate, ultimate, heating values; data are presented in Table 1. Ash x-ray fluorescence analysis of CWF and its feed stocks are presented in figure 4.

COMBUSTION TESTS

Pilot-scale combustion tests were conducted to determine the range of secondary air swirl required to maintain a stable combustion flame. Swirl is defined as the ratio of tangential momentum to axial momentum of the secondary air stream. Results obtained during flame stability testing have been tabulated and are presented in Table 2.

Table 2. Summary of Flame Stability Test Results											
Test Number:	AF-CTS-712			AF-CTS-713				AF-CTS-714			
Date:	8/02/95			8/03/95				8/04/95			
Time	1120	1145	1220	1030	1100	1120	1135	0930	1320	1345	1415
Swirl Setting	0.55	0.40	0.20	0.55	0.40	0.20	0.50	0.80	0.55	0.20	0.40
Carbon in Ash, %	2.83	1.68	1.94	2.20	1.62	1.35	1.65	4.06	3.36	3.88	3.92
Fuel Feed Rate, lb/hr	140.2			112.5				85.4			
Heat Input, Btu/hr	834,330			669,488				508,215			
FEGT, °F	2130	2137	2166	2136	2129	2132	2106	2011	1997	2016	2012
Furnace HVT Temp., °F	2195	2117	2142	2195	2187	2180	2167	2063	2038	1980	2002
Flue Gas Composition											
O ₂ , % dry	3.15	2.76	2.40	3.71	3.36	3.43	3.67	3.64	3.82	3.66	3.31
CO ₂ , % dry	16.5	17.9	16.4	16.8	17.6	17.6	17.5	15.2	14.9	15.1	15.3
SO ₂ , ppm	2895	3191	2943	2807	2806	2853	2813	2858	2403	2498	2665
NO _x , ppm	480	452	442	471	424	424	375	237	242	256	243
Excess Air, %	17.78	15.49	12.84	21.95	19.55	20.07	21.79	20.86	22.15	21.25	18.56

The coal-water fuel was fired at three firing rates (834,330 Btu/hr, 669,488 Btu/hr, and 508,215 Btu/hr) and at three burner settings for each firing rate. Flame temperature at a single point in the furnace was measured using a water cooled probe. The bituminous CWF was fired in a series of pilot-scale tests designed to determine the level of carbon conversions as a function of residence time and firing rate. Results of extractive sampling during a test run at 834,330 Btu/hr are presented in Table 3.

Table 3. Summary of Particle Extraction Test Results			
Test Number	AF-CTS-712		
Date	8/02/95		
Feed Rate lb/hr	140.2		
Firing Rate, Btu/hr	834,330		
Time	1311	1410	1522
Sampling Location	Bottom	Middle	Top
FEGT, °F	2153	2153	2172
Gas Volume, acfm	974.7	978.7	972.2
Residence Time, sec	0.59	1.10	1.68
Flue Gas Composition			
O ₂ , % dry	2.72	2.81	2.64
CO ₂ , % dry	15.9	15.9	16.7
SO ₂ , ppm	2264	2197	2213
NO _x , ppm	458	383	473
Excess Air, %	14.75	15.35	14.42
Moisture, %	2.12	2.71	2.07
LOI, %	84.01	39.60	6.44

Figure 1 Particle size distribution of plant coal

Simulated convective pass fouling probes were inserted in the refractory-lined ductwork at the furnace exit to collect deposits during extractive sampling. A summary of test fouling results is given in Table 4. Related test results are given in reference[3]. The chemical constituents of ash deposits as determined by x-ray fluorescence analysis are presented in Figure 7.

DISCUSSION OF THE RESULTS

The ultimate analysis given in Table 1 shows the sulfur content of CWF (1.84%) to be lower than the sulfur content of either plant coal or the recovered coal fines. This low percentage of sulfur was anticipated. The average sulfur content of the bituminous coal is 2.31%[4]. The oxygen level of the CWF is 45.71%, which is much higher than the plant coal (8.14%) and the fines (5.42%). The particle size distribution for the plant coal, recovered coal fines and CWF as shown in Figures 1, 2, and 3 give the percentage of the total mass within a size range. The maximum percentage of the particles by weight, was found to be in the size range of 36 to 88 microns, 3 to 27 microns and 9 to 77 microns for plant coal, recovered coal fines and coal-water slurry respectively. Figure 4 gives the elemental oxides for plant coal, recovered coal fines and coal-water slurry fuel. As seen from this figure the most detrimental oxides are SiO_2 , Al_2O_3 and Fe_2O_3 in which SiO_2 has the highest percentage in all the three samples. Some of the oxides such as P_2O_5 , CaO , MgO , Na_2O and K_2O have higher percentage in the recovered coal fines than in the plant coal. This is due to the fact that the waste coal fines contain mineral oxides.

Table 4. Summary of Ash Fouling Probe Test Results			
Test Number	AF-CTS-712	AF-CTS-713	AF-CTS-714
Date	8/02/95	8/02/95	8/02/95
Feed Rate, lb/hr	140.2	112.5	85.4
Firing Rate, Btu/hr	834,330	669,488	508,215
Length of runs, hrs	3.58	4.02	5.03
Operating Conditions:			
FEGT, °F	2,170	2,089	1,992
Probe Metal Temp., °F	996	1,004	978
Excess Air, %	14.01	21.39	21.20
Ash Input Rate, lb/MMBtu	17.97	17.97	17.97
Equivalent 5% Na_2O Ash input, lb/MMBtu	4.67	4.67	4.67
Ash Fouling Probe Sinter Layer Weight, g	971.4	839.8	608.3
Ash Specific Deposit Rate, g/Kg-input ash	40.64	39.00	29.74
Deposit Strength	454	347	329

NO_x emissions in ppm at a firing rate of 834,330 Btu/hr is shown in figure 5. As seen in the figure, the level of NO_x is just below 500 ppm which is less than the standards set by EPA (250-500 ppm). Since SO_2 emissions are not dependent on the furnace operating conditions; they are proportional to the amount of sulfur content in the fuel. The sulfur content in the fuel is considerably high, therefore, SO_2 emissions are about 2500 ppm as shown in Figure 6. Combustion results given in Table 2 reveal that at each of the two highest firing rates, combustion was relatively complete regardless of the swirl setting, therefore burner setting may be adjusted to provide a visually stable flame without concern for higher carbon in ash as a function of burner settings. At the lowest firing rate, each of the samples indicated similar fly-ash carbon contents, nearly twice the carbon content of the higher firing rates. Table 3 shows three sampling location, bottom, middle and top. As seen in the table the percent variation of O_2 and CO_2 is minimal.

The level of NO_x in ppm for the middle location is less than the level at the other two locations. This is due to the increase in percentage of excess air flow. Results given in Table 4 indicate that the fouling rate and deposit strengths increase with the firing rate and furnace exit gas temperature. The ash deposit data listed in Figure 7 show similar compositions for all components during each test. The main difference between each deposit is the sodium content, which can be seen to decrease with decreasing temperature and firing rate. When available, sodium plays a major role in determining the fouling rate and strength of deposits formed. The available sodium will react with free silica to form the low melting point phases which are responsible for deposit growth and strength development.

Figure 2 Particle size distribution of recovered coal fines

Figure 5 Concentrations of NO_x in the flue gas during a test run at 834,330 Btu/hr

Figure 3 Particle size distribution of CWS fuel

Figure 6 Concentrations of SO_2 in the flue gas during a test run at 834,330 Btu/hr

Figure 4 Ash x-ray fluorescence analysis of CWS and feedstocks

Figure 7 X-ray fluorescence analysis of ash deposits

CONCLUSIONS

The results of this study strongly support the following conclusions:

1. A method to recover and utilize the waste fines from preparation plant, effluent stream and tailing ponds has been proposed.
2. Information on plant coal, recovered coal fines, slurry fuel and ash deposits have been presented.
3. The sulfur and ash contents of the coal-water slurry fuel was found to be lower than plant coal and recovered coal fines.
4. The NO_x level was found to less than 500 ppm, which is less than the standards set by EPA.
5. The amount of ash for fuel was found to be less than the blend of plant coal and recovered coal fines.
6. The utilization of waste coal fines has an enormous impact on the environment by saving the land area previously reserved for effluent ponds.

ACKNOWLEDGMENTS

This research was supported by U. S. Department of Energy, Pittsburgh Energy Technology Center, under the Grant No. DE-FG22-94PC94122. This support is gratefully acknowledged. The authors wish to thank Peabody Coal Company for providing the coal samples; and Mr. Jay Gunderson at Energy and Environmental Research Center at the University of North Dakota for technical advise.

REFERENCES

1. Sciulli, A. G., Ballock, G. P., and Wu, K. K., 1986, "Environmental Approach to Coal Refuse Disposal," Mining Engineering, pp 181.
2. Tatscha, J. H., 1980, "Coal Deposits: Origin, Evolution, and Present Characteristics", Tatsch Associates, Sudburgh, Massachusetts, pp 36.
3. Masudi, H., and Surender, S., 1996, "Chemical Constituents of Coal-Water Slurry Prepared from Plant Coal and Effluent Recovered Coal Fines and its Combustion Disposals," Energy Week 96, Houston, Texas, Feb 1996.
4. White, D. M., Edwards, O. L., and Dubose, D. A., 31 Aug, 1993, "Trace Elements in Texas Lignite," Final report prepared for Texas Energy and Natural Resources Advisory Council Energy Development Fund, Project # 80-L-710C.

APPENDIX B

Emissions data obtained during a test run at 834,330 Btu/hr

Time(actual)	Time(min)	O2	CO2	CO2	SO2	SO2	CO	NOx	EXCESS-AIR (%)	FUEL-INP(lb/hr)	FIR-CALC(Btu/hr)
11:12 AM	0	4.778	15.529	14.359	2735.71	2413.28	0	491.211	20.204	126.03	750000
11:17 AM	5	4.489	15.793	14.542	2774.79	2537.86	0	473.633	18.555	126.03	750000
11:22 AM	10	4.279	15.595	14.634	2843.18	2606.25	0	480.469	17.463	126.03	750000
11:27 AM	15	4.607	15.529	14.45	2870.05	2584.27	0	485.352	18.517	126.03	750000
11:31 AM	20	4.817	15.513	14.328	2796.77	2574.49	0	504.883	21.872	126.03	750000
11:36 AM	25	4.108	16.831	15.373	2940.88	2677.08	0	476.563	16.019	126.03	750000
11:41 AM	30	3.977	17.308	15.844	2928.67	2725.94	0	452.148	15.705	126.03	750000
11:46 AM	35	4.24	17.059	15.583	2940.88	2677.08	0	480.957	16.765	126.03	750000
11:51 AM	40	4.289	17.29	15.729	2957.98	2659.99	0	478.027	16.49	126.03	750000
11:56 AM	45	4.441	17.542	15.745	2896.92	2691.74	0	445.801	17.9	126.03	750000
12:01 PM	50	3.933	17.999	16.444	2967.75	2774.79	0	437.012	14.981	126.03	750000
12:06 PM	55	3.361	18.259	17.096	3080.11	2860.28	0	436.523	14.04	126.03	750000
12:11 PM	60	3.322	18.315	17.218	4052.27	2882.26	0	460.938	14.02	126.03	750000
12:26 PM	65	3.522	16.657	15.518	2936	2799.21	0	454.59	11.425	126.03	750000
12:31 PM	70	4.128	16.093	15.245	2948.21	2696.62	0	432.129	15.02	126.03	750000
12:36 PM	75	3.229	16.57	16.242	2938.44	2882.26	0	406.25	12.394	126.03	750000
12:41 PM	80	2.985	16.709	16.444	2975.08	2899.36	0	460.938	11.433	126.03	750000
12:46 PM	85	3.898	16.093	15.518	2916.46	2769.9	0	454.102	13.924	126.03	750000
12:51 PM	90	3.894	16.178	15.47	2896.92	2706.4	0	482.91	13.478	126.03	750000
12:56 PM	95	3.913	16.127	15.389	2940.88	2716.17	0	481.445	13.469	126.03	750000
1:16 PM	110	4.074	15.876	15.071	2264.28	2699.07	0	458.008	14.753	126.03	750000
1:21 PM	115	4.03	15.842	15.309	2269.17	2755.25	0	457.52	13.845	126.03	750000
1:26 PM	120	4.016	16.076	15.421	2266.73	2718.61	0	446.777	13.921	126.03	750000
1:31 PM	125	3.889	16.195	15.47	2249.63	2706.4	0	453.125	12.872	126.03	750000
1:36 PM	130	3.928	16.093	15.55	2357.1	2725.94	0	423.828	12.582	126.03	750000
1:41 PM	135	4.05	15.959	15.325	2249.63	2696.62	0	477.051	13.407	126.03	750000
1:46 PM	140	4.406	15.431	14.742	2110.4	2635.56	0	464.355	17.191	126.03	750000
1:51 PM	145	4.362	14.251	15.008	2178.79	2667.31	0	454.102	26.905	126.03	750000
1:56 PM	150	4.377	14.667	14.805	2169.02	2655.1	0	461.914	21.667	126.03	750000
2:01 PM	155	4.089	14.839	15.103	2173.91	2681.97	0	457.031	19.757	126.03	750000
2:06 PM	160	4.216	13.741	15.118	2203.22	2603.81	0	412.598	30.063	126.03	750000
2:11 PM	165	4.099	11.424	15.214	2215.43	2674.64	0	366.211	55.704	126.03	750000
2:16 PM	170	4.123	10.913	15.229	2195.89	2674.64	0	297.852	67.464	126.03	750000
2:21 PM	175	4.138	12.628	15.214	2156.81	2677.08	0	375	45.35	126.03	750000
2:26 PM	180	4.162	11.98	15.166	2176.35	2664.87	0	364.258	55.315	126.03	750000
2:31 PM	185	4.108	13.565	15.341	2203.22	2694.18	0	395.02	36.865	126.03	750000
2:41 PM	190	4.108	15.892	15.277	2166.58	2684.41	0	520.508	16.063	126.03	750000
2:46 PM	195	4.099	15.926	15.277	2232.53	2689.3	0	506.348	16.525	126.03	750000
2:51 PM	200	4.123	15.942	15.198	2222.76	2721.05	0	507.324	16.171	126.03	750000
2:56 PM	210	4.118	16.06	15.198	2178.79	2718.61	0	485.84	16.819	126.03	750000
3:01 PM	215	4.06	15.776	15.277	2230.09	2721.05	0	514.648	14.389	126.03	750000
3:06 PM	220	4.079	16.043	15.198	2198.33	2706.4	0	522.461	14.725	126.03	750000
3:10 PM	225	4.084	16.11	15.134	2276.5	2708.84	0	522.461	14.582	126.03	750000
3:15 PM	230	4.089	16.622	15.15	2230.09	2713.72	0	513.184	14.373	126.03	750000
3:20 PM	235	4.045	16.813	15.245	2195.89	2703.95	0	467.285	14.004	126.03	750000

Emissions data obtained during a test run at 834,330 Btu/hr

3:25 PM	240	4.446	16.779	15.008	754.763	2474.35	0	439.453	14.88	126.03	750000
3:35 PM	245	4.226	16.744	15.182	2950.65	2882.26	0	442.871	14.24	126.03	750000
3:40 PM	250	4.177	17.042	15.182	2975.08	2686.85	0	439.941	13.924	126.03	750000
3:45 PM	255	3.635	17.633	16.275	2989.74	2757.69	0	440.918	10.896	126.03	750000
3:50 PM	260	3.224	17.633	16.141	3048.36	2850.51	0	446.777	10.339	126.03	750000
3:55 PM	265	3.029	17.362	16.191	3094.77	2845.62	0	486.816	8.761	126.03	750000
4:00 PM	270	3.703	16.918	15.389	3045.92	2752.8	0	496.094	10.354	126.03	750000
4:05 PM	275	4.309	17.13	14.805	3065.46	2657.54	0	480.469	10.182	126.03	750000
4:10 PM	280	3.879	17.326	15.277	3106.98	2708.84	0	483.398	7.161	126.03	750000
4:15 PM	285	3.918	17.742	15.229	3092.33	2703.95	0	490.234	7.418	126.03	750000
4:20 PM	290	3.786	18.166	15.198	3148.51	2750.36	0	471.68	5.578	126.03	750000
4:30 PM	295	4.748	15.809	14.222	2906.69	2603.81	0	493.652	19.244	126.03	750000
4:35 PM	300	5.208	15.562	14.013	2818.75	2496.33	0	466.309	21.169	126.03	750000
4:40 PM	305	5.129	15.677	14.027	2823.64	2518.32	0	480.469	21.027	126.03	750000
4:45 PM	310	5.213	15.776	14.102	2816.31	2503.66	0	459.961	20.987	126.03	750000
4:50 PM	315	5.203	15.992	14.072	2811.43	2491.45	0	465.332	21.055	126.03	750000
4:55 PM	320	5.237	16.06	14.147	2838.3	2513.43	0	509.766	21.364	126.03	750000
5:00 PM	325	5.217	16.127	14.162	2826.08	2523.2	0	468.75	21.241	126.03	750000
5:05 PM	330	5.217	16.313	14.192	2857.84	2530.53	0	433.594	20.977	126.03	750000

Emission data obtained during a test run at 669,488

Time(actual)	Time(min)	O2	CO2	CO2	SO2	SO2	CO	NOx	EXCESS-AIR	FUEL-INP	FIR-CALC
10:22 AM	0	6.248	15.545	13.571	2576.94	2076.2	0	520.508	30.188	105	624855
10:27 AM	5	5.716	15.992	14.253	2713.72	2244.74	0	508.789	26.292	105	624855
10:32 AM	10	5.657	16.279	14.298	2769.9	2318.02	0	490.723	24.764	105	624855
10:37 AM	15	5.598	16.45	14.313	2774.79	2337.56	0	489.746	23.152	105	624855
10:42 AM	20	5.32	16.692	14.68	2811.43	2379.09	0	475.098	22.083	105	624855
10:47 AM	25	5.467	16.779	14.557	2801.66	2398.63	0	448.242	22.931	105	624855
10:52 AM	30	4.665	17.596	15.277	2874.93	2513.43	0	453.613	16.831	105	624855
10:57 AM	35	5.012	17.272	14.945	2833.41	2440.15	0	448.242	18.862	105	624855
11:02 AM	40	5.017	17.76	14.929	2808.98	2437.71	0	405.762	19.247	105	624855
11:07 AM	45	5.164	17.578	14.758	2777.23	2413.28	0	429.199	20.009	105	624855
11:12 AM	50	5.051	17.614	14.914	2806.54	2449.92	0	430.176	19.487	105	624855
11:17 AM	55	5.125	17.506	14.742	2830.97	2462.14	0	431.152	19.455	105	624855
11:22 AM	60	5.242	17.651	14.758	2838.3	2462.14	0	421.875	20.139	105	624855
11:27 AM	65	5.227	17.47	14.898	2879.82	2493.89	0	429.199	20.298	105	624855
11:32 AM	70	5.105	17.542	14.914	2840.74	2491.45	0	419.922	19.784	105	624855
11:37 AM	75	5.296	17.87	14.789	2857.84	2520.76	0	362.793	20.968	105	624855
11:42 AM	80	5.672	17.308	14.588	2743.03	2386.41	0	376.465	22.932	105	624855
11:47 AM	85	5.442	17.578	14.742	2796.77	2447.48	0	377.441	21.496	105	624855
11:52 AM	90	5.403	17.47	14.789	2826.08	2476.79	0	368.652	21.167	105	624855
11:57 AM	95	5.554	17.308	14.573	2843.18	2452.36	0	387.695	22.369	105	624855
12:02 PM	100	5.462	16.831	14.511	2835.85	2423.05	0	358.887	23.897	105	624855
12:07 PM	105	5.261	16.883	14.742	2794.33	2452.36	0	365.234	22.632	105	624855
12:27 PM	125	6.009	12.738	13.211	2496.33	2310.69	0	318.359	36.173	105	624855
12:32 PM	130	5.882	12.18	13.268	2462.14	2308.25	0	315.918	40.727	105	624855
12:37 PM	135	5.799	14.266	13.455	2613.58	2357.1	0	341.309	8.384	105	624855
12:42 PM	140	5.721	14.651	13.571	2838.3	2388.86	0	361.816	23.33	105	624855
12:47 PM	145	5.471	14.823	13.688	2845.62	2430.38	0	315.43	21.219	105	624855
12:52 PM	150	5.369	14.95	13.849	2904.25	2447.48	0	331.543	20.729	105	624855
12:57 PM	155	5.486	15.061	13.835	2904.25	2471.91	0	343.75	21.046	105	624855
1:02 PM	160	5.594	15.205	13.629	2936	2454.81	0	303.711	21.699	105	624855
1:07 PM	165	5.305	15.318	14.192	2931.11	2498.77	0	324.219	20.315	105	624855
1:12 PM	170	5.252	15.302	14.132	2901.8	2496.33	0	358.887	20.101	105	624855
1:17 PM	175	5.286	15.366	14.072	2914.02	2506.1	0	382.813	20.225	105	624855
1:22 PM	180	5.735	14.745	13.658	2811.43	2437.71	0	387.207	23.548	105	624855
1:27 PM	185	5.437	15.253	13.732	2835.85	2454.81	0	359.375	21.678	105	624855
1:32 PM	190	5.364	14.543	13.776	2738.15	2467.02	0	353.516	27.985	105	624855
1:37 PM	200	5.594	14.205	13.615	2681.97	2484.12	0	310.547	30.919	105	624855
1:42 PM	205	5.613	13.697	13.498	2635.56	2469.46	0	307.617	34.521	105	624855
1:46 PM	210	5.628	12.247	13.6	2498.77	2498.77	0	304.688	50.363	105	624855
1:56 PM	220	5.642	15.045	13.455	2816.31	2469.46	0	378.906	21.898	105	624855
2:01 PM	225	5.467	15.334	13.673	2860.28	2513.43	0	373.535	19.971	105	624855

Emission data obtained during a test run at 669,488

2:06 PM	230	5.642	15.125	13.47	2867.61	2501.22	0	363.77	21.708	105	624855
2:11 PM	235	5.691	15.077	13.542	2838.3	2474.35	0	340.82	21.264	105	624855
2:16 PM	240	5.765	15.125	13.397	2882.26	2508.54	0	335.449	21.637	105	624855
2:21 PM	245	5.662	15.205	13.498	2848.07	2493.89	0	363.77	20.914	105	624855
2:26 PM	250	5.677	15.141	13.383	2901.8	2518.32	0	375.488	21.213	105	624855
2:31 PM	255	5.589	15.061	13.383	2855.39	2489	0	400.391	20.693	105	624855
2:36 PM	260	5.838	14.886	13.126	2892.03	2501.22	0	405.273	22.279	105	624855
2:41 PM	265	6.004	14.792	13.056	2835.85	2464.58	0	389.648	22.646	105	624855
2:46 PM	270	5.96	14.966	13.126	2828.53	2435.27	0	377.93	21.692	105	624855
2:51 PM	275	5.989	14.871	13.126	2872.49	2474.35	0	369.629	22.892	105	624855
2:56 PM	280	5.989	15.061	13.169	2874.93	2464.58	0	391.602	22.592	105	624855
3:01 PM	285	5.862	15.029	13.297	2911.57	2467.02	0	416.992	21.606	105	624855
3:06 PM	290	5.833	15.302	13.326	2877.38	2449.92	0	387.695	20.556	105	624855
3:11 PM	295	5.75	15.399	13.513	2938.44	2501.22	0	414.063	20.025	105	624855
3:16 PM	300	5.471	15.71	13.746	2940.88	2506.1	0	375.488	17.36	105	624855
3:21 PM	305	5.383	15.66	13.79	2936	2537.86	0	399.414	17.579	105	624855
3:26 PM	310	5.97	15.334	13.297	2906.69	2510.99	0	390.625	20.215	105	624855
3:31 PM	315	5.931	15.334	13.311	2894.48	2496.33	0	401.367	19.867	105	624855
3:36 PM	320	5.628	15.892	13.644	2999.51	2493.89	0	398.926	15.167	105	624855

Emissions data obtained during a test run at 508,215

Time(actual)	Time(min)	O2	CO2	CO2	SO2	SO2	CO	NOx	EXCESS-AIR(%)	FUEL-INP(lb/hr)	FIR-CALC Btu/hr)
8:49 AM	0	9.443	10.962	10.019	2054.22	1629.21	0	376.953	69.289	85	505835
8:54 AM	5	8.525	12.14	10.959	2298.48	1814.85	0	325.684	51.763	85	505835
8:59 AM	10	7.816	12.78	11.614	2462.14	1993.16	0	296.875	44.628	85	505835
9:04 AM	15	7.772	12.892	11.232	2449.92	2005.37	0	286.621	43.361	85	505835
9:09 AM	20	6.649	13.874	12.406	2606.25	2188.56	0	290.039	33.157	85	505835
9:14 AM	25	4.875	15.611	14.117	2914.02	2525.64	0	267.09	18.068	85	505835
9:19 AM	30	5.711	15.125	13.24	2828.53	2425.5	0	266.113	23.128	85	505835
9:24 AM	35	5.525	15.205	13.658	2879.82	2401.07	0	254.395	21.02	85	505835
9:29 AM	40	5.427	15.061	13.629	2879.82	2447.48	0	258.301	22.629	85	505835
9:34 AM	45	5.54	14.745	13.556	2816.31	2430.38	0	237.305	23.66	85	505835
9:39 AM	50	4.704	15.611	14.465	2879.82	2525.64	0	229.98	17.467	85	505835
9:44 AM	55	4.993	15.237	14.207	2855.39	2545.18	0	223.633	19.7	85	505835
9:49 AM	60	5.31	15.109	13.761	2838.3	2469.46	0	213.867	20.357	85	505835
9:54 AM	65	5.203	14.95	13.938	2872.49	2501.22	0	205.566	19.173	85	505835
9:59 AM	70	5.256	14.886	13.953	2857.84	2469.46	0	209.961	20.43	85	505835
10:04 AM	75	5.325	13.785	13.746	2955.54	2474.35	0	173.34	30.292	85	505835
10:09 AM	80	5.369	13.26	13.909	2769.9	2445.04	0	181.152	36.399	85	505835
10:14 AM	85	5.569	15.189	13.776	2730.82	2449.92	0	222.656	20.662	85	505835
10:19 AM	90	5.598	15.221	13.776	2840.74	2452.36	0	200.195	21.025	85	505835
10:24 AM	95	5.491	15.173	13.761	2872.49	2486.56	0	203.125	20.657	85	505835
10:29 AM	100	5.442	15.189	13.835	2879.82	2481.68	0	195.313	20.768	85	505835
10:34 AM	105	5.452	15.302	13.82	2889.59	2491.45	0	199.219	20.909	85	505835
10:39 AM	110	5.408	15.189	13.849	2914.02	2525.64	0	195.801	21.051	85	505835
10:44 AM	115	5.686	14.966	13.542	2813.87	2479.23	0	187.5	23.851	85	505835
10:49 AM	120	5.662	14.839	13.673	2852.95	2449.92	0	166.016	23.768	85	505835
10:54 AM	125	5.447	14.886	13.849	2870.05	2457.25	0	179.199	23.711	85	505835
10:59 AM	130	5.491	15.157	13.879	2843.18	2469.46	0	188.477	22.442	85	505835
11:04 AM	135	5.559	15.302	13.79	2811.43	2432.82	0	200.195	21.586	85	505835
11:08 AM	140	5.506	15.366	13.968	2855.39	2484.12	0	203.125	21.036	85	505835
11:13 AM	145	5.476	15.399	14.222	2865.16	2386.41	0	197.754	20.939	85	505835
11:18 AM	150	5.379	15.431	14.359	2860.28	2513.43	0	173.34	20.596	85	505835
11:33 AM	165	5.413	12.1	13.513	2525.64	2405.96	0	177.246	47.656	85	505835
11:38 AM	170	5.471	14.776	13.513	2489	2423.05	0	223.633	21.417	85	505835
11:43 AM	175	5.457	14.902	13.527	2525.64	2413.28	0	231.934	20.47	85	505835
11:48 AM	180	5.53	14.855	13.455	2484.12	2413.28	0	228.027	21.088	85	505835
11:53 AM	185	5.442	14.934	13.644	2542.74	2440.15	0	224.121	20.34	85	505835
11:58 AM	190	5.418	14.997	13.644	2498.77	2423.05	0	244.141	20.359	85	505835
12:03 PM	195	5.393	15.013	13.629	2532.97	2437.71	0	242.188	20.224	85	505835

Emissions data obtained during a test run at 508,215

12:08 PM	200	6.092	14.45	12.957	2425.5	2344.89	0	243.164	25.053	85	505835
12:13 PM	205	6.165	14.419	12.748	2432.82	2330.24	0	246.094	25.845	85	505835
12:18 PM	210	6.219	14.266	12.693	2359.55	2274.06	0	225.098	26.833	85	505835
12:23 PM	215	5.818	14.558	13.112	2506.1	2418.17	0	215.332	24.3	85	505835
12:28 PM	220	5.716	14.266	13.112	2469.46	2403.51	0	223.633	24.831	85	505835
12:33 PM	225	5.686	14.574	13.226	2454.81	2401.07	0	234.375	22.79	85	505835
12:38 PM	230	5.686	14.667	13.283	2432.82	2381.53	0	219.238	22.895	85	505835
12:43 PM	235	5.491	14.729	13.426	2542.74	2467.02	0	206.543	21.974	85	505835
12:48 PM	240	5.291	14.886	13.542	2559.84	2491.45	0	219.727	21.098	85	505835
12:58 PM	250	5.105	15.513	13.879	2586.71	2528.09	0	235.352	16.492	85	505835
1:03 PM	255	5.144	15.48	13.571	2618.46	2535.41	0	241.211	16.68	85	505835
1:08 PM	260	5.134	15.726	13.82	2567.17	2498.77	0	249.023	15.96	85	505835
1:13 PM	265	5.403	15.677	13.571	2547.63	2481.68	0	246.094	16.466	85	505835
1:18 PM	270	5.76	15.366	13.14	2506.1	2423.05	0	243.652	19.6	85	505835
1:23 PM	275	5.809	15.157	13.112	2513.43	2457.25	0	238.281	19.334	85	505835
1:28 PM	280	5.97	15.205	13.056	2427.94	2354.66	0	227.051	20.142	85	505835
1:33 PM	285	6.903	14.297	12.583	2256.96	2169.02	0	260.254	27.756	85	505835
1:38 PM	290	6.619	14.527	12.721	2369.32	2274.06	0	239.746	25.006	85	505835
1:43 PM	295	5.931	15.431	13.24	2447.48	2391.3	0	243.164	18.491	85	505835
1:48 PM	300	6.248	15.66	13.013	2420.61	2379.09	0	238.281	16.139	85	505835
1:53 PM	305	6.961	14.589	12.887	2205.66	2098.19	0	270.996	30.73	85	505835
1:58 PM	310	4.778	15.611	14.45	2650.22	2591.59	0	264.16	16.907	85	505835
2:03 PM	315	5.178	14.342	13.879	2532.97	2493.89	0	254.395	24.558	85	505835
2:08 PM	320	4.851	15.253	14.162	2681.97	2630.67	0	252.93	17.907	85	505835
2:13 PM	325	4.446	15.285	14.758	2757.69	2738.15	0	234.863	18.049	85	505835
2:18 PM	330	3.884	15.726	15.68	2669.76	2601.36	0	239.258	16.186	85	505835
2:23 PM	335	4.709	15.093	14.162	2640.44	2618.46	0	247.07	19.452	85	505835
2:28 PM	340	4.949	14.981	14.027	2594.04	2562.28	0	251.465	20.564	85	505835

Figure 1. Concentrations of SO₂ and NO_x from flue gas during a test run at 834,330 Btu/hr

Figure 2. Concentrations of SO₂ and NO_x from the flue gas during a test run at 669,488 Btu/hr

Figure 3. Concentrations of SO₂ and NO_x in the flue gas during a test run at 508,215 Btu/hr

Figure 4. Concentrations of O₂ and CO₂ from the flue gas during a test run at 834,330 Btu/hr

Figure 5. Concentrations of O₂ and CO₂ from the flue gas during a test run at 669,488 Btu/hr

Figure 6. Concentrations of O₂ and CO₂ in the flue gas during a test run at 508,215Btu/hr