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COMBUSTION CHARACTERIZATION OF COAL FINES RECOVERED FROM THE HANDLING PLANT

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ABSTRACT

The main goal of this research project is to evaluate the combustion characteristics of the slurry fuels prepared from the recovered coal fines and plant coal fines. A specific study was completed which collected data on combustion behavior, flame stability, ash behavior and emission of SO_2 NO_x, and particulate in a well insulated laboratory scale furnace in which the residence time and temperature history of the burning particles are similar to that of utility boiler furnace at 834,330 Btu/hr input and an average of 15% excess air. The slurry fuel was prepared at 53.5% solid to match the generic slurry properties. The coal blend was prepared using a mix of 15% wet milled pond fines and 85% plant fines. Combustion characteristics of the slurry fuels were determined at three different firing rates: 834,330 Btu/hr, 669,488 Btu/hr and 508,215 Btu/hr. Finally a comparison of the results is being developed to determine the advantages of coal water slurry fuel over the plant coal blended form.

OBJECTIVES

The main objective of this project is to determine the combustion characteristics of coal-water slurry fuel prepared from the recovered coal fines and plant coal fine fractions.

The specific goals of this project are:

- Preparation of a stable coal water fuel and evaluation of its rheological properties
- Determination of the flame stability properties of the resultant fuel as a function of burner settings and firing rates
- Determination of the combustion efficiency for the coal water slurry fuel as a function of residence time in the furnace and firing rates
- Evaluation of the fuel's fouling potential at each firing rate
- Examination of emissions of SO_2, NO_x, CO, CO_2, and O_2

INTRODUCTION

During this period, experiments associated with the evaluation of bituminous coal water fuel were completed. The experiments were conducted from August 2 - 4, 1995 at the Engineering Environmental Research Center (EERC) at North Dakota State University. The principal investigator, Dr. H. Masudi, and the graduate research assistants, S. Samudrala and O. Mohannad, were present at the facility to monitor the experiments. The coal used in the experiment was donated by the Peabody Coal Company and was shipped directly from their coal mines in Marissa, Illinois to the EERC.

EXPERIMENTAL PROCEDURE SUMMARY

Task 2 - Preparation of the Bituminous Coal-Water Fuel

Approximately 1850 lb of 2" x 0" Peabody plant coal and approximately 1090 lb of black water pond fines slurry was prepared into a coal -water fuel for testing. An as-received sample of the plant coal was analyzed for proximate, ultimate, heating value, and ash composition analyses. After the plant coal was floor dried to remove surface moisture, it was stage crushed to 1/4" top size using a hammer-mill pulverizer/mechanical separator system. The pulverized coal was also analyzed for moisture content and particle size.

The pond fines slurry was thermally dewatered using a steam coal to evaporate water. The fines slurry was analyzed for particle size distribution and then comminuted using a mechanically stirred ball mill and 1/8" stainless steel media. A sample of the milled fines slurry was analyzed for proximate, ultimate, heating value and ash composition. These fines were also analyzed for particle size distribution.

Bench scale rheological testing was performed using pulverized plant coal and wet milled pond fines blended in a 85/15 by weight ration. The pulverized plant coal and wet milled fines slurry was admixed with the required amount of deionized water in a 500 gallon stirred tank. The slurred was then pumped into barrels where minor adjustments to the water content were made to achieve the desired viscosity. A sample of the final coal-water slurry product was also analyzed for proximate, ultimate, heating value and ash composition.

The proximate analysis for the plant coal, as received coal fines and coal-water fuel are shown in Table 1. The ultimate analyses for these materials is contained in Table 2. Heating value, sulfur input and ash input data are in Table 3. And, ash composition analyses are shown in Table 4.

Table 1. Proximate Analysis of Bituminous CWF & Feedstocks

	Plant Coal	Fines	CWF
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	19.75
Ash, mf	12.71	56.72	19.75

Table 2. Ultimate Analysis of Bituminous CWF & Feedstocks

	Plant Coal	Fines	CWF
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

Table 3. Heating Value, Sulfur and Ash Input for Bituminous CWF & Feedstocks

	Plant Coal	Fines	CWF
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

Table 4. Ash Composition for Bituminous CWF & Feedstocks

	Plant Coal	Fines	CWF
wt%			
SiO_2	56.1	60.9	55.6
Al_2O_3	20.9	18.2	21.4
Fe_2O_3	12.7	7.1	10.3
TiO_2	1.1	0.8	0.8
P_2O_5	0.0	0.3	0.2
CaO	2.4	4.2	3.7
MgO	1.9	2.7	2.3
Na_2O	0.7	1.3	1.3
K_2O	1.6	2.4	2.2
SO_3	2.6	2.1	2.1
Total	100.0	100.0	99.9

Task 3 - Feed Line/Furnace/Burner Characterization

Calibration and characterization of all equipment was performed by the EERC.

Task 4- Combustion Characterization of Slurry Fuel

To determine flame stability characteristics and combustion efficiency as a function of burner settings and firing rate, the fuel was fired at three distinct firing rates (834,330 Btu/hr, 669,488 Btu/hr, 508,215 Btu/hr) with three distinct burner settings for each firing rate.

At each burner setting, primary and secondary air flow measurements, % carbon in ash, and furnace exit gas temperatures were recorded. In addition, a flue gas analysis was performed at each burner setting. This data is recorded in Table 5. From observations of the % carbon in ash at the two highest firing rates, it is clear that burner setting adjustments will not cause higher percentages of carbon in ash. Similarly, at the lowest firing rate, burner settings can be adjusted without causing drastic changes in the percentage of carbon in ash. However, at this low firing rate, the carbon content is approximately twice as high as the carbon content for the two highest firing rates.

At each firing rate, the burner was also set to a constant swirl setting. During a 5.25 hour period, ash fouling particulate was extracted from the bottom, middle, and top of the furnace. Flue gas composition, carbon content (LOI%), and moisture content was recorded for the particulate in order to observe carbon conversion as a function of residence time and firing rate. The particulate data is shown in Table 6.

Simulated convective pass fouling probes were inserted in the refractory-lined ductwork at the furnace exit to collect deposits during extractive sampling. Due to the high ash content of the coal-water fuel, the test period was less than the standard 5.25 hours. The results shown in Table 7, indicate that fouling rate and deposit strength increase with firing rate and furnace exit gas temperature.

Table 5. Summary of Flame Stability Test Results

Test Number: / Date:	AF-CTS-712 8/02/95			AF-CTS-713 8/03/95				AF-CTS-714 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
Primary Air Flow, scfm	15.88	16.10	15.57	13.08	12.08	11.83	11.97	8.80	8.56	8.61	8.44
Secondary Air Flow, scfm	118.62	115.13	116.30	100.43	99.20	100.49	100.03	70.19	69.65	69.96	69.59
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

Table 6. Summary of Particulate 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	1615	1644	1658
Sampling Location	Bottom	Middle	Top	Top	Middle	Bottom
FEGT, °F	2153	2153	2172	2191	2159	2155
Gas Volume, acfm	974.7	978.7	972.2	963.1	1019.8	1020.3
Residence Time, sec	0.59	1.10	1.68	1.70	1.06	0.56
Flue Gas Composition						
O_2, % dry	2.72	2.81	2.64	2.44	3.65	3.63
CO_2, % dry	15.9	15.9	16.7	16.9	15.8	16.2
SO_2, ppm	2264	2197	2213	3103	2818	2842
NO_x, ppm	458	383	473	481	468	451
Excess Air, %	14.75	15.35	14.42	13.19	21.06	21.11
Moisture, %	2.12	2.71	2.07	2.85	2.54	3.22
LOI, %	84.01	39.60	6.44	6.60	22.41	84.84

Test Number	AF-CTS-713					
Date	8/03/95					
Feed Rate, lb/hr	112.5					
Firing Rate, Btu/hr	669,488					
Time	1205	1227	1257	1337	1414	1450
Sampling Location	Bottom	Bottom	Middle	Middle	Top	Top
FEGT, °F	2086	2070	2077	2085	2078	2087
Gas Volume, acfm	831.6	840.2	819.6	821.6	821.6	826.6
Residence Time, sec	0.69	0.68	1.32	1.32	1.99	1.98
Flue Gas Composition						
O_2, % dry	3.89	4.19	3.69	3.74	3.74	3.87
CO_2, % dry	16.9	14.5	15.0	14.9	15.1	14.9
SO_2, ppm	2815	2479	2898	2723	2863	2846
NO_x, ppm	362	317	324	333	347	379
Excess Air, %	23.26	24.69	21.17	21.51	21.54	22.41
Moisture, %	1.78	1.92	1.59	1.27	0.00[1]	0.00[1]
LOI, %	84.78	84.76	15.48	17.02	1.45	2.33

[1]The calculation of moisture content resulted in a negative value.

Summary of Particulate Extraction Test Periods (Table 6 cont.)

Test Number Date Feed Rate, lb/hr Firing Rate, Btu/hr	AF-CTS-714 8/04/95 85.4 508,215					
Time Sampling Location	0956 Top	1027 Top	1056 Middle	1128 Middle	1221 Bottom	1243 Bottom
FEGT, °F	2002	1988	1977	1979	1957	1961
Gas Volume, acfm	616.8	620.3	631.4	619.8	641.4	627.9
Residence Time, sec	2.65	2.64	1.71	1.74	0.90	0.91
Flue Gas Composition						
O_2, % dry	3.53	3.64	3.98	3.60	4.30	3.88
CO_2, % dry	15.0	15.2	15.0	15.4	14.4	14.7
SO_2, ppm	2856	2864	2855	2860	2433	2488
NO_x, ppm	210	200	178	173	220	213
Excess Air, %	19.99	20.82	23.31	20.60	25.57	22.43
Moisture, %	0.00[1]	0.33	1.28	1.83	1.91	1.20
LOI, %	1.25	3.65	19.03	28.50	84.89	84.93

[1]The calculation of moisture content resulted in a negative value.

Table 7. Summary of Ash Fouling Probe Test Results

	AF-CTS-712	AF-CTS-713	AF-CTS-714
Date	8/02/95	8/03/95	8/04/95
Feed Rate, lb/hr	140.2	112.5	85.4
Firing Rate, Btu/hr	834,330	669,488	508,215
Length of Run, 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[1], 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
Deposit Composition, wt%			
Sample Number	95-0912	95-0913	95-0914
SiO_2	54.80	55.20	55.10
Al_2O_3	18.30	18.50	18.20
Fe_2O_3	13.40	13.50	14.60
TiO_2	0.90	0.90	0.90
P_2O_5	0.30	0.10	0.20
CaO	5.70	5.70	6.20
MgO	1.60	1.60	1.40
Na_2O	2.80	2.00	1.00
K_2O	2.40	2.40	2.50
SO_3	0.00	0.00	0.00
Total	100.20	99.90	100.10
SiO_2/Al_2O_3	2.99	2.98	3.03

PROJECT STATUS

• Task 1 - Procurement and Processing of Test Samples	COMPLETE
• Task 2 - Preparation of the Coal-Water Slurry	COMPLETE
• Task 3 - Feed Line/Furnace/Burner Characterization	COMPLETE
• Task 4 - Combustion Characterization of Slurry Fuel	COMPLETE

• Literature Review on Rheology and Properties of Coal-Water Slurry Fuel by S. Samudrala is contained in Appendix A.

CONCLUSION

At present, S. Samudrala and O.Mohannad are evaluating experimental data to compare the performance of coal fine-plant coal blend fuel with coal fine-water slurry fuel (Tasks 5 & 6). This comparison is being conducted with regard to emissions, combustion efficiency, ash behavior, etc. An economic analysis will also be completed. All experimental data received from the EERC is on disk and is being analyzed and compiled. Carol Wright was recently added to the project and is currently conducting literature reviews on the subject.

APPENDIX A

Literature Review on the Properties and Rheology of Coal-Water Slurry Fuels

Important aspect in the preparation of the Coal-water slurry is to maximize the coal content of mixture. In order to achieve this coal particle size and viscosity play an important role. A decrease in particle size increases the surface area available for reaction and hence increase the rate of char burnout[1]. Higher combustion Efficiency for CWS containing high volatile coals compared with those formed from low volatile coals are widely reported (McHale, et. al 1982, Scheffee, et, al, 1982). Allen and others estimate that the coals used for CWS should have a minimum of 25% volatile matter(on dry basis). The rheological properties of CWS play a vital role in their storage, transportation , atomization and combustion. The fundamental understanding of the preparation and handling of the highly loaded CWS with low viscosity and desirable atomization and combustion properties is necessary in the commercialization of the CWS[2]. Solid concentration and the particle size are the two important hydraulic variables and particle size distribution is of considerable importance in the CWS formulation[3]. Due to the variability in the characteristics such as the particle size distribution, shape of the particle, concentration of solids, surface chemistry of particles and dispersant used to stabilize the suspensions the governing parameters have to be determined experimentally [4,5].

Some of the observations made by Frank et al [6] by an experimental study of the effect of particle size distribution on coal-water slurry are as follows, all the five different slurry used exhibited Non-Newtonian flow and the packaging efficiency of the particle was found to govern the slurry behavior. Rheological analyses of the flow curves show that the flow behavior changed from dilatent to pseudoplastic as the packaging concentration increased. Also, the viscosity was found to decrease with the increase in the packing concentrations of the slurries. This is an indication that a wider distribution is necessary for more efficient packing. It is also observed that the viscosity remains fairly constant after a shear rate of 4000 s^{-1}. Solids with low packing efficiency have relatively high time-independent yield points and also have high viscosities at shear rate of 100 s^{-1}. The behavior of the slurry at high temperature is dependent on the additive type.

The value of volatile matter content is used as an indication of coal classification and ignitabiity, and , in general, high volatile matter content(approx. 30% or above) is desirable in coal firing as it enhances fuel ignition and flame stability[7]. The erosion of the boiler tubes is a function of the ash composition and ash content in the slurry fuel. several investigations (Borio, et al) have indicated that the potential for boiler pressure part erosion could be a significant load limiting factor, and would adversely affect the economics of CWF conversion in some cases.

Studies made by R.C. Laflesh, et. al on the Combustion characteristics of coal-water fuel are as follows:

Most of the Cwf's exhibit Non-Newtonian behavior and this fact complicates the analytical prediction of viscosity related CWF characteristics, such as piping pressure losses and atomization quality. A series of parametric viscosity measurements were made on the five CWF's were made to characterize the complex non-Newtonian rheology. These measurements were conducted over a range of shear rates from $100sec^{-1}$ to $8000sec^{-1}$. It is been observed that the fuels are clearly non-Newtonian with each being dilatent in nature.

Fuel atomization is considered to be the most parameter in the efficient combustion of CWF. Some of the Preliminary performance objectives(PPO's) established by (LaFlesh, et. al.) Combustion Engineering in the specific area of atomizer design, it was deemed to have:

1) an atomized spray droplet mass mean diameter of less than 200 microns at 100% load,
2) less than 1% by weight of total spray droplets exceeding 300microns in diameter and
3) an atomizer assist fluid consumption ration(A/F) of less than 0.25 lb air/lb fuel at 100% of full load firing rate.

The above PPO's aid as guide lines as to what mass mean diameter, weight of spray droplet and A/F should be.

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