COMBUSTION ANALYSIS OF COAL-WATER SLURRY FUEL PREPARED FROM PLANT COAL AND RECOVERED COAL FINES

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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
FlueGas 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

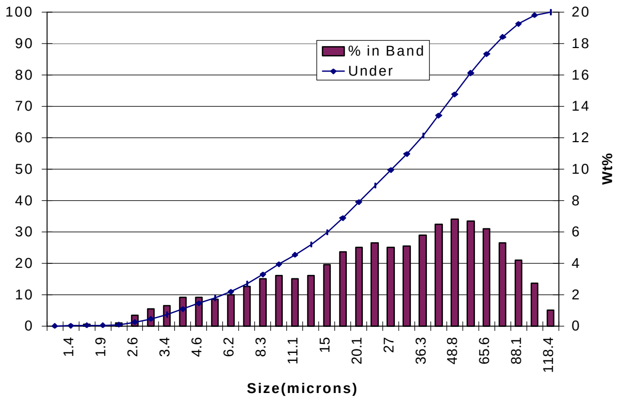

Figure 1 Particle size distribution of plant coal

Simulated connvective 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

NOx 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 NOx 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.

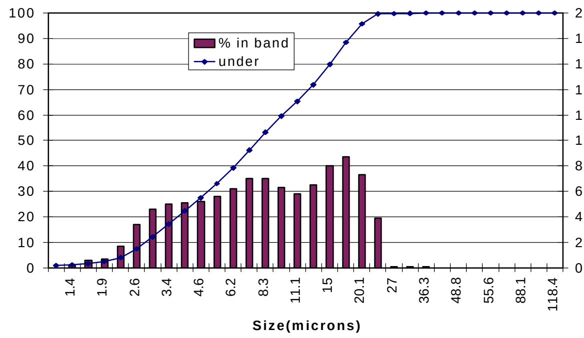

Figure 2 Particle size distribution of recovered coal fines

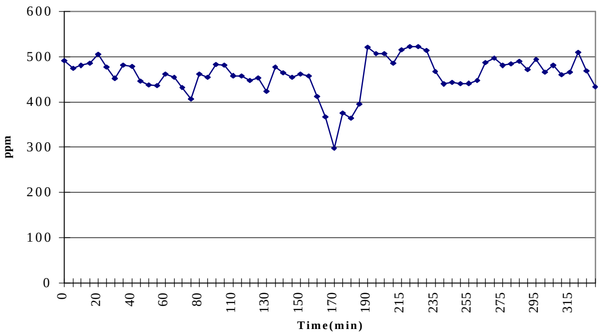

Figure 5 Concentrations of Nox in the flue gas during a test run at 834,330 Btu/hr

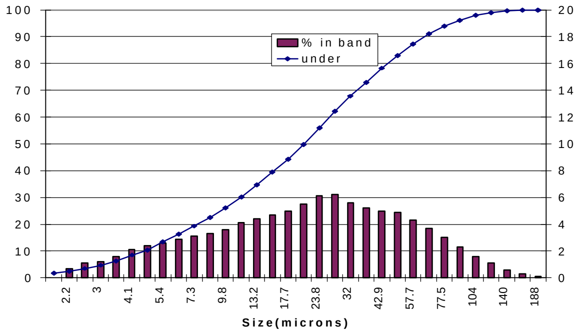

Figure 3 Particle size distribution of CWS fuel

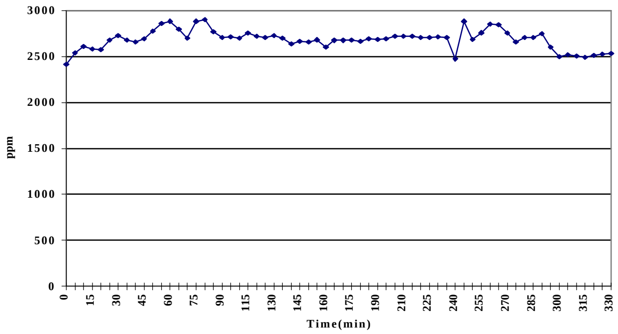

Figure 6 Concentrations of SO$_2$ in the flue gas during a test run at 834,330 Btu/hr

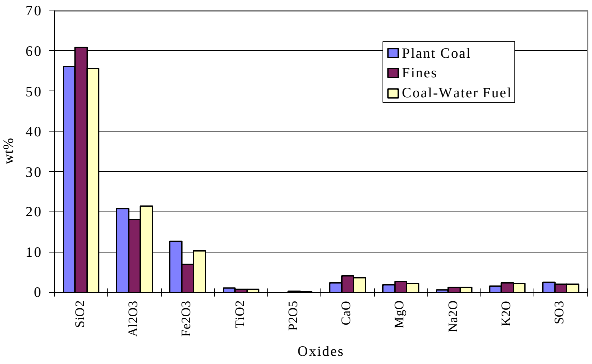

Figure 4 Ash x-ray fluorescence analysis of CWS and feed stocks

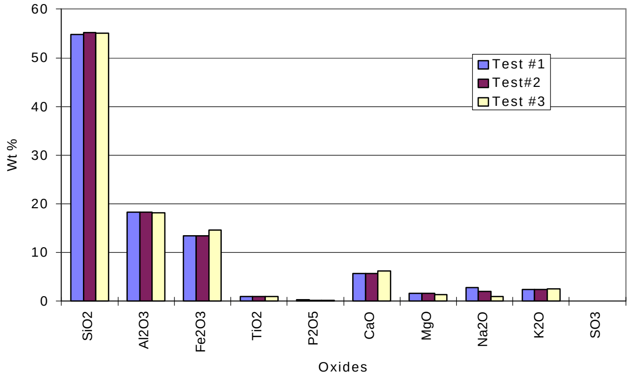

Figure 7 X-ray fluorescence analysis of ash deposits

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.

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