COMBUSTION CHARACTERIZATION OF COAL-WATER SLURRY FUEL

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ABSTRACT

As a result of coal cleaning operations, a substantial amount of coal is disposed as waste into the ponds, effecting and endangering the environment. This study includes a technique to recover and utilize the waste coal fines from the preparation plant effluent streams and tailing ponds. Due to the large moisture content of the recovered coal fines, this investigation is focused on the utilization of coal fines in the coal-water slurry fuel. It is our belief that a blend of plant coal and waste coal fines can be used to produce a coal-water slurry fuel with the desired combustion characteristics required by the industry. The coal blend is composed of 85% clean coal and 15% recovered coal fines. The coal-water slurry is prepared at 60% solids with a viscosity less than 500 centipose and 80-90% of solid particles passing through 200 mesh. This paper contains analysis of clean coal, recovered coal fines, and coal-water slurry fuel as well as combustion characteristics.

INTRODUCTION

Due to the over abundance of bituminous, the potential to meet the energy needs of the United States will be met well into the next several centuries from the development and application of coal products. Over 6 trillion tons of bituminous coal is estimated to exist in the United States [1]. In the state of Texas, an estimated amount of 10 billion tons of lignite exists near the surface and 100 billions of lignite at a depth between 200 to 5000 ft below the surface[2].

However, along with the over abundant supply of coal there are drawbacks to the mining and processing of coal. According to the recent studies, nearly 30 percent of the minerals from the underground coal mining operations are rejected as waste in the United States [3]. This accumulation of approximately 3 billion standard tons of coarse and fine coal refuse is primarily from coal cleaning processes. The coal fines that are rejected have a high percentage of pyrite sulfur, which causes significant ground water pollution when it is dumped into effluent ponds. In addition, coal refuse disposal causes other environmental and tribological problems, such as acid formation, erosion, and sediment control. Acres of land would be saved annually if coal fines being dumped could be recovered by a case effective process.

Many techniques have been developed to recover fines from effluent ponds. Even after a thorough dewatering process, the recovered fines can only achieve 22-25 percent moisture level. Due to a 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 a 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. In order 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 feedstock is necessary. The production, application and utilization of coal-water slurry fuel will have a positive impact on the environment, while being one of our most abundant natural resources.

EXPERIMENTAL PROCEDURE

Experiments dealing with the evaluation of bituminous coal-water slurry fuel were conducted by the Energy and Environmental Research Center (EERC) at North Dakota State University from August 2-4,1995. The EERC collected data on combustion behavior, flame stability and ash composition. Approximately 1,850 lb of 2″ X 0″ Peabody plant coal and 1,090 lb of black water (pond) fines were prepared into a coal-water slurry fuel for subsequent combustion tests. A 5-gallon composite as-received (AR) plant coal was analyzed for proximate, ultimate, and heating values. The analyzed data are presented in the Table 1.

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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 AR plant coal was predominantly less than 1/4" but contained some large portions up to 2". The AR plant coal with a moisture content of 13.70 percent by weight was visibly wet on surface. As a consequence, the plant coal was floor dried to remove surface moisture to facilitate proper functioning of equipment. The Plant coal was then stage crushed to 1/4" top size with a hammer-mill crusher, 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 by Malvern laser diffraction analysis as shown in Fig. 1.

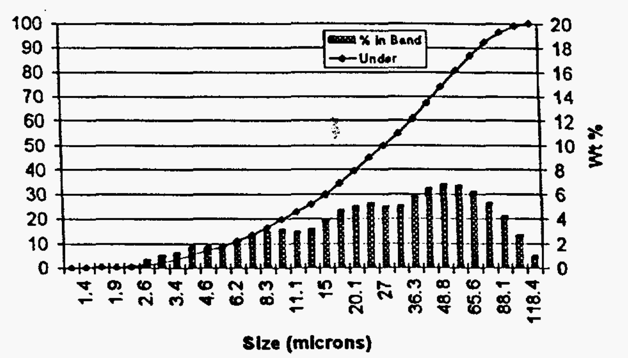

Fig. 1 Particle Size Distribution of Plant Coal

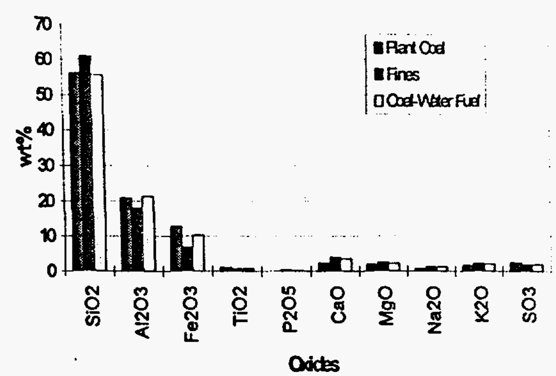

Fig. 2 Ash X-ray fluorescence analysis of CWF and Feed Stocks

The pond fines slurry was thermally dewatered using a steam coil to evaporate water. The concentrated slurry solids content was 41.95 percent weight with an AR solids content of 21.63 percent weight. Initially, to dewater pond fines slurry, a recessed plate frame filter was mechanically used. Due to finely dispersed clay particles the filters became quickly blinded. Through wet sieve and Malvern laser diffraction, the concentrated fine slurry were analyzed along with wet milled fines for the particle size distribution, using a mechanically stirred ball mill and 1/8" stainless steel media. Wet milling reduces the coarse coal particles that plugs the CWF pumping and injection system. A composite sample of the milled fines slurry was analyzed for proximate, ultimate and heating values, which are presented in Table 1. Ash x-ray fluorescence data are given in Fig. 2. The wet milled fines were also analyzed for particle size distribution by Malvern laser diffraction analysis.

Bench-scale rheological testing was performed using pulverized plant coal and wet milled pond fines blended in 85/15 weight ratio. The mass of CWF required for combustion testing was estimated from the ash-fouling furnace firing rate(s) and heating value(s) of the CWF. The pulverized plant coal and wet milled fines slurry were then mixed with the required amount of deionized water in a 500-gallon stirred tank. The slurry was then pumped into 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 wt%. A sample of the as-fired CWF was analyzed for proximate, ultimate and heating values. See Table 1.

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. The coal-water fuel was fired at three firing rates (834,448 Btu/hr, 669,488 Btu/hr, and 508,215 Btu/hr) and at three burner settings for each firing rate. At each burner setting, gaseous emissions of CO, CO_2, O_2, SO_2 and NOx were recorded. Fig. 3 represents the gaseous emissions during a test run at 834,448 Btu/hr firing rate. The gaseous emissions test data for other two firing rates at different burner settings are reported in reference[4].

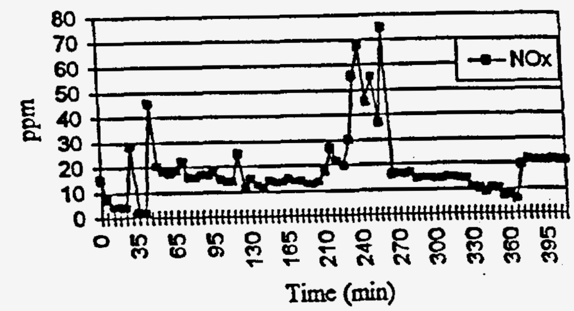

Fig. 3 Concentrations of NOx in the flue gas during a test run at 834, 330 Btu/hr

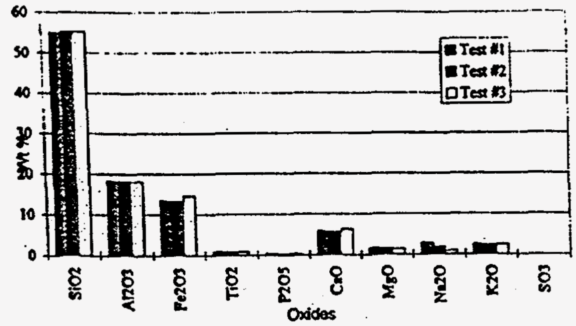

Fig .4 X-ray flouresence analysis of the ash deposits

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. Three sample locations were used to extract the carbon and fly ash samples from the test furnace, the residence time at each location varies with firing rate and excess air. A summary of flame stability test results are listed in Table 2. Simulated convective pass fouling probes were inserted in the refractory-lined ductwork at the furnace exit to collect deposits during extractive sampling. Related test results are given in reference[5]. The chemical constituents of ash deposits as determined by X-ray fluorescence analysis is presented in Fig. 4.

Table 3. 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

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 as anticipated. The average sulfur content of the bituminous coal is 2.31% [6]. 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 plant coal as shown in Fig. 1 gives 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. Fig. 2 gives the elemental oxides for plant coal, recovered coal fines, and coal-water slurry fuel. As seen from the 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 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. NOx emissions in ppm at a firing rate of 834,448 Btu/hr is shown in Fig. 3. As seen in the figure the level of NOx remains constant within a time period which is below the EPA standards. Combustion results given in Table 2. reveal that at each of the two highest firing rates, combustion was relatively complete regardless of swirl setting, therefore burner settings 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. Results given in Fig. 4 indicates similar compositions for all ash 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 deposit strength. The available sodium will react with free silica to form the low melting point phases which are responsible for deposit growth and strength development.

CONCLUSION

A method to recover and utilize the waste fines from preparation plant, effluent stream and tailing ponds has been proposed. The chemical constituents of recovered coal fines, plant coal, slurry fuel and ash deposits have been presented. The sulfur and ash contents of the coal-water slurry fuel was found to be lower than plant coal and recovered coal fines. The utilization of waste coal fines has an enormous impact on the environment by saving the land area previously reserved for effluent ponds.

ACKNOWLEDGMENTS

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