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COMBUSTION CHARACTERIZATION OF COAL FINES RECOVERED FROM THE HANDLING PLANT

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TABLE OF CONTENTS

	Page No
Abstract-----	1
Executive Summary-----	1
Introduction-----	1
Results and Discussion-----	2
Conclusion-----	3
Appendix A-----	4
Appendix B-----	8
Appendix C-----	13

ABSTRACT

Ash disposals, coal-water slurry fuel and its feedstocks were analyzed for concentrations of major mineral elements based on sulfur free and ash basis. Elements with most concentration levels were found to be silicon , aluminum and iron with silicon having the highest concentration level. The size analysis of the fly ash particles revealed that 90% of particles have sizes less than 30 microns.

EXECUTIVE SUMMARY

X-ray fluorescence analyzer was used to analyze plant coal, recovered coal fines, slurry fuel and fly ash for major mineral oxides (SiO_2 , Al_2O_3 , Fe_2O_3 , SiO_2 P_2O_5 , CaO , MgO , Na_2O and K_2O). Then , they were evaluated for elemental concentrations based on sulfur free and ash basis. The analysis indicated that silicon, aluminum and iron concentrations were found to be the most dominating elements. In essence, silicon had the highest concentration with the level of 50.9, 56.5, 50.1 and 51.1 (sulfur free basis) and 49.9, 54.6, 49.2 and 51.1 (ash basis) for plant coal, recovered coal fines, slurry fuel and fly ash respectively. A cyclone located at the end of the combustion run (EOR) was used to collect the bulk fly ash particles. The fly ash, slurry fuel and its feedstocks were analyzed for particle size distribution via Malvern laser diffraction analyzer. The fly ash particle size distribution revealed that 90% of particles by weight had a size less than 30 microns. The majority of particles by weight were found to be in the range of 15-20 microns.

INTRODUCTION

During this reporting period (October 1 - December 31), research activities were focused on :

1. Analysis of fly ash for concentrations of major mineral oxide elements.

2. Fly ash particles size distribution

3. Comparison of fly ash elemental concentration and fly ash particle size distribution

with those of slurry fuel and its feedstocks respectively.

The work performed during this period is presented in Appendix A and appendix B, which includes two papers, one was presented at Energy Week '97 in Houston, Texas, January 28-30 (Appendix A). The other paper entitled "Effect of Burner settings on Flame Stability During the Combustion of Coal-Water Slurry Fuel", will be presented at Fifth Annual Historically Black Colleges and Universities and other Minority Institutions Program - Energy Research and Development Technology Transfer Symposium, in Baton Rouge, Louisiana, during the month of March 1997.

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The results of fly ash analysis on sulfur free basis and ash basis as well as particle size distribution are presented below:

RESULTS AND DISCUSSION

Table 1. Appendix C shows ash x-ray fluorescence analysis of fly ash based on sulfur free and ash basis. As seen from this table silicon, aluminum and iron have the highest percentage rates by weight. The ash x-ray fluorescence analysis of plant coal, recovered coal fines and slurry fuel are given in Figure 1 & 2, Appendix B. It can be noted that the Silicon concentration is the most detrimental. For fly ash the silicon concentration level is about 2.5 times that of aluminum. The results of particle size for fly ash are shown in Table 2., Appendix C. Additional size distribution for plant coal, recovered coal and slurry fuel are presented in figure 4, 5 and 6. Appendix B. As viewed from these figures, 90 percent

of particles by weight have sizes less than 70 microns for plant coal, less than 20 microns for recovered coal fines, less than 77 microns for CWS and less than 30 microns for fly ash. Additionally, majority of particles have size range between 36 to 88 microns for plant coal, between 3 to 27 microns for recovered coal fines, between 9 to 77 microns for CWS and between 6 to 27 microns for fly ash.

CONCLUSIONS

1. Fly ash, slurry fuel and its feedstocks were analyzed for major mineral elements. The major mineral elements were found to be silicon, aluminum and iron with silicon having the highest concentration.
2. The maximum percentage of the particles by weight were found to be 36 to 88 microns, 3 to 27 microns, 9 to 77 and 6 to 27 microns for plant coal, recovered coal fines, CWF and fly ash respectively.

Appendix A

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EFFECT OF BURNER SETTINGS ON FLAME STABILITY DURING THE COMBUSTION OF COAL-WATER SLURRY FUEL

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ABSTRACT

Combustion tests were conducted to determine the range of secondary air swirl required to maintain a stable combustion flame. Results obtained during the flame stability testing show no significant effect of swirl settings on NO_x, SO₂ and CO₂ for three combustion tests (834,330 Btu/hr, 669,488 Btu/hr and 508,215 Btu/hr). At each of the two higher firing rates, combustion was relatively complete regardless of swirl settings, 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. The parameters affecting flame stability are mainly coal particle size, volatile matter, ash content and excess air. Tests conducted at three different locations (Top, Middle and Bottom) revealed that the gaseous concentrations such as NO_x, SO₂ and CO₂ were a function of residence time for each of the firing rates.

INTRODUCTION

A flame is observed to be stable when it is fully contained within the burner quarl. Flame stability is assessed by the visual observation of the flame in relation to the burner quarl as a function of secondary air swirl and operating conditions. An important aspect of maintaining a stable flame is creating an internal recirculating zone within the flame which allows for greater mixing of the combustion air and fuel. This phenomena can be implemented by creating a swirl. Swirl is defined as the quotient of tangential momentum to axial momentum of the secondary air stream. In order to allow the proper mixing of combustion air and fuel, an internal recirculation zone is set up to cause alternate paths of radial and tangential flow. Once the swirl is applied to the combustion air, the heating rate of coal particles are increased causing an increase in the release of volatiles and char combustion. The swirl setting when increased from a lower number to a higher number, the flame becomes more compact and intense upto a certain number which is considered to be optimum. Any further increase in the swirl number beyond the optimum level may cause the flame to be

extracted into the burner region, exposing the burner components to the high intensity of heat, causing damage to the parts and possible combustion in the pipe. When the char combustion is being fast, it offsets the cooling effect of the secondary air mixing. Therefore, it maintains the high recirculation and flame temperatures required for fast coal pyrolysis[1]. Heat losses by radiation is considered to be an important factor effecting the flame stability followed by the external recirculation of combustion products. Nitrogen oxide emissions could be effected by increasing the swirl in order to provide flame stability and higher carbon conversions. Excessive burner swirl can cause increase in NO_x formation. Additionally the position of flame front plays an important factor in NO_x formation[2]. NO_x may form under the conditions of high flame temperature, increased coal/air mixing ratios associated with swirl number. In order to maintain the NO_x formation at low level, the swirl settings need to be adjusted below its optimum setting.

EXPERIMENTAL PROCEDURE

Combustion experiments on coal-water slurry fuel, prepared from 85 percent plant coal and 15 percent recovered coal fines were conducted at Energy and Environmental Research Center (EERC), University of North Dakota. Coal-water slurry fuel preparation is described in detail in references[3 and 4]. The bituminous coal-water slurry fuel was fired over nine test periods (three burner settings at each of the distinct firing rates, 834,330 Btu/hr, 669,488 Btu/hr and 508,215 Btu/hr) to determine the flame stability characteristics and combustion efficiency as a function of burner settings and firing rates. Tests were conducted using a pilot scale combustion system with an electrostatic precipitator on the back end for particulate collection.

An International Flame Research Foundation (IFRF) type secondary air swirl generator was used during testing. The swirl burner was designed to achieve secondary air swirl numbers between 0(no swirl) and a maximum of 1.9. The combustion

* Graduate students

firing rate provided a furnace exit gas temperature about 2200°F at an excess air level near 20%. Burner settings were adjusted accordingly during testing to determine the point at which the flame separates from the burner, hence, indicating flame instability and the point at which the flame is fully contained within the burner quarl; indicating stable condition.

Data was recorded at each burner setting, flame temperature at a single point in the furnace and the heat flux at the specified location. Flame temperature was determined by a high-velocity thermocouple and heat flux was measured by using a water cooled probe.

RESULTS AND DISCUSSION

Initially, tests were conducted to determine the range of secondary air swirl required to maintain a stable combustion flame.

Figure 1. Effect of swirl number on NO_x at three different firing rates

Figure 2. Effect of swirl number on SO₂ at three different firing rates

Figure 3. Effect of swirl number on CO₂ at three different firing rates

The relative variation of NO_x, SO₂ and CO₂ with respect to swirl numbers for three combustion tests (834,330 Btu/hr, 669,488 Btu/hr and 508,215 Btu/hr) are given in Figures 1, 2 and 3 respectively. As seen in Figures 1 and 2, the swirl numbers have no significant effect, in parts per million, for NO_x and SO₂. In addition, test 2 (669,488 Btu/hr) and test 3 (508,215 Btu/hr) in Figure 3 show no significant change in percentage of CO₂ with respect to the change in swirl number. Except in test 1, Figure 3, the swirl number 0.4 shows inconsistent value for CO₂.

Figure 4. Effect of varying swirl number on percentage of carbon in ash at three firing rates

Figure 4 shows the effect of swirl settings on percent of carbon in ash for the three different tests. As seen in this figure, the percent of carbon content in ash at the lowest firing rate is nearly twice the carbon content of the higher firing rates.

Figure 5. Effects of firing rates on NO_x measured at three locations of the combustion chamber

The effects of firing rates on NO_x, SO₂ and CO₂ at three different locations (Top, Middle and Bottom) are shown in Figure 5, 6 and 7 respectively. As seen in these figures, as the firing rate increases the gaseous concentration in parts per million increases. Additionally, the concentration in parts per million increases from location bottom to location top.

Figure 6. Effect of firing rate on SO₂ measured at three locations of the combustion chamber

Figure 7. Effect of firing rate on CO₂ measured at three locations of the combustion chamber

CONCLUSIONS

1. Partial evaluation of flame stability analysis have been presented. At each of the two higher firing rates combustion was relatively complete regardless of swirl numbers.

2. Effects of firing rates on gaseous concentration at three different locations (Top, Middle and Bottom) were evaluated. It was found that the increase in gaseous concentration is proportional to the residence time.

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Appendix B

CHEMISTRY OF ASH DEPOSITS RESULTED FROM COMBUSTION OF COAL-WATER SLURRY FUEL

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Abstract

In regard to the environmental problems associated with the disposals of the waste coal fines, an innovative approach was considered to utilize the effluent recovered coal fines in combination with plant coal fines to form a coal-water slurry fuel. The prepared coal-water fuel was fired in a combustion test facility at three different firing rates (508,215, 669,488, 834,330 Btu/hr) with excess air and at different burner settings. Chemical analyses were conducted on slurry fuel, feedstocks, ashes and disposals for a better understanding of combustion characteristics. The slurry fuel ash analysis was obtained through x-ray fluorescence which generated concentrations of major mineral (Si, Al, Fe, S, P, K, Ca, Mg, Na, Ti). It was found that the most influential elements were silicon and aluminum. The size distribution of fly-ash reveals that eighty percent of the particles have sizes less than twenty microns, as compared to the slurry fuel where the eighty percent of the particles have sizes less than fifty-seven microns.

Introduction

As a result of the current political and economic conditions in the United States, there exists a need for more efficient alternative energy. Coal is a resource that the United States can depend on as its alternative source of energy. It is estimated that over six trillion tons of bituminous coal exists in the States [1]. Since there exists a vast amount of coal in the United States, the development and application of coal products have the potential to meet the energy needs of the U.S. well into the next few centuries. In essence, coal-water slurry fuel is one possible approach to enable the States to become more independent in its use as energy alternative.

Although the production of coal into effective energy products is quite promising, there are however, some environmental hazards involved with the mining and processing of coal. Recent research has revealed that nearly 30 percent of the minerals from the underground coal mining operations in the states are rejected on the surface as waste[2]. In the process of coal cleaning operations, there is an accumulation of approximately three billion standard tons coarse and fine coal refuse. This waste is usually dumped into nearby effluent ponds and usually contains a high percentage of pyrite sulfur. The disposal of coal refuse generates other environmental and tribological problems such as acid formation, erosion, and sedimental control. Although the coal fines are dumped into adjourning effluent ponds, these fines can be recovered by a cost effective process; in the long run saving money and acres of land yearly.

Several methods to recover fines from effluent ponds have been developed. Unfortunately, the recovered coal fines have a large amount of moisture content. Even though a dewatering process may be used, the recovered coal fines can only achieve 20-25 percent moisture level [3,4]. This leads to the implementation of recovered coal fines in the form of slurry. Hence, a blend of 85% of clean coal and 15% recovered coal fines can be prepared to produce a coal-water slurry fuel with combustion characteristics desired for use by industry. Plant coal, recovered coal fines, coal-water slurry and electrostatic precipitator (ESP) ash were analyzed for mineral elements and particle size distribution.

Experimental Procedure

The preparation and combustion procedures of bituminous coal fuel are described in references. The coal-water slurry consists of 53.5% solids with a viscosity less than 500 centipose and 80-90% of solid particles through 200 mesh. The slurry fuel was fired at three firing rates (508,215, 669,488, 834,330 Btu/hr) and three burner settings for each firing rates. The mass of CWS required for combustion testing was estimated from the ash-fouling furnace firing rates and heating value of the CWS. The pulverized plant coal and wet milled fines slurry were then admixed with the required amount of deionized water. The slurry was then pumped down to barrels where minor adjustments of water content were made to achieve the desired viscosity.

Combustion tests were conducted over nine test periods (three burner settings at each of the three firing rates); using a pilot scale combustion system with an electrostatic precipitator on the back end for particulate control. A cyclone located at the end of the run (EOR) was used to collect the bulk fly ash particles which were analyzed for carbon content, size distribution and elemental oxide composition using x-ray fluorescence.

Results and Discussion

A sample of plant coal, recovered coal fines, slurry fuel and fly ash particles were analyzed for elemental concentrations on ash-free basis and sulfur-free basis. The results are shown in figure 1, 2 and 3. As seen in these silicon, aluminum and iron have the highest percentage rates by weight.

Also, it can be noted that the silicon concentration is the most detrimental element, with a concentration level of about 2.5 times of the aluminum level.

Figure 1. Ash x-ray fluorescence analysis of CWS and feed stocks on ash basis

Figure 2. Ash x-ray fluorescence analysis of CWS and feed stocks on a sulfur-free basis

Figure 3. Ash x-ray fluorescence analysis of fly ash

Figure 4. Particle size distribution of plant coal

Figure 5. Particle size distribution of recovered coal fines

Figure 6. Particle size distribution of CWS

Figure 7. Particle size distribution of fly ash

In addition, the solids were analyzed for particle size distribution via wet sieve and Malvern laser diffraction. The results are presented in figures 4, 5, 6 and 7.

As viewed from these figures, 90 percent of particles by weight have sizes less than 70 microns for plant coal, less than 20 microns for recovered coal fines, less than 77 microns for CWS and less than 30 microns for fly ash. Additionally, majority of particles have size range between 36 to 88 microns for plant coal, between 3 to 27 microns for recovered coal fines, between 9 to 77 microns for CWS and between 6 to 27 microns for fly ash.

Conclusions

Chemical analysis were conducted for CWS, feedstocks and fly ash particles, the most influential elements were found to be silicon aluminum and iron with silicon having the highest concentration. The maximum percentage of the particles by weight were found to be 36 to 88 microns, 3 to 27 microns, 9 to 77 and 6 to 27 microns for plant coal, recovered coal fines, CWF and fly ash respectively.

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 advice.

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Appendix C

**Table 1. X-ray Fluorescence Analysis of Flyash
on Sulfur Free and Ash Basis**

Elements	Ash	Ash (S-free basis)
Si	51.1	51.1
Al	19.4	19.6
Fe	15.9	16.1
Ca	3.1	3.2
K	3.4	3.4
Mg	3.1	3.2
Na	1.5	1.5
Ti	1.4	1.5
S	0.9	0
P	0.1	0.1

Table 2. Particle Size Distribution of Fly ash

Size Microns	% in Band	Under
118.4	0	100
102.1	0.2	100
88.1	0.4	99.8
76	0.7	99.4
65.6	1	98.7
56.6	1.4	97.7
48.8	1.9	96.3
42.1	2.4	94.4
36.3	3.1	92
31.3	3.8	88.9
27	4.6	85.1
23.3	5.7	80.5
20.1	6.8	74.8
17.4	8.2	68
15	8.1	59.7
12.9	7	51.6
11.1	5.9	44.6
9.6	6.1	38.7
8.3	6.7	32.6
7.2	6.4	25.9
6.2	5.1	19.5
5.3	3.9	14.4
4.6	2.9	10.5
4	2.2	7.6
3.4	2.2	5.4
3	2.1	3.1
2.6	0.6	1
2.2	0.3	0.4
1.9	0	0.1
1.6	0	0.1
1.4	0	0
1.2	0	0