A STUDY ON THE INFLUENCE OF FUEL PROPERTIES ON NO_x EMISSION BEHAVIOR

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INTRODUCTION

Coal combustion in the recent past has been a challenge not from the burning point of view but from meeting emission standards point of view. Coal cleaning is used as a method to reduce sulfur and to some extent even hazardous air pollutants such as heavy metals. Mineral matter in coals can also be reduced by coal cleaning. Sulfur dioxide emissions have been correlated with the sulfur content of the coals. It is also known that there are no practical methods to reduce nitrogen by cleaning. Coals with very similar nitrogen content can vary widely in the NO_x emissions. A lot of attention was paid in understanding the effect of design and operating conditions of the combustor on the NO_x emissions. However, there seems to be a lack of clear understanding on the influence of fuel properties on the NO_x emission behavior. Although fuel switching is a solution to reduce SO_2 emissions, it is not a viable option for NO_x emissions. Cleaning changes the composition of coals (usually reduces the mineral matter, increases the heating value and alters the volatile matter). Volatile matter content has shown to influence the NO_x emissions. Higher volatile matter is reported to lower the NO_x emissions.

OBJECTIVE

The objective of this paper is to examine the influence of volatile matter and coal cleaning on the NO_x emission behavior. Tests were conducted to evaluate the NO_x emission characteristics of blends of an Indonesian coal (low ash, low sulfur, high moisture content), a Powder River Basin (PRB) coal and a Colorado (CO) subbituminous coal with a non-compliance coal from Pennsylvania in various proportions in a 1000 lb/h (steam) Research Boiler. The effect of coal cleaning was examined in a 0.5 MMBtu/h Down- Fired Combustor (DFC). Coal from the Upper Freeport seam was cleaned by CQ Inc., PA for evaluation of the effect of coal cleaning on hazardous air pollutants emissions.

EXPERIMENTAL

Sample Preparation for the Research Boiler Tests

Two tons of each coal were received in 55 gallon drums for the study. The as received samples (2 x 0") were mixed gravimetrically in the required proportion for each test. The mixtures were crushed and ground to approximately 70% passing though a 200 mesh screen, with no more than 0.5% retained on a 50 mesh screen. The particle size distributions of the pulverized coals was determined using a Malvern Particle Size Analyzer (Series 2600). The compositional analysis of the as-fired coal was determined using Leco proximate and ultimate analyzers. Calorific values of the fuels were determined using a Parr Adiabatic Calorimeter.

Description of the Equipment Used

The combustion tests were conducted in a 1,000 lb steam /h water tube research boiler with a maximum thermal input of 2 million Btu/h. The boiler is a standard Cleaver Brooks "A-frame", water-tube boiler. A schematic diagram of the boiler and auxiliaries is given in Figure 1. The boiler operates at a maximum steam pressure of 200 psig. The combustion chamber is 3 ft wide, 3 ft high and 7' ft long.

To promote evaporation and ignition of difficult-to-burn fuels, a ceramic quarl extends the length of the combustion chamber by two feet. The quarl and the boiler are preheated by burning natural gas prior to introducing of the test fuel. The preheated quarl acts as a source of radiant heat to help support the flame. Pulverized coal was fed from a two foot diameter hopper to an eductor via a 1.5-inch diameter screw feeder. The pulverized coal was entrained into an annular section and then through a swirler. The feed rate of pulverized coal was monitored by load cells. The products of combustion (O_2, CO_2, CO, NO_x and SO_2) are monitored at the economizer outlet with a series of on-line gas analyzers. The baghouse, used for particulate collection, contains sixteen 5 inches diameter by 8 ft long high-temperature fiber glass bags with out-to-in flow and pulse- jet cleaning. Details on the boiler are found elsewhere (Pisupati et al., 1996).

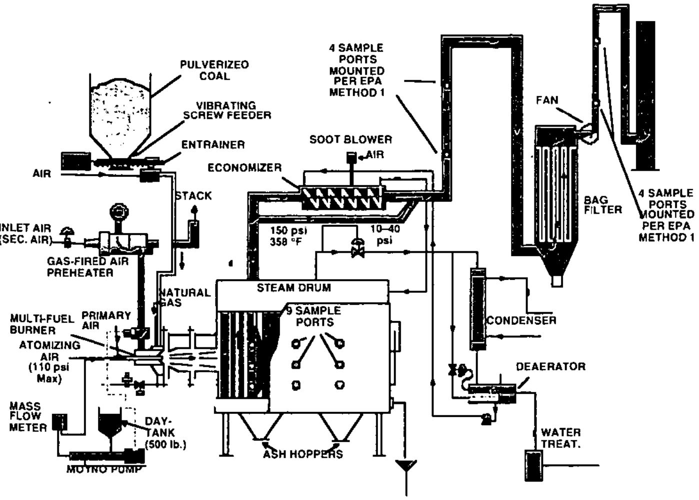

Figure 1. Schematic Diagram of the 1,000 lb/h Research Boiler

The Down Fired Combustor (DFC) has a 20 inch internal diameter, and is 10 feet high. A multifuel burner, capable of firing coal oil and natural gas, was installed at the top of the combustor. Coal was conveyed to the buner pneumatically. All combustion air streams (primary, secondary, and tertiary) were introduced at the same height in the burner. A firing rate of approximately 350,000 BTU/h was used in this study. Details on the combustor are provided elsewhere (Pisupati et al., 1997a)

RESULTS AND DISCUSSION

Table 1 provides the compositional analysis of the coals used in the study.

Table 1. Compositional analyses (Wt.%, dry basis)

	Coal Sample			
	100% PA	100% Indonesian	100% Colorado	100% PRB
Volatile Matter	20.47	46.20	38.11	45.22
Fixed Carbon	67.19	52.14	51.48	48.41
Ash	12.34	1.66	10.41	6.37
Moisture (as-fired)	1.69	21.44	6.81	25.86
Higher Heating Value (BTU/lb as fired)	13,680	10,098	11,668	9,072
Carbon	74.90	72.95	70.9	71.22
Hydrogen	4.45	5.18	5.09	5.37
Sulfur	0.81	0.12	0.46	0.46
Nitrogen	1.25	1.06	1.71	0.94
Oxygen	6.25	19.03	11.43	15.64
Ash	12.34	1.66	10.41	6.37

The ASTM volatile matter content of the coals tested in the Research Boiler ranged from 20 to 46 wt.% on a dry basis. Table 2 shows the operating conditions for the tests. The combustion efficiency reported in the Table was calculated using Ash Tracer Technique. NO_x emissions in lb/MMBtu were calculated per the 40 CFR, Part 75.

Table 2. Summary of the test conditions and flue gas emissions

Parameter	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 7	Test 8	Test 9	Test 10
Firing Rate (MMBtu/h)	1.71	1.6	1.6	1.5	1.57	1.63	1.61	1.6	1.6	1.6
Combustion Air Flow (lb/h)	794	699	716	681	655	773	863	757	667	665
Tertiary Air Flow (lb/h)	420	278	320	301	420	411	420	420	420	419
Coal Transport Air Flow (lb/h)	108	118	144	118	108	108	113	111	108	120
Flue Gas Composition (O_2)	5.98	5.25	6.29	5.54	6.73	6.55	6.72	6.07	6.12	5.83
CO (ppmv)	111	93	85	53	103	90	70	111	92	42
CO_2 (%)	12.67	13.27	12.7	13.67	12.4	12.6	12.6	13.09	13.06	13.17
SO_2 (ppmv)	400	290	227	45	344	348	249	364	329	45
NO_x (ppmv)	612	616	635	551	556	604	662	554	506	394
SO_2 @ 3% O_2 (ppmv)	480	331	277	53	434	433	314	439	398	295
NO_x @ 3% O_2 (ppmv)	734	705	777	642	702	753	835	668	612	467
NO_x emissions (lb/MMBtu)	0.96	1.03	1.23	1.08	0.98	1.07	1.22	0.97	0.96	0.87
Combustion Efficiency (%)										

* Test1-100% Indonesian coal; Test #2-80% PA coal/20% Indonesian coal; Test #3-50% PA coal/50% Indonesian coal; Test #4-100% Pennsylvania Coal; Test #5-80% PA coal/20% Colorado coal; Test #6-50% PA coal/50% Colorado coal; Test #7-100% Colorado coal; Test #8- 80% PA coal/20% PRB coal; Test #9-50% PA coal/50% PRB coal; Test #10-100% Powder River Basin coal

It can be seen from Table 2 that most the tests were conducted with similar air staging. It has been reported that for conventional unstaged combustion, an increase of NO_x emission with an increase of the amount of volatile matter, whereas, for low- NO_x configuration, NO_x decreased with increase in volatile matter. Several other researchers also established the importance of parameters like volatile content and Fuel Ratio (Fixed Carbon to Volatile matter Ratio) (Carpenter, 1995; Monroe et al., 1997; Rozendaaal et al., 1997). In addition to the NO_x emissions, carbon burnout was also correlated with volatile matter and Fuel Ratio. Figure 2 shows the influence of volatile matter on the NO_x emissions (lb/MMBtu) of the parent coals. In another current study being conducted in The Combustion Laboratory, it was observed that for a suite of five bituminous coals (with unstaged and staged air) the NO_x emissions decreased with increase in volatile matter (Pisupati, 1997b).

It can be seen from the Figure that the ASTM volatile matter content is not a good indicator of NO_x emissions for this suite of coals. The NO_x emissions for the Colorado coal and Indonesian coals are higher than the Pennsylvania coal inspite of the higher volatile matter content. However, for the PRB coal the NO_x emissions were lower than the Pennsylvania coal. Figure 3 shows the NO_x emissions of parent coals and blends with PA coal.

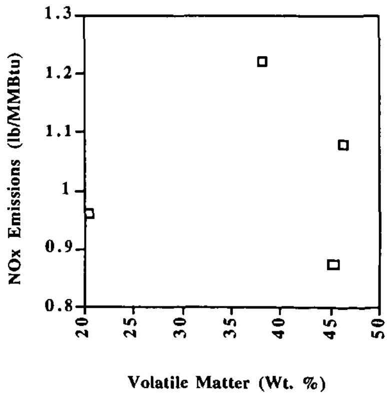

Figure 2. NOx Emissions as a function of volatile matter of the parent coals

It can be observed from Figure 4 that the NO_x emissions in general tend to increase with the nitrogen content in the fuel. Nitrogen content of the fuels appears to be an important property for predicting NO_x emissions. To study the distribution of nitrogen between the volatiles and char phases, chars were generated from the parent coals at 950 °C and were analyzed for the nitrogen content and heating value. Table 3 provides the analysis of the chars of the four coals. From the data, the fraction of nitrogen in the volatiles and the calorific value of the volatiles was computed.

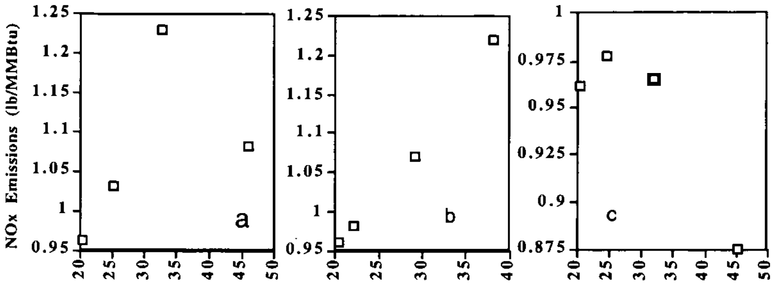

Figure 3. NOx emissions of the parent coals and blends a) Indonesian and PA coals; b) Colorado and PA coals; c) PRB and PA coals

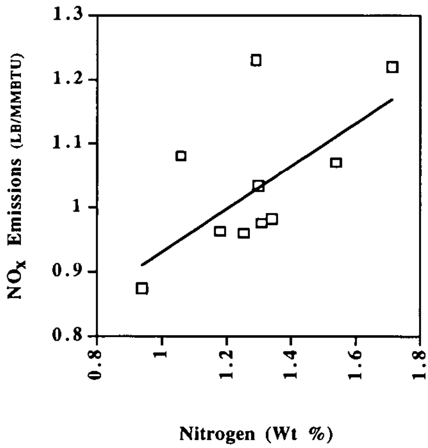

Figure 4. NO_x emissions as a function of fuel nitrogen content

Figures 5 shows the nitrogen content and the calorific value of the volatiles as a function of the volatile matter. It can seen from the plot that higher the amount of volatiles released, higher is the amount of nitrogen associated with the volatiles and lower is the calorific value of the volatiles. Lower calorific value of the volatiles is due to the higher oxygen and moisture content of the coals. This also implies that the volatile are leaner in combustible hydrocarbons capable of reducing the nitrogen oxides to nitrogen. The volume of the inert species increases the velocity and thereby the residence time in the ceramic quarl used in the study. The higher nitrogen content of the volatiles (especially lower rank higher moisture fuels) therefore, results in higher NO_x emissions. Data in Table 2 show that as the percent Indonesian or Colorado or PRB coal is increased there is an increase in the combustion efficiency of the blend. The results also showed, as expected, that the average SO_2 emissions are also lower for the blends with increasing percent Indonesian or Colorado, or PRB coals.

Table 3. Properties of the chars produced from the parent coals

Parameter	PA Coal	Indonesian Coal	Colorado Coal	PRB coal
Nitrogen (Wt.%)	1.30	1.34	1.61	1.37
Higher healing value of the char (Btu/lb)	11,463	13,482	11,467	12,055
Calculated HHV of the Volatiles (Btu/lb)	12,803	8,630	10,521	7,761

Effect of Coal Cleaning

A Pennsylvania coal with high ash content was cleaned by CQ Inc., to study the influence of cleaning on HAPs emissions. The ash content was reduced from 26.00 to 7.69% and sulfur from 1.87 to 1.47% on a dry basis. The cleaning process resulted in higher nitrogen content in the clean coal from (1.38% as opposed to 1.10% in the raw coal). Volatile matter contents of the raw and clean coals were 26.47 and 32.41%, respectively. Coals being of the same rank, the effects of nitrogen increase and volatile matter increase resulted in a marginal decrease in NO_x emissions from 1.00 lb/MMBtu to 0.9 lb/MMBtu.

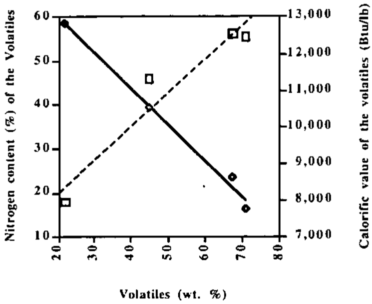

Figure 5. Nitrogen content and the calorific value of the volatiles of the parent coals

SUMMARY

NO_x emission behavior of a bituminous and three lower rank coals, and blends in various proportions was characterized. The results showed that the NO_x emissions vary significantly with volatile matter. Volatile phase nitrogen increased with the volatile matter. The calorific value of the volatiles was observed to decrease for coals with higher volatile matter (particularly high moisture, low rank coals). The study revealed that the quality of volatile matter is important than the quantity of volatile matter in predicting the influence of volatile matter on NO_x emissions particularly low rank coals. The results indicated that the average SO_2 emissions are lower for the blends with increasing percent low sulfur coals. The effect of coal cleaning on NO_x emissions was not significant because of the two opposing effects of higher fuel nitrogen and volatile matter contents in the clean coals.

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