DOE/PC/94223--T5

QUARTERLY REPORT
FOR
GRANT NO. DE-FG22-94PC94223
ENTITLED
"ADVANCED COMBUSTOR DESIGN CONCEPTS
TO CONTROL NOX AND AIR TOXICS"

SUBMITTED BY

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DECEMBER 31, 1995

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1.0 Program Overview

Direct coal combustion must be a primary energy source for the electric utility industry and for heavy manufacturing during the next several decades because of the availability and economic advantage of coal relative to other fuels and because of the time required to product major market penetration in the energy field. However, the major obstacle to coal utilization is a set of ever-tightening environmental regulations at both the federal and local levels. It is, therefore, critical that fundamental research be conducted to support the development of low-emission, high efficiency pulverized coal power systems.

The University of Utah, Massachusetts Institute of Technology (MIT), Reaction Engineering International (REI) and ABB/Combustion Engineering have joined together in this research proposal to develop fundamental understanding regarding the impact of fuel and combustion changes on ignition stability and flame characteristics because these critically affect: NO_x emissions, carbon burnout, and emissions of air toxics. Existing laboratory and bench scale facilities are being used to generate critical missing data which will be used to improve the NO_x and carbon burnout submodels in comprehensive combustion simulation tools currently being used by industrial boiler manufacturers. To ensure effective and timely transfer of this technology, a major manufacturer (ABB) and a combustion model supplier (REI) have been included as part of the team from the early conception of the proposal.

ABB/Combustion Engineering is providing needed fundamental data on the extent of volatile evolution from commercial coals as well as background information on current design needs in industrial practice. Since they will ultimately be a recipient of the enhanced design methodology, they are also providing ongoing review of the practical applicability of the tools being developed. MIT is responsible for the development of an improved char nitrogen oxidation model which will ultimately be incorporated into an enhanced NO_x submodel. Reaction Engineering International is providing the lead engineering staff for the experimental studies and an overall industrial focus for the work based on their use of the combustion simulation tools for a wide variety of industries. The University of Utah is conducting bench scale experimentation to (1) investigate alternative methods for enhancing flame stability to reduce NO_x emissions and (2) characterize air toxic emissions under ultra-low NO_x conditions because it is possible that such conditions will alter the fate of volatile and semivolatile metal species and the emission of heavy hydrocarbons. Finally the University of Utah is responsible for the development of the improved NO_x and carbon burnout submodels.

2.0 Progress During Last Quarter

2.1 Char Collection

NO_x modeling in coal requires an understanding of NO_x formation from both the volatile-N and char-N fractions of coal. This study has focused on NO_x formation from the char-N fraction of coal. The first step in the study was to isolate the char-N from the volatile-N by collecting partially burned coals from a 100,000 BTU/hr pulverized coal-fired furnace. As reported in the quarterly report ending 9/95, the collection of chars from four different coals was successful. The chars were analyzed for C,H,N and ash, and then chars were combined according to the following criteria: (1) same parent coal,

and then chars were combined according to the following criteria: (1) same parent coal, (2) same method of quenching of char oxidation, (3) similar carbon burnout levels. The chars were combined in order to provide large enough samples to burn in the U furnace. (See previous quarterly report for drawing of U furnace.) The combined chars were then reanalyzed (ultimate analysis and heating value). Table I shows the resulting char combinations along with analysis results and total mass of each char.

2.2 Char-N Experiments

Once the various chars had been collected and characterized, experiments were begun to study NO_x formation from char-N at pulverized coal conditions. The first step was to determine whether or not the combustion of real coal could be simulated by the combustion of a natural gas/char mixture. The gas is used as a nitrogen-free substitute for the volatile fraction of coal, simulating the ignition of coal without the effects of volatile-N. Therefore, any NO_x measured in the combustion products must come from either the char-N or the nitrogen in the combustion air (thermal NO_x). The total amount of NO_x resulting from char-N can then be determined by measuring the thermal NO_x from a gas flame with the same firing rate as the gas/char flame and subtracting the difference between the gas only NO_x reading and the gas/char NO_x reading. Alternatively, the gas/char mixture can be burned using a nitrogen-free oxidant. With no volatile-N, no nitrogen in the natural gas, and no possibility for thermal NO_x formation, the only possible source of NO_x is char-N. Both these methods for determining NO_x formation from char-N were used to obtain the results shown below.

The question that arises when using a gas/char mixture to simulate a parent coal is what should the relative firing rates of gas and char be. Should enough gas be added to account for the degree of carbon burnout in the char? Should the char and gas firing rates be held constant for all the gas/char mixtures tested? To test the importance of relative firing rates, the gas firing rate was held constant while the char firing rate was varied, and then the char firing rate was held constant while the gas firing rate was varied. All these tests were performed using the Utah bituminous coal char (7-13 Sept. 1995). The results of this test are plotted in Figure 1, where the fraction of total heat input from the char is shown versus the % conversion of char-N to NO_x . This test was performed using air as the oxidant, so conversions were computed as described above (i.e. determining the thermal NO_x effect and subtracting it out). It is clear from Figure 1 that although there is some variation in char-N to NO_x conversion with total heat input from char, the effect is not large and is probably a secondary effect. Therefore, most subsequent char/gas tests were performed at a constant gas firing rate of 85,000 BTU/hr and a constant char firing rate of 15,000 BTU/hr. Also of note in this figure is the relatively high char-N to NO_x conversions, which are higher than previously thought.

The second question to answer is whether or not the method of quenching used in char collection affects char-N to NO_x conversion. Figure 2 shows the results obtained from three different Pittsburgh No. 8 coal chars. The three chars were collected using air quenching, nitrogen quenching, and air plus water quenching. As seen in Figure 2, the char preparation method does not cause measurable differences in char-N to NO_x conversion levels.

The importance of thermal NO_x during combustion of a parent coal (Pittsburgh No. 8) and of a char/gas mixture is shown in Figure 3. These data were obtained by burning the coal (or char/gas mixture) first in air and then in a nitrogen-free artificial oxidant made up of Ar, CO_2 , and O_2 . The relative amounts of Ar and CO_2 in the mixture

contributor to total NO_x in either the coal case or the char/gas case, it cannot be ignored, especially when determining char-N to NO_x conversions. In the case of the gas/char flame, thermal NO_x is 25% of the total NO_x .

These preliminary data are being used to design experiments using the other chars. It does not appear necessary to varying gas and char firing rates, but further experimental work in $\text{Ar}/\text{CO}_2/\text{O}_2$ flames should provide valuable information on both char-N oxidation and on thermal NO_x formation.

3.0 Plans for Next Quarter

Further investigation of the influence of various operating parameters such as the initial NO concentration, flame temperature, local oxygen concentration, and char type on the conversion of char-N to NO_x will be performed in the next quarter. Data from these experiments will provide valuable information regarding the role of char-N in NO_x formation in pulverized coal furnaces. The data will then be used to improve a char-N to NO_x submodel in a comprehensive combustion code.

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Sample Name	%C	%H	%N	%O	%S	%Ash	BTU/lb	% Burnout	Total Mass, g
Cooling with Air									
Pitt No. 8 (25, 26, 29 sept)	60.96	0.72	1	1.04	0.41	35.53	9178	81.61%	5,800
III No. 6 (14,19,20,21 sept)	65	0.52	1.13	0.05	0.4	32.61	9518	85.39%	7,735
III No. 6 (18sept95)	75.95	1.21	1.61	2.71	0.51	17.85	11451	68.81%	2,610
III No. 6 (22sept95)	70.3	0.56	1.28	0.05	0.41	27.57	10227	81.31%	2,190
Utah (7-13 sept)	65.39	1.05	1.07	0.05	0.36	32.15	9184	77.54%	10,000
Utah (13sept95)	65.64	0.71	1.14	0.05	0.37	34.07	9393	78.72%	1,090
Cooling with Nitrogen									
Pitt No. 8 (27, 28, 29 sept)	68.08	0.7	1.14	2.4	0.48	26.91	10387	72.89%	8,000
III No. 6 (12,13 oct)	63.03	0.49	1.12	0.05	0.46	34.89	9101	86.76%	1,000
III No. 6 (16oct95)	70.65	0.69	1.13	0.05	0.51	27.34	10301	81.06%	1,600
Knife River (29, 30 oct)	51.23	0.66	0.64	1.93	1.62	43.42	7656	83.53%	760
Cooling with Air + Water Spray									
Pitt No. 8 (19,24 oct)	65.44	0.48	1.06	0.33	0.62	31.14	9484	77.48%	3,700
Knife River (26oct95)	47.31	0.44	0.46	0.05	1.58	49.36	6592	86.62%	1,200
Knife River (31 oct, 1 nov)	51.58	0.77	0.51	2.85	1.39	42.02	7718	82.86%	1,150

Table I

Dependence of Char-N Conversion on Char or Gas Feed Rate

Figure 1

Comparison of Alternative Char Preparation Methods

Figure 2

Importance of Thermal NOx

Figure 3