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INVESTIGATION OF MINERAL TRANSFORMATIONS AND ASH DEPOSITION DURING STAGED COMBUSTION

Quarterly Technical Progress Report
October 1, 1996 to December 31, 1996

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FOREWORD

This report summarizes technical progress during the thirteenth quarter (October 1, 1996 to December 31, 1996) of a study conducted for the Department of Energy (DOE) under Contract No. DE-FG22-93PC93226. The principal investigator for this work was Dr. John N. Harb; Mr. James Hickerson was the technical representative for DOE.

The technical work reported for this quarter was performed by graduate students Peter Slater and Neal Adair. John Dobbs, an undergraduate student in chemical engineering at BYU, also made important technical contributions to this report.

ABSTRACT

The key issues addressed this quarter were related to operational problems in the coal feed system, namely, the inability to accurately measure all of air entering the system, and plugging of coal in the feed lines due to poor entrainment. Both of these problems caused unacceptable uncertainty and/or fluctuations in the operating conditions and therefore required solutions.

The coal entrainment problem was solved by installing a new eductor designed for entraining solids in gas streams. All of the air entering the reactor now flows through the eductor, either as motive air or through the suction air inlet. This ensures that the coal is entrained at relatively high velocity, so that it will flow to the reactor without forming slugs in the lines. A new feeder shroud was also installed with an air jet directed towards the auger to sweep off the tip in order to reduce pulsations when feeding coal.

The problems associated with accurately metering the air have been somewhat more difficult to resolve. New strategies for completely closing the system have been tested and look promising. A new flowmeter was also purchased with cost sharing funds to directly measure the air flow rate of the two phase stream (after the coal injection point). If the system can be operated without leaks, then the changes will provide two independent measurements of the air flow to ensure accuracy. If the system cannot be sealed, the new flowmeter will still provide reliable measurement of the air flow and permit proper operation of the combustor. Consequently, we feel that the problems have been resolved and we look forward to a productive next quarter.

OBJECTIVES AND SCOPE

A. Background

A thorough understanding of the fundamental processes which govern the mineral behavior is essential to the development of tools to predict and manage ash deposition. The purpose of the current project is to perform a fundamental study of mineral transformations and ash deposition during staged combustion of pulverized coal. Staging of combustion air is a strategy used to reduce NOx emissions from coal-fired units. It is applicable to both advanced combustion systems currently under development (e.g. HITAF) and low NOx retrofits for existing units. These low NOx combustion strategies produce fuel rich or reducing conditions in the lower furnace. Therefore, the combustion history of the coal particles is significantly changed from that experienced under normal combustion conditions. A carefully designed experimental study is needed to examine the effects of altered combustion conditions on mineral matter release, fly ash formation, particle stickiness and deposit formation. This project uses state-of-the-art analytical equipment and a well-characterized laboratory combustor to address this need.

B. Objectives

This report describes work in the thirteenth quarter of a fundamental study of mineral transformations and ash deposition during staged combustion. The objectives of this project are:

1) Creation of an experimental database which documents the behavior of inorganic constituents during staged combustion under well-defined conditions,

2) Identification of key mineral species or reactions which may be problematic,

3) Development of increased understanding and insight into the mechanisms which control ash formation and deposition.

C. Research Task Summary

Task 1: Select specific coals, prepare the coals for use in the laboratory combustor, and perform a detailed characterization of samples from the prepared coals.

Task 2: Prepare and test reactor facilities and sampling probes for use in the proposed experiments.

Task 3: Conduct a parametric study of mineral transformations and particle stickiness during staged combustion by performing a series of tests at a variety of conditions and collecting both particulate and deposit samples for each of the tests.

Task 4: Analyze particulate samples collected in Task 3 in order to determine the size, shape, and composition of the particles. Also, examine particle stickiness by analyzing the composition (bulk and local) and morphology of deposits collected as part of Task 3.

Task 5: Design and perform additional tests based on the results of Tasks 3 and 4 in order to define mechanisms, identify critical conditions, etc.

D. Progress Report

This section of the report describes progress made during the thirteenth quarter. Progress is summarized by task.

Task 1

As mentioned above, the purpose of this task was to select specific coals, prepare the coals for use in the laboratory combustor, and perform a detailed characterization of samples from the prepared coals. This task has been largely completed and no additional work on this task was performed during the quarter.

Task 2

The purpose of this task was to prepare and test reactor facilities and sampling probes for use in the current experimental program. Ongoing maintenance and repair have also been included as part of this task. Almost all of the efforts from the previous quarter were focused on repairing and improving the reactor (see twelfth quarterly report). Unfortunately, many of the changes made last quarter did not prove successful. Consequently, most our efforts this quarter were also focused on operational issues rather than the gathering and analysis of data. It is our opinion that these problems must be satisfactorily resolved before we can confidently resume taking data. Once the problems have been resolved, we will carefully evaluate and replicate the results obtained to date.

The key issues addressed this quarter were related to operational problems in the coal feed system, namely, the inability to accurately measure all of air entering the system, and plugging of coal in the feed lines due to poor entrainment. Both of these problems caused unacceptable uncertainty and/or fluctuations in the operating conditions and therefore required solutions.

The coal entrainment problem was solved by installing an eductor (solids conveying venturi eductor, Fox Valve Development Corporation; see Fig. 1) designed for entraining solids in gas streams. All of the air entering the reactor now flows through the eductor, either as motive air or through the suction air inlet. This ensures that the coal is entrained at relatively high velocity, so that it will flow to the reactor without forming slugs in the lines. In previous configurations, most of the air entered the system through a secondary air line so that the particle loading was much higher in the primary (entrainment) line.

Observation of the feeder in operation with the new entrainment system showed pulsating coal flow due to the auger. These pulses had been damped to some degree by the previous feed system. Unfortunately, that system was prone to plugging. Consequently, a new feeder shroud was installed with an air jet directed towards the auger to sweep off the tip in order to reduce the pulsations when operating with the new eductor. The new configuration successfully damped the pulsations, although they were not completely eliminated. The combination of the eductor and the feeder shroud appeared to solve the problems associated with feeding the coal.

The problems associated with accurately metering the air have been somewhat more difficult to resolve. Although the new eductor was effective in solving our entrainment problems, it resulted in a large unmetered stream of air which entered with the coal into the system. Two possible solutions to this problem were explored: 1) closing the system so that no unmetered air could enter, and 2) use of a flowmeter capable of measuring air flows of two phase streams downstream of the coal entrainment point.

Previous attempts to build a "box" enclosing the entire feeder system were unsuccessful because of leaks. However, after construction of the new feeder shroud, it was observed that a closed connection could be made between the feeder and the eductor. Air could then be introduced through the feeder or shroud, so that all of the air entering the system could be measured. We have been much more successful at sealing only portions of the feeder and the shroud than our previous attempts at a closed system. However, it has only been possible to seal the system for experimental runs of 0.5 to 1 hours with the preliminary designs tested to date. Drawings and specifications of a more permanent design have been made and the new shroud is currently being built.

The other alternative was the purchase of a new flowmeter. Such a meter (thermal element mass flowmeter, FT502, Kurz Instruments; see Fig. 2,) was purchased with cost sharing funds from the university to help address the air metering problem. The meter was installed between the eductor and the reactor entrance. Both air and coal flow through the meter, but the coal is dilute and the thermal element is relatively insensitive to the particles. The FT502 was factory calibrated over the air flow rates of interest in our program using NIST-traceable standards. Using the FT502, we should be able to accurately account for all of the air in our system.

Initial tests with the new flowmeter were performed by comparing air flow measurements from the meter with those from the current orifice airflow meter. Unfortunately, there was a discrepancy in the measurements as shown in Table 1. As the new meter was just recently calibrated at the factory, it is our opinion that the orifice meters are in error. Apparently, the wet test meters used to calibrate the orifice meters were not calibrated correctly. Therefore, both the air and natural gas flow rates previously reported are incorrect. These errors are significant and may lead to an error in the stoichiometric ratio when burning coal. As illustrated in Table 1, an experimental test which was thought to be at SR = 0.75, was actually at SR = 0.66. All flowmeters have since been recalibrated against the new FT502.

Table 1. Reported and Actual Conditions

	Reported	Actual	Error (%)
Air (kg/h)	11.0	10.7	3.0
Natural Gas (kg/h)	0.31	0.45	-29
SR	0.76	0.66	15

Another set of tests were performed to verify that flow rates measured with the FT502 were indeed independent of particle loading. Figure 3 shows the results of one such test where both the measured air flow and the coal feed rates are shown. Only a small change in the air flow was observed when the coal was turned on and off. There was, however, some scatter in the data from the mass flowmeter. This scatter is due to pressure fluctuations associated with coal feeding and should decrease with the new shroud currently under construction. The influence of particles on the flow rate will be carefully evaluated at each set of test conditions and corrections will be made as necessary.

While awaiting delivery of the FT502, we constructed another air flow meter using an oxygen sensor (Figaro USA) and an absolute pressure transducer (Omega). Since our reactor uses natural gas to stabilize the flame, the gas phase just above the burner contains both natural and air. With the oxygen concentration known, the air flow rate can be determined by mass balance with the known flow rate of the natural gas. Testing of the oxygen sensor revealed that the sensor provides a reasonable value for the oxygen concentration, but is too noisy to use for practical air flow determination. However, the sensor does provide a backup or "sanity check" on the other air flow measurements. It will also be able to detect major leaks downstream of the FT502. In addition, the O_2 sensor may be useful for analyzing the flue gas.

The efforts of this quarter have essentially resolved the problems which have plagued us over the past three quarters. However, it appears that some of the data previously taken were not taken at the precise stoichiometric ratios reported. It is believed that the conditions of the previous tests can be replicated with the mass flow meter in-line so that the proper stoichiometric ratio can be obtained *ex post facto*. We are therefore optimistic that the study can be completed reliably and accurately in the next few months.

Task 3

No new samples were collected during the quarter.

Task 4

No new sample analyses were performed during the quarter.

E. Plans for the Next Quarter

1. Gather samples of ash from the Pittsburgh #8 coal under the same conditions reported previously. These samples will be used to validate the previous results.
2. Analyze the samples collected in #1 and compare the results with those previously reported for this project.

3. If the new and old results agree, prepare one or more peer-reviewed publications documenting the work. If the results do not agree, perform replicate tests to validate the most recent findings and report the updated work. Also provide an explanation for any discrepancies that exist.
4. Analyze Black Thunder ash samples and determine the effect of staged combustion on ash formation. Analyses will be similar to those used for the Pittsburgh #8 coal.
5. Collect and analyze deposit samples from both the Black Thunder and Pittsburgh #8 coals and quantify the effects of staged combustion on deposit formation.

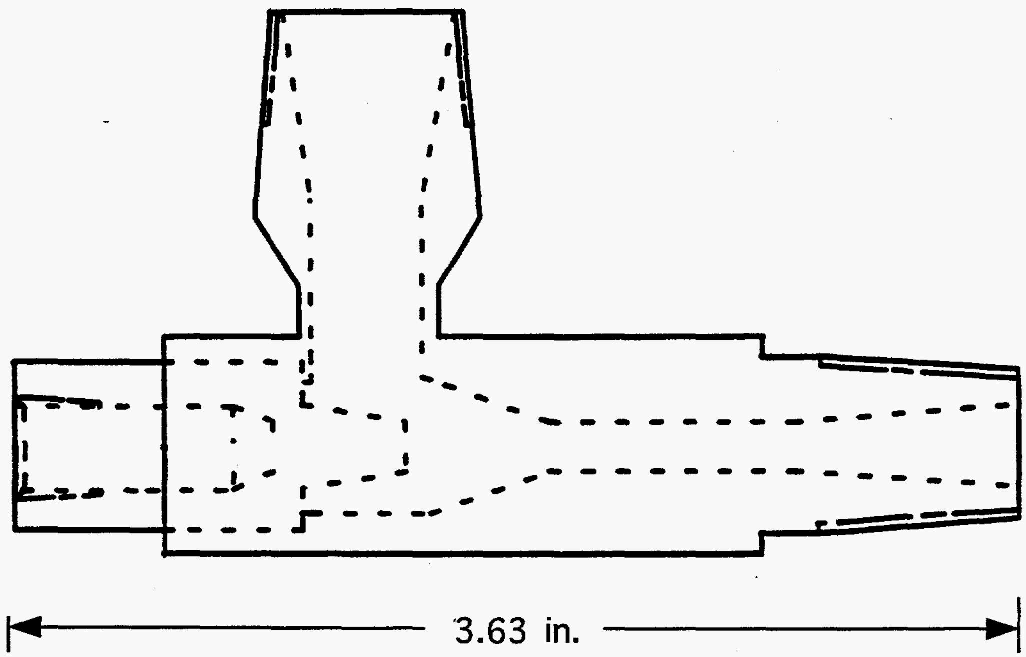

Figure 1. Fox Valve Venturi Eductor

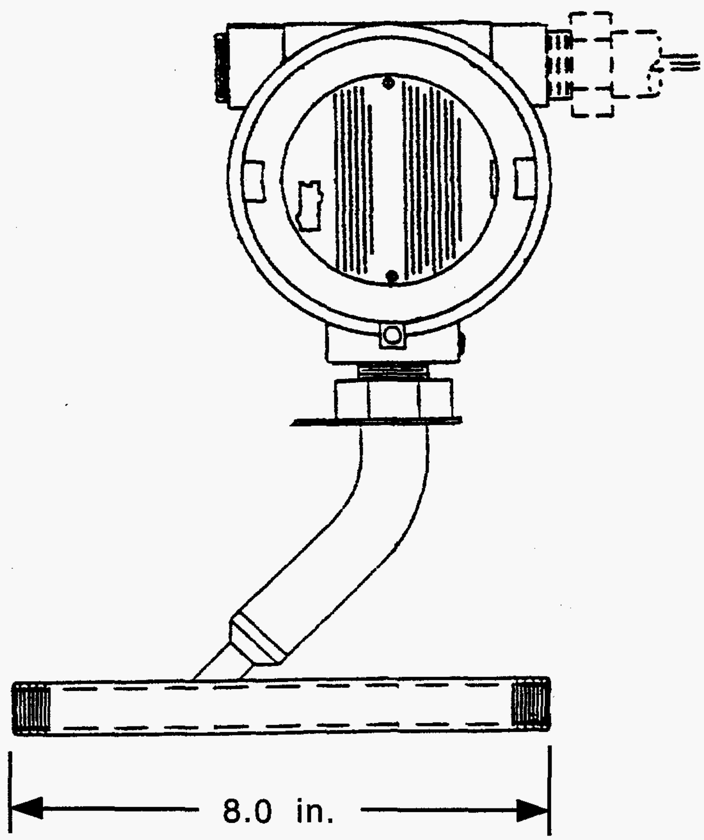

Figure 2. Kurz Instruments FT502 Mass Flow Meter

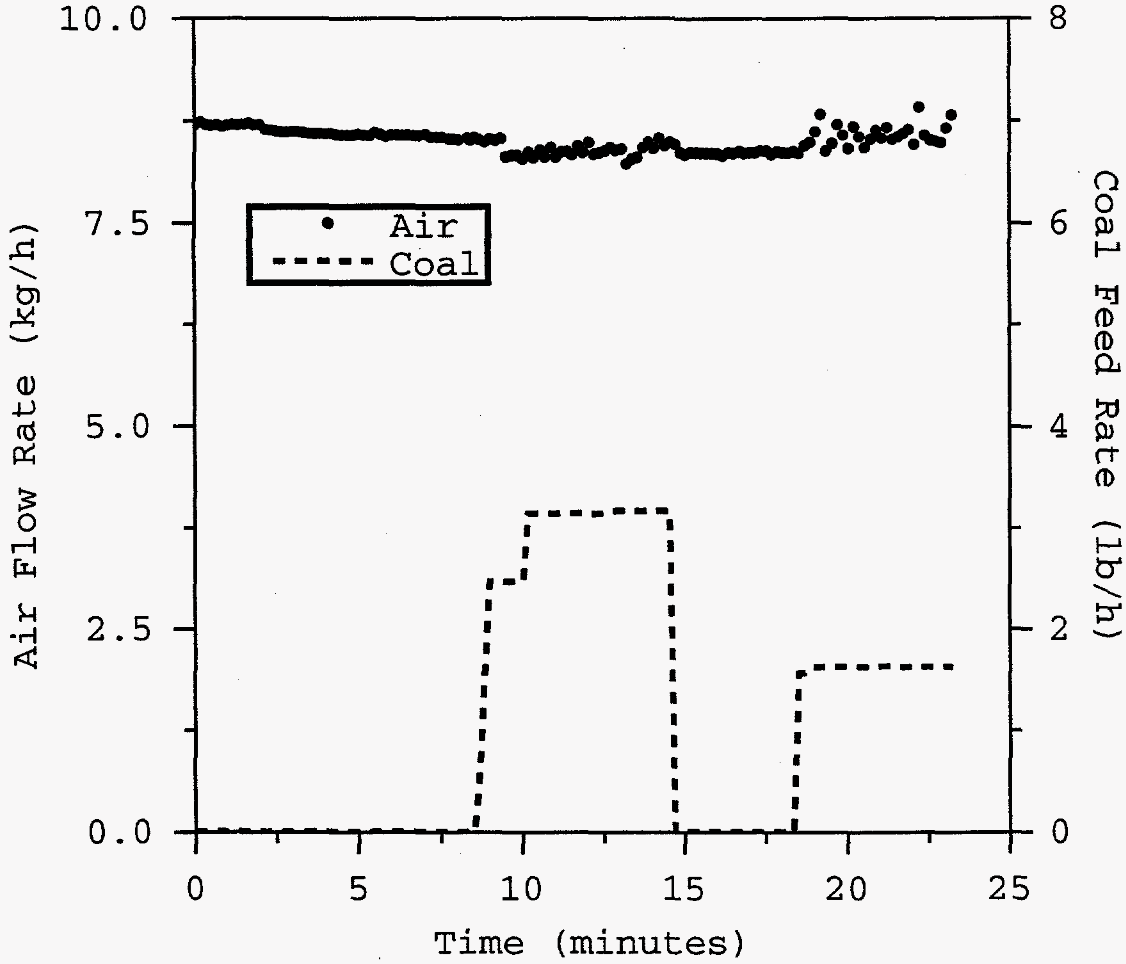

Fig. 3 Effect of Coal on Air Flow Measurement