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INVESTIGATION OF MINERAL TRANSFORMATIONS AND ASH DEPOSITION DURING STAGED COMBUSTION

Quarterly Technical Progress Report
January 1, 1994 to March 31, 1994

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This report summarizes technical progress during the second quarter (January 1, 1994 to March 31, 1994) of a three-year 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.

Students Neal Adair and Peter Slater contributed to the technical accomplishments reported for this quarter and to the preparation of the report.

ABSTRACT

Progress during the second quarter of a three-year study was made in two areas: 1) coal selection and characterization (Task 1), and 2) combustor modifications and preliminary testing (Task 2). Potential sources for coal have been identified and an attempt will be made to use the same coals as a similar DOE study. Advances have continued in our SEM-based analytical techniques. Modifications to an existing reactor system have been initiated. A new coal feeder has been installed and tested. Finally, specific tasks for the next quarter have been identified and reported.

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 NO_x emissions from coal-fired units. It is applicable to both advanced combustion systems currently under development (e.g. HITAF) and low NO_x retrofits for existing units. These low NO_x 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 second quarter of a fundamental, three-year 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.

PROGRESS REPORT

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

Task 1

Two coals have been selected for use in the study. Black Thunder is a Powder River Basin coal from the Anderson seam. Pittsburgh #8 is an eastern bituminous coal. In addition, Illinois #6 will be used for initial tests. Since these are similar to those in use by other DOE investigators, their use will serve to facilitate collaboration and to broaden the data base on these coals.

Considerable advancements were made in our scanning electron microscope analytical techniques during the last quarter. For example, we have greatly enhanced the statistical validity of our measurements of the mineral particles associated with large coal particles. Since large particles do not occur frequently in pulverized coal grinds, only a few of them were found and reported by our old technique. The paucity of samples led to substantial measurement uncertainties regarding the mineral matter in these particles and their impact on the overall analysis. Since SEM fields typically contain many, many small particles but very few large (>75 micron) diameter particles, it is not practical to analyze more large particles by simply analyzing more fields. The bulk of the time thus spent is used on small particles, which already produce acceptable statistics. Therefore, we developed a new algorithm which distinguishes coal particle sizes before performing X-ray analysis of the mineral particles. Using the size discrimination algorithm, we can quickly scan over a large sample area analyzing only large particles without wasting time on the abundant small particles. This allows us to produce reliable large particle data in a reasonable period of time. Peter Slater was responsible for the design of this algorithm.

Data reduction from a typical CCSEM analysis requires the processing of hundreds of SEM images and the combination of particle size and association information obtained from the images with X-ray composition data. Previously, image analysis was performed with software that runs on our Oxford eXL X-ray analyzer/image processor and required approximately one hour per image. Software written by Peter Slater now allows the image processing to be done on a high-performance workstation. A program to combine the output from this software with the X-ray data was written by Galen Richards, a student working under separate funding. Running on an HP 9000/755 workstation, the package can process two hundred images and their accompanying X-ray data in about half an hour. We expect that these two developments will be a great boon to the study in that they will make fast, reliable analytical turnarounds possible for guiding the experimental work.

A CCSEM analysis of the Black Thunder coal has been completed, yielding a picture of the discrete particle portion of the coal's inorganic constituents. Eleven mineral species account for 99% of the discrete inorganic matter (Figure 1). The two dominant species are quartz and aluminosilicate (clay), which together comprise 70% of the total content. The particle size distribution of these minerals (Figure 2) is heavily weighted towards the small size ranges. Only aluminosilicates occur to any substantial extent as large particles. Coal-

Figure 1

Mineral Particle Size Distribution

Figure 2

mineral association data for quartz and aluminosilicates have been charted in Figure 3. Both species occur as included and excluded particles. The aluminosilicate distributions appears to be bimodal, with 30% excluded and 34% associated with particles that are 40-50% mineral. The quartz is more widely distributed, with large quantities occurring everywhere except in particles that are 60-80% mineral.

Task 2

Experiments will be performed in a laboratory combustor available in the Advanced Combustion Engineering Research Center (ACERC) at Brigham Young University. The steady plug-flow reactor to be used in this study is down-fired and consists of six 0.3048 m (1 ft) long sections. The outer diameter of the reactor is 0.368 m (1.2 ft) and the inner diameter is 0.127 m. The walls consist of layered insulation 0.114 m thick. The reactor may be run in a coal-fired or gas-fired mode, or particles may be seeded into a stable gas flame.

The deposition experiments to be performed in this study will require that the combustor be operated for extended periods of time. This time includes 2 to 3 hours of preheating with natural gas as well as the coal firing time. The burner screen originally installed in the combustor was designed for use in short-duration experiments only. In particular, the flame tended to flash back when running with premixed natural gas/air ratios near stoichiometric. A new water-cooled burner screen has been designed and installed. To test the new screen, the reactor was fired with natural gas at $SR=1$ for 45 minutes. The flame was completely attached to the screen during the test, but the burner temperature was kept below 100°C by the cooling water. Wall temperatures reached 1000°C during the test firing.

A previously existing cyclone separator located downstream of the combustor for the removal of particulates from the flue gas had become corroded and plugged with ash and unburned char. The separator has been repaired with new parts that will not rust and the plumbing has been cleaned and replaced as necessary. Work on the combustor was performed by Neal Adair.

Plans for Next Quarter

1. Acquire Pittsburgh #8 coal.
2. Continue coal characterization.
3. Upgrade data acquisition and computer equipment used to control the reactor (Departmental funds have been authorized for this).
4. Continue test firing of the reactor.
5. Characterize temperatures in the reactor as a function of operating conditions.
6. Evaluate the need to preheat air (especially staged air) before it enters the combustor.

7. Evaluate whether or not additional insulation or wall heating is needed for downstream sections of the combustor.

Coal/Mineral Associations

Figure 3

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