INVESTIGATION OF MINERAL TRANSFORMATIONS AND ASH DEPOSITION DURING STAGED COMBUSTION

Quarterly Technical Progress Report
October 1, 1993 to December 31, 1993

John N. Harb
Brigham Young University
Provo, Utah 84602

Date published- January 28, 1994

PREPARED FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Contract No. DE-FG22-93PC93226

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FORWARD

This report summarizes technical progress during the first quarter (October 1, 1993 to December 31, 1993) 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.

The following students contributed to the technical accomplishments reported for this quarter: Peter Slater, Neal Adair, and Jeff Widener. Dr. Harb was the principal author of the report. Collaboration with Dr. Calvin H. Bartholomew (under separate ACERC funding) on Mössbauer spectroscopy is also acknowledged.

ABSTRACT

Progress during the initial 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. Initial Mössbauer spectroscopy analysis of an eastern coal has been performed in collaboration with other investigators. 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 initial 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.

D. Discussion of Research Tasks

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.

Coal Selection. We anticipate using two different coals and a blend of those coals in the proposed study. One of the coals will be a Powder River Basin (PRB) coal. PRB coals are typically low in sulfur and contain calcium which is organically bound to the coal matrix; these strip-mined coals are popular because of their low sulfur content and low price. The second coal will be an Eastern Bituminous coal which contains significant amounts of minerals commonly associated with ash deposition (e.g. pyrite and illite). Precise coal selection will depend on availability, as well as potential overlap with coals in use by other investigators at Brigham Young University. Use of the same coals by different investigators provides additional information to all of the research groups involved.

Coal Preparation. The amount of preparation required will depend on the form in which the selected coal is available and the purpose of the particular experiment in which the coal will be used. Initial experiments will use a coal size distribution typical of a utility grind. Pulverizing will be done in-house if required. Subsequent experiments may use more selective coal classification (e.g. a particular size fraction or gravity fraction) in order to provide specific information.

Coal Characterization. A computerized laser-based particle sizing apparatus will be used to determine the particle size distribution of the coal. In addition, standard ASTM procedures will be used to determine the proximate and ultimate analysis of the coal, as well as the mineral oxide composition. Although useful, these standard analyses do not provide the detailed information on the abundance, size, and association of coal inorganic matter which is needed in order to understand the behavior of inorganic constituents during combustion [1]. A powerful, state-of-the-art computer controlled scanning electron microscope at Brigham Young University will be used to provide a detailed analysis of the coal inorganic matter [2,3]. In addition to analysis with the scanning electron microscope, chemical fractionation will be used on coal samples to determine the quantity of organically bound inorganics [4].

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

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 made of 0.00635 m (quarter inch) steel, with flanges on the top and bottom

to facilitate assembly. 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 either a coal-fired or gas-fired mode. Alternately, particles may be seeded into a stable gas flame. A modular data acquisition system driven by a microcomputer is used to monitor the gas flows, coal feed rates, and thermocouple temperatures as a function of time. The computer is also used to move and record the position of probes in the reactor. A new high-precision coal feeder (Acrison Model 406-BDFM) has recently been purchased with university funds and is available for use in the proposed study.

Several modifications to the combustor will be needed in conjunction with the current study. The new feeder will need to be installed and the current plumbing modified or replaced. A new reactor section equipped with a cross-flow deposition probe will be assembled. A new particle sampling probe will also be designed and built. Staging of air will be accomplished by injecting a fraction of the total air into the combustor downstream from the burner between the first and second modular sections. Alternately, the staged air may be injected further downstream (e.g. between second and third sections) or in multiple locations. The operating conditions best suited for subsequent experiments will be defined as part of this task. Temperatures in the combustor will be characterized as a function of operating conditions. Particle burnouts will also be determined.

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.*

This task will be performed with the reactor operating in the coal-fired mode. A "non-staged" base case will first be established for the two target coals and the coal blend. Excess air sufficient to yield an outlet oxygen concentration of approximately 4% will be used for all experiments. The test plan includes tests at three different levels of staging, two coal feed rates, and two different locations of the staged air inlet for half of the tests. Multiple runs at each combination of these conditions will be needed in order to collect particle samples at a minimum of two different locations, and to collect at least two different types of deposit samples. The principal part of the testing for the project will be performed as part of this task.

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.*

Analysis of particulate samples will be performed with use of the analytical techniques described in Task 1 to determine the size, shape, and composition of the particles. The particle size distribution will be used to evaluate the importance of fragmentation and to provide insight into the mechanisms which influence ash particle formation. Particle shape provides a qualitative measure of the combustion history of the particle; for example, particles which have been molten in the reactor will be spherical in shape. Changes in the bulk and local composition of the particle inorganic matter provide a measure of the extent of mineral release and the types and quantity of mineral transformations. The composition profile of particle cross-sections will also be examined for some samples to determine if heterogeneous

effects are important. Our ability to distinguish between organic and inorganic phases will be especially useful in the examination of particle behavior under conditions of incomplete burnout. All of the data from these analyses will be compiled as a function of the test conditions to document mineral matter transformations and release during staged combustion.

Deposition samples will also be analyzed to determine the nature of particle to particle bonds, particle to substrate bonds, and particle deformation. Both the bulk and local compositions of the deposit will be determined. Preparation of deposit samples for analysis will require careful removal of the deposition probe with the deposit intact. The deposit and the substrate will then be cast in epoxy and polished for examination in the SEM.

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.*

Hypotheses will be developed to explain the observed data based on a comparison of the analysis of samples from Task 4 with the coal samples from Task 1. Attention will be given to the difference between mineral behavior observed under base case combustion conditions and that observed during staged combustion. The role of the transition from reducing to oxidizing conditions is of particular interest. Once developed, these hypotheses will be used to design the next series of experiments.

PROGRESS REPORT

This section of the report describes progress made during the most recently completed quarter. In this and future reports, progress will be summarized by task.

Task 1

Work was initiated this quarter on the selection of two coals to be used for the bulk of tests to be performed in Task 3. It is estimated that a minimum of two barrels (200 lb) of each coal will be needed. An investigator from a closely related study on mineral behavior under reducing conditions, also funded by DOE, was contacted regarding their selection of coals. The coals they will be using include an eastern bituminous coal (Pitt #8) and a PRB coal (Black Thunder). These coals fit nicely the description of the fuels anticipated for use in the present study. The source of their coals has been identified, and we are examining the possibility of using the same coals as this would benefit both studies.

In addition to coal selection, we have made considerable advancements in our SEM-based characterization techniques for coal. Many of these advances were made by Peter Slater, a new doctoral student, who will be working on this project over the next three years. Application of these techniques to the selected coals will be described in a future report.

An initial attempt to characterize iron compounds in coal with Mössbauer spectroscopy was also performed during this quarter. This analytical work was done in collaboration with Professor Calvin H. Bartholomew at Brigham Young University under separate funding. Results are shown in Fig.1 for a NIPSCO U.S. eastern bituminous coal. The spectra provide evidence for both pyrite and iron aluminosilicates. We recognize that the real advantage of the Mössbauer technique will be in the analysis of ash and deposits. However, we will continue using coal until ash and deposit samples are available.

Task 2

Much of the effort during the last quarter was focused on this Task 2. Existing reactor facilities must be modified to meet the requirements of this study. Two students have been employed to work on this task. The first, Neal Adair, is an undergraduate student who will continue on this project as a graduate student beginning in Spring, 1994. Another undergraduate student, Jeff Widener, has been hired on a temporary basis to help prepare and test the combustor.

One of the key modifications to the reactor is the addition of a new coal feeder. The coal feeder previously used with the facility did not provide steady or consistent feed rates over the time period necessary for our tests. For this reason, we have purchased, with university funds, a new Acrison MDII 400 series feeder for use in this study. The feed system includes a single auger feeder mounted on a balance and equipped with a sensitive control system. The feeder has been installed in such a way as to minimize vibrations that might introduce error into the scale readings. A new electrical outlet was required and installed to supply power to the feeder.

Much of our recent efforts have been focused on damping or smoothing out the inherently

Species	I.S.	Q.S.	%Area	Mineral
Fe ²⁺	1.13	2.56	35.4	Fe/Al-Si
Fe ³⁺	.28	.63	64.6	FeS ₂

Figure 1 Mössbauer Spectroscopy of NIPSCO Eastern Coal

nonuniform feed rate from the auger feeder. A method was also needed for entrainment of the coal in air without pressurizing the feed system. A small nozzle (adapted from a paint sprayer) appeared suitable for both of these purposes. The nozzle has been installed and tested, and appears to work well. Some additional plumbing is needed before testing and characterization of the reactor can be continued. We plan to fire the combustor for preliminary testing during the next quarter.

The design of the sample probes needed for the present study has also been initiated. We hope to complete the design and begin construction of the probes during the next quarter.

Plans for Next Quarter

1. Select and acquire at least one of the coals needed for the study.
2. Begin coal characterization.
3. Upgrade computer used to control the reactor (departmental funds).
4. Resolve feeding problems to the extent possible.
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.

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