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Development of Methods to Predict Agglomeration and Disposition in FBCs

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and Deposition in FBCs**

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OBJECTIVES

This 3-year, multiclient program is providing the information needed to determine the behavior of inorganic components in FBC units using advanced methods of analysis coupled with bench-scale combustion experiments. The major objectives of the program are as follows:

- To develop further our advanced ash and deposit characterization techniques to quantify the effects of the liquid-phase

components in terms of agglomerate formation and ash deposits

- To determine the mechanisms of inorganic transformations that lead to bed agglomeration and ash deposition in FBC systems
- To develop a better means to predict the behavior of inorganic components as a function of coal composition, bed material characteristics, and combustion conditions

BACKGROUND INFORMATION

The successful design and operation of advanced combustion systems requires the ability to control and mitigate ash-related problems. The major ash-related problems are slag flow control, slag attack on the refractory, ash deposition on heat-transfer surfaces, bed agglomeration, corrosion and erosion of equipment materials, and emissions control. These problems are the result of physical and chemical interactions of the fuels, bed materials, and system components. The interactions that take place and ultimately control ash behavior in fluidized-bed combustion (FBC) systems are controlled by the abundance and association of the inorganic components in coal and by the system conditions. Because of the complexity of the materials and processes involved, the design and operations engineer often lacks the information needed to predict ash behavior and reduce ash-related problems.

Even though the FBC operates at a relatively low temperature, a number of potential ash-related problems exist. For example, deposition on in-bed superheater tubes and supports has been noted for several bubbling FBCs. The amount of deposition is quite variable and dependent upon fuel type. A 40°F loss in superheat temperature over a 4-month period at the Montana-Dakota Utilities (MDU) Heskett Station is one example.

In-bed agglomeration, also noted, has been responsible for unscheduled shutdowns. Agglomeration of this extent limits the range of fuels that can be burned in the FBC.

Deposition in the convective pass has also been noted by bubbling-bed FBC users. This deposition results in loss in steam temperature. Knowing the propensity of certain coal ashes to deposit in the convective section is important for the design of tube spacing and sootblower coverage and schedule.

Similar problems have been identified in circulating fluidized-bed combustion (CFBC) applications. Again, deposition in the convective pass results in a loss in steam temperature. Knowing deposition rates and deposit strengths will be important for designing tube spacing and sootblower coverage and schedule. Another problem inherent to certain fuels in the CFBC is deposition in the cyclone and other cooled surfaces. Some deposits can fall down, plugging drains and loop seals. The deposits can also serve as sites for alkali corrosion.

Agglomeration in the loop seal and bed of the CFBC is responsible for unscheduled shutdowns. As in the bubbling bed, the CFBC requires high bed turnover rates or limitations on bed material selection for control of agglomeration. These problems limit the range of fuels that can be burned in the CFBC.

PROJECT DESCRIPTION

This is a multifaceted program designed to further our understanding of ash-related problems in FBCs. The major tasks include enhancement of analytical techniques, analyses of material from full-scale FBCs, bench-scale reactor development, applied fundamental chemistry and physics, and development and verification of predictive techniques and mitigating measures.

Samples from full-scale units will be analyzed in detail with scanning electron microscopy. The information collected will allow detailed analyses of the fuel causing agglomeration or deposition problems; identify the coating and bonding material causing the agglomeration and deposition; indicate the mineral species contributing to strength development; provide data for developing a model to predict agglomeration and deposition; and ensure validity and relevance of bench-scale tests.

The bench-scale fluidized-bed reactor will be used to perform combustion tests to determine the effect on agglomeration of operating conditions, bed material, sorbents, and additives. The information collected will provide an extensive database of fuel, bed, and sorbent properties and operating conditions for model development. This task should result in information to use to predict agglomeration and provide a device for studying mitigating measures.

Samples from the full-scale units and the bench-scale reactor will be used to 1) determine the physical and chemical processes that result in the partitioning of ash components in FBCs and 2) to better understand the physical and chemical interactions of ash components upon cooling, sintering, and deposition. The information collected during this task will identify specific processes and conditions responsible for operational problems and provide input to the development of predictive techniques and mitigating measures for FBCs.

A computer model currently available to predict deposition in pulverized coal (pc)-fired units will be adapted for FBC use. The ultimate model would be an empirical algorithm to predict the rates of fines generation, sticky particle generation, elutriation, deposition on in-bed tubes and supports, agglomeration and defluidization, deposition on walls, and deposition on convective pass tubes. It is desirable to be able to predict these rates as a function of firing mode, velocity, bed type and size distribution, fuel type and size, sorbent, and oxygen concentration.

RESULTS

Fluidized-Bed Agglomeration

The detailed analyses of agglomerate, deposit, and bed material samples from the Montana-

Dakota Utilities (MDU) Heskett Station and the Tidd pressurized fluidized-bed combustor (PFBC) provided the information required to develop mechanisms of formation for FBC agglomeration and deposition. The proposed mechanism is shown in Figure 1. Bed material agglomerates can typically be classified into four distinctly different categories. One type of agglomerate forms from relatively small bed particles that stick together, forming larger masses of bed material. In this case, coal ash reacting with bed material forms the substance that acts as the "glue" in agglomeration. These ash-related interactions occur under normal atmospheric FBC operating conditions and include the formation of low melting points between sodium-, potassium-, calcium-, and sulfate-rich components and possibly some solid-solid reactions. These agglomerates have a solid core and resemble raspberries.

The second type of agglomeration appears as hollow "eggs." These can be drained out of the bed with spent-bed material in mild cases, but will cause defluidization and a forced shutdown in severe cases. These agglomerates form around burning coal particles. After the coal burns out, a hollow egg-shaped agglomerate remains. Agglomerates ranging from about ½ in. to 3 in. in diameter have been noted by EERC personnel from various units.

A third type of agglomeration is the result of localized hot spots of bed material, where temperatures in the FBC can exceed the typical 1700°F limit. Temperatures capable of melting various ash species can be attained even during relatively stable operation of the FBC. This type of agglomerate appears as a sintered mass with obvious signs that melting had occurred. This type of agglomerate is typical of localized zones of poor fluidization, such those that may exist during start-up or turndown of a multicell unit. Agglomerates of this type are also formed when defluidization occurs because of other

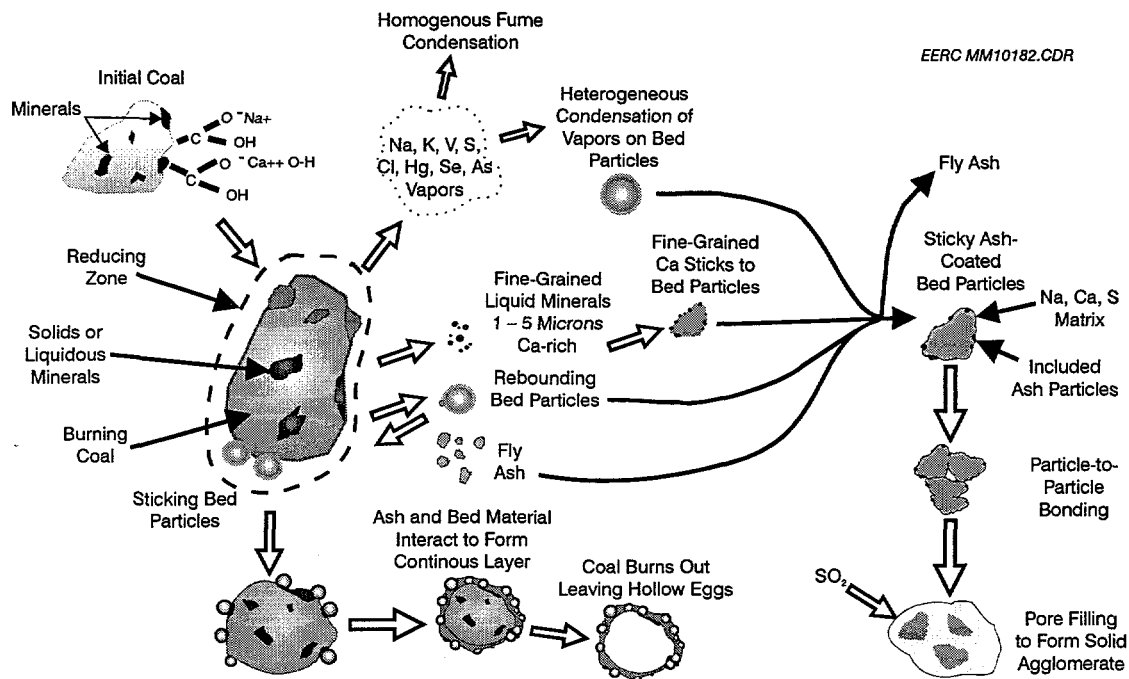


Figure 1. Pictorial Reproduction of the Mechanisms of Ash Formation and Bed Material Agglomeration in Fluidized-Bed Combustion

mechanisms, and local temperatures increase as a result of the poor fluidization.

A fourth type of agglomerate consists mainly of sintered fly ash, with some fine sorbent material intermixed. This type of agglomerate is very fine-grained and dense. Typically these agglomerates are much weaker and can be broken up more easily than can the other three types of agglomerates. These sintered fly ash agglomerates are more commonly found in loop seals or other areas of low or stagnant flow.

The primary components of the fuel that are typically associated with agglomeration are the alkaline-earth elements, specifically, organically bound or water-associated sodium or potassium. Other elements that have been associated with agglomeration in atmospheric systems at normal

operating temperatures (<1700°F) include iron, vanadium, and calcium. Higher operating temperatures and pressures can also cause certain silicon and aluminum compounds to participate in the agglomeration mechanisms.

Factors Enhancing Agglomerate Formation

Egg-type agglomerates will form if conditions within the bed promote melting of the fuel ash. Therefore, agglomeration is enhanced by the mineral content of the fuel. The size and composition of the minerals in the fuel must be known to determine whether agglomerates may be a problem with a particular fuel.

Agglomeration is enhanced by local reducing zones, since the liquidus temperature of the mixture is lower for reducing than for oxidizing

zones. The viscosity is also lower in the reducing zones, making sinter formation easier.

Agglomeration becomes more severe when the melting temperatures of the various mineral phases are approached. Therefore, higher temperature, especially at the surface of the burning coal particle, will enhance agglomeration.

As pressure increases, even for a fixed bed temperature, the temperature of the burning coal particle increases. This increase in temperature is caused by the high reaction rates related to the higher partial pressure of oxygen.

The propensity to agglomerate increases with the presence of a fluxing agent. Sodium and calcium are good fluxing agents, lowering the melting point of certain silicate-based clays. The ability of the calcium to flux increases as the particle size decreases because of the increased surface area.

Ash Formation and Boiler Tube Fouling

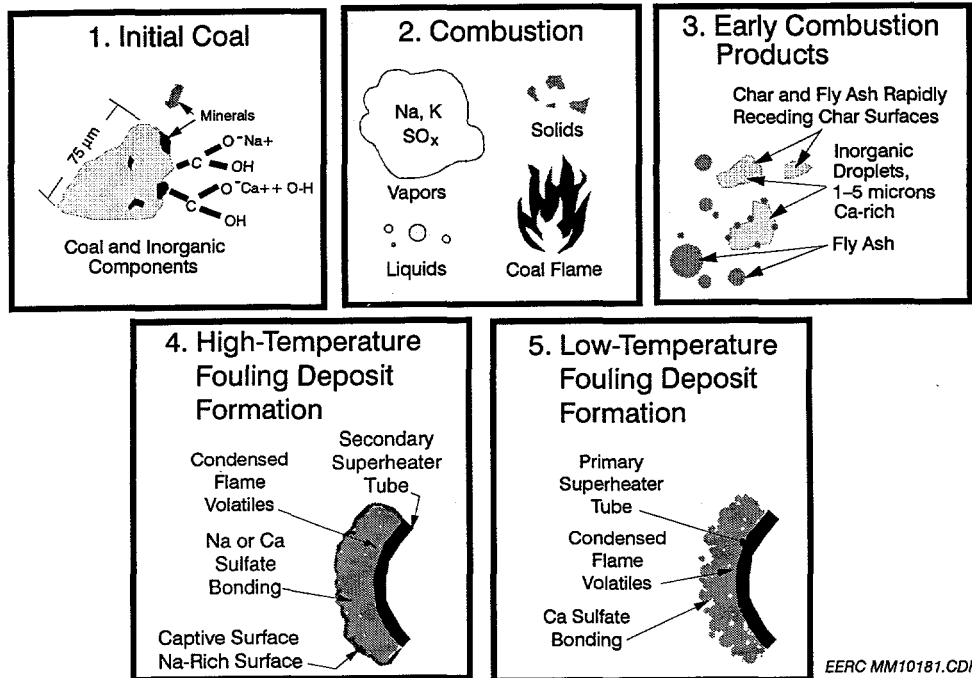
The ash formation and fouling mechanism for boiler tube deposition is shown in Figure 2. This mechanism shows that the combustion of the initial coal particles again results in the formation of vapor-phase species (such as Na, K, S) and the formation of fine-grained liquid droplets (as calcium-rich oxides and sulfates) and fly ash particles. The fouling mechanism is initiated by the condensation of alkaline salts from the vapor phase on the surface of the tube to form a concentrated alkali sulfate layer. This layer increases in thickness until the reduced heat transfer allows the 1- to 5-micron inorganic Ca-rich droplets to impact the condensed alkali sulfate layer, where sintering of the calcium sulfate bonds the fine-grained ash to the tube surface. As the sintering of the deposit continues, a thicker, more dense deposit develops in which other ash species

can become trapped on the captive surface of the deposit. Thus, coals with more organically bound cations of sodium and calcium show higher deposition rates than coals with no alkalis or clay-associated alkalis. The presence of certain aluminosilicates in the coal ash has been shown to react with some of the alkali elements, thereby reducing the alkali-induced deposition.

Bench-Scale Testing

A fluidized-bed reactor (FBR) has been constructed to simulate the bed chemistry, ash interactions, and emissions from a fluidized-bed combustor under closely controlled conditions. This reactor is used for sorbent characterization, gaseous emissions including trace elements, agglomeration, and hot-gas cleanup testing in a cost-effective manner over a wide range of operational conditions. The 55-in.-tall reactor, constructed of 3-in. Schedule 80 pipe, is externally heated with three ceramic heaters. A hot cyclone collects the ash and bed material that are carried out of the reactor. The preheated fluidizing gas can be a mixture of air and nitrogen or just air; in addition, one additional gas such as carbon dioxide, carbon monoxide, sulfur dioxide, or a nitrogen oxide can be added to result in a fuel gas similar to that generated in a full-scale fluidized-bed combustor. Preheated gas at temperatures up to 1000°F is supplied at the bottom of the reactor through a 1-in. Schedule 40 pipe. The fluidizing gas is supplied at sufficiently high velocities to prevent the sized bed material from dropping out during operation. A schematic of the bench-scale FBR is shown in Figure 3.

Table 1 shows the operating conditions and duration of the tests performed on the FBR. The fuel for each test was sized to -1/8-in., and sand was used as a start-up bed material for all but Test KR2-1995, which used Gabbro bed material. Superficial gas velocity was approximately 6 ft/s



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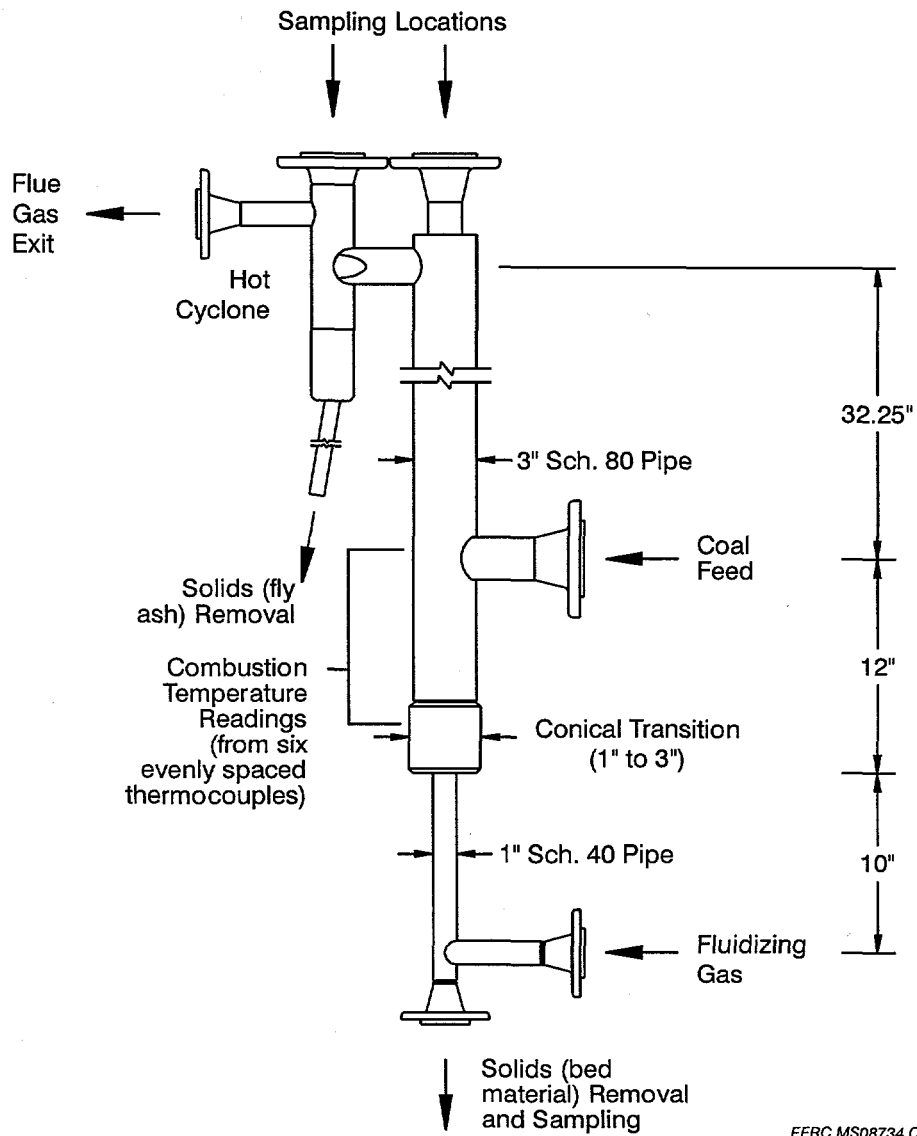
Figure 2. Ash Formation and Fouling in Fluidized-Bed Combustion

for all tests except KR1-0295, which had a velocity of 11 ft/s. Standard test length was 16 hr; bed material and fly ash samples were collected every 4 hours. These samples were analyzed with x-ray fluorescence (XRF) to determine the change in bed chemistry over time and scanning electron microscopy (SEM) to examine the coating on bed material particles and sticking between particles.

accurate method will have been developed to predict the propensity for fouling and agglomeration, along with methods to reduce or eliminate these ash-related problems.

FUTURE WORK

Work on this project will continue through December 1995. Funding continues from Ahlstrom Pyropower, EPRI, Northern States Power Company, and the North Dakota Lignite Research Council. Funding through the new DOE-EERC Jointly Sponsored Research Program is also in place for the final year of the project. It is hoped that at the end of this 3-year project, an



EERC MS08734.CDR

Figure 3. Side View of FBR

Table 1. Operating Conditions and Results of Bench-Scale Testing

Test Number	Bed Temp., °F	Excess Air, %	Bed Material	Results
KR1-0195	1500	30	Washed sand	Ran 16 hr.
KR1-0295	1700	30	No. 30 Red Flint sand	Ran 15 hr; air flow rate unknown. Trouble with reactor heaters.
KR1-0395	1600	15	No. 30 Red Flint sand	Temps unstable; defluidized after 5 hr.
KR1-0495	1700	2.5	No. 30 Red Flint sand	Defluidized after 3 hr.
KR1-0595	1500	2.5	No. 30 Red Flint sand	Ran 16 hr.
KR1-0695 ¹	1700	30	No. 30 Red Flint sand	Ran 8.5 hr, until coal supply ran out.
KR2-0795 ²	1500	30	No. 30 Red Flint sand	Defluidized after 40 min.
KR2-1095 ²	1500	30	No. 30 Red Flint sand	Defluidized after 1 hr.
KR2-1295 ³	1500	30	No. 30 Red Flint sand	Ran 16 hr.
B1-1395	1500	30	No. 30 Red Flint sand	Ran 113 hr.
KR2-1495	1600	15	No. 30 Red Flint sand	Defluidized after 1.85 hr; tried again and ran 50 min.
KR2-1595	1700	30	No. 30 Red Flint sand	Defluidized after 2.95 hr.
KR2-1695 ⁴	1700	30	No. 30 Red Flint sand	Defluidized after 3.33 hr.
KR2-1795 ⁴	1500	30	No. 30 Red Flint sand	Defluidized after 6.28 hr.
KR2-1895 ⁵	1500	30	No. 30 Red Flint sand	Defluidized after 0.93 hr; tried again and ran 2.38 hr.
KR2-1995	1500	30	-10 +20 mesh gabbro	Defluidized after 9.52 hr.

¹ Repeat of KR1-0295, using air instead of water cooling.

² Repeat of KR1-0195, using air instead of water cooling and using Red Flint sand as bed material.

³ Included kaolin addition at the rate of 0.093 lb kaolin/lb fuel.

⁴ Added 2000 ppm SO₂ with combustion gas.

⁵ Added Plum Run dolomite at the rate of 125 g/3200 g coal.