CHARACTERIZING THE STRUCTURE OF ASH DEPOSITS FROM COAL COMBUSTORS

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ABSTRACT

The results of a study of ash deposit microstructure based on the analysis of two-dimensional images of planar sections are presented for two Powder River Basin subbituminous coals. The status of new work using a three-dimensional imaging technique, X-ray microtomography, is also described. This technique represents an important advance in the ability to quantify the three-dimensional connectivity of deposits, which is difficult to obtain from planar sections.

INTRODUCTION

A principal goal of research in coal combustion is to move the design and operation of coal-fired plants from a base of experience to one of knowledge. To accomplish this goal, many fundamental aspects of coal combustion must be better understood, including the physical properties of ash deposits. In materials research, a key to better understanding material properties has been the ability to observe and quantitatively characterize microstructure. Applying this approach to ash deposits will produce similar results, leading to a better understanding of ash deposit properties and suggesting ways of reducing the impact of these deposits on boiler performance. Specifically, the information obtained by studying ash deposits microstructure will (1) identify deposit formation mechanisms, (2) provide the geometric information necessary for computational modeling of deposit properties, and (3) make possible the interpretation of deposit physical property measurements.

This paper describes the measurement of microstructural parameters for ash deposits produced by two subbituminous coals from the Powder River Basin, using methods based on the analysis of photomicrographs of planar sections of the specimens. These direct measurements eliminate the need for an idealized model of the material (which is the case with physical methods, such as porosimetry, gas adsorption, and compressive strength) and yield localized results that allow the study of structural gradients within the deposits.

A typical scanning electron microscope (SEM) image of a Powder River Basin ash deposit is shown in Figure 1. In this image, the bright regions are cross-sectional profiles of the solid phase of the deposit and the dark regions correspond to the pore phase. The solid phase comprises particles of ash and mineral matter that have been sintered or cemented together in a continuous structure. The pore phase, which is filled with ambient gas in the boiler, has been filled with epoxy to facilitate specimen preparation. The relatively small fraction of solid phase in the image reflects the low solid fraction of the deposit.

Figure 1 also illustrates a major challenge to studying the microstructure of ash deposits, which is the loss of connectivity information caused by planar sectioning. In this figure, the continuous solid phase appears as isolated particles and clusters of particles. The connecting paths, which are not in the plane of section, are not visible and thus cannot be measured.

Figure 1. SEM image of a planar section of a Powder River Basin ash deposit.

The measurement of connectivity information requires the use of three-dimensional imaging, such as X-ray microtomography (Kinney and Nichols, 1992). During FY96, collaboration began with X-ray microtomography facilities at Lawrence Livermore National Lab and the NASA Lewis Research Center. The current status of this work will be described at the end of this paper.

EXPERIMENTAL PROCEDURE

Specimen

Two ash deposit specimens were studied in this work, one from coal A and the other from coal B, both generated under identical conditions in the Multi-Fuel Combustor in the Combustion Research Facility at Sandia National Laboratories. The surface temperatures of the combustor wall and the 17-mm diameter, stainless steel probe were maintained at 1300°C and 500°C, respectively.

Structural Parameters

A comprehensive description of the methods used to measure the structural parameters of the ash deposits and a detailed analysis of the uncertainty of the results are found in Rumer and Martello [1995]. In the discussion below, the subscript α represents the solid phase and β the pore phase.

Volume Fraction

The solid volume fraction, V_V, is the volume of solid phase per unit volume of deposit. This is the single most important structural parameter in correlating the effective thermal conductivity of two-phase materials, such as the fouling and slagging deposits in boilers [Wain, et al., 1992]. The solid volume fraction has also been shown to have a marked effect on the mechanical properties of ash deposits that affect their removability, namely the compressive strength, the elastic modulus, and the thermal shock resistance [Wain, et al., 1992].

Figure 2. Spatial profiles of $V_{V\alpha}$ in deposits from coals A and B.

The variation of V_V across deposits A and B is shown in Figure 2. The surprising feature of these curves is the lack of a strong increase in V_V from the tube surface to the flame surface. Larger increases would have been expected because of increased sintering with distance from the tube surface and the formation of a molten phase at the flame surface of the deposit.

Specific Surface Area

The specific surface area, S_V, is the surface area of the solid phase per unit volume of deposit. This parameter describes the fineness of the deposit and has a dominant effect on its optical properties, such as reflectivity [Wall, et al., 1993].

The spatial profiles of S_V in Figure 3 show that it remained constant for coal A and decreased slightly for coal B. Combining the results for S_V and V_V indicates a small decrease in the surface-to-volume ratio of the solid phase with distance from the tube surface for both coals, caused by a coarsening of the solid phase. This coarsening was confirmed by visual observation.

Contiguity

The contiguity, C, is defined as the dimensionless ratio of particle-particle contact area to total particle surface area. This degree of contact between particles is a measure of sintering, an important mechanism of strength development in ash deposits [Nowok, et al., 1990].

Figure 4 shows a dramatic increase in C across the deposit. This increase is evidence that sintering, not larger particles, was responsible for the coarsening of the solid phase. It was visually observed that the sintering resulted from both increased particle coalescence and encapsulation of particles by a glassy, molten phase.

Figure 3. Spatial profiles of $S_{V\alpha\beta}$ in deposits from coals A and B.

Figure 4. Spatial profiles of C in deposits from coals A and B.

Bulk Values

The bulk averages of the measured parameters are presented in Table 1. These results are the same for both coals, an expected outcome because the coals are similar and the combustion conditions were identical. Coal A is known to have a greater low-temperature fouling tendency than coal B [Hurley, et al., 1991]; however, the combustion conditions were in the high-temperature fouling regime where the behaviors of both coals are similar.

Table 1. Bulk values of structural parameters.

	Coal A	Coal B
V_V	0.25	0.22
S_V	0.60×10^5 m^{-1}	0.58×10^5 m^{-1}
C	0.24	0.23

THREE-DIMENSIONAL IMAGING

During the second quarter of FY96, a collaborative project of three-dimensional imaging of ash deposits was begun with Larry Baxter of Sandia National Labs. Deposit specimens were prepared and sent to John Kinney at Lawrence Livermore National Lab (LLNL) and George Baaklini at the NASA Lewis Research Center. The facility at LLNL uses an accelerator as a high-intensity source of x-rays and has a resolution of 5 μm. The instrument at NASA Lewis uses a small laboratory x-ray source, and its resolution is 25 μm.

Software to analyze the three-dimensional images is currently under development at PETC. As part of this development, an ash deposition simulation was created based on the simple ballistic deposition of log-normally distributed spherical particles. Sample results from this simulation are presented in Figure 5. The solid volume fraction in this image is 24%, which is similar to the bulk values in Table 1. Planar sections of the deposit visible in the intersections with the X-Z, Y-Z, and X-Y planes are very similar to that observed in Figure 1.

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Figure 5. Structure of simulated ash deposit.