A CLASSIFICATION OF COAL-FIRED BOILER DEPOSITS

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INTRODUCTION

Ash deposition in boilers has been studied by numerous investigators from virtually all areas of physical science. Several books (1) (2), and publications too numerous to reference have been published on this subject. Unfortunately the information flow between boiler operators and researchers has not always been ideal. In the absence of a workable classification system, valuable information concerning the nature and conditions of formation of boiler deposits may be lost. Field observations can greatly enhance information derived from laboratory study, and can lead to a more meaningful interpretation of the causes and, ultimately, to the solution of boiler deposits. As such, the system proposed here provides basic steps in the documentation of field observations together with a simple megascopic and microscopic classification scheme.

Whereas this system was designed to describe deposits from coal-fired steam generators, it may be applied to other environments or equipment with similar high-temperature mineral transformations. This system only addresses cooled deposits, as opposed to those that exist at the higher temperatures of boiler operation.

DEPOSITS IN BOILERS: FIELD OBSERVATIONS

Boiler Description

The type of boiler influences the properties and significance of the deposits (3). A simple description of the boiler and operating conditions provides information on processes and environments to which the coal and ash may have been exposed. This description should include, at a minimum, firing method (stoker, PC, cyclone), unit size including steam flow, heat input and plan area, and, if known, gas temperatures and velocities through out the system. All of these variables can influence deposit formation (4). Much of this information, in addition to the proximate, ultimate and heating values for the design fuel, is provided on the boiler manufactures' perfomance sheet.

Fuel Description

Variations in ash content and composition of the feed coal can lead to a variety of boiler problems as discussed by Hatt (5). A

detailed description of the feed coal is important and could include, where available, proximate, HHV, total sulfur, sulfur forms, ash-fusion temperatures, and ash chemistry. Other, more detailed coal analyses can be helpful in determining coal quality impacts on deposit formation (6).

Location of Deposits

The physical appearance of the deposit should be given using the megascopic system presented below, together with location and extent of the deposit, preferably by providing a simple sketch of the boiler in a side and top sectional view (as shown in Figure 1). Photographic documentation is useful but can be difficult to obtain. The location of deposit samples taken during the boiler inspection can be documented on this sketch. Samples should be taken to represent the entire deposit. Guidelines on sampling can be found in the British Standard (7), and in a future publication (8).

MEGASCOPIC CLASSIFICATION

Boiler deposits can be classified as either molten deposits (slags) or deposits bonded by sulfate salts (fouling deposits)(3). Each type of deposit has characteristics that can be used to describe the material and can provide clues about the conditions of formation. Figure 2 shows an outline of the megascopic system.

Slags or Molten Deposits

Slags or molten deposits can be classified into four basic types.

- Metallic - These slags have a metallic luster and are usually associated with the combustion of pyrite-rich coals under reducing conditions. The high specific gravity of the metal generally allows it to separate from the slag, and to remain isolated from any subsequent oxidizing atmospheres (Figure 3a).
- Amorphous - Amorphous slags are dark, solid, glassy, and generally show a conchoidal fracture. Amorphous slags are usually found in the higher temperature regions of the boiler (Figure 3b).
- Vesicular - Glassy slags with trapped bubbles (a sponge-like appearance) can be classified as vesicular. These are usually associated with higher temperature regions in the boilers. Trapped gas bubbles may be distorted due to viscous flow (Figure 3c).
- Sintered - Deposits that are composed of partially fused particles may be classified as sintered. These are gritty in texture, are typically found in

the upper furnace and convection passes, and may be associated with vesicular slags (Figure 3d).

Additional useful information could include physical characteristics such as tube imprints, gas flow direction, color, and size.

Fouling Deposits

Fouling deposits are differentiated from slags according to the type of bonding that occurs between particles. In slags, bonding is produced by melting or fusion of the ash particles; in fouling deposits, the ash particles are bound together by sulfate salts (3). Gas temperatures in furnace regions where fouling occurs are generally lower than those associated with slagging; there is, however, some overlap where both bonding mechanisms can occur. Fouling deposits are generally dull in luster, have a gritty or brick-like texture, and lack the glassy and vesicular textures observed in slags. Distinguishing features include color, shape, size, internal structures such as laminations, and strength. The location and orientation of the deposit with respect to the tubes and gas flow can provide additional information. Strength is one of the most important characteristics of fouling deposits, and may be categorized using the following relative index:

Very Strong - Deposits are hard, and may be broken only with the aid of a hammer, chisel or other tool.

Strong - Deposits can be broken by hand but do not crumble easily.

Weak - Deposits crumble when handled.

Unconsolidated - Deposits are not bonded and result from accumulations of material which settle out of the flue gas.

Although qualitative in nature, this strength rating provides an indication of the degree of bonding in the deposit, and can be used to determine the level of difficulty that removal of a deposit could present.

MICROSCOPIC CLASSIFICATION

Microscopic examination of ash deposits indicates the degree and nature of bonding. This microscopic classification system is designed to be used with both polarized-light and scanning electron microscopy. It is analogous to the megascopic system in that it differentiates between slagging and fouling deposits based on the presence or absence of sulfate salts. In many cases several phases may be discernible under the microscope, i.e. both amorphous and vesicular, or sintered with sulfate salts. This can make the categorization of some deposits problematic, and in these cases all of the appropriate descriptions should be noted. Figure 4 is an outline of the microscopic system.

Amorphous Slag Phases

Amorphous slags are usually alumino-silicate melts with varying amounts of basic (fluxing) elements. Using a polarizing microscope, crushed samples can be used to show the conchoidal fracture. Magnetic minerals can be identified by placing a magnet near the glass slide on which the crushed sample is mounted in oil or water. In thin section, amorphous slags do not exhibit any birefringence. Conchoidal fracture can also be observed using a scanning electron microscope. Quartz can be trapped inside of the slag as an inclusion; dendritic species can be formed during cooling of the deposit during unit shut down. Mullite needles are also present in some samples. (3) The presence of bubbles and their shape provides information on the viscosity and gas flow direction. Figures 5a & 5b shows several examples of amorphous slags viewed microscopically.

Partially Fused or Sintered Phases

Sintered phases are characterized by the presence of fused ash particles. The degree of fusion can vary within a single sample, and can tend towards complete fusion of the particles, i.e., the formation of an amorphous slag. The degree of fusion between particles has been correlated with the strength of the deposits (2) and with the chemical composition (7).

In the classification system presented here the degree of fusion between particles is not quantified; only the presence or absence of fusion is noted. If the ash exhibits no fusion or bonding, other classification systems, such as that proposed for fly ash by Fisher (8) or Roy (9) can be used. In addition, sintered deposits may contain non-bonded or slightly bonded particles, which add considerable bulk to the deposit. Figures 5c & 5d show examples of sintered ash particles.

Sulfate Salt Bonding

The presence of sulfate salt or similar bonding material is indicative of fouling mechanisms. The classification of these deposits is similar to that of slag, i.e. totally bonded versus partially bonded.

Total Bonding

When the individual fly-ash particles are bonded totally by sulfate salt, the deposit is generally hard and is representative of the classic fouling deposit. Another category of a totally bonded deposit occurs where sintered deposits are enveloped in a sulfate "glue." The combination of both sintered and fouling bond types makes these deposits particularly hard to remove. These dual-bonded deposits represent slagging and fouling at the same location, and possibly at the same time. Sulfate-salt bonding is not generally associated with amorphous slags. (Figure 6a & b)

Partial Bonding and Surface Crystals

Partial sulfate salt bonding and surface crystals can be observed in some deposits, with the degree of bonding increasing towards totally bonded types of deposits. The presence of this partial bonding can add strength to a sintered type slag. (Figures 6c & 6d)

CONCLUSIONS

The classification system presented here represents an initial attempt in the description of boiler deposits. The use of such a system should aid in communication about the nature of deposits encountered, allowing the engineer or operator to more precisely communicate his problem with the researcher.

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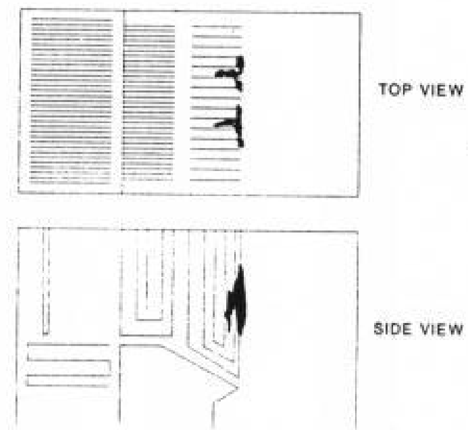

FIGURE 1. SIMPLE SKETCH OF BOILER

DEPOSIT	SLAG (FUSED DEPOSITS)	METALLIC	COMMONLY DERIVED FROM PYRITE DURING COMBUSTION UNDER REDUCING CONDITIONS
		AMORPHOUS	TYPICALLY FOUND IN HIGH-TEMP. ZONES OF BOILERS AND WITH LOW FUSION COAL
		VESICULAR	AMORPHOUS SLAG WITH BUBBLES
		SINTERED	PARTIALLY FUSED PARTICLES COMMONLY FOUND IN CONVECTION PASSES OF BOILERS
	FOULING (SULFATE SALTS)	VERY STRONG	CANNOT BE BROKEN WITH HANDS, YOU MUST USE A TOOL
		STRONG	CAN BE BROKEN WITH HANDS, BUT DOES NOT CRUMBLE
		WEAK	DEPOSITS CRUMBLE WHEN HANDLED
		UNCONSOLIDATED	DUST ACCUMULATIONS

FIGURE 2. MEGASCOPIC CLASSIFICATION SYSTEM

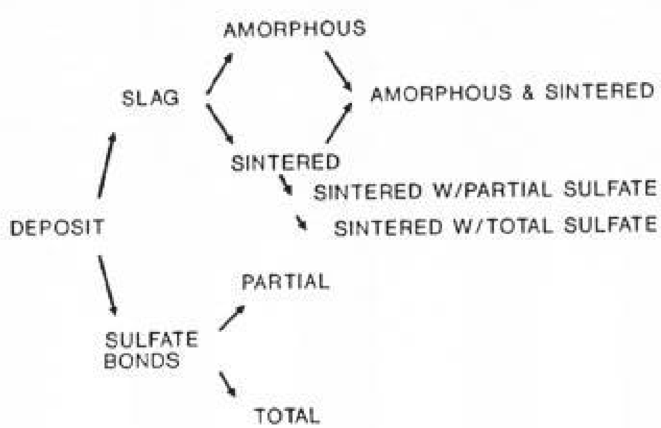

FIGURE 4. OUTLINE OF MICROSCOPIC SYSTEM

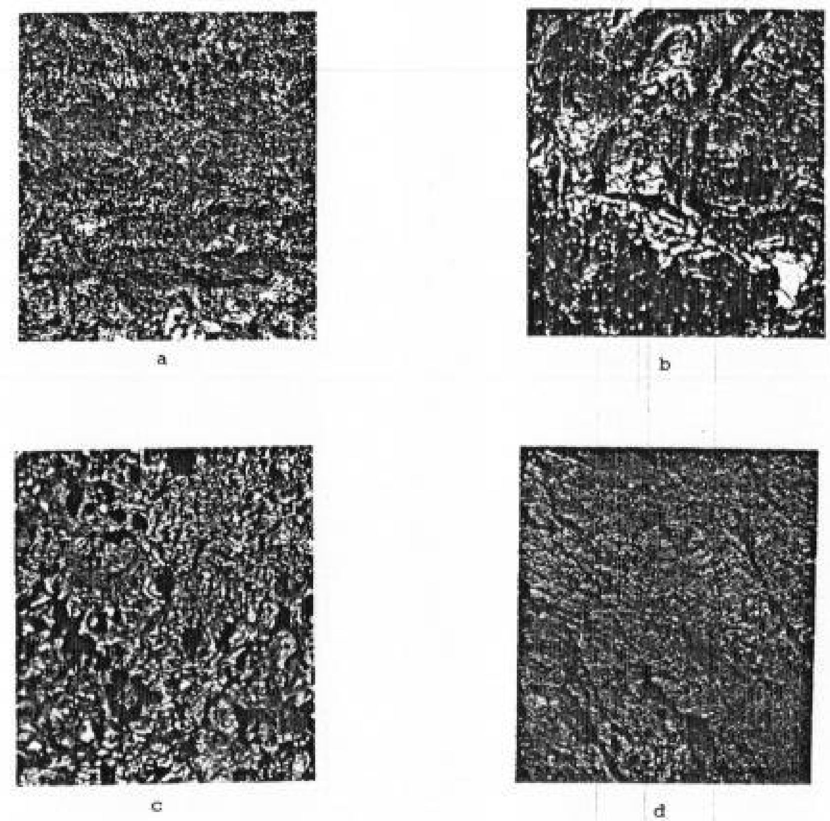

Figure 3, Examples of different types of slags: a, Metallic; b, Amorphous; c, Vesicular; d, Sintered.

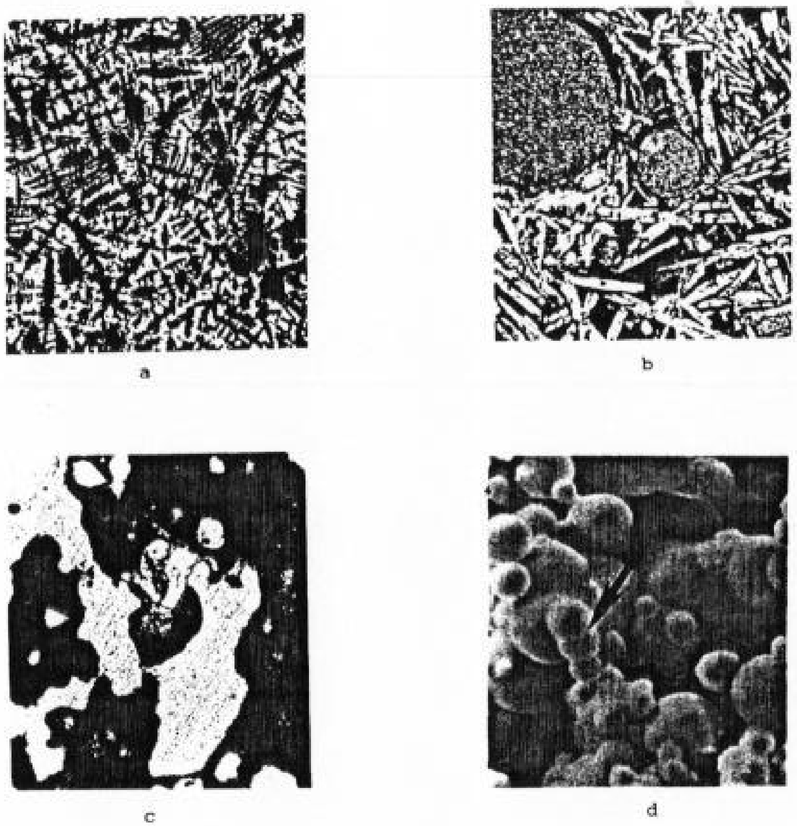

Figure 5. Microscopic view of slags: a, Dendritic crystals in amorphous slag (plain polarized light, thin section): b, Mullite crystals in vesiculr slag (plain polarized light, thin section): c, Sintered slag with quartz crystal (PPL, thin section); d, Sintered slag (SEM, plain mount).

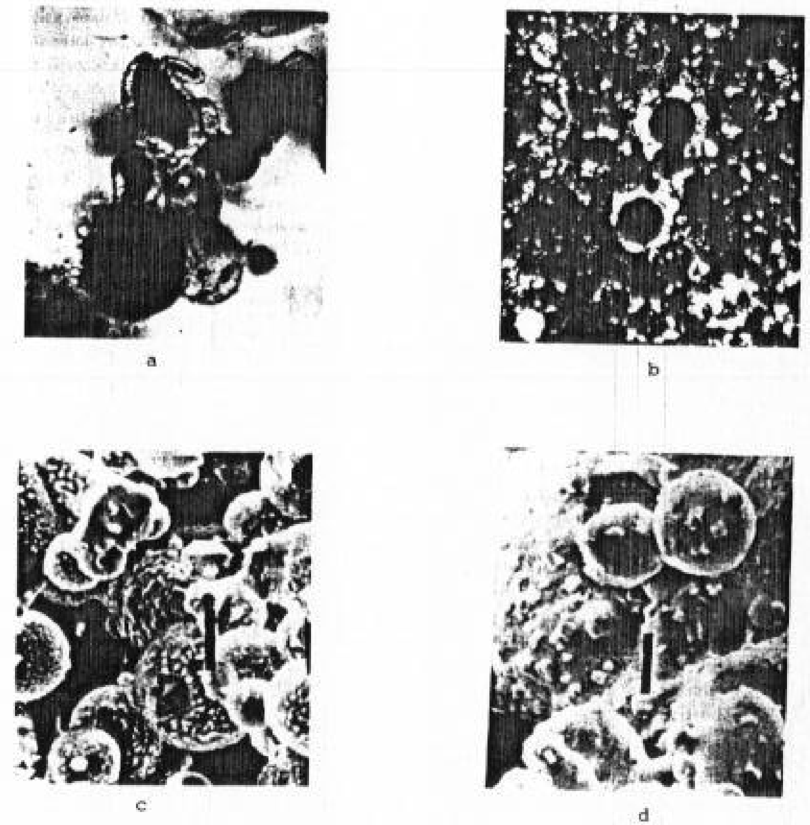

Figure 6. Microscopic view of Fouling Deposits: a, Total sulfate bonding (plain polarized light, crushed sample in oil); b, Total sulfate bonding (cross polars, thin section); c, Partial sulfate bonding of sintered deposit (SEM, plain mount); d, Surface crystals on sintered deposit (SEM, plain mount).