

# CLASSIFICATION AND SAMPLING OF DEPOSITS FROM COAL-FIRED BOILERS

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## Abstract

Slagging and fouling deposits represent a significant problem in the operation of coal-fired furnaces. Attempts to understand processes involved in the formation of these deposits are hampered by both the lack of a usable megascopic (or field) classification system and a suitable sampling regime that will ensure the preservation of important genetic information. In the proposed scheme, slagging (or molten) deposits are classified as metallic, amorphous, vesicular, or sintered based upon characteristics that include luster, specific gravity, fracture, internal structure, and texture. In addition to these criteria, strength is used to classify fouling deposits (those bonded by sulfate salts). Inorganic composition of the feed coal, variations in boiler operating conditions, and location within the boiler can influence the nature of the deposits. Detailed sampling with attention to deposit type and location is imperative in the solution of boiler-deposit problems. A sampling and analytical scheme is presented.

## Introduction

The nature and formation of boiler deposits has been studied extensively, from a variety of scientific disciplines, resulting in several books<sup>1,2</sup> and numerous publications.<sup>3-7, and others</sup> Unfortunately, the information flow between boiler operators and researchers has not always been ideal: in the absence of a workable, megascopic classification system, valuable information concerning the nature and conditions of formation of boiler deposits is lost. Field observations can facilitate interpretation of laboratory data, which can result in a clearer understanding of the causes of deposition and to the solution of the problem. The proposed system provides basic procedures for field observations, megascopic classification, and sampling. Whereas this approach was designed for deposits from coal-fired steam generators, it may be applied to other equipment which experience comparable 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*

Boiler type influences the properties and significance of a deposit.<sup>8</sup> A simple description of the boiler and operating conditions provides information on processes and environments to which the coals and ash may have been exposed. This description should include firing method (stoker, PC, cyclone), unit size including steam flow, heat input and plan area, and, if known, gas temperatures and velocities throughout the system. Changes in these variables can influence deposit formation.<sup>9</sup> These types of information, in addition to proximate and ultimate analyses and heating values for the design fuel, are generally provided on the boiler manufacturer's performance sheet.

### *Fuel Description*

Variations in ash content and composition of the feed coal can lead to a variety of boiler problems, as has been summarized by Hatt.<sup>10</sup> A detailed description of the feed coal should include proximate, HHV, total sulfur, sulfur forms, ash-fusion temperatures, and ash chemistry. Other, more detailed coal analyses, including gravity fractionation techniques, can be helpful in determining coal quality impact on deposit formation.<sup>11</sup>

### *Location of Deposit*

The physical appearance of the deposit should be described using the megascopic system presented below. The location and extent of the deposit should be indicated on 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. Samples should be located on the sketch, and should be representative of the entire deposit.

## Megascopic Classification

Boiler deposits can be classified as either molten deposits (slags) or deposits bonded by sulfate salts (fouling deposits).<sup>8</sup> Each type of deposit has characteristics that

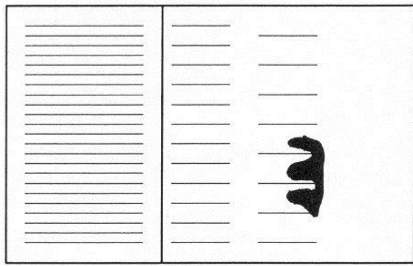


Figure 1. Simple sketch of boiler showing extent of deposit.

can be used to classify 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 (Figure 3a). The high specific gravity of the metal generally allows it to separate from the slag and to remain isolated from any subsequent oxidizing atmospheres.

*Amorphous:* Amorphous slags are dark, solid, glassy, and generally show a conchoidal fracture (Figure 3b). Amorphous slags are usually found in the higher temperature regions of the boiler.

*Vesicular:* Glassy slags with trapped bubbles (a sponge-like appearance) can be classified as vesicular (Figure 3c). These are usually associated with the higher temperature regions of the boilers. Trapped gas bubbles may be distorted due to viscous flow.

*Sintered:* Deposits that are composed of partially fused particles may be classified as sintered. These are gritty in texture (Figure 3d), are typically found in the upper furnace and convection passes, and may be associated with vesicular slags.

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 by the type of bonding that occurs between particles. In slags,

|         |                               |                |  |
|---------|-------------------------------|----------------|--|
| DEPOSIT | SLAG<br>(FUSED<br>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 |
| DEPOSIT | FOULING<br>(SULFATE<br>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.

bonding is produced by melting or fusion of the ash particles; in fouling deposits, the ash particles are bound together by sulfate salts.<sup>8</sup> In furnace regions where fouling occurs, gas temperatures 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 be significant.

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 or other tool.

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

*Weak:* Deposits crumble when handled.

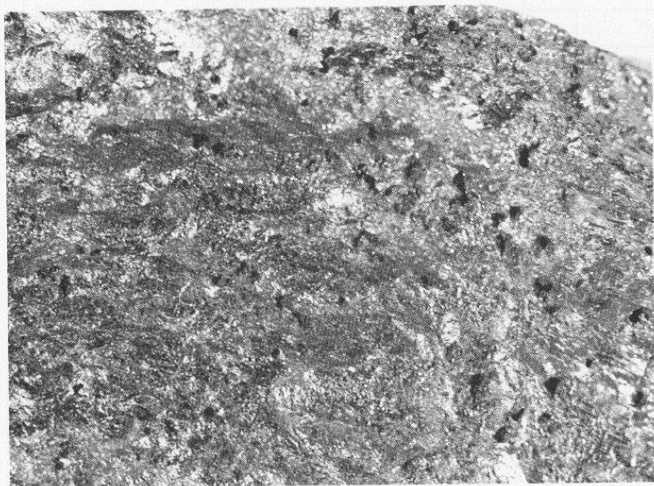
*Unconsolidated:* Deposits are not bonded and result from accumulations of material which settle out of the flue gas.

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 ease of removal of the deposit.

#### Sampling of Boiler Deposits

The objective of sampling and analysis of boiler deposits is to determine their cause and to reduce or eliminate problems associated with such deposits. The heterogeneity of boiler deposits arises from the inherent variability in coal ash and in boiler conditions. Because of this variability, a representative sample is difficult to obtain and yet imperative for the valid interpretation of subsequent analyses. Several items of equipment are required to sample deposits effectively and safely. These include: 1) boiler identification sheet or sketch of boiler (Figure 1); 2) sample containers (jugs, bags, boxes, etc.) and permanent marker; 3) safety equipment (hard hat, safety glasses or goggles, dustmask or respirator, gloves, flashlight, safety strap); and 4) miscellaneous items including coveralls, hammer, knife, crowbar, bucket, and camera.





a



b



c



d

Figure 3. Examples of slag types: a. metallic; b. amorphous; c. vesicular; and d. sintered.

### Sampling Guidelines

Boiler deposits are best documented and sampled immediately after shut-down, once the boiler has cooled. Company regulations concerning equipment, management and operator notification, and permits must be followed. Safety equipment must be used, and extreme caution exercised to avoid personal injury; in particular, overhead deposits that could break loose present a specific hazard. Sampling teams are advisable, with one member remaining outside the boiler. In most cases, sampling will be performed in the dark; therefore a strong flashlight, or a miner's hat and lamp, is recommended.

An important objective of this sampling scheme is to include samples that represent the two basic temperature zones. One such zone is related to the local gas temperature. In general, temperature decreases as the gas flows through the boiler (Figure 4). The second involves the temperature gradient within the deposit: the outside of the deposit may approximate local gas temperatures,

whereas the deposit-tube interface approximates the steam or water temperature inside the tube (Figure 5).

The following steps are offered as guidelines for sampling:

1. Determine whether or not boiler cleaning or ash removal has been performed.
2. Sketch location and extent of deposits on boiler diagram (Figure 1); photograph deposit, if possible.
3. Sample at least three locations across the tube bank for each temperature zone (Figure 4). Where possible, the sample should include the tube interface through to the outer layer (Figure 5).
4. If deposits are large and have to be broken or if they break up easily, identify original orientation and relative positions.
5. For large boiler deposits, a 20–50 pound sample is appropriate.
6. Label each sample and locate on the boiler sketch (Figure 1).

## TYPICAL GAS TEMPERATURES

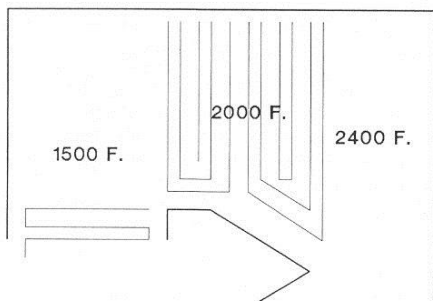


Figure 4. The different temperature zones within the boiler are important to sample separately.

## Sample Examination and Preparation

### Examination of Fireside Deposits

Important information concerning the nature and mode of formation of fireside deposits can be obtained through visual and microscopic examination.

1. *In-situ examination of deposits.* In-situ examination is necessary to determine the extent of the deposit, and provides an indication of the severity of the problem, both with respect to boiler efficiency and deposit removal. It can provide the first clues as to the cause of the deposit. This step is normally done during the boiler inspection through sketches of deposits on the boiler tube identification sheet and photographs.

2. *Macroscopic examination of hand-specimens.* Macroscopic examination should include a description of the sample in hand specimen, possibly with the aid of a hand lens or low-power stereo microscope. Samples should be described using the megascopic classification system presented above, paying particular attention to luster, texture, and internal structures and laminations within individual layers.

3. *Microscopic analysis (transmitted- and reflected-light).* Microscopic examination of boiler deposits provides significant information concerning the mode of formation of the deposits, particularly when supplemented by chemical analysis. Distinct layers should be separated and examined separately. The microscopic analysis should identify and indicate relative amounts of amorphous glassy material, tentatively identify crystalline matter, and determine the bonding mechanism. Details of a microscopic classification system are presented in Hatt and Rimmer.<sup>12</sup>

4. *Scanning electron microscopy (with energy dispersive X-ray analysis).* The final step in sample examination involves the use of scanning electron microscopy, which has a resolution of 100–200 Å or smaller (about 5–20 times greater than that of reflected- and transmitted-light microscopy). SEM analysis provides information on the morphology and interrelationship of particles and, when an energy dispersive X-ray analyzer (EDAX) is used in conjunction, can provide elemental analysis for elements with atomic numbers greater than ten.

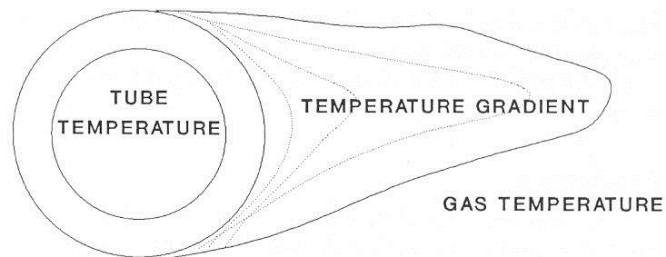


Figure 5. The temperature zones or gradients within the deposit are important to sample.

### Preparation of Deposits for Laboratory Analysis

Samples that are used for megascopic, microscopic, and subsequent chemical analyses should be correlative to allow meaningful interpretation of the chemical data. The following steps should be followed for preparation of deposit samples:

1. *Separation of Layered Samples.* The layers in bonded deposits or corrosion products may be indicative of plant operational history (variations in gas temperature, feed coal, etc.), may result from temperature gradients which can develop as deposit accumulates (Figure 5), or may indicate variations in gas composition. If a deposit separates naturally during sampling, retain portions as individual samples. Coherent samples should be split in the laboratory according to natural layering. Carefully record the physical appearance and habit of the sample.

2. *Drying.* Analyses must be performed on a dried sample. Details of methods for preparing test samples from most types of deposits are given in British Standard 2455 (Part 2). Weighed samples should be dried in an oven at 105–110°C for a period of 2 h, and resultant weight loss (%) recorded.

3. *Crushing.* Break or crush the dried samples into small fragments (<5 mm); if necessary, reduce sample to approximately 20 g by quartering. Grind the sample to -60 mesh (250 μm). Store samples in labelled, airtight containers (glass or plastic).

4. *Analytical Procedures.* Sub-splits of the dried, ground sample can be used for chemical and other analyses. Analyses could include the following:

a. Major, minor and trace elements. Elemental data can indicate mineralogy of deposits and feed coal, and the potential for corrosion. Various elements can be enriched in different regions of the boiler.

b. Forms of iron. Variations in forms of iron can influence slag viscosity.

c. Ash-fusion. This can be useful for comparison with feed coal ash-fusion data and in comparison of slags.

d. X-ray diffraction. Identification of mineral or crystal phases may be useful in the reconstruction of temperature history.

e. Thermogravimetric analysis. A comparison of weight loss associated with heating (up to 1600°C (2900°F)) indicates volatile material, water of hydration and decomposition of minerals, and can be useful in identification of phases.

f. Differential thermal analysis. Differential scanning



calorimetry can be used to indicate phase changes, fusion temperatures, and energy loss or gain.

g. The pH of 1% solution. This can be used to compare acidity of cold-end deposits.

## Conclusions

The inherent variability in the nature, mode of occurrence, and composition of boiler deposits presents a significant problem in the identification and solution of boiler-deposit problems. This paper introduces a megascopic classification system which can be used in the field or the laboratory, and which is based on readily visible characteristics (luster, specific gravity, internal structure, texture, and strength). Used in conjunction with a detailed sampling regime that retains details on the historical sequence of deposition (banding or layering), boiler deposits can be described, analyzed, and more successfully diagnosed.

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## Features

# EFFECT OF CLEANING COAL ON ITS REACTIVITY\*

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## Abstract

The purpose of this study is to determine the change in coal and char reactivities following the cleaning of Lower Kittanning seam coal fines (90% by weight through 33 micron sieve), by the Michigan Technological University (MTU) static flotation system. The method reduces the ash content from 6.20 to 0.61 percent and the total sulfur content from 2.11 percent to 0.69 percent.

The coals were decomposed in a DuPont 951 ther-

mogravimetric analyzer at a constant heating rate (10 K min<sup>-1</sup>) and gas flow rate (50 ml min<sup>-1</sup>). The results indicate that cleaning the coal by the static flotation system results in a reduction of overall mass loss rate in the devolatilization stage, and a slight increase in the maximum burning rate of coal in air. The last effect is attributed to the somewhat larger surface area of the cleaned coal, more than compensating for the expected reduction in reactivity as a result of minerals removal. There is no significant difference in the reactivities of the chars from the coal cleaned by the flotation system and the parent coal.

\* Part of this work was presented at the 17th NATAS Annual Conference, October 1988.