

FIRESIDE DEPOSITS IN COAL-FIRED UTILITY BOILERS

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Abstract—Coal ash deposits in coal-fired boilers represent a significant problem for many utilities. The use of laboratory coal analyses to predict deposit formation and the deposit analysis have advanced considerably in the last twenty years. Unfortunately, there are still a large number of unanswered questions. This paper will describe the major depositional problems experienced by utilities and several approaches used to understand the mechanism of deposit formation. A classification and sampling system for ash deposits is described and the analytical work used to characterize them is referenced.

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1. INTRODUCTION

Deposits derived from the minerals and inorganic components of coal represent a significant boiler operational problem. The boiler manufacturers have tried to design their equipment to reduce or eliminate deposit buildup as they gain more experience. Unfortunately, as the size of boilers increased rapidly during the 1960s and 70s, many units experienced deposition problems. The major domestic utility boiler manufacturers¹⁻⁴ have expended considerable amounts of effort in understanding and predicting the behavior of coal ash in boilers. Many publications exist detailing their accomplishments. Several of these are listed in Refs 5-19 with summaries noted in Refs 20-23. The utilities themselves have published papers describing their experiences and potential solutions.²⁴⁻²⁶ There have been many pilot and bench scale tests performed at universities, contract research laboratories and energy companies that have used more controlled conditions than the full-sized utility boilers. This paper should be useful to those individuals who are not familiar with utility boilers or the ash deposit problems that they can experience.

There are two basic types of deposit that form in utility boilers:²⁰ (1) Slagging deposits which generally form in the combustion or furnace zone and consist of molten ash; and (2) fouling deposits which form in the post combustion or convection pass of the boiler, and are bonded together by sulfate salts. Figure 1 is a

schematic of a typical utility pulverized coal-fired boiler with the major components labeled.

2. CLASSIFICATION

A classification system for deposits has been proposed by Hatt and Rimmer²⁷ and will be used to describe the different types of deposits. Definitions of the classification terminology for slag type deposits is shown below. Deposits may consist of one or more types of slag.

(1) **Metallic**—These slags have a metallic luster and are usually associated with combustion of pyrite-rich coals under reducing conditions. The high specific gravity of the metal generally allows it to separate from slag, and to remain isolated from any subsequent oxidizing atmosphere.

(2) **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.

(3) **Vesicular**—Glassy slags with trapped bubbles (a sponge-like appearance) can be classified as vesicular. These are also associated with higher temperature regions in the furnace; they can be found associated with sintered type deposits in the hotter regions of the convection pass. Trapped gas bubbles may be distorted due to viscous flow.

(4) **Sintered**—Deposits that are composed of

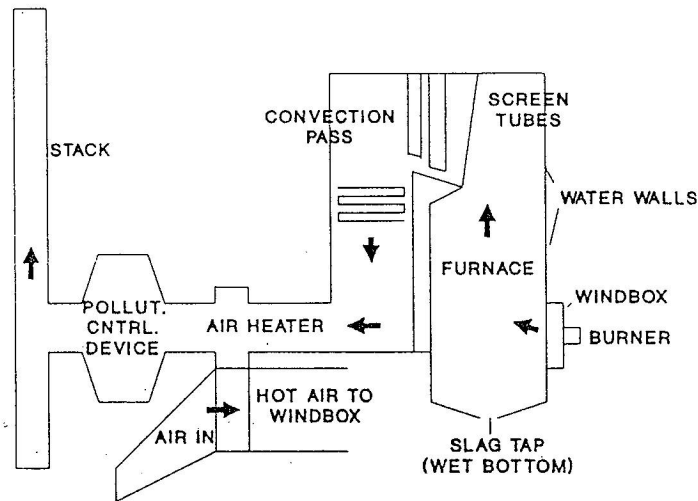


FIG. 1. Major parts of a boiler (arrows point in direction of gas flow).

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.

Most slagging deposits form from coals that have pyrite as a major mineral component. The iron from the pyrite reacts with the alumino-silicates (clays) to form low melting point or low viscosity molten deposits. These tend to be classified as amorphous and vesicular. Several authors have studied the role of pyrite in deposit formation.²⁸⁻³⁴ If the pyrite is not oxidized the iron can form metallic type deposits. Another type of slagging deposit has sodium and/or calcium as the primary fluxing agent, rather than iron.

3. WET BOTTOM BOILERS

There are boilers that are designed to handle a portion of the coal ash as a molten slag. These 'wet-bottom' or 'slag-tap' boilers have burner configurations that produce high heat release zones and corresponding high flame temperatures. The ash viscosity of the design coals is low enough that a large portion (30-70%) of the total ash forms an amorphous slag that flows out of the furnace floor through an opening usually called a 'monkey'. Deposition problems occur with this type of boiler if the slag viscosity is too high. The slag tap opening or 'monkey' can plug up, restricting or stopping the flow of molten slag. There has been success in reducing the slag viscosity with mineral additions to the coal such as limestone, crushed sea shells or colemanite. Unfortunately, once the slag tap seals shut, only drastic measures such as manually poking the slag with steel rods, or using dynamite or torches to reopen the tap can be used to avoid boiler shut down.

Slag viscosity can be measured using a high temperature viscometer or calculated using major and minor elemental analysis of coal ash.³⁵ The most common method is that of Sage and McIlroy,⁶ commonly known as the B&W method.²⁰ Others that

can be used are: Watt and Fereday³⁶ and Nicholls and Reid.³⁷ The temperature at which a slag has a viscosity of 250 poise is used as a reference. This T-250 temperature was originally set at a maximum of 2600°F by B&W^{10,20} for cyclone-fired boilers, but industrial experience has shown that a maximum T-250 of 2450°F is more realistic in avoiding slag tap pluggages. The author has shown²³ that coals with T-250 greater than 2450°F can be used if they possess high heat content. These coals generally have low moisture and ash content and, therefore, more heat is available to reduce the viscosity of the ash.

4. WALL SLAG

The furnace walls of utility boilers consist of tangent or membrane connected tubing through which water flows. Heat from the combustion process boils this water to generate steam. This steam generating section of the boiler absorbs about half of the heat released during combustion. With many types of coal a certain amount of slag is expected. The amount of slag is controlled by using air, steam or (rarely) water soot blowers. These blowers enter the boiler through a small opening in the wall and then rotate 180° or 360° directing a jet of the blowing medium at the slag. In boilers designed for high to severe slagging potential coal, a lack of slag can produce a steam side problem due to increased heat transfer to the water walls. This results in too much steam production and not enough convective heat transfer to achieve the designed steam temperature.

In any boiler when the amount of slag becomes excessive, problems can result. The excessive slag can be due to several reasons, either acting alone or in combination. These are listed in Table 1. The major problems that occur are:

(1) In boilers not designed as wet bottom (i.e. dry bottom) the wall slag changes from sintered to vesicular or amorphous and can run down the wall plugging the opening at the bottom of the furnace.

TABLE 1. Major causes of wall slag

Coal related	Large excluded pyrite particles that could impact the inner wall before they complete combustion Illites—clay minerals that contain impurities such as iron, potassium, or sodium that flux aluminosilicate glasses Interaction of included pyrites, quartz and clays to form viscous glassy phases
Equipment related	Soot blowers not in operation or not used properly Coal size from pulverizer too large Improper fuel/air ratio Burners damaged or not adjusted properly Furnace size too small to handle coal properties of coal being burned

The ash eventually can bridge over sealing off the outlet for bottom ash removal.

(2) Wall slag acts as an insulator and impedes heat transfer to the water wall. This increases the furnace exit gas temperature (FEGT) and allows molten particles to escape the furnace where they can cause slagging of the screen tubes and convection passes.

(3) Slag buildup around burners (called 'eyebrows') can occur blocking the coal flow into the furnace. This can result in combustion taking place behind the burner causing damage to the burner, windbox and coal pipe.

As described, wall slag itself is not necessarily a problem, but exacerbates other deposition problems. The most common is when wall slag acts as an insulator and raises the FEGT (No. (2) above) and contributes to superheater slagging.

5. SUPERHEATER SLAGGING

Utilities use superheated steam to increase the overall unit efficiency. The steam is generally raised to 1000°F using tubes in both the horizontal and vertical sections of the convection pass. In addition to the superheater sections, the convection pass also contains reheater tubes. The steam is reheated after passing through the turbine to maintain superheated steam temperatures at a lower pressure. Figure 2 shows a typical convection pass arrangement including an economizer tube section. For a more detailed discussion of boiler tube arrangements, see Refs 20 and 21.

The first convection pass tubes that the flue gas contacts are either the superheater tubes or extensions of the wall tubes called screen tubes. These tubes are generally spaced 18–36" apart to minimize the chances of slag bridging across them. It is when slag does bridge across that the deposits become troublesome. The bridged slag, usually of the sintered or viscous type, like that shown in Fig. 3, reduces the cross sectional area for the flue gas to flow through. As the

slag grows in size, the flue gas velocity increases. This increased velocity and the decreased heat transfer due to slag insulated tubes tends to cause slag buildup in the next section of the convection pass.

As the slag builds up, its strength increases. At some point, soot blowing is ineffective in removing the deposit. In addition, Hatt and Bull²⁶ have shown that the iron in the slag can oxidize from Fe(II) to Fe(III) as the deposit roasts in the hot gas stream. This change could raise the viscosity of the molten portions, further increasing the deposit's strength. There are several operational considerations that influence slag formation. Pulverizer fineness (too large particle size) can cause pyrite rich particles to impinge on the furnace wall or extend the flame up to the convection pass. Improper air/fuel ratio can produce a reducing atmosphere condition which influences the oxidation of pyrite to various species which can influence the particles characteristics.

Methods such as water lancing or shot gunning the slag have been used with limited success. These methods are also risky due to the danger of high pressure (1800–4000 psi) tube ruptures, besides the apparent dangers. Another method that has been successfully used is to drop load. This not only lowers the FEGT but can cause some differential contraction of the tubes and slag that may shear the slag off. If the deposit is large and does break free damage can result to the furnace floor.

Several boiler modifications and coal quality changes can solve slagging problems. The boiler modifications generally try to decrease the FEGT by adding additional furnace surface area, or by adding additional wall blowers to improve furnace heat absorption. Lowering boiler capacity is another method to lower the FEGT. Coal quality can influence slagging in two areas; (1) the slagging potential or slag viscosity, and (2) the total amount of coal ash. Coal switching or quality improvements can solve slagging problems. It may, in severe cases, take both boiler modifications and coal quality improvements to eliminate all slagging problems. Several case histories have been presented in the literature.^{26,38–40} There are also several reports of copper oxychloride being used to reduce or eliminate slagging in utility boilers.^{41,42}

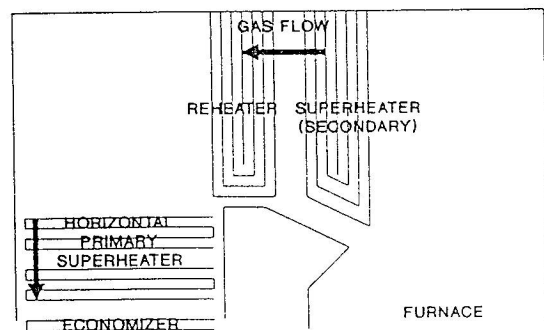


FIG. 2. Typical convection pass arrangement.

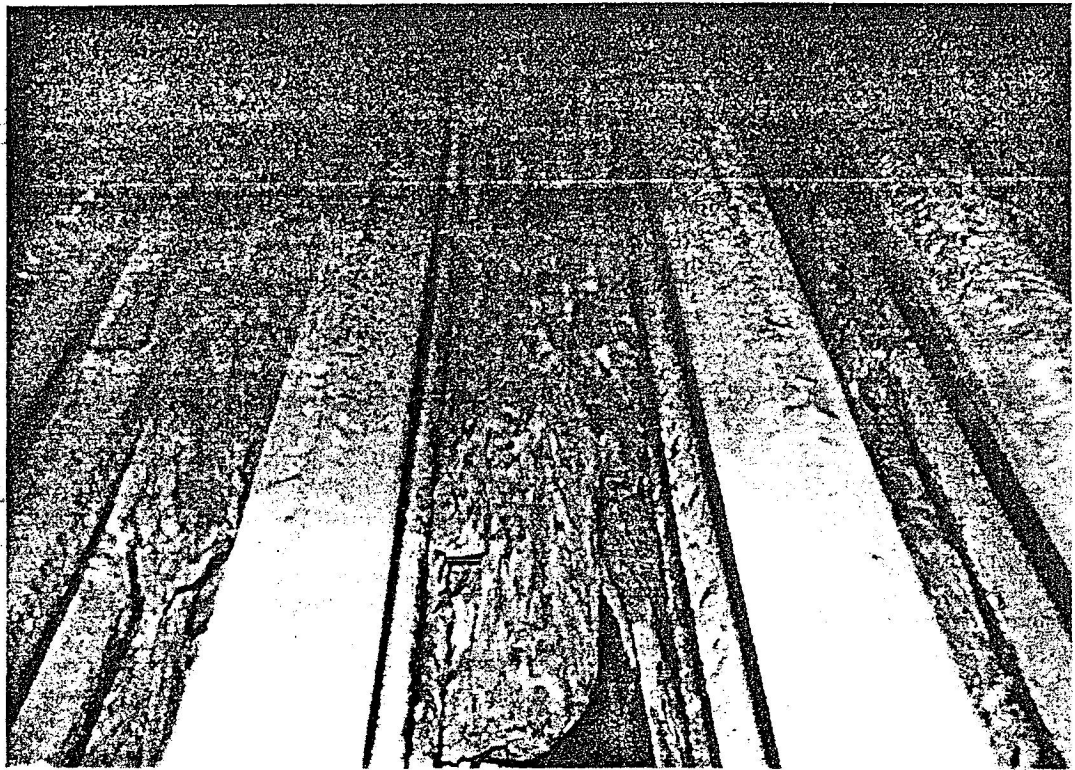


FIG. 3. Sintered slag deposit bridging across superheater tubes in a utility boiler (tube spacing is approximately 8 inches).

6. CONVECTION PASS FOULING

Fouling deposits occur when sulfur oxides from the flue gas combine with alkali ash components to form alkali sulfates. These sulfate salts act as glue, bonding fly ash particles together. Figure 4 shows an electron microphotograph of calcium sulfate bonding. These types of deposits tend to occur in the convection passes of boilers, in particular, the reheater, horizontal superheater and the economizer sections. The furnace sections tend to be too hot for solid sulfate formations. The close tube spacing in some convection pass sections (1/2–2") allows even small deposits to become troublesome. The main problem is pluggage that restricts gas flow. The deposits tend to progress from weak to strongly bonded as their exposure time to the flue gas increases. There are a considerable number of publications describing the nature and causes of these types of deposits.^{24,25,43,44}

The majority of U.S. coals that have caused fouling type deposits are mined in the Western United States. These coals generally have lignitic type ash ($\text{CaO} + \text{MgO} > \text{Fe}_2\text{O}_3$) and therefore, have higher concentrations of alkali components than coals from the Eastern United States. The primary alkali components of concern are sodium and calcium, derived from inorganic minerals or organically bound to the coal matrix.⁴⁵

Utilities have had little success in solving fouling

problems in boilers not designed for high fouling coals. Most solutions have been to increase the number of soot blowers in the affected region, or to increase soot blowing frequency or intensity. Devices such as sonic horns have also been used to assist in removing the weakly bonded deposits, before they become strong and unremovable.

The boiler designers have incorporated larger furnace areas to heat input ratios¹⁹ as a method of lowering flame temperature. Good combustion efficiency can still be obtained due to the higher reactivity of the sub-bituminous and lignitic coals.⁴⁶ Wider tube spacing in the convection pass sections is also used to decrease the chances of pluggage, in addition to tower convective pass designs and lower gas velocities.

7. LOW TEMPERATURE FOULING (AIR HEATER PLUGGAGE)

After the flue gas leaves the convection passages of the furnace it still contains a considerable amount of energy. The gas temperature is typically 500–800°F. To recover as much of this energy as possible heat exchangers (or air heaters) are used to preheat combustion air. There are two primary types used in utility sized boilers: (1) recuperative or tubular and (2) regenerative or rotating plate.^{20,21} Tubular air heaters preheat the air by passing the combustion air around



FIG. 4. SEM micrograph of fly ash particles bonded by calcium sulfate in a fouling deposit from a utility boiler (large fly ash sphere approximately 20 microns).

tubes in which the flue gas is passing through. The rotating plate type pass metal sheets first through the hot flue gas to absorb heat, and then into the cold combustion air to release the heat.

Both types of air heaters experience pluggages due to sulfuric acid condensing from the flue gas and mixing with fly ash to form an acid smut. These deposits are problems because they restrict gas and air flow and are corrosive to the steel. The amount of sulfur in the coal along with other factors, such as excess air, influence the amount of sulfur trioxide (SO_3) formed in the flue gas. The amount of SO_3 in the gas determines the dew point. Typically the acid dew point can be in the 240–300°F range. This is the limiting factor for determining the minimum gas temperature. Unfortunately, the designs of the air heaters do not have evenly distributed gas temperatures. Even if the average gas temperature leaving the air heater is 320°F there can be regions that are substantially below the acid dew point.

The boiler or air heater manufacturers usually specify a minimum average backend temperature of 150–190°F. This is the average of the gas temperature leaving the air heater and the temperature of the air entering. The higher the sulfur in the coal the higher the average temperature required. Soot blowers are also used to remove buildups. Unfortunately the plant operators may not have the ability to adjust the average backend temperature substantially, if pluggage occurs. A method that has had some success is the addition of magnesium oxide to neutralize the acid.¹⁷ Preheating the air entering the air heater or

heater or lowering the sulfur content of the coal are usually the best solutions to prevent pluggage.

8. STACK DEPOSITS

Deposits similar in nature to the air heater or acid smut type described earlier can form on the stack and associated duct work. During start ups/shutdowns and upset conditions they can break loose and exit the stack to the local environment. These acidic flakes can cause damage to cars, boats, buildings and foliage in the vicinity of the plant. This is a common occurrence with units burning high sulfur coal. There is little published data concerning the characterization and prevention of these types of deposits. The utility company typically provides car washes, or some form of compensation for damages.

9. CONCLUSION

The major ash deposit problems being experienced by coal-fired utility boilers have been summarized with only a portion of the vast amount of published work being cited. Several good books and abstracts exist which are shown in Refs 48–52.

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