

# **Influence of Coal Quality and Boiler Operating Conditions on Slagging of Utility Boilers**

by

**Rod Hatt**  
**Coal Combustion, Inc.**  
**Versailles, KY**  
**859-873-0188**

## Introduction

Ash deposits formed from the combustion of coal and other fuels have plagued the steam production industry from the start. The ash fusion test has been around for over eighty years. As steam plant size increased, so have the problems associated with ash deposits. This workshop is designed to cover: 1) The basic types of deposits, 2) Causes of deposits, 3) Analytical procedures for resolving, or at least providing information about deposits and fuels, and 4) Deposit removal and reduction techniques.

This workshop is informally based so, please ask questions as they come up.

## Types of Ash Deposits

There are two basic forms of ash deposits: molten ash and alkali salts. The molten deposits are called slag and occur primarily in the furnace area of the boiler. The alkali salts generally occur in the convection or cooler portions of the boiler and duct work. Mr. Hatt's article titled "Fireside Deposits in Coal-Fired Utility Boilers"(1) provides a good description of the particulars concerning the location and nature of most ash deposits.

### Wall Slag

Wall slag is the molten slag that builds up on the furnace walls. Wall slag is shed naturally as boilers cycle through their load range. It is usually controlled by soot blowers using air, steam and in some cases water as a removal medium. Most boilers have some degree of wall slag and it does not necessarily cause problems. In fact boilers that do not have enough wall slag due to a change to high fusion coal may have problems with maintaining steam temperatures. Western coals may produce a thin wall slag that is hard to remove and yet causes problems due to its reflective nature. Excessive wall slag leads to the following problems:

1. Wall slag flows to bottom of furnace, cools and plugs the opening situated there. The ash eventually bridges 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 ash to deposit in the superheater and convection pass regions.
3. Slag buildup around the burner regions, called eyebrows, interferes with the coal and air flow. This type of buildup can cause damage to the burners, among other things.

### Superheater Slag

Superheater slags are those molten deposits that form in the superheater and other convection sections of the boiler.

### Convection Pass Fouling

Convection pass fouling is caused by the formation of alkali sulfates, primarily  $\text{CaSO}_4$  and  $\text{Na}_2\text{SO}_4$ , that bond the flyash together. These types of deposits are usually associated with the use of Western coal.

### Low Temperature Deposits

Low temperature deposits such as air heater pluggages and stack deposits are formed due to the condensation of sulfuric acid mixing together with the flyash to form an acid mud.

## Causes of Ash Deposits

The main causes of ash deposits depend where you work. If you work in steam plant operations the main cause is lousy coal, if you are a coal buyer the main cause is lousy steam plant design, and if you are in engineering the main cause is lousy steam plant operation. All are right in a sense. Scientific analytical investigations reveal that it is usually a combination of all three of these areas.

The following table presents the major causes of ash deposits:

**TABLE I - Major Causes of Ash Deposits**

Fuel Related	<p>Large pyrite particles that impact the furnace wall before they completely combust</p> <p>Clay minerals that contain significant amounts of iron, calcium, sodium or potassium causing them to have low melting temperatures</p> <p>Interaction of pyrite, clays and alkalis with aluminosilicates to form low viscosity melts</p> <p>Extremely fine or organically bound alkalis</p>
Equipment Related	<p>Soot blowers not in operation or used improperly</p> <p>Poor pulverization of fuel</p> <p>Improper air to fuel ratio</p> <p>Burners damaged or improperly adjusted</p> <p>Changes in operation of boiler or other equipment</p>
Design Related	<p>Furnace size too small for fuel</p> <p>Tube material and/or spacing inadequate</p> <p>Soot blowing coverage inadequate</p> <p>No means provided to observe slag buildup</p>

## Analytical Procedures

### Slag

Lets start our review with an overview of coal mineralogy and its relationship to coal ash chemistry, melting & slagging properties, and fusion temperature. There are not distinct melting points for coal ash like with ice or other pure compounds, so when melting is mentioned it is used to represent a decrease in viscosity, rather than a melting point. When coal ash melts it occurs on both a large scale and a microscopic scale. On the large or bulk scale the ash behaves like a glass. As the temperature of the material increases, its viscosity decreases. At temperatures less than 2000° F. the ash may appear solid, or at least stiff, such as a Tootsie Roll. On a microscopic scale several minerals may have all ready melted, but their concentrations are low when compared to other minerals with higher melting temperatures. As the temperature is increased the ash becomes less viscous or more liquid like. Many reactions are now occurring between the minerals as they melt and become more fluid. As the molten components mix they become more like molten glass. This molten material starts to dissolve the non molten materials like quartz and other minerals. In this way the melting temperature of minerals such as sandstones and shales are lowered by other minerals such as pyrite and limestone.

The ASTM Fusion Temperature Test is a documented observation of this process occurring in coal ash shaped like a small cone, and placed in a furnace with increasing temperatures. The initial deformation temperature, ID, is usually a hundred or more degrees above where the first low melting temp. minerals start to melt. The remaining fusion temperatures represent an ever increasing amount of molten material, and a lowering of the viscosity of the glass like material. It should be noted that even at the fluid temp. there may be solid or non-melted minerals such as quartz. The atmosphere of the furnace is controlled to either an oxidizing (like air) or a reducing (CO present) condition. This is important due to the oxidation behavior of iron (Fe) atoms. Reduced iron lowers melting and fusion temperatures of ash much better than the oxidized form. In coals that have significant iron levels, like those in the Illinois Basin, the oxidation state of the iron is critical. The difference between the oxidizing and reducing fusion temps. can be hundreds of degrees. This phenomenon is one of the variables that make consistent fusion temperature data hard to obtain.

When trying to determine the behavior of coal ash in a boiler, both the type and size of minerals present is important information. Unfortunately it is both difficult and expensive to determine the actual minerals in coal. The ash chemistry or major and minor elements in coal ash are the next most useful information. This is because melting properties can be estimated and minerals can be inferred. Although the cost of ash chemistry is higher than fusion tests, the information obtained is well worth the expense. The fusion temperature test is a lower cost technique with reasonable turnaround time. Fusion temperatures have been used for years, and

are contained in most coal contracts. Unfortunately, fusion temps. provide no mineralogical information, are notoriously imprecise and are influenced by all sorts of factors that cause variability. It is the authors experience that different laboratories can produce fusion temperatures that vary well outside the ASTM guidelines, and both laboratories are performing satisfactorily.

#### Ash levels

Ash levels in coal are generally reported from the lab as a percent of ash. This is convenient for the lab but not completely representative of what the boiler sees. Boilers demand Btus, not tons of fuel. A more representative (for the boiler) way to express ash levels is to use pounds of ash per million Btu. These units are easy to calculate using the following expression:

$$\text{Lb. Ash/MBtu} = \% \text{Ash}/(\text{Btu/lb.}/10,000)$$

The author has on numerous occasions found that the ash deposits formed in utility sized boilers correlates best with ash and elemental loading data, rather than fusion temperatures or traditional slagging and fouling indices.

#### Elemental loading

Pounds of iron per million Btu

Pounds calcium, sodium, and other elements

### **Slagging with Bituminous Type Ash - High Iron**

This example will show how a utility was able to lower its ash fusion specification by understanding how different coals behave in the boiler. Typically utilities have specifications for total ash (in percent) and a fixed fusion temperature spec. Published accounts of utilities experience in this area have led many slag specialists to consider the amount of ash loading to be important. When ash levels are expressed in pounds per million Btus, they more closely reflect the levels seen by the boiler. The author has also proposed that the Iron loading (**lbs.Fe<sub>2</sub>O<sub>3</sub>/MBtu**) level is an important consideration. In several Eastern/ Midwest US coal slagging events worked on by the author, the problematic coal had elevated iron loading levels. Using this information several utilities have conducted test burns of coals with lower fusion characteristics. Their strategy was to limit the iron loading by considering lower ash, higher iron coals. These coals had lower than design fusion temperatures but it was suggested that the lower ash levels would offset this. The results of the test confirmed that the iron loading levels more accurately predicted the slagging behavior of the coal than the fusion temperature of the coal.

## Ash fusion temperatures

Ash fusion temperature tests have been around for almost a century. At first there was just one, then three, and finally we know have four reported fusion temperatures.

Designed for stoker furnaces

Many deficiencies when used for evaluation of slagging or fouling deposits in pulverized coal furnaces. The fact that the test can be run in both reducing and oxidizing conditions does provide clues about the role of combustion conditions on the mineral behavior.

Advanced ash fusion techniques have not grown in demand.

## Ash Chemistry

Not Minerals, just oxides

### Acids or glass formers

Silicon dioxide	SiO <sub>2</sub>
Aluminum oxide	Al <sub>2</sub> O <sub>3</sub>
Titanium dioxide	TiO <sub>2</sub>

### Bases or fluxing agents

Iron oxide	Fe <sub>2</sub> O <sub>3</sub>
Calcium oxide	CaO
Magnesium oxide	MgO
Potassium oxide	K <sub>2</sub> O
Sodium oxide	Na <sub>2</sub> O

Base to acid ratio

Sum of bases/sum of acids  
B/A vs. Fusion Temps.

Slagging index

Dry sulfur x B/A  
Iron squared term

Computer Controlled Scanning Electron Microscopy provide some of the best mineralogical information but has not come into common use.

## Fouling Deposits

Chemical Fractionation

Active alkali

Water soluble

Ammonium Acetate soluble

Weak acid soluble  
Micro crystals

### Cyclone and Wet Bottom Furnaces

Each cyclone is individual furnace

Balanced air to fuel ratio

Must have wet slag to work

Must be hot, maintain minimum loading

Coal Sizing is important to good combustion

Ash loading minimum

Must be low fusion ash

Many don't use fluid fusion temperature

T-250 temperatures

Temperature at which slag will flow

T-250 methods

T-250 vs. Heating value

### Deposit Analyses

Proper Sampling (2)

Optical and Electron Microscopy

### **Pulverized Coal Sizing Important**

This example will show how a utility was able to lower its ash fusion specification by understanding how different coals behave in the boiler. Typically utilities have specifications for total ash (in percent) and a fixed fusion temperature spec. Published accounts of utilities experience in this area have led many slag specialists to consider the amount of ash loading to be important. When ash levels are expressed in pounds per million Btus, they more closely reflect the levels seen by the boiler. The author has also proposed that the Iron loading level is an important consideration. In several boiler slagging events worked on by the author, the problematic coal had elevated iron loading levels. Using this information several utilities have conducted test burns of coals with lower fusion characteristics. Their strategy was to limit the iron loading by considering lower ash, higher iron coals. These coals had lower than design fusion temperatures but it was suggested that the lower ash levels would offset this. The results of the test confirmed that the iron loading levels more accurately predicted the slagging behavior of the coal than the fusion temperature of the coal.

Coal fineness also plays an important role in being able to utilize coals with elevated iron levels. Many slagging problems associated with high sulfur-low fusion coals can be traced back to poor grinding (fineness) of the coal. Large pyrite particles escape from the mill and do not completely oxidize in the flame. The molten particles contain unoxidized iron that can flux the aluminosilicate materials in the ash into low melting type glasses. This effect is most dramatically seen in the

difference between the oxidizing and reducing fusion temperatures. The spread between these fusion temps can be several hundred degrees in high iron coals. Again maintaining mill performance can significantly impact the use of lower fusion eastern type coal.

## Deposit Removal and Reduction Methods

### Tube Material Testing

It is generally felt that stainless and other austenitic steels have superior corrosion resistance and do not bond as strongly to deposits. It may be useful to perform several tests to confirm this and to evaluate impacts. A simple and low cost method is to construct test probes. These probes can be constructed from various materials and placed into the furnace for a given time and the resultant deposit evaluated for strength of bonding to the tube and internal strength. The use of two or more metal types on the same probe will provide a good means of comparison. The use of shielding could also be explored.

### Industrial Use of Firearms

As an experienced slag gunner, I feel that shotguns offer an effective method for deposit removal. There are inherent safety issues and little if any publications describing effective methods. In discussions with sales reps. from Remington Industrial Products it was apparent that there are many ammunition options.

### Safety

In addition to the procedures already in place at your station, the following are offered for your consideration. The proper firearm exists for each situation, consider using firearms that are designed for industrial use. Low recoil ammunition is available, this may be a better option than gun modification. It may be worthwhile to purchase a custom designed mounted gun with safety interlocks inherent to the design.

### Methods

There are most likely methods used to shoot slag that are more effective than others. The author has seen all sorts of methods used and indeed there are some operators that are more effective than others in cleaning up the situation. It is recommended that different methods for shooting slag be documented and evaluated for their effectiveness. More effective methods have the potential to reduce the number of shots fired and minimize potential damage to the tubes. The current Remington method offers room for improvement. It indicates that the

operator should shoot directly at the tubes using their #2 or #4 loads developed especially for power plants. It also recommends shooting some scrap tubes to determine if any damage to the tube occurs. This may be fine for off-line removal of slag, but does not consider the significant strength differences that tubes may undergo at operating temperatures. It has been the author's experience that most plants prefer that the tubes not be shot at. In addition to the damage to the tubes, the resulting rough surface may provide additional footing for the deposit to adhere.

### Video Monitoring Systems

Operators cannot react to something they cannot see. Deposit formation is one of those phenomenon that do not show up on any control room readings until it is too late. Steam temperatures, furnace drafts, gas temperatures and others may give some indication that there are problems developing, but generally do not detect initial stages of formation. Video monitoring systems provide real time information about deposit formation and can allow removal techniques to be initiated before the deposit grows beyond a removable stage. Additionally, the use of tape backup allows the review of removal techniques and a direct comparison their effectiveness. This would be a good method for comparing shooting techniques as mentioned above. A good system will also help remove the operator subjectivity as to the extent of the problem, one man's view is not the same as another. A group can view the monitor together and discuss what they see.

### References

1. Hatt, Roderick M., "Fireside Deposits in Coal-Fired Utility Boilers", Progress in Energy and Combustion Science, Vol 16, pp.235-241, 1990.
2. Hatt, Roderick M. and Rimmer, Susan M., "Classification and Sampling of Deposits from Coal-Fired Boilers", Journal of Coal Quality, Vol 8, No. 2. pp. 40-44, April-June 1989