

Coal Properties, Sampling & Ash Characteristics

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Introduction

The Powder River Coal is classified as sub-bituminous ranked coal. Coal rank is an indication of how much transformation the original plant material has undergone. The American Society for Testing and Materials (ASTM) defines coal rank for lignite and PRB type coals using the heating or Btu value expressed in a moisture, ash free (maf) basis. This basis eliminates the impacts of ash and moisture levels on the heating value. The heating value is used for lower ranked coals, the maf volatile is used to classify higher ranked bituminous and anthracite type coals. The first phase of coalification (fossilization) is to preserve the plant material from oxidation. This peat moss like material is still basically plant material. The first coal like material formed is lignite, or brown coal. The coalification process basically squeezes out *oxygen* and *water*. As the plant material becomes less like wood and more like oil, the pore structure constricts limiting the water retention capacity of a coal. This water retention capacity is measured using the equilibrium moisture (EQ moisture) test. Sub-bituminous coals like the PRB coals are the next step in the coal ranking system. Then comes the low ranked Bituminous C type coal. This is the ranking of many Illinois Basin coals. The higher ranked Bituminous B and C coals are generally found in the Appalachian coalfields.

Most of the coal tests that ASTM has standardized were written around higher ranked bituminous and anthracite coals. The tight pore structures of these coals limited the amount of inherent moisture they could hold. Typically these high ranked coals have EQ moistures of 1-10. The first step of determining coal quality in the lab is to air-dry the sample to near equilibrium with the laboratory humidity levels. This is done to minimize any impact on lab results of additional drying or absorption of water from the air. In high rank coals, the moisture lost in the air-drying step is near equivalent to the surface moisture.

The residual moisture is that moisture that is still locked up in the coal after air-drying. The higher ranked coals that ASTM standards were based on possess this well-defined split between the air-dried or surface moisture and the residual or near EQ moisture. This is not the case for low rank coals like PRB coal. The sponge-like or wood like nature of PRB coals make the split between surface moisture and inherent moisture a rather fuzzy line.

Quality

Most of the quality differences between PRB coal and the higher ranked coal can be explained by understanding that the PRB coal has this looser pore structure and additional moisture retention capacity. PRB coal also has more oxygen chemically bonded to the coal.

Quality Table

Btu/lb. .	Higher moisture and oxygen result in lower Btu/lb.
Sulfur	The low sulfur nature of PRB coal is due to fresh water exposure rather than sea water.
Volatile	High volatile nature due to low rank has many oxygenated compounds like CO.
Ash	Low inherent ash has large non-rock or organically bound calcium and sodium fraction.
HGI	near mid fifties as seen by mills, hare to measure accurately due to moisture impacts.
Fusion	Generally low fusion due to high CaO content. Does not predict ash deposits as well as in eastern US coals.
Ash Chemistry	Sulfur Trioxide SO ₃ is high due to capture of sulfur by calcium in ash. This can bias the percent ash compared to actual amount of fly ash and bottom ash produced.

Chemical Fractionation
Fouling Deposits
Ash Viscosity
Abrasion
Spontaneous Combustion

Sampling

The sampling of PRB coal is a little harder to do properly due to the coal's ability to gain and lose moisture. This requires good ribbon flow and a tight sampler. Use the ASTM requirements for raw coal, as out of seam dilution is a main component of higher ash products. Clean sampler regularly to avoid coal build-up and fire hazards.

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	Large pyrite particles that impact the furnace wall before they completely combust
	Clay minerals that contain significant amounts of iron, calcium, sodium or potassium causing them to have low melting temperatures
	Interaction of pyrite, clays and alkalis with alumino silicates to form low viscosity melts
	Extremely fine or organically bound alkalis
Equipment Related	Soot blowers not in operation or used improperly
	Poor pulverization of fuel
	Improper air to fuel ratio
	Burners damaged or improperly adjusted
	Changes in operation of boiler or other equipment

Design Related	Furnace size too small for fuel
	Tube material and/or spacing inadequate
	Soot blowing coverage inadequate
	No means provided to observe slag buildup

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 author's experience that different laboratories can produce fusion temperatures that vary well outside the ASTM guidelines, and both laboratories are performing satisfactorily.

Analytical Procedures

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:

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

Ash fusion temperatures

Ash fusion temperature tests have been around for almost a century. At first there was just one History Stoker furnaces

Deficiencies **Does not work well with PRB coals**

Reducing vs. Oxidizing conditions

Advanced ash fusion techniques

Ash Chemistry

Not Minerals, just oxides

Acids or glass formers

Silicon dioxide	SiO ₂
Aluminum oxide	Al ₂ O ₃
Titanium dioxide	TiO ₂

Bases or fluxing agents

Iron oxide	Fe ₂ O ₃
Calcium oxide	CaO
Magnesium oxide	MgO
Potassium oxide	K ₂ O
Sodium oxide	Na ₂ 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

Elemental loading

Pounds of iron per million Btu

Pounds silica and other elements

Computer Controlled Scanning Electron Microscopy

Fouling Deposits

Most fouling problems caused by Calcium sulfate 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

Ash loading minimum

Must be low fusion ash

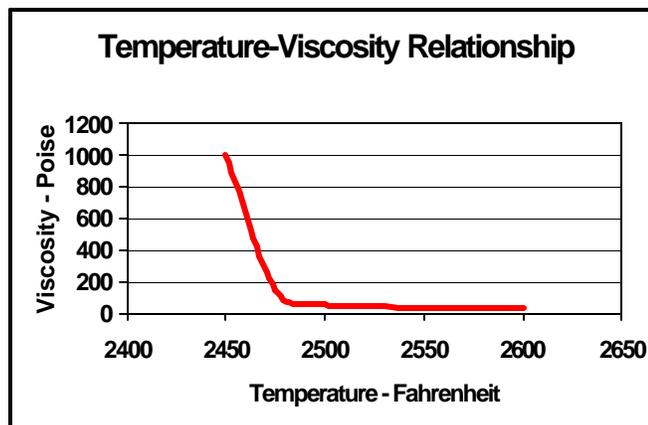
Many don't use fluid fusion temperature

T-250 temperatures

Temperature at which slag will flow

T-250 methods

T-250 vs. Heating value



Ash Viscosity Measurement

Deposit Analyses

Proper Sampling (2)

Optical and Electron Microscopy