

# Coal Quality & Combustion Impacts on Ash Chemistry

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## Abstract

This paper describes how the minerals and organically bound elements found in coals impact the ash chemistry. The role of quartz, pyrite, clays, and organically bound elements all play a role in final ash chemistry. Combustion impacts, particularly low NO<sub>x</sub> firing, can influence Loss On Ignition (LOI) or unburnt carbon in the ash. All these parameters can be qualitatively predicted by looking at coal geology and mining practices used by the power plant coal supplies.

The coal quality changes in the US based on the depositional environmental history of the deposit. Coals from each region can have similar and predictive ash qualities. The original coal deposit, the mining practices, and plant operation, all influence the ash quality. By understanding a plants coal supply (found in EIA 923 data) reasonable estimates of ash quality can be made. Sulfur is associated with iron (Fe<sub>2</sub>O<sub>3</sub>) in the ash, so higher sulfur coals tend to have more Fe<sub>2</sub>O<sub>3</sub>, or Type F Ash. Low rank sub-bituminous coals have organically bound calcium (CaO) and sodium (Na<sub>2</sub>O), and with low sulfur these coals tend to produce Type C Ash. Bituminous coals are less reactive than sub-bituminous coals and therefore are more prone to LOI issues.

## INTRODUCTION

The rocks and minerals and other forms of elements in coal, along with how the coal is burned can all influence the ash chemistry. Depositional environment and mining practices influence the coal quality. Specifically impacted are the qualities, sulfur, ash, and Btu/lb. Many elements found in coal ash will vary based on levels of ash and sulfur. High moisture low rank sub bituminous and lignite coals can also have significant levels of organically bound sodium and calcium. Flame conditions can impact elemental partitioning between bottom and fly ash, potentially biasing the ash values compared to the coal values. Flame conditions can also impact unburnt carbon or LOI (loss on ignition) levels.

## DEPOSITIONAL ENVIRONMENT

The conditions of the original swamp/forest can impact the quality of coal found in the ground. Soil conditions, plant species, streams, rivers, ponds, and lakes can all play a role in final (today) in ground coal quality. The nature of formation of the rock material that covers the peat can impact quality. It also provides the heat and pressure that

transforms the peat to coal. Fresh water eroded rocks are different than bottom of ocean formed rocks. Sea water is a main source of the sulfur in coal. High sulfur coal most likely came into contact with seawater. Clay type minerals tend to be in coal and floor of coal mines. Sandstones and higher quartz containing rocks tend to cover the coal or be in the roof material of the mine.

The interactions of sulfates,  $\text{SO}_4^{-2}$  in sea water with the reducing environments in the coal tends to result in two forms of reduced sulfur. Organic sulfur combined with the coal, and iron sulfides, like the mineral pyrite,  $\text{FeS}_2$ . The iron pyrite in the coal can be hard to remove and result in the  $\text{Fe}_2\text{O}_3$  in the ash. Iron from any mineral is reported as the fully burnt (oxidized) form,  $\text{Fe}_2\text{O}_3$  in coal and ash test results. In reality in the coal furnace, depending on conditions, it can remain unburnt as iron sulfide  $\text{FeS}_2$ . It can partially burn to  $\text{FeS}$ . Further oxidation can form  $\text{FeO}$  and  $\text{Fe}_3\text{O}_4$ . In the best flame conditions it can burn to  $\text{Fe}_2\text{O}_3$ . A simple test for  $\text{Fe}_3\text{O}_4$  or magnetite in ash, is to stick a magnet in the ash and pull it out.

Low rank coals like sub bituminous and lignite have high moisture levels, typically over 25%. One of the reasons for high moisture in these coals is they have high oxygen levels. This coal bound oxygen can ion exchange with water born elements like sodium and calcium. When the coal burns away, these atoms of sodium and calcium can react to form new materials. Sodium tends to condense on high silica,  $\text{SiO}_2$  fly ash, forming a more molten layer on the outside of the ash particle. Calcium tends to react with sulfur oxides like  $\text{SO}_3$  in the flue gas, to form  $\text{CaSO}_4$ . These types of organically derived elements can form particles much smaller than rock formed ash particles.

## MINING PRACTICES

The rocks, minerals, and organic elements in the coal are not evenly distributed in the coal seam. The mineral pyrite can be concentrated in the top of the seam, where the sea water makes the most contact. Clay and shale partings in the seams are common and can range in size from microscopic to meters. These partings tend to be concentrated in aluminosilicates like clays and shales. Calcite,  $\text{CaCO}_3$  can be deposited from ground water in voids and cleats in the seam. Organically bound sodium can be ion exchanged with calcium from flowing groundwater in the coal seam. The base or floor material is usually clay. The roof of mines is usually harder sedimentary rocks with higher quartz contents. This roof and floor material when mixed with coal is called "out of seam dilution" or OSD.



Figure 1. Out of seam dilution visible in coal pit.

More OSD typically raises the ash level of the final coal product. High ash coal would tend to have higher quartz and aluminosilicates that could dilute the coal based minerals like pyrite and calcite. The lowest ash levels from a particular coal seam would have the highest percentages of elements like iron,  $\text{Fe}_2\text{O}_3$  and calcium,  $\text{CaO}$ . This is because in most cases these elements are found in the coal, but not the OSD. As the OSD go up in a coal, the  $\text{SiO}_2$  and  $\text{Al}_2\text{O}_3$  levels in the ash increase. This results in the  $\text{Fe}_2\text{O}_3$  and  $\text{CaO}$  percentages going down.

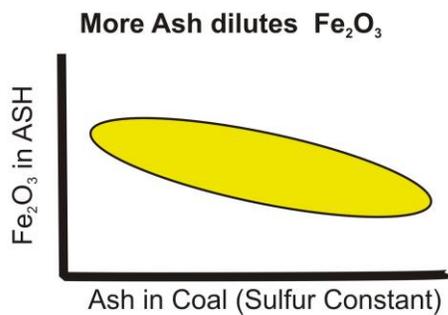


Figure 2. Higher ash due to OSD dilutes iron percent in ash.

If the ash is constant and the sulfur goes up. The iron pyrite tends to follow total sulfur. This indicates that higher sulfur coals have higher  $\text{Fe}_2\text{O}_3$  levels in the ash.

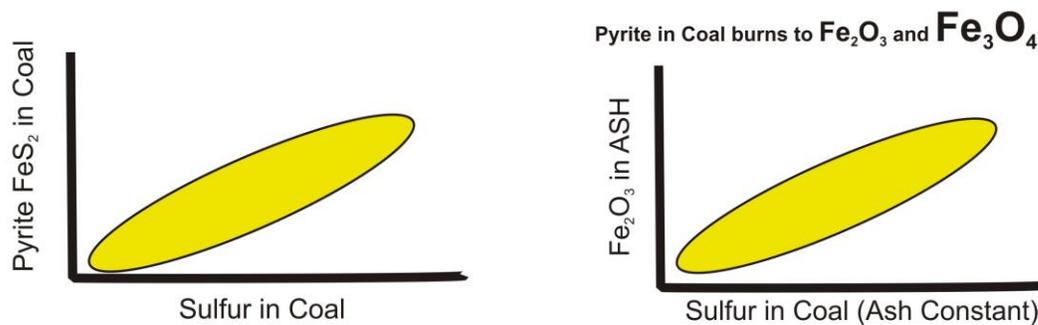


Figure 3, 4. Showing relationships to sulfur and pyrite (Fig 3) and  $\text{Fe}_2\text{O}_3$  in ash (Fig 4)

With sub bituminous and lignite coals the calcium, CaO, and sodium, Na<sub>2</sub>O, are in the coal. OSD has mostly SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub>. As the ash increases in these coals the percentages of these elements goes down.

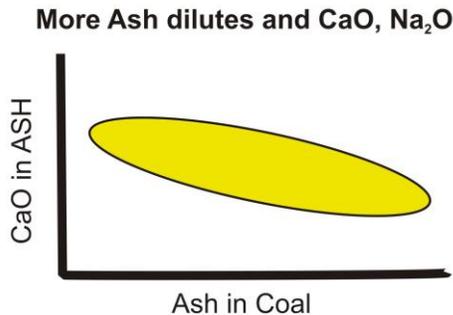


Figure 5. Increase in ash due to OSD dilutes calcium levels in coal ash.

#### COAL LAB ASH OVEN IMPACTS

The ashing of coal in coal laboratories is done at a much longer time than coal is burned at a power plant. Minutes compared to milliseconds. It is also performed at about 750<sup>0</sup>C. Calcium reacts with sulfur gases slowly in the temperature range of 750<sup>0</sup> to 1000<sup>0</sup> to form CaSO<sub>4</sub>. Fluid bed boilers take advantage of this and operate in this temperature range. Pulverized coal boilers can burn coal in 1000-2000 milliseconds. This is at temperatures of >1400<sup>0</sup>C. The ash passes through the 750<sup>0</sup> to 1000<sup>0</sup> temperature range for just a few hundred milliseconds. This is why a coal ash analysis can have high SO<sub>3</sub> values when compares to power plant ash SO<sub>3</sub> levels.

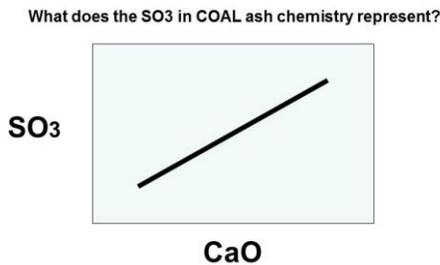


Figure 6. Coal lab coal ash test results show increased SO<sub>3</sub> levels proportional to CaO.

#### ELEMENTAL PARTITIONING

Elemental levels reported in coal ash can partition between bottom ash and fly ash. Dense minerals like pyrite can preferentially report more to the bottom ash. Quartz particles can do the same. Depending on the bottom/fly ash split this partitioning can be from hardly noticeable to several percentage point changes.

The organically based elements calcium and sodium can report more towards the fly ash due to their volatile nature.

## UNBURNT CARBON OR LOI

Low rank sub bituminous and lignite coals are quite reactive and like to burn. These coals tend to have spontaneous combustion issues. Coal that does not burn can end up in the ash. Unburnt coal can be estimated using the Loss on Ignition or LOI test. This Low rank coals should have LOIs of less than <1.0%. If they do not, they have a combustion issue. Most likely this is caused by lack of air in a portion of the boiler. Bituminous and other less reactive fuels like petroleum coke should have LOIs greater than >1.0% more likely in the 4-8% range. This is because in addition to lack of air, they are more sensitive to pulverized coal sizing. If boilers using these types of fuels have an LOI over >7%, they most likely have a combustion issue.

Keep in mind that LOI is the ratio of carbon to ash. LOI can fluctuate both due to unburnt carbon and the amount of ash. Want low LOI – burn high ash coal.

Low NO<sub>x</sub> firing is the main cause of lack of air.

## CONCLUSION

Many factors can impact the ash chemistry and quality. Hopefully some of the basic parameters impacting ash quality have been described here.