

Using Coal Additives for a Fuel Flexibility Program: Getting an Edge in Today's Competitive Market

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ABSTRACT

Faced with the difficulty of competing with cheaper operating gas plants, coal-fired power plants continue to look at ways to improve economics. Fuel costs are a major factor in driving the dispatch of coal units. Plants must consider burning less expensive coals. In the Southeastern U.S., the main choices for more economical fuels are higher sulfur Illinois Basin Coals and Northern Appalachian Coals. These fuels offer reduced generation costs provided that the plant has adequate pollution controls to mitigate the increased sulfur content and a means of dealing with the higher slagging tendencies

This paper will review a case study involving the use of chemical additives to mitigate slagging when burning Illinois Basin Coals on Tangentially-Fired Units. Although there may be many challenges with opportunity fuels: higher sulfur, higher moisture content, varying fineness, etc, this paper will focus solely on the adverse effect of tenacious boiler slag created by these coals.

INTRODUCTION

The burning of Illinois Basin (ILB) coals as part of a fuel flexibility program is not new to the industry. Prior to this project Environmental Energy Services (EES) developed CoalTreat, a pre-combustion, fuel chemistry innovation that has proven highly effective in reducing furnace slagging and heat transfer surface fouling. CoalTreat additives have been used successfully at numerous plants across the US and more locally in the Southeast for similar fuels. Additionally, the utility referenced here previously had successful experiences with CoalTreat at several other stations. This station was averse to using fuel additives long-term and intended to improve combustion following test burns to mitigate the slagging problems.

Opportunity fuel testing began and we received a call from the plant informing us that excessive slagging had occurred. The urgent question to us from the plant was “can you unslag a slagged boiler”. They explained that the slag was “bridging” in the unit and feared they would have to shut down prior to a scheduled outage. We were confident we could help them based on successful experiences with similar (T-Fired) units. For this project, we were fortunate to have some equipment nearby (within a few hour drive). We were on site with CoalTreat equipment within 3 days and treating coal on the fourth day.

FUNDAMENTALS OF SLAG FORMATION

¹ Many factors drive slag production in coal-fired boilers, such as coal particle combustion temperature, residence time, oxygen present in the furnace, sulfur species, and the presence of other metals. The type of coal being burned also plays an important role in the type of slag formed. For example, PRB coal contains high levels of calcium where bituminous coals have almost no calcium, which has an impact on the type of slag formed.

Most of the research on high temperature slagging is based on the many crystal compounds that form from the decomposition of clays and other alumina-silicates and the effect of elements like calcium, iron, sodium and potassium on ash viscosity and melting temperatures. For example, particles high in silica will tend to form amorphous slags (amorphous glass at high temperatures) while those low in silica will crystallize. The removal methods for each are different. There are three other important slag properties that must be considered.

Melting point temperature. The MgO-Al₂O₃-SiO₂ three-phase diagram is used to determine the structure of the compound formed for known mole fractions (Figure 1, Left). The ratio of the different metals and the oxidation/reduction state of the furnace will determine which compounds are formed in the slag and their melting points. In theory, magnesium may be added to alter the melting point of an alumina-silicate-based slag to raise the ash softening temperature. In practice, there may be interactions with many metals and combustion conditions, especially the distribution of oxygen in the furnace, that are critical factors in the analysis.

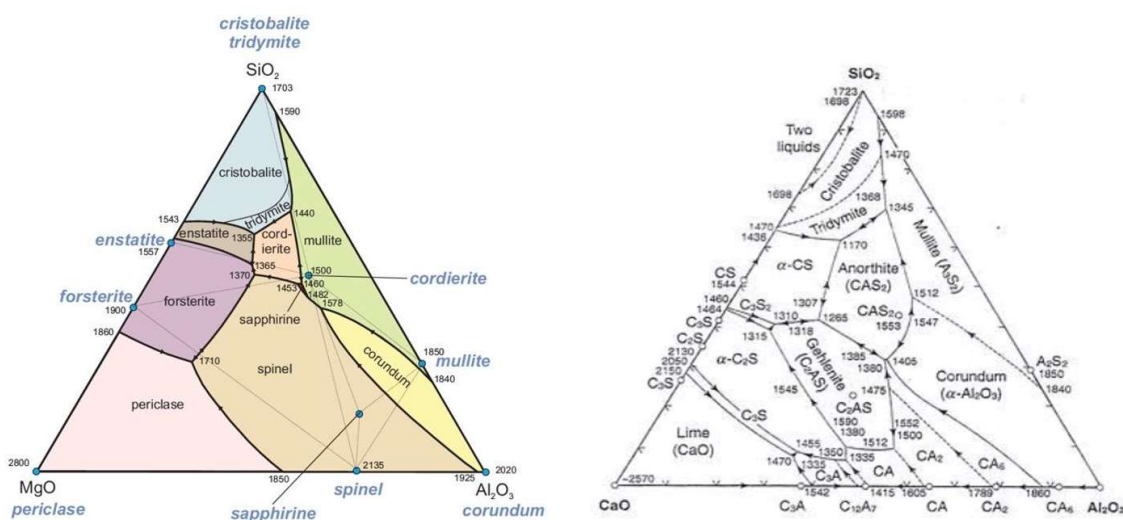


Figure 1. The MgO-Al₂O₃-SiO₂ three-phase diagram is shown on the left and the CaO-Al₂O₃-SiO₂ diagram on the right. The mole ratio of each compound will determine the material's melting point.

Pure lime (CaO) has a high melting point, but changes in the mole ratios of silica and alumina in the ash will decrease the melting point temperature. Most of the alumina silicate formations in slag are amorphous, meaning it is without a crystal shape. If a brittle (or friable) crystalline

structure forms then the slag is very likely to fracture during soot blowing. Anorthite, located in the center of the CaO-Al₂O₃-SiO₂ diagram (Figure 1, right), has a brittle crystalline structure with a melting temperature of 2,836F. The compound is formed when two moles of silicon dioxide react with one mole each of aluminum oxide and calcium oxide. Fortunately, most bituminous coals have a silica to alumina ratio of 2 to 1 and will form Anorthite in the presence of calcium. However, bituminous coals generally lack calcium. If a highly reactive form of calcium is added to the combustion zone then the more easily fractured Anorthite is formed.

Pyritic sulfur formation. Sulfur and iron also exist naturally in coal as pyrite (FeS₂). During combustion, pyrite will either: remain unchanged (if large particles); convert to Fe³⁺ sulfates; or oxidize fully to hematite (at 932F) releasing pyritic sulfur, which will react with any alkalis, Ca, or Mg present in the furnace. The oxidation process path taken is strongly dependent on particle size, which is a function of the unit's mill performance. If a coal particle is too large then it will not have sufficient time to completely combust (Figure 2).

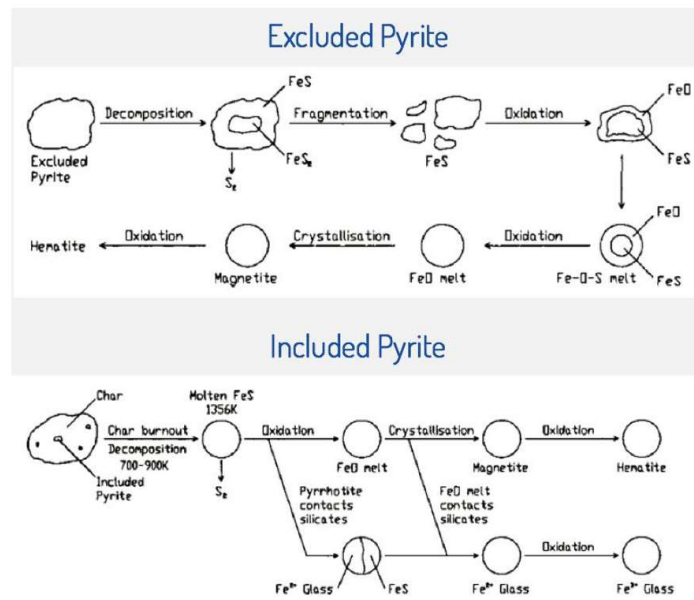


Figure 2. Processing pyrite in coal combustion. “Excluded” and “Included” pyrite follow slightly different oxidation processes.

Our tests have shown that when pyrite is reacted with the alumina-silicates in the ash, iron migrates into the Al-Si structure. Consequently, adding a highly reactive form of calcium to the combustion process will efficiently capture pyritic sulfur, forming high melting point hematite instead of the low melting point ferrous sulfate. The importance of this observation will become apparent shortly.

Sintered ash deposits. Sodium sulfate melts at 1,622F while mixed alkali-metal sulfates can form a molten phase at much lower temperatures (~1,200F), which will condense on boiler tube surfaces. The result is a sticky layer of ash on tubes which attract more fly ash creating a build up of slag. As the layer grows and moves away from the insulating effects of the steam tubes, the temperature increases causing the new particles to melt and flow together (known as viscous

flow sintering). Adding magnesium or calcium to the mixture forms their respective sulfates which significantly increases the mixture's melting point (>2,200F) thus eliminating the sticky first layer of slag formed by alkali deposition, stopping further deposit growth.

SLAG MITIGATION

Ideally, controlling furnace slagging begins with mill performance and coal fineness. Primary airflow, coal pipe distribution and burner optimization also have key roles in slag formation as do burner, OFA and total airflows. Measuring and mapping the oxygen content within the combustion zone and the temperature distribution in the upper furnace are critical. Optimizing all of these parameters can still leave you with slagging issues. A little coal ash chemistry modification in combination with a properly tuned unit may be far more effective and economical than tuning alone.

CoalTreat ash modification programs begin with comparison of the target coal chemistry characteristics with EES' extensive database of previously treated coals. Slag samples may be collected on the surface of a high temperature probe (HTP) and analyzed to determine the proper reagent type and dosage necessary to alter the ash chemistry of the coal to ease removal from furnace tubes (**Figure 3**). An example of the HTP before and after treatment is shown in **Figure 4**. Scanning electron microscope (SEM) and x-ray diffraction (XRD) analyses may also be used to identify the crystal composition of the slag. There are a variety of reagents, CoalTreat 300, 600, 710, 780, that may be selected or mixed depending on the structure of the slag.



Figure 3. A high temperature probe duplicates generating tube surface temperatures to simulate deposit bond and deposition rate. Deposits are then collected and analyzed by a third-party laboratory. The tests are repeated to optimize reagent type and dosage.



Figure 4. The baseline high temperature probe (HTP) testing at a PRB-fired 640MW opposed wall furnace produced a heavy layer of black glass that adhered to the probe (top). The coal was pretreated with CT-300 at an initial "shock" dosage and later optimized to a reduced maintenance dosage. HTP testing was repeated one day later and the coating on the probe was more porous, friable, and cracked off as it was removed from the inspection port (bottom), confirming the sticky alkali layer of slag was prevented from forming.

The method of application must be selected once the proper chemical reagent and application rate are determined. Chemicals must be added to the coal prior to combustion for the most efficient reaction. Reagents are applied to coal on the main transfer conveyor when bunkering or to coal just prior to entering the mills. The application spray pattern is of minor importance since the mills handle final mixing of the reagent with the coal.

SLAG PREVENTION IN PRACTICE

While this paper focuses on a specific case study treating a slagged boiler, most of EES' commercial experience is in treatment to prevent excessive slagging. An example of this follows:

This case study profiles a 650 MW PC Unit that was challenged by burning high levels of ILB coal along with some of the highest slagging NAPP coals known to EES. The station is strategically positioned alongside the Ohio River, receiving all coal via barge. EES participated in an EPRI sponsored 2-week demonstration to test the use of boiler cameras fitted with slag detection software to compare furnace buildup of slag generated from high iron/high alkalis, low fusion temperature ILB/NAPP coal blends. The extremely challenging blends would provide the station with lower fuel costs. The station experienced frequent forced derates and the need for online washing numerous times per year prior to the demonstration. The demonstration was designed to compare results from the slag cameras for blends burned with, and without additives with appropriate field adjustment of CoalTreat dosages.

The station was able to burn very high Hansel-Halfinger Index coal blends at a consistently high load for five consecutive days while using CoalTreat. The pendant and nose arch areas were effectively maintained by normal soot-blowing during these challenging coal burns. Slag cameras were found to be extremely useful tools for monitoring slag deposits over the course of

the demonstration. **Figure 6** is a snapshot of the type of data collected by the cameras and associated slag recognition software. The effectiveness of soot-blowing can be clearly seen in the chart below, showing the side by side pendant/nose arch photo and software representation of slag accumulation.

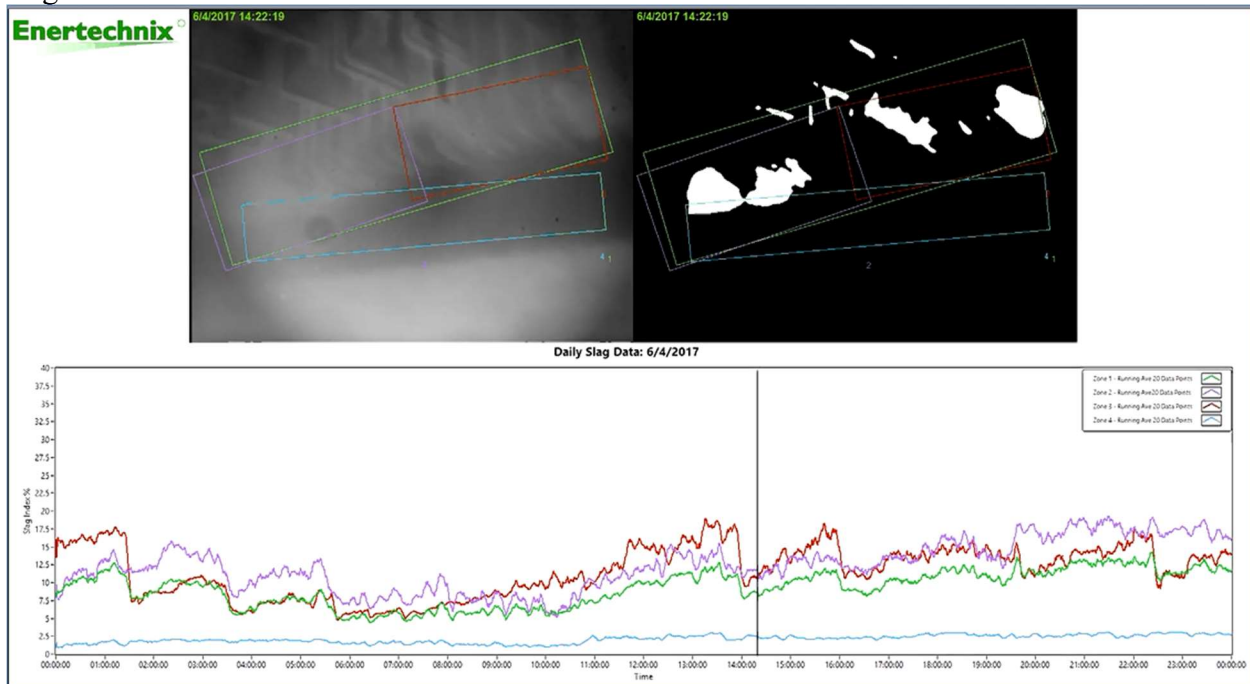


Figure 6. IR Camera photo of tube bank and soot blower performance trend

TREATING THE SLAGGED BOILER

This focal case study profiles a 750MW tangential fired CE Tangentially-Fired Boiler burning ILB and NAPP coals with mid-high sulfur and high iron content. The unit was consistently de-rated due to slagging, with bridging in the furnace pendants just above the nose arch of the furnace. Portable IR cameras were utilized by the plant to monitor slagging.

EES was called in to treat a slagged furnace with the goal of allowing them to run during a crucial time of power sales until their upcoming outage. Their plan was then to have us remove our equipment as they would fix the combustion problem (thought to be one pulverizer) that was causing the excessive slag.

Treatment of the coal was successful in gradually removing slag build up. Ash modification mechanisms go beyond just modifying the ash created from combusting the additive containing coal. The modified ash migrates onto the surface of the upper furnace slag deposits facilitating further transfer of the modified ash chemistry into the deposits. Myriads of high melting point MgO particles become part of the slag matrix creating a more friable surface for effective removal via soot-blowing. This process slowly shrinks existing slag deposits as well as mitigating buildup.

Figure 7 represents before and after CoalTreat photos.

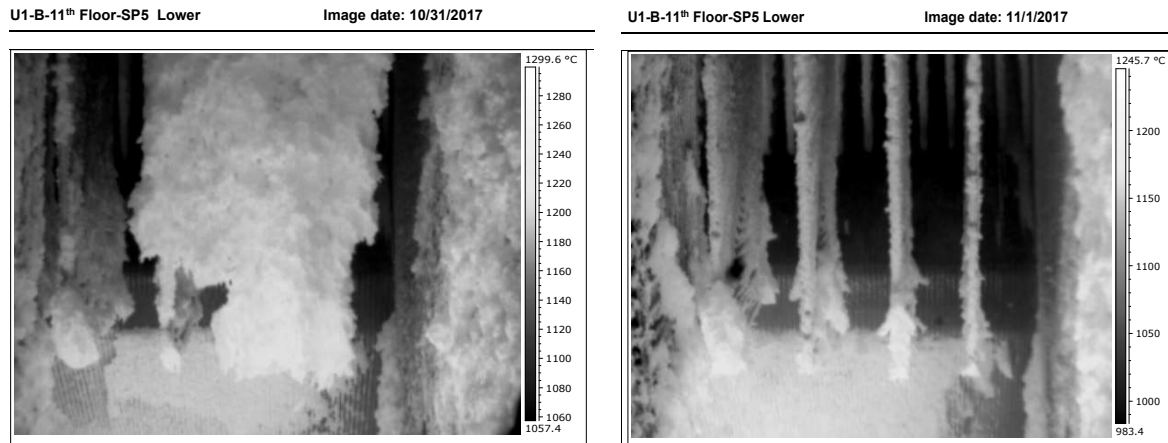


Figure 7. Lower 11th Floor before and Lower 11th Floor after treatment

Even though the initial treatment with CoalTreat additives was successful in allowing the plant to reach its outage, the plant requested that EES remove its equipment during the outage. Shortly after the plant came back on line, EES was asked to return with equipment to treat coal on all four of their units.

It has now been over 18 months since the initial trial and EES continues to provide CoalTreat additives for all four of the units. Using the high temperature slag probe we continue our efforts to optimize dosing of the coal. EES' combustion optimization group is also working with the plant to explore opportunities for combustion enhancement to minimize additive used.

Another suspected benefit of CoalTreat application is the reduction of gaseous arsenic, a known poison of the SCR catalyst. Initial testing at the plant showed significant increases in particulate arsenic in the particle sizes expected with CoalTreat reagent capture. Further testing of CoalTreat's effect on catalyst life enhancement is planned at a sister plant.

Coal Treatment Economics

Each unit and fuel combination are unique, so the cost of treatment is site specific. However, experience provides some general guidance. For estimating purposes, the cost of CoalTreat ranges from \$ 0.35 to \$ 1.20/ton of coal treated depending on the type of coal, the complexity of the CoalTreat ash correction formulation, and the final dosage of chemical required to achieve the desired result. For a 500MW unit with a 10,000Btu/kWh heat rate, the cost of CoalTreat is about \$1.0 million/year.

This economic equation must be balanced with the revenue generated by fuel savings and a more efficiently operating unit. For example, a PRB unit treated with CoalTreat resulted in a decrease in furnace exit gas temperatures of 100°F. Given the rule of thumb that every 10°F decrease in

furnace out temp results in a heat rate improvement of 0.25%, the unit average heat rate improved after CoalTreat by 2.5% or 250Btu/kWh. At \$0.75/mmBtu for PRB and 70% capacity factor, the unit saves approximately \$0.5 million/year in fuel purchases. Also, CoalTreat increased the maximum output of the plant by 10MW. Power at this plant was sold for \$50/MWh, thus the increase in revenue was approximately \$3.0 million/yr. Annual net revenue for the plant increased by \$2.5 million. Not included in this simple estimate are revenue losses incurred by forced outage hours, reduced capacity factor, lost on-peak power sales, or the additional labor and material costs associated with cleaning slagged furnace tubes as well as their impact on tube life.

CONCLUSIONS

Correcting coal ash chemistry in real time has now been in practice for many years. Evaluating coal, ash and an individual combustion process allows for the proper selection of additives for a given plant. This project also helped us confirm that reducing the slag already built up in a unit is feasible. Another result of this program was the development “CoalTreat on Demand” to quickly respond to customers with slag issues in an effort to extend operation.

A CoalTreat SMART system was also recently commissioned that receives iron and sulfur content signals from an on-line coal analyzer to automatically adjust the chemical blend ratio and dosage of reagents as the coal is bunkered. The SMART system ensures the customer only treats incoming coal when needed. This process also relieves the customer from manually blending coal deliveries in the coal yard to meet the fuel quality needs of the furnace.

EES continues to make developments in the field of coal chemistry to help its customer operate more cost effectively in this competitive power production environment.

REFERENCES

¹Custom Chemical Reagents Reduce Slagging in Coal-Fired Boilers, Mark Pastore, Vice President Technology, Environmental Energy Services, Modern Power Systems Magazine November, 2018