CORRELATING THE SLAGGING OF A UTILITY BOILER WITH COAL CHARACTERISTICS

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

ABSTRACT

This paper will describe how a utility was able to correlate intermittent slagging problems a boiler was experiencing with coal ash chemistry. The coal ash fusion temperatures alone were not sufficient to be able to separate the good versus poor performing coals. Further investigation revealed that the iron levels in the coal ash, and several indexes such as Base to Acid ratio, slagging factor and iron loading provided good bases for separating the coals that caused problems and those that did not. A total of nine coal supplies were burned in the boiler of which four caused furnace slagging problems. This utility experience further demonstrates the value of the ash chemistry data and the necessity of including more data than the fusion temperatures in coal specifications. The split between successful and unsuccessful coals is specific to this plant and should not be used universally. This work does demonstrate that ash chemistry can provide information for determining weather or not a coal can be successfully used at this plant.

INTRODUCTION

For years the fusion temperature or cone melt down test has been used to evaluate the melting and slagging behavior of coal ash. These tests have been applied to all sorts of situations, some appropriate, others not so. The American Society of Mechanical Engineers (ASME) Research Committee on Corrosion and Deposits from Combustion Gases has long advocated the weakness of the ash fusion test and provided several formats to make advancement and use of other means of evaluating the depositional behavior of coal ash. The ASME ASH FUSION RESEARCH PROJECT (1) provided a good review of the various ash fusion tests used around the world, along with several examples of poor applications of the fusion test. The use of fusion temperatures in contract specifications to eliminate poor performing coals can lead to several detrimental situations. Two common ones are: coals that meet the specifications and cause problems, and the elimination of coals that don't meet the spec., but perform well. The utility experience described in this paper will again demonstrate the inability of the ash fusion temperature test to quantify plant performance. It will further show good correlation of plant experience with ash chemistry.

Please note that all coal analyses were conducted at a variety of private and commercial laboratories. All laboratories indicated that they used American Society for Testing and Materials (ASTM) standards (2). No account was taken for any potential laboratory differential. The laboratory results are typical of the type of information available to coal producers and utilities.

THE PLANT

The plant, although anonymous, can be described as a large pulverized coal unit with a high heat release per unit volume. This design constraint limits the coal used to high fusion central Appalachian coal, typically in the seven to ten percent ash range. Regular monitoring of the carbon in the fly ash indicated that the unit was able to achieve good combustion. All boiler slag formation tests were conducted at or near full load conditions during a sustained time frame. Those coals listed as successful had no apparent operational problems, the unsuccessful coals had excessive slag build up rates.

TYPICAL FUEL

The coals utilized by the plant had similar characteristics. Ranges of common analyses are shown below in Table I.

Table I
Typical Coal Analyses

As Received	Typical Value	Range
Moisture	5.5	3.0 - 8.0
Ash	7.4	5.2 - 10.6
Sulfur	0.88	0.67 - 1.12
Btu/lb	13,000	12,400 - 13,300
HGI	43	39 - 45
Fusion Temp. ID F.	2,803	2,742 - 3,000+
Fusion Temp. Fluid F.	2,850+	2,800+ - 3,000+

FUSION TEMPERATURE RESULTS

When the coals are separated into successful and unsuccessful categories and the fusion temperatures are displayed, you cannot set a temperature that separates the categories. Figure 1 shows the initial deformation temperatures for the coals studied. As indicated, it would be hard to distinguish which coals would be successful or not. It should be noted that in many cases the fusion temperature was beyond the maximum furnace temperature, and was reported as 2,800+ or 2,850+ degrees F.

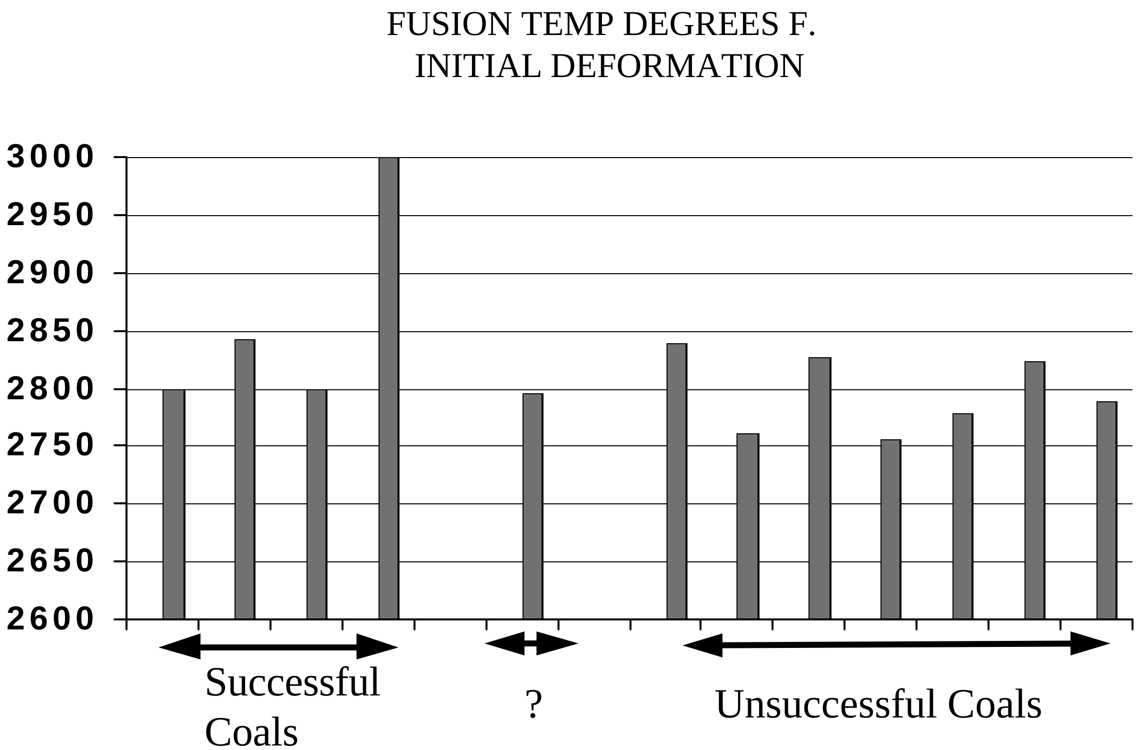

Figure 1. Initial deformation temperature for coals by successful/unsuccessful categories, ? is coal that had some problems, but not as severe as unsuccessful coals.

The fluid fusion temperatures are even harder to interpolate as the majority of the results are at the maximum furnace temperature. These results are shown in Fig. 2.

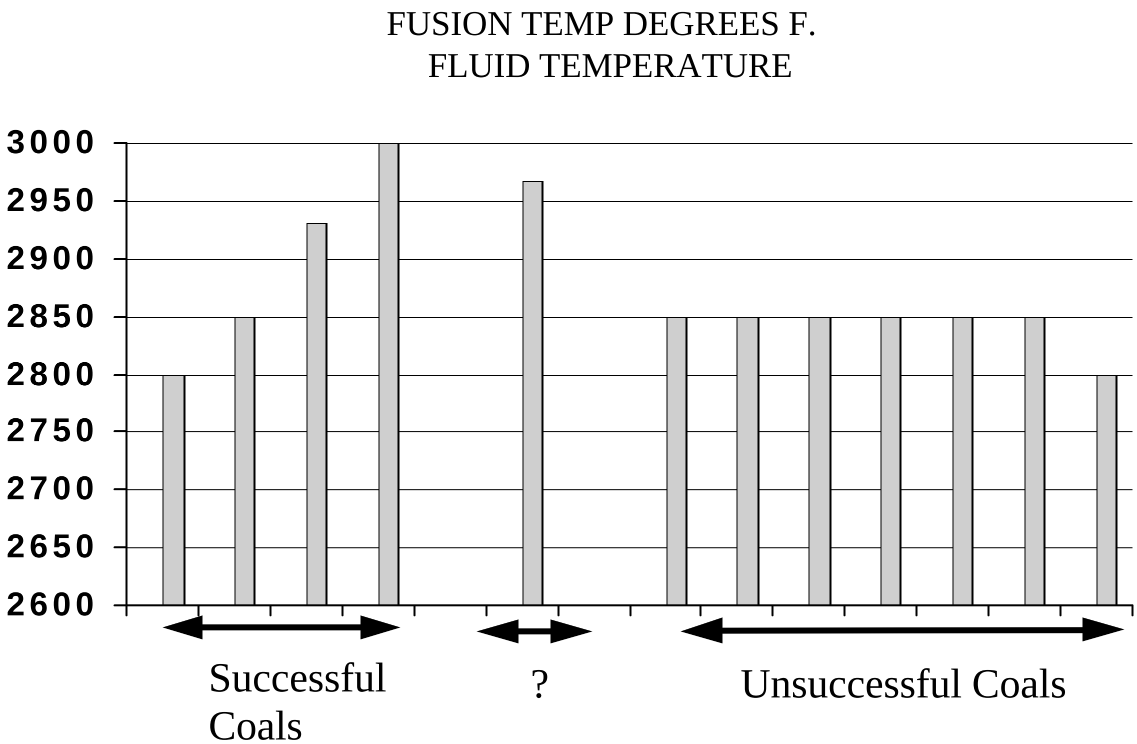

Figure 2. Fluid temperature for coals by successful/unsuccessful categories, ? is coal that had some problems, but not as severe as unsuccessful coals.

Figures 1 and 2 represent the challenge faced by many utilities today. In this instance the fusion test was asked to differentiate between coal ashes that melted at or over the furnace design limits. In addition, a high fusion temperature did not ensure a successful rating.

ASH CHEMISTRY

The ash chemistry of all the coals showed high levels of silicon and aluminum. When reported as oxides these to elements make up eighty to ninety percent of the ash. These two elements along with one to two percent titanium dioxide make up the acidic oxides. Iron oxide is the third most abundant element, and the highest percentage of basic oxide. Figure 3 shows the iron oxide levels of the coal ashes in a similar manner as Fig. 1 and 2.

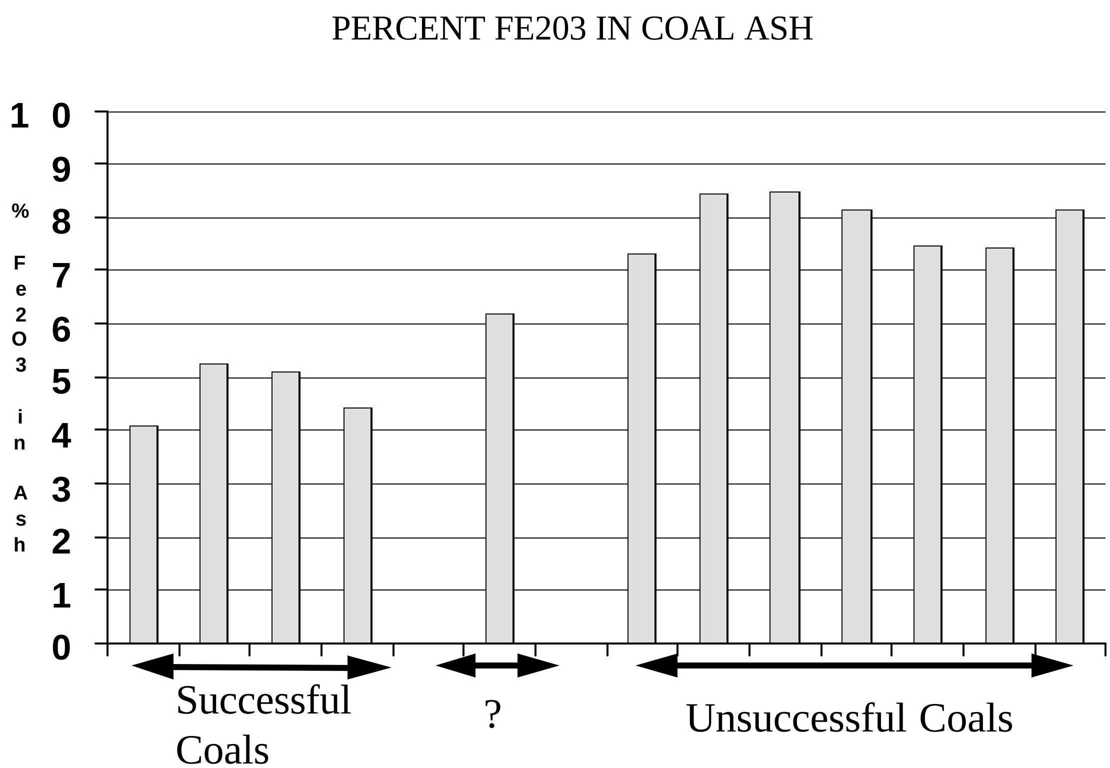

Figure 3. Iron oxide (Fe203) levels in coal ash by successful/unsuccessful categories, ? is coal that had some problems, but not as severe as unsuccessful coals.

As shown in Fig. 3 the iron oxide levels of all the coals that were successful are below six percent. Those coals that were deemed unsuccessful have iron oxide levels greater that seven percent. The coal that had intermediate performance had an iron oxide level between six and seven percent.
The Silica Percentage as described by Reid (3) is expressed as

$$\text{Silica \%} = 100(SiO_2/SiO_2 + Fe_2O_3 + CaO + MgO)$$

Figure 4 shows the Silica % results by slagging performance category. Like the iron oxide levels the Silica % is able to group the coals into successful and unsuccessful categories. The break is at about eighty seven percent, unfortunately the parameter placed the intermediate performing coal with the successful coals.

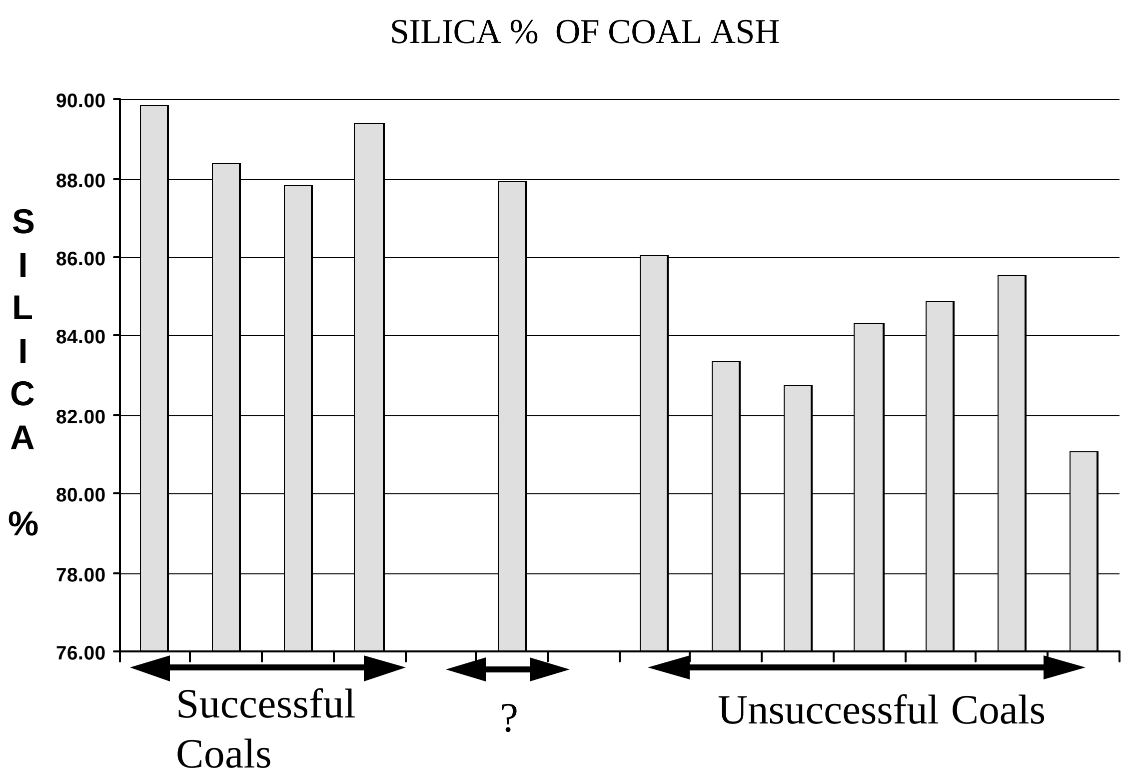

Figure 4. Silica percentage for coals by successful/unsuccessful categories, ? is coal that had some problems, but not as severe as unsuccessful coals.

The ratio of basic to acidic oxides as expressed by the B/A has been described by Winegartner (4). Numerically it is found by using the following formula:

$$B/A = \frac{Fe_2O_3 + CaO + MgO + K_2O + Na_2O}{SiO_2 + Al_2O_3 + TiO_2}$$

Figure 5 shows the results of the base to acid ratio versus slagging performance. Like the Silica percentage the B/A groups the coals well in terms of separating the successful coals from the unsuccessful coals. The B/A also placed the intermediate performing coal with the successful coals. The unsuccessful coals all had B/A at or above 0.14, the successful coals were at or below 0.11, with the intermediate coal also at 0.11.

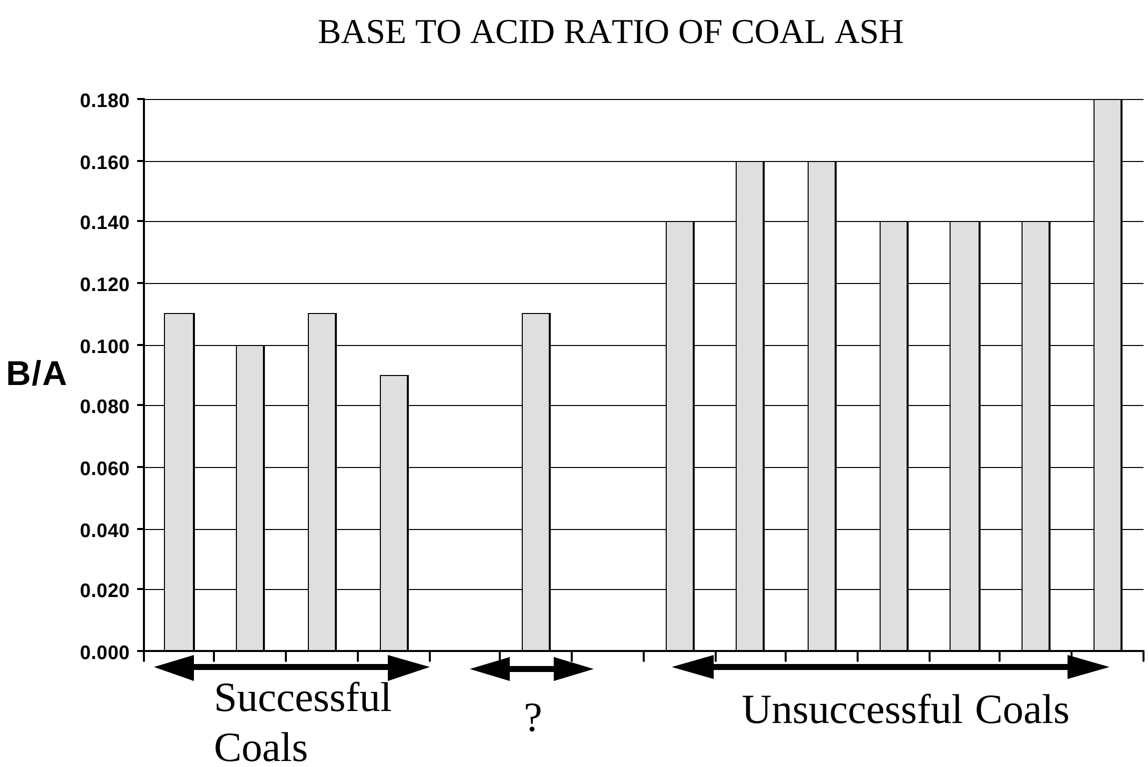

Figure 5. Base to acid ratio, B/A for coals by successful/unsuccessful categories, ? is coal that had some problems, but not as severe as unsuccessful coals.

Attig and Duzy (5) have derived an empirical slagging index by multiplying the base to acid ratio by dry sulfur.

Slagging Index, Rs = dry S% x B/A

If a portion of the sulfur in coal exists as pyrite it can be seen that the slagging index is doubling the impact of iron by including both sulfur and iron oxide in the numerator. All of the coals in this study rate low slagging potential by having a slagging index less than 0.6. Figure 6 shows the results of the slagging index for these coals.

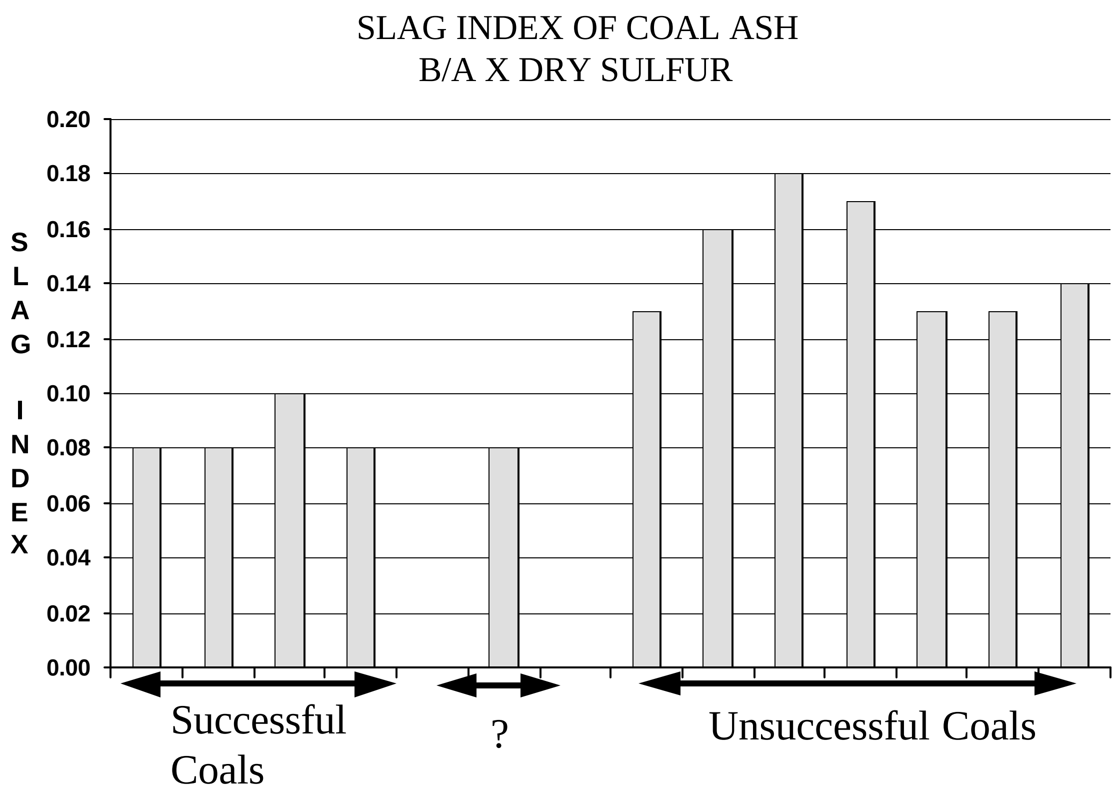

Figure 6. Slagging Index, Rs for coals by successful/unsuccessful categories, ? is coal that had some problems, but not as severe as unsuccessful coals.

Again the slagging index separates the coals into successful and unsuccessful categories. Like the B/A and the Silica percentage it groups the intermediate performing coal with the successful coals.

The author has found on several occasions the usefulness of an iron loading term, typically pound of iron oxide per million Btus. This term has successfully separated the full scale performance of a boiler using high sulfur Illinois basin coals where a low ash-high iron percentage coal had less slagging than a higher ash-lower iron level coal. Figure 7 shows the results of the iron loading calculation for the coals. This term is found using the following equation:

$$\textbf{Iron Loading, lb. iron/MBtu} = \frac{\%Fe_2O_3 \times (\%Ash/100)}{(Btu/lb / 10{,}000)}$$

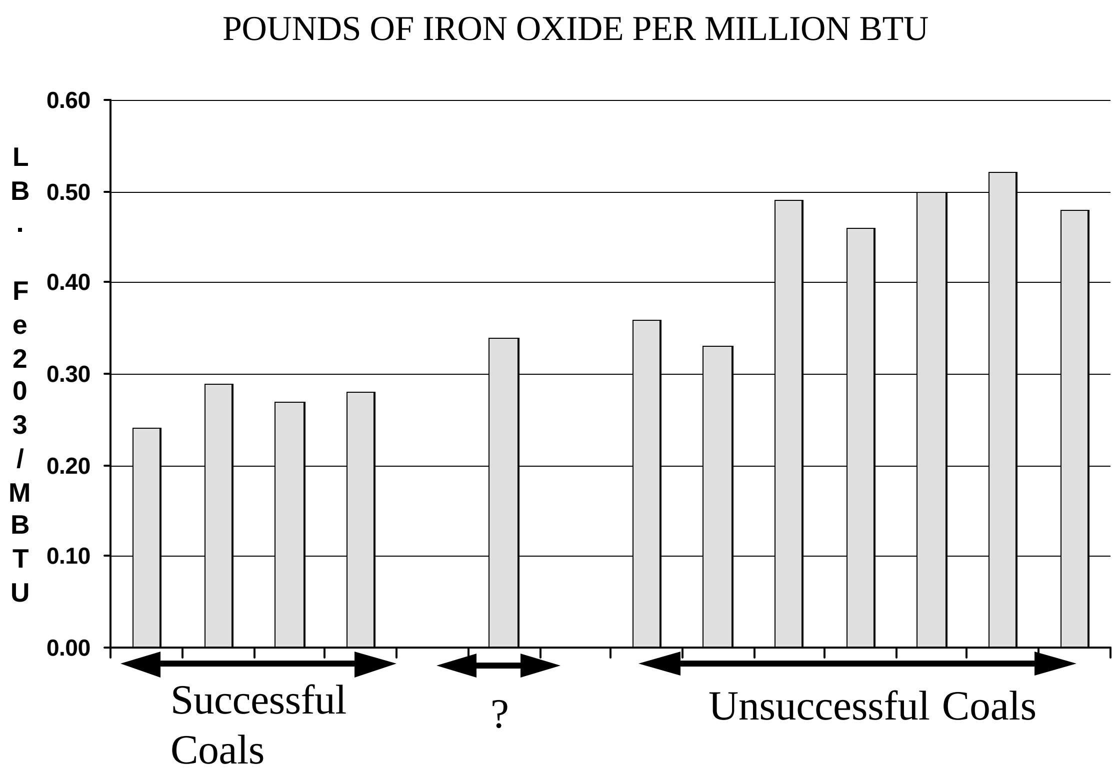

Figure 7. Iron loading expressed as lb. Fe2O3 per million Btu for coals by successful/unsuccessful categories, ? is coal that had some problems, but not as severe as unsuccessful coals.

As shown the iron loading term separates the successful and unsuccessful performing coals. In addition, it also places the intermediate coal with the unsuccessful coals. Most utilities would prefer to use terms that are more conservative and place coals with intermediate performance with the coals that do not perform. It is felt that the iron loading term is useful due to it incorporating the amount of material, rather than just the characteristics of the ash. The fusion temperature, Silica %, base to acid ratio, and slagging index only characterize the ash, not the amounts of material available to form deposits.

CONCLUSION

This paper describes one utility's experience with coal slag. The coals studied were similar in nature and all possessed low slagging potential. Due to boiler design with higher than typical furnace heat release rate, the boiler was occasionally subject to slagging deposits. Using only the ash fusion temperatures the slagging potential of a given coal could not be predicted. By incorporating the ash chemistry into the evaluation and reviewing past experience, several techniques were found to better quantify coal characteristics with plant operating experience. Several commonly used expressions were found to be useful in segregating the successful and unsuccessful coals, but could not quantify the performance of an intermediate performing coal. The percent iron oxide and the iron oxide loading were able to better quantify the behavior of the coals.

References

1. ASME ASH FUSION RESEARCH PROJECT, CRTD-18, For availability contact: ASTM/CRTD, 1828 L St. NW, Suite 906, Washington DC 20036

2. Annual Book of ASTM Standards, Vol. 5.05 Gaseous Fuels; Coal and Coke, ASTM 1916 Race Street, Philadelphia, PA 19103-1187, USA.

3. Reid, W.T. and Cohen, P. "The flow characteristics of coal ash slags in the solidification range" *Jour. Eng. Power, Trans. ASME Series A,* 66, 83, 1944.

4. Winegartner, E. C. (ed.). *Coal Fouling and Slagging Parameters.* ASME research Committee on Corrosion and Deposits from Combustion Gases, ASME pub.,1974.

5. Attig, R. C. and Duzy, A. F., "Coal ash depositional studies and application to boiler design" *Amer. Power Conf.*, Chicago, Ill., Illinois Institute of Technology, 1969.