ELECTRIC POWER RESEARCH INSTITUTE

Impact of Alternative Fuels and Blends

A Simple Tool for Ranking Coal and Blends for Slagging Potential

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Technical Update, December 2012

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PRODUCT DESCRIPTION

This report provides a summary of ongoing work to identify, develop, and validate advanced tools to assess the impact of fuel quality on boiler performance.

Background

The deposition of ash particles during the combustion of coal—or blends of coals—is one of the major issues associated with power companies' lost generation. The ash deposition process, driven by accumulation of molten/sticky, sintered, or loosely condensed deposits on waterwalls, tube banks, and heat transfer surfaces can lead to substantial downtime, efficiency losses, and financial losses.

Objectives

The objectives of this study were to explore existing simple slagging predictor tools that use conventional coal ash and ASTM analysis, such as the numerical slagging index (NSI), to quickly rank the relative deposition potential of different coal types and blends. NSI's predictive capability was evaluated against boiler observations for different coal types—such as Powder River Basin (PRB), bituminous, and lignite coals—and the results compared to conventional empirical indices. When possible, improvements to the existing capabilities were identified.

Approach

In previous studies, researchers assessed the performance of the NSI index for 15 coals and 4 coal blends by comparing the NSI predictions to field observations. In this EPRI study, to further evaluate the validity of NSI for a wide range of fuel types, the index predictions were compared to the field data obtained from a variety of domestic sources for the three coal types: bituminous, subbituminous, and lignite coals. Because the NSI index does not account for other factors such as boiler design and operational features that could also affect the deposition potential, the performance of the index was evaluated primarily for coal types for a given boiler configuration.

Results

A new empirical slagging index (NSI) based on ash viscosity, ash fusibility, and ash loading was developed at the Center for Computational Fluid Dynamics at University of Leeds, United Kingdom. EPRI evaluated the performance of this predictor against boiler observations for different coal types (such as PRB, bituminous, and lignite coals) and compared the results to conventional empirical indices. Some of the conclusions drawn from this evaluation and the prospect of using this index as a generic method for predicting pre-combustion slagging behavior of coals are discussed.

Applications, Value, and Use

This report is intended for coal-fired plant engineers and other personnel interested in quickly assessing the impact of a new coal and its propensity for slagging behavior. The NSI uses readily available data from standard laboratory analysis and can be solved on a simple spreadsheet program. Although the index has been tested with several coals, it does warrant further validation with plant field observations.

Keywords

Coal
Combustion
Empirical indices
Simple predictive models
Slagging

ABSTRACT

Ash deposition during the combustion of coal—or sometimes blends of coals—is one of the major issues associated with power generation companies. Because of the potential severity of the problem, the ability to predict the deposition potential of a particular fuel composition prior to its combustion is essential. Over the years, limitations in the use of existing empirical indices have led to several EPRI-funded research efforts to develop advanced prediction tools such as FACT, PCQUEST, and Slag Advisor. However, to quickly evaluate the effect of minor changes in fuel specifications, the use of these advanced tools could be both time consuming and labor intensive. In this work, a novel numerical slagging index (NSI) that uses conventional coal and ASTM mineral ash analysis has been evaluated to predict the slagging potential of different coal types and blend configurations. The prospect of using this index as a generic method for predicting slagging behavior of coals is discussed, and recommendations to improve the model predictions are provided.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

The deposition of ash particles during the combustion of coal or sometimes a blend of coals is one of the major issues associated with utility power generation. The ash deposition process, driven by accumulation of molten/sticky, sintered, or loosely condensed deposits on the tube banks, can lead to substantial financial losses. These losses are generally a result of decreased heat-transfer rates, increased heat rate, increased frequency of sootblowing, reduced plant capacity, plant availability and high maintenance cost due to erosion, blockage and corrosion.

Because of the potential severity of the problems associated with ash deposition, the development of an ability to predict coal and boiler specific deposition rates is essential. Traditionally, electric utilities have used empirical indices based on the bulk ash composition of the coal to evaluate deposition tendencies. Most of these indices rely upon measured ash fusion temperature, ash viscosity and ash chemistry for characterizing the coal ash deposition tendency. These slagging and fouling indices, suitable for narrow coal-boiler configurations, may be highly inaccurate when applied to new fuels or blends of dissimilar fuels. This discrepancy can be attributed to the use of overall (bulk) ash composition, even though deposition is initiated by individual particles with varying composition and size. For this reason, prediction of the behavior of complex blends of coals through the use overall bulk ash chemistry is particularly challenging.

Such shortcomings observed in the conventional empirical tools have resulted in considerable research efforts, funded by EPRI and U.S. Department of Energy (DOE), in understanding the fundamental process of ash formation and deposition in coal fired utility units. The advent of new analytical techniques such as Computer-Controlled Scanning Electron Microscopy (CCSEM) and chemical fractionation (CHF) provide more detailed information and understanding of the mineral matter in the boiler. Equilibrium thermodynamic modeling is another tool that uses conventional coal analyses for prediction of liquid, solid and gaseous components in flue gas streams, thus providing a better understanding of the slagging and fouling mechanisms. This research has led to the creation of advanced software tools such as PCQUEST, FACT calculations [1] and PSI's Slag Advisor [2] packages to provide boiler operators with guidance in switching fuels, blending or changing operation in order to maximize power production efficiency by minimizing ash related deposition issues such as slagging and fouling.

Despite the apparent advantages of using advanced tools, the need for comprehensive input data is both time consuming and labor intensive when it comes to quickly evaluating the effect of minor changes in fuel specification. The focus of this work was to explore novel simple prediction tools/indices that are capable of giving relatively quick responses in terms of slagging tendencies when simulating the effects of different fuels types for a given boiler configuration.

Objectives

The objectives of this study are:

1. Explore existing simple slagging predictor tools that utilize conventional coal ash and ASTM analysis for quickly ranking the relative deposition potential of different coal types and blends.
2. Evaluate the performance of the predictor against boiler observations for different coal types such as; PRB, Bituminous and Lignite coals and also compare the results to conventional empirical indices.
3. Explore possible improvements to model prediction capability.

2
BACKGROUND OF SIMPLE SLAGGING PREDICTOR TOOLS

Ash Fusion Test

For decades, the Ash Fusion Test (AFT) and cone melt down tests have been employed in evaluating the slagging potential of coal ash. The standard AFT test was originally designed for assessing the clinker formation of ash from lump coal in stoker boilers. The time/temperature history, which coal particles undergo in pulverized coal fired (Pf) furnaces, is different from stoker furnace and hence AFT do not always accurately predict the performance of coal ash in Pf combustion. AFT test is considered more of an observation than a measurement and hence susceptible to subjective assessment.

Ash Particle Viscosity Models

The ash particle viscosity is an important factor in determining the extent of capture and consolidation of the particles on furnace walls. Most coals exhibit a continuous increase in viscosity with a decrease in temperature. Therefore, viscosity is a major physical property that affects deposit strength in regions of high temperature such as > 2000°F (> 1093°C). Under high temperature conditions, ash particles become molten with low viscosities that cause the initial slagging in coal combustors. Although several viscosity models have been developed, the application of these models to predict slagging tendencies of coal is limited and in many cases unsuccessful. This is primarily because most of these empirical viscosity models were based on ash composition and were not validated against measured viscosities of ashes and actual boiler slag observations [3, 4].

Empirical Slagging Indices

Conventional empirical slagging indices like base to acid ratio (B/A), iron oxide percentage (% Fe_2O_3), Attig and Duzy factor (B/A×S), silica ratio, iron to calcium ratio (Fe/Ca) and multi viscosity index are all mostly derived from chemical analysis of coal ash and do not always reliably predict field slagging performance. The reason for this could be that most of these indices were designed for a particular coal ash type and are hence are not universally applicable for all coals. Also, the existing indices do not incorporate the ash content in coals which is a very important factor in determining the extent of slagging for a particular coal.

Bharat Heavy Electrical Ltd. (BHEL) Index

The index uses Thermo Mechanical Analysis (TMA) data to measure ash shrinkage rate (R_m) as a function of temperature (T_m) while taking into account the total ash content normalized by the calorific value of the respective coal [3]. Based on the above discussion the BHEL index is defined as:

$$BHEL\ index = \left(\frac{Rm}{Tm}\right) \times weight\ of\ ash\ in\ g/Mkcal \qquad (1)$$

The performance of the index was tested against field observation data obtained for several high ash lignite coals in a recent study [3]. The index offers a reliable correlation with reported field observations and performs better than conventional slagging indices that do not account for ash loading. The index needs further validation for different coal types and boiler configurations. The need for experimental TMA instrumentation could be a limitation owing to the cost and time associated with collecting the data and calculating the index. In addition the NSI index was also compared with slagging predictions from the correlations used by the EPRI Vista software.

Numerical Slagging Index (NSI)

Recently, a new empirical slagging index based on ash viscosity, ash fusibility and ash loading was developed at the Center for Computational Fluid dynamics at University of Leeds, UK [4]. The index referred to as Numerical Slagging Index (NSI) was validated against measurement data of 15 different coals, including lignite, bituminous coals and certain blend combinations. The proposed index was successful in ranking the coals/blends investigated against field performance and showed significant improvements in ranking fuel slagging propensity compared to conventional slagging indices tested in that study [4]. The following sections documents further validation of the NSI index against field slagging observations obtained from earlier EPRI studies as well as those reported in literature for different coal types, boiler configurations and blend combinations. The results are also compared to the prediction from conventional indices. Based on this evaluation further improvements to the index are suggested.

3
NUMERICAL SLAGGING INDEX VALIDATION

Empirical Formulation

The ash viscosity is one of the most widely used bases for predicting slagging tendency. Therefore the effect of ash viscosity is considered in the proposed NSI model [4]. The calculation follows the basic Watt-Fereday viscosity model approach with minor variations in the correlations using Bomkamp modifications as shown:

$$\mu_p = 10^{y-1} \quad (2)$$

Where y is calculated using the equation

$$y = \frac{10^7 m}{(T-150)^2} + c, \text{ T (°C)} \quad (3)$$

Therefore,

$$Log(\mu_p) = \frac{m\ 10^7}{(T(°C)-150)^2} + C \quad (4)$$

Bomkamp modifications to Watt-Fereday Viscosity Model:

$$m = (0.0104291)SiO_2 + (0.0100297)Al_2O_3 - 0.296285 \quad (5)$$

$$c = (0.0154148)SiO_2 - (0.0388047)Al_2O_3 - (0.0167264)Fe_2O_3 - (0.0089096)CaO - (0.012932)MgO + 0.04678 \quad (6)$$

Slope, m, and the intercept, c, are computed in weight % assuming normalized compositions

$$SiO_2 + Al_2O_3 + Fe_2O_3 + CaO + MgO = 100 \text{ (wt.\%)} \quad (7)$$

T is then calculated from the equation,

$ST = a(SiO_2) + b(Al_2O_3) + c(Fe_2O_3) + d(CaO) + e(MgO) + f(\alpha) + g$ where (ST = empirical softening temperature) (8)

Note: Coefficients a-g in the above equation are extracted from Table 3-1 based on their compositions, γ is then calculated using Equation (9).

$$\gamma = \frac{ash\ content\ per\ kg}{CV\ (\frac{MJ}{kg})} \quad (9)$$

Finally NSI index is defined as ratio of the ash content for the respective coal to the empirically calculated viscosity, Equation (9)/Equation (4);

$$NSI = Sx = \gamma / Log(\mu_p) \quad (10)$$

Table 3-1
Values for Constants Used to Calculate ST [4]

Content in ash	*a*	*b*	*c*	*d*	*e*	*f*	*g*
$SiO_2 \leqslant 60\%$ $Al_2O_3 > 30\%$	69.94	71.01	65.23	12.16	68.31	67.19	−5485.70
$SiO_2 \leqslant 60\%$ $Al_2O_3 \leqslant 30\%$ $Fe_2O_3 \leqslant 15\%$	92.55	97.83	84.52	83.67	81.04	91.92	−7891
$SiO_2 \leqslant 60\%$ $Al_2O_3 \leqslant 30\%$ $Fe_2O_3 > 15\%$	−3.01	5.08	−8.02	−9.67	−5.86	−3.99	1531
$SiO_2 > 60\%$	10.75	13.03	−5.28	−5.88	−10.28	3.75	453

Testing of NSI Performance

Researchers at University of Leeds [4] tested the performance of NSI index for 15 different coals and four coal blends by comparing the NSI predictions to field observations. To further evaluate the validity of NSI for a wide range of fuel types, the index predictions were compared to the field data obtained from a variety of sources for the three different coal types namely sub-bituminous, bituminous and lignite coals. Since the NSI index does not take into account other factors like boiler design and other operational features that could also affect the deposition potential, the performance of the index was evaluated primarily for coal types for a given boiler configuration. Also, to compare the numerical estimates calculated using the NSI index to the field observations; specific values were assigned to the field data to represent low, medium and high levels of slagging. The values assigned in this study are; low – 0.17, medium – 0.50, medium/high – 0.66, high – 0.84 respectively. These results are briefly discussed in the following sections.

NSI vs Indian Lignite Coals

The performance of NSI index was compared to the field observations reported in reference [3] for 13 high ash Indian coals using the data provided in the published article [4]. The calculated NSI values based on the ash composition, ash % and heating values for the respective coals are plotted in Figure 3-1 and tabulated in Table 3-2. Both data, namely; calculated NSI and the respective field observations for the coals used in the study were scaled for the ease of comparison. Hence, the data should be viewed solely based on the comparative performances of the different coals. For coals (H, I, J) and coals (L&M) the NSI predictions show high values of Sx in equation (10) ranging from a minimum of 0.92 to a maximum of 1.35. These values agree with the field observations indicating higher slagging potential for these coals. Coals B, C, E, F, G and K have calculated NSI values less than 0.92 and the field data indicate low slagging potential for these coals. The two exceptions (identified by ↓ in Figure 3-1) are coals D and N where the NSI values exceed 0.92 but do not agree with the field observations for low slagging. The NSI values for the respective coals are also compared to calculated empirical indices such as Attig & Duzzy factor (Rs), Silica ratio and % Fe_2O_3 as shown in Table 3-2.

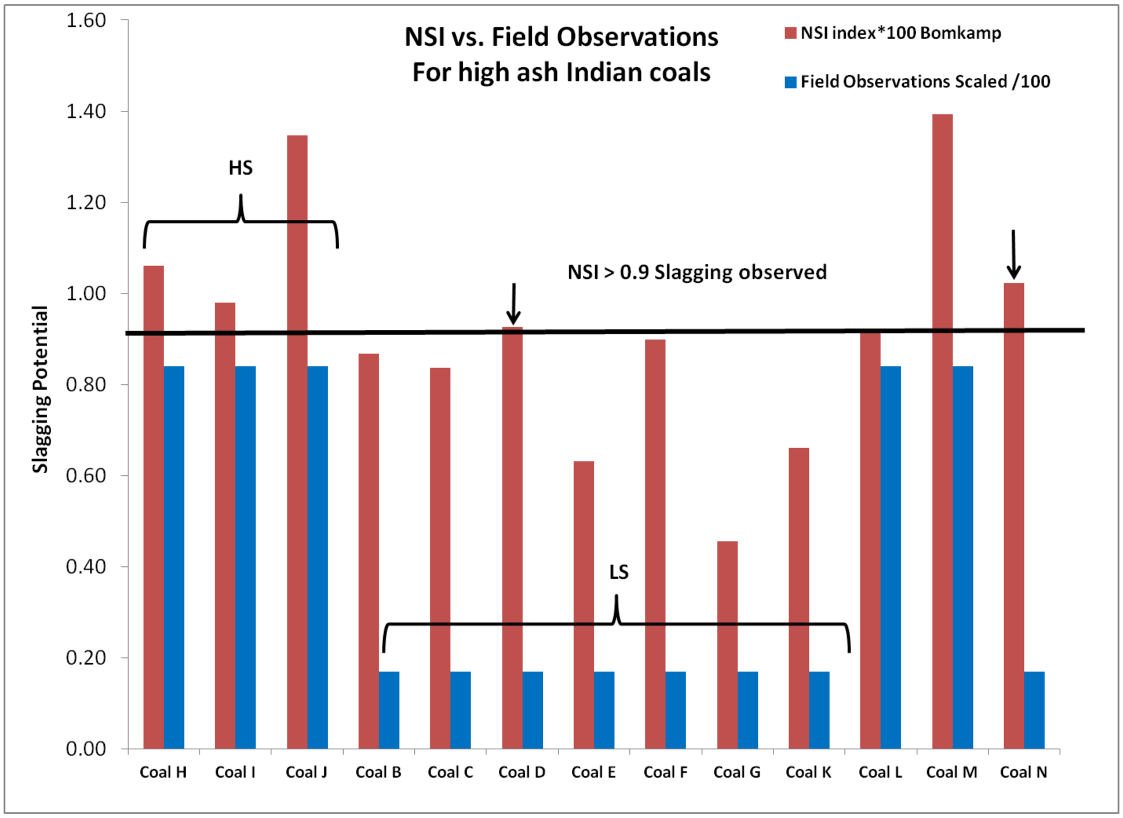

Figure 3-1
NSI Index vs. Field Observations for High Ash Indian Coals. HS: Reported High Slagging; LS: Reported Low Slagging

Table 3-2
NSI Index Values for Indian Coals vs. Field Data, Rs Factor, Silica Ratio and % Fe_2O_3 in Ash

Coals Lignite Indian	NSI (Sx) index*100 (No units)	Field Data	Field Data (numerically represented)	Rs factor (B/A*%S) *10	Silica Ratio	% Fe_2O_3
Coal H	1.06	Slagging	0.84	0.87	83.18	6.40
Coal I	0.98	Slagging	0.84	0.62	89.96	5.10
Coal J	1.35	Slagging	0.84	0.42	89.93	5.30
Coal B	0.87	No-slagging	0.17	0.34	89.30	5.90
Coal C	0.84	No-slagging	0.17	0.68	87.83	6.30
Coal D	0.93	No-slagging	0.17	0.67	87.82	5.70
Coal E	0.63	No-slagging	0.17	0.83	82.26	8.90
Coal F	0.90	No-slagging	0.17	0.58	87.55	5.60
Coal G	0.46	No-slagging	0.17	1.21	86.83	4.50
Coal K	0.66	No-slagging	0.17	0.49	87.45	4.50
Coal L	0.92	Slagging	0.84	0.27	85.90	4.70
Coal M	1.39	Slagging	0.84	0.40	91.95	3.70
Coal N	1.02	No-slagging	0.17	0.37	90.27	4.90

NSI vs. Bituminous Coals

Field observations for four bituminous type coals from two different sources are compared to the NSI values using the reported ash data for the fuels. Two of the coals were US coals studied at Energy & Environmental Research Center (EERC) pilot scale boiler [5,6] while other two coals were from Colombia and South Africa, fired at a full-scale 350 MWe unit in Denmark [7]. The calculated NSI values for the coals and the respective field observations numerically represented are shown in Figure 3-2 and Table 3-3. NSI predicted higher value for the high slagging Illinois No. 6 (2) coal compared to the low slagging coals from both studies. It should be noted that the magnitude of NSI values obtained for the bituminous coals are much lesser than the Indian coals discussed in the previous section probably due to the differences in ash content between both sets of coals.

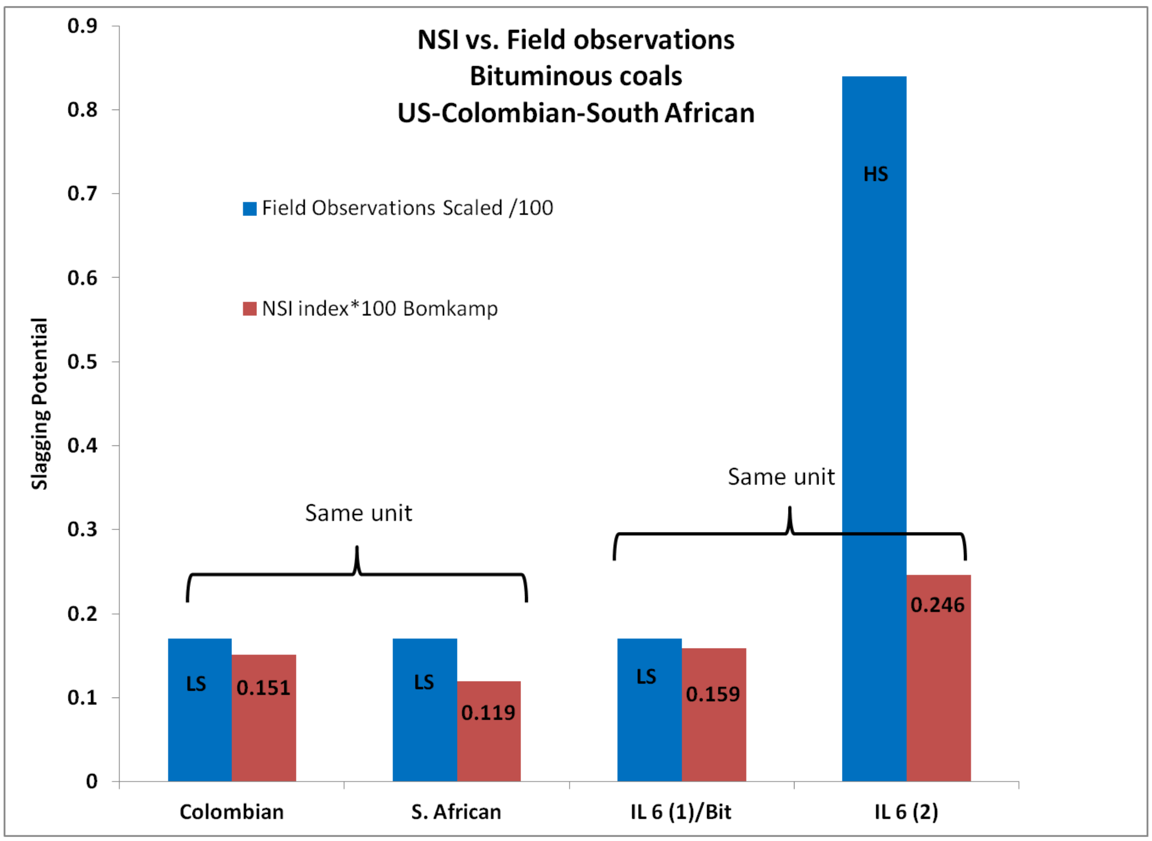

Figure 3-2
NSI Index vs. Field Observations for High Sulfur Bituminous (Bit) Coals from Two Different Studies. HS: Reported High Slagging, LS: Reported Low Slagging

Table 3-3
NSI Index Values for Bituminous Coals vs. Field Data, Rs Factor, Silica Ratio and % Fe_2O_3 in Ash

Coals Bituminous	NSI (Sx) index*100	Field Data	Field Data (numerically represented)	Rs factor (B/A*%S) *10	Silica Ratio	% Fe_2O_3
Colombian	0.151	Low-Slagging	0.17	1.39	83.24	7.60
S. African	0.119	Low-Slagging	0.17	0.73	80.33	3.15
IL 6 (1)	0.159	Low-Slagging	0.17	10.40	73.44	14.20
IL 6 (2)	0.246	High-Slagging	0.84	17.55	66.14	19.40

NSI vs. Sub-Bituminous Coals

The NSI values for sub-bituminous coals are plotted against field observations from different studies [2], [8] in Figures 3-3 and 3-4 respectively. The data is also presented in the Table 3-4.

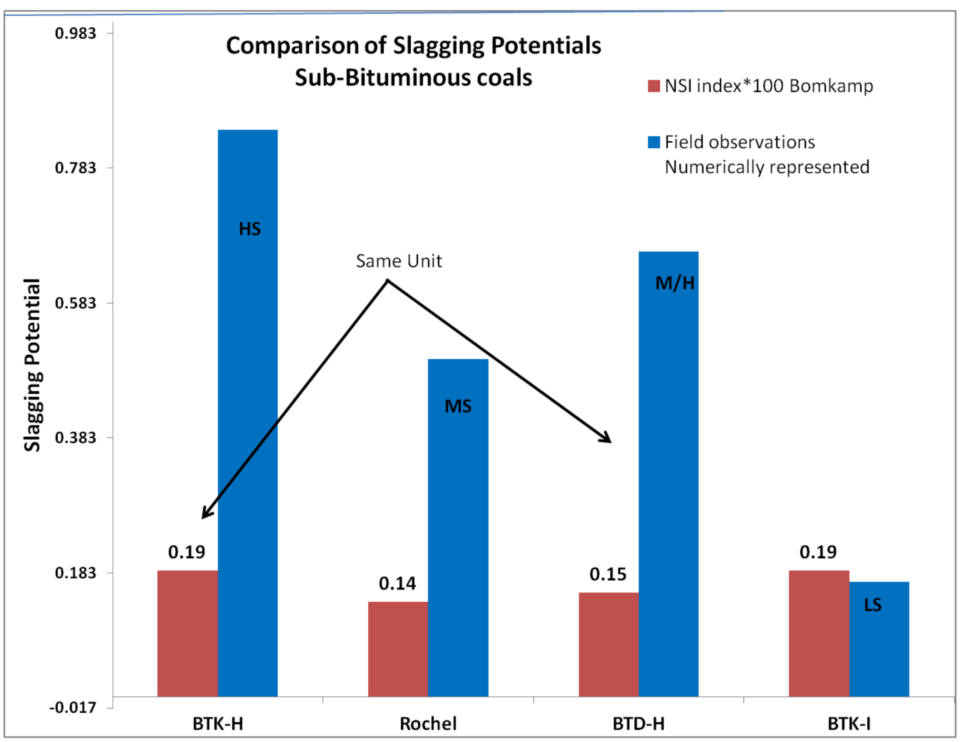

Figure 3-3
NSI Index vs. Field Observations [2] for Sub-bituminous coals.
HS: High Slagging, LS: Low Slagging; MS: Medium Slagging; M/H: Medium/High;
H&I are Two Different Stations.

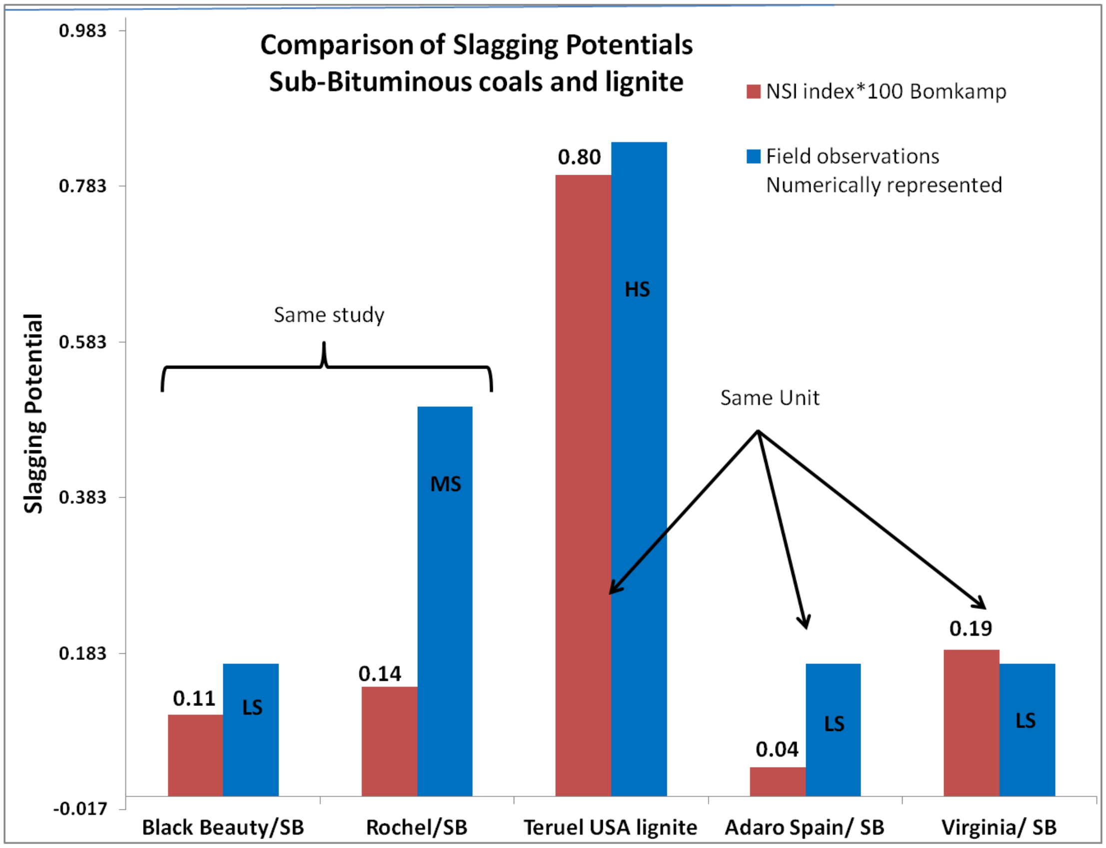

Figure 3-4
NSI Index vs. Field Observations [8] for Sub-bituminous (SB) Coals Compared to Lignite in the Same Boiler (Teruel, Adaro, Virginia). Also Shown are Two SB Coals from the Same Boiler (Black Beauty Rochel).

Table 3-4
NSI Index Values for Sub-bituminous Coals vs. Field Data, Rs Factor, Silica Ratio and % Fe_2O_3 in Ash

Coals Sub-Bituminous	NSI (Sx) index*100	Field Data	Field Data (numerically represented)	Rs factor (B/A*%S)* 10	Silica Ratio	% Fe_2O_3
Adaro / Sub Bit	0.037	Low slagging	0.17	0.61	58.6	12.55
Virginia/ Sub Bit	0.188	Low slagging	0.17	0.81	91.5	3.96

For the first case shown in Figure 3-3, three sub-bituminous coals were tested at three different units. The coal-BTK was fired at stations H and I to examine the effect of boiler design for a given coal type while, coal BTD was fired at station H to look at fuel quality effects for a given boiler design. As expected, NSI values are the same for BTK-H and BTK-I since the index does not take into account boiler configuration in its formulation. For the two fuels fired in the same unit, NSI agrees with field observations in predicting BTK as a higher slagging fuel than BTD.

Again, for the second case shown in Figure 3-4, output from two different studies are compared to field data. NSI clearly identifies Teruel/lignite as a high slagging coal compared to the two sub-bituminous coals, Adaro & Virginia, fired in the same unit. Also in the second study, Rochel/SB is calculated to have a higher slagging potential than Black Beauty/SB, in agreement with observed performance in the field.

NSI vs. Coal-Blends

For blends, NSI values were calculated assuming homogenous mixing of 50:50 for the respective blend ratio. The calculated values and field observations are shown in Figure 3-5.

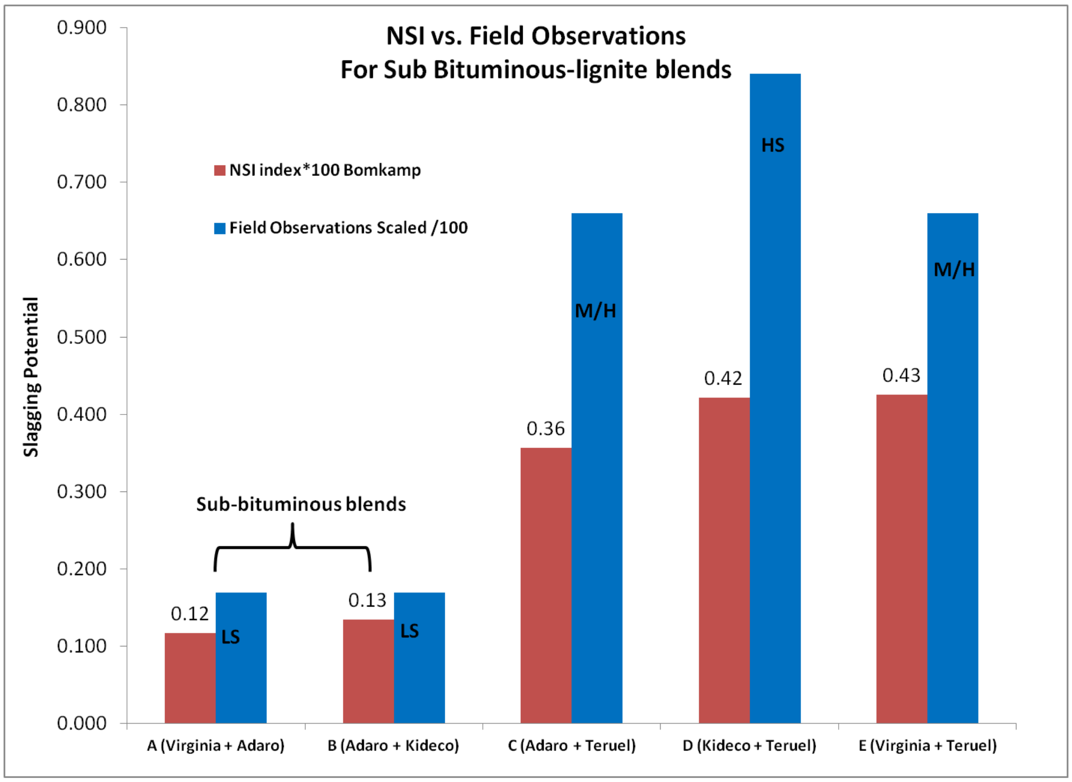

Figure 3-5
NSI vs. Field Observations for Sub-bituminous Blends and SF-Lignite Blend Combinations

These values are compared to conventional empirical predictions and field observations in the Table 3-5.

Table 3-5
NSI Index Values for Blend coals vs. Field Data, Rs Factor, Silica Ratio and % Fe_2O_3 in Ash

Coals Blends	NSI (Sx) index*100	Field Data	Field Data (numerically represented)	Rs factor (B/A*%S) *10	Silica Ratio	% Fe_2O_3
A (Virginia + Adaro)	0.117	Low	0.17	0.51	85.8	5.13
B (Adaro + Kideco)	0.135	Low	0.17	2.65	40.9	16.64
C (Adaro + Teruel)	0.357	Medium/ High	0.66	5.50	61.1	17.88
D (Kideco + Teruel)	0.421	High	0.84	5.89	56.6	18.2
E (Virginia + Teruel)	0.426	High	0.66	5.38	70.0	14.15

The field observations for the blends reported in the study [8] were actually output from a TMA analysis using BHEL index as proposed in reference [3]. Overall, NSI clearly identifies low slagging sub-bituminous blends (A and B) from high slagging sub-bituminous-lignite blends (C, D and E) that have higher NSI values. However, NSI predicts blend E as the combination with highest slagging potential contrary to the filed data that rates the blend as Medium/high.

Failed NSI Predictions

The last two cases examined in this study were two PRB coals from Wyoming tested at a 540 MW unit and the results from field observations and NSI predictions are shown in Figure 3-6. The NSI values indicate Caballo Rojo as having higher slagging potential than Cordero, contrary to the field observation of low and medium slagging for the two coals respectively. It is possible that the higher Fe content in Caballo Rojo (9.31% compared to 6.79 %) could have resulted in a higher NSI prediction for this case though Cordero has a slightly higher ash content (5.66 % compared to 4.86%) than Caballo Rojo.

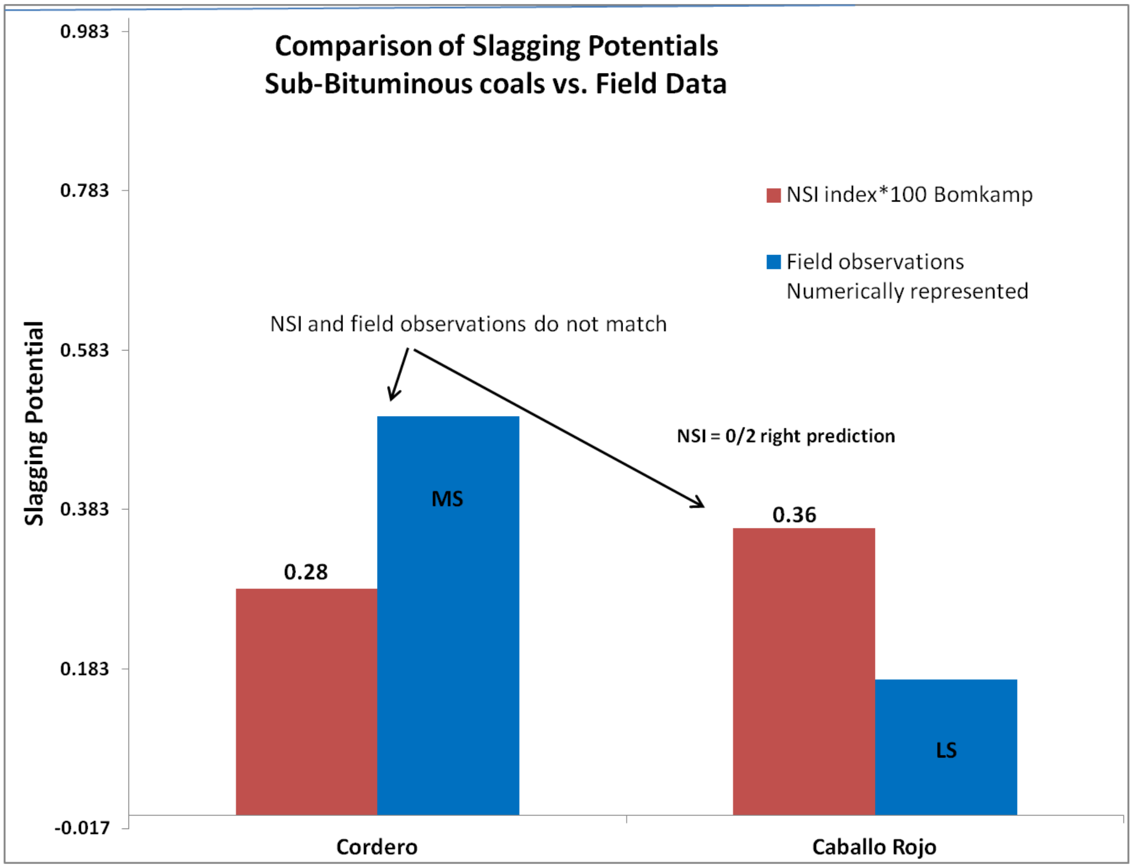

Figure 3-6
NSI vs. Field Data for PRB Coals Fired in a 540 MW Unit

4
DISCUSSION

The NSI index has been calculated for a series of coal types ranging from Sub-bituminous, Eastern Bituminous, lignite and for certain blend combinations using the empirical correlations, Equations (2) to (10), discussed in Section 3. The predicted slagging potential values are plotted against observed field data represented numerically for the sole purpose of comparison.

By and large the NSI predictions agree well with field observations (11 out of 13 coals agree) for high ash lignite coals. Similarly, for the limited bituminous coals tested in this evaluation, NSI values clearly differentiate between high and low slagging coals as shown in Figure 3-2. For the majority of the sub-bituminous coals and blend combinations tested, the predicted index values agree well with field observations. The index predictions do not seem to agree with the field observations when comparing performance of a particular coal for different unit configurations (Figure 3-3) and in cases where the coals have similar ash content (Figure 3-6). Another limitation of NSI index is; for coals having low SiO_2 and high CaO concentrations in their ash as shown in Table 4-1.

Table 4-1
NSI Predictions for Certain Coal Ash Compositions

Coals	SiO_2 %	CaO %	Sx
Beulah/lignite	16.5	19.5	-0.996
Kideco/SB	23.89	26.5	-.250
Coal K/Sub	10.3	23.2	-0.039
Coal L/Sub	15.8	18.5	-0.301

The reason behind these negative NSI values is not clear. The correlations used in Equation (4) yield negative values when SiO_2 concentrations are below 25% and CaO concentrations exceed the silica levels.

NSI vs. Performance of Conventional Empirical Indices

Widely used conventional empirical indices like B/A× % S (Rs), % Fe_2O_3 index and Silica ratio (SR) were also calculated for some of the coals and blends evaluated in this study. The calculated results from these indices were compared to NSI predictions and respective field observations for slagging potential.

Silica Ratio (SR) Calculations vs. NSI and Field Observations

SR was calculated for thirteen high ash lignite coals, two sub bituminous coals and four blend combinations and plotted in Figures 4-1 and 4-2.

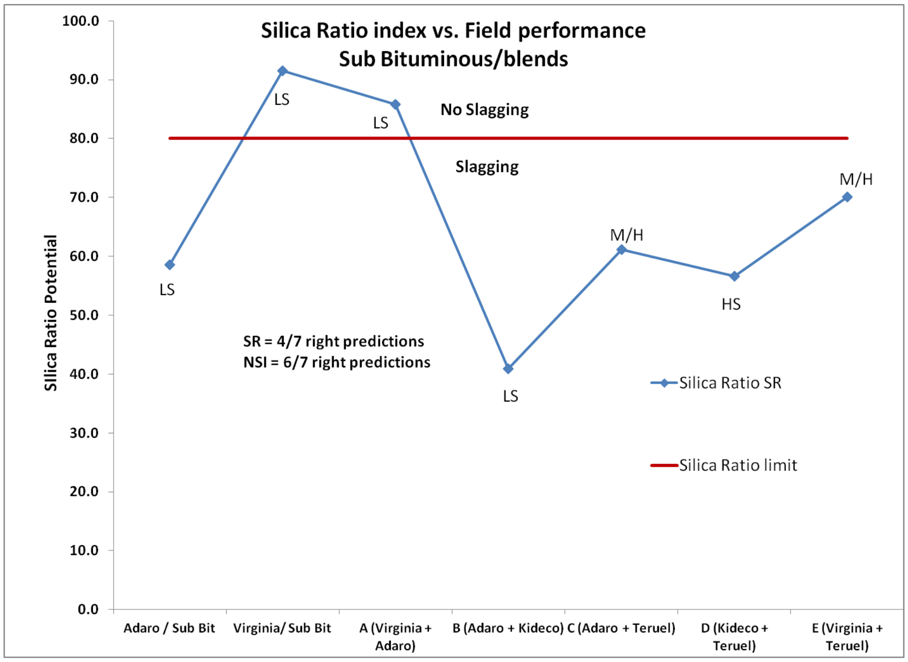

Figure 4-1
Silica Ratio vs. Field Performance for Sub-bituminous Coals and Blends.
Field Observation: LS= Low Slagging, M/H = Medium High Slagging, HS= High Slagging

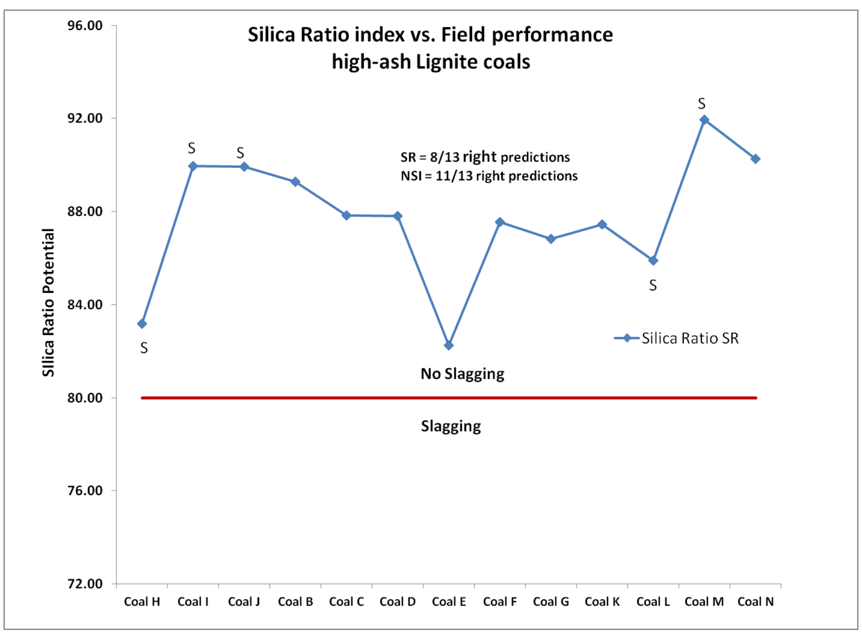

Figure 4-2
Silica Ratio vs. Field Performance for High Ash Indian Coals. Field Observation: S =Slagging

% Fe_2O_3 Index Calculations vs. NSI and Field Observations

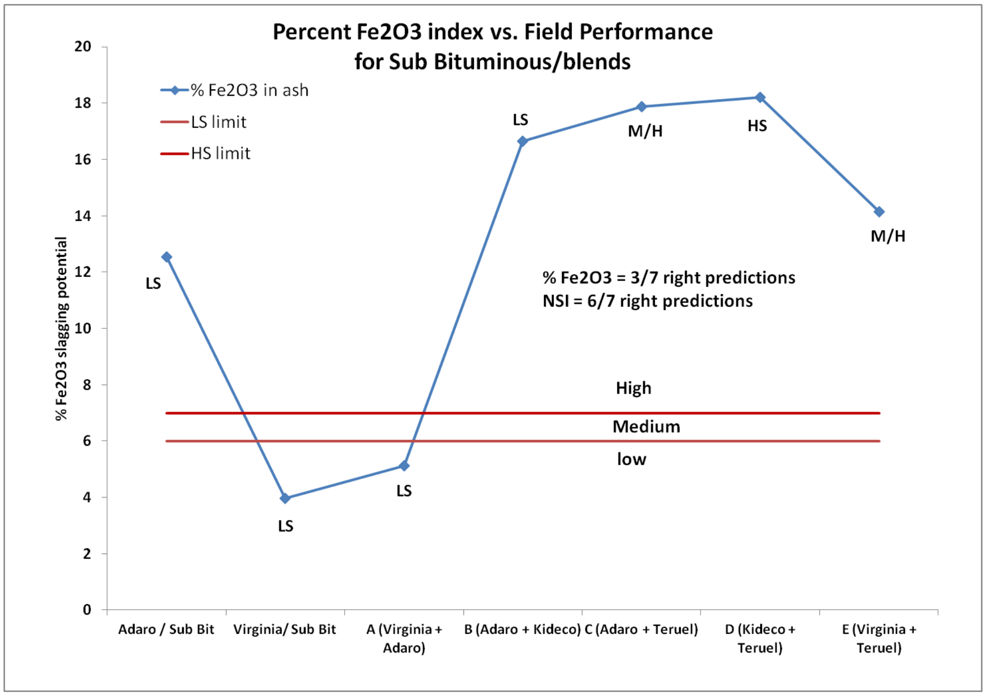

Figure 4-3
% Fe_2O_3 in Ash vs. Field Performance for Sub-bituminous Coals and Blends

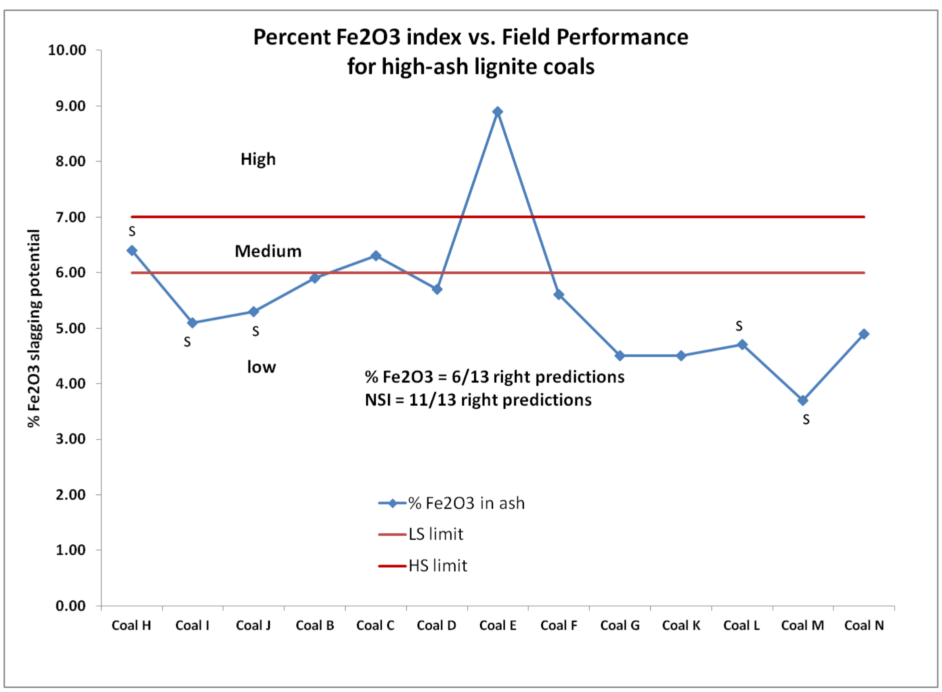

Figure 4-4
Fe_2O_3 in Ash vs. Field Performance for High Ash Indian Coals

Rs Factor (B/Ax%S) Calculations vs. NSI and Field Observations

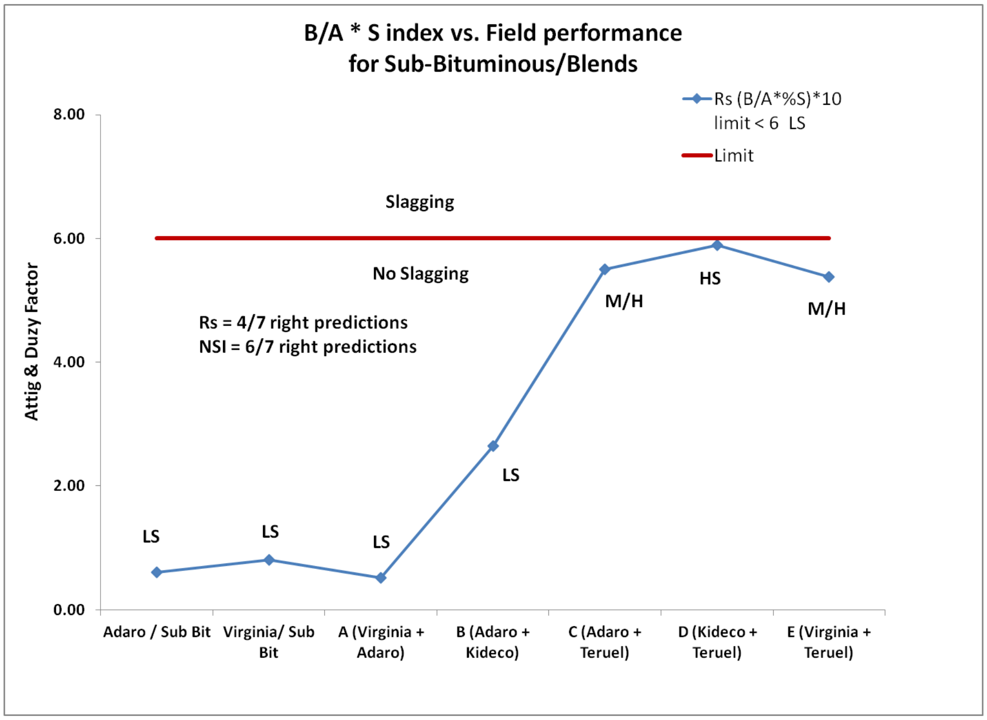

Figure 4-5
Rs Factor vs. Field Performance for Sub-bituminous Coals and Blends

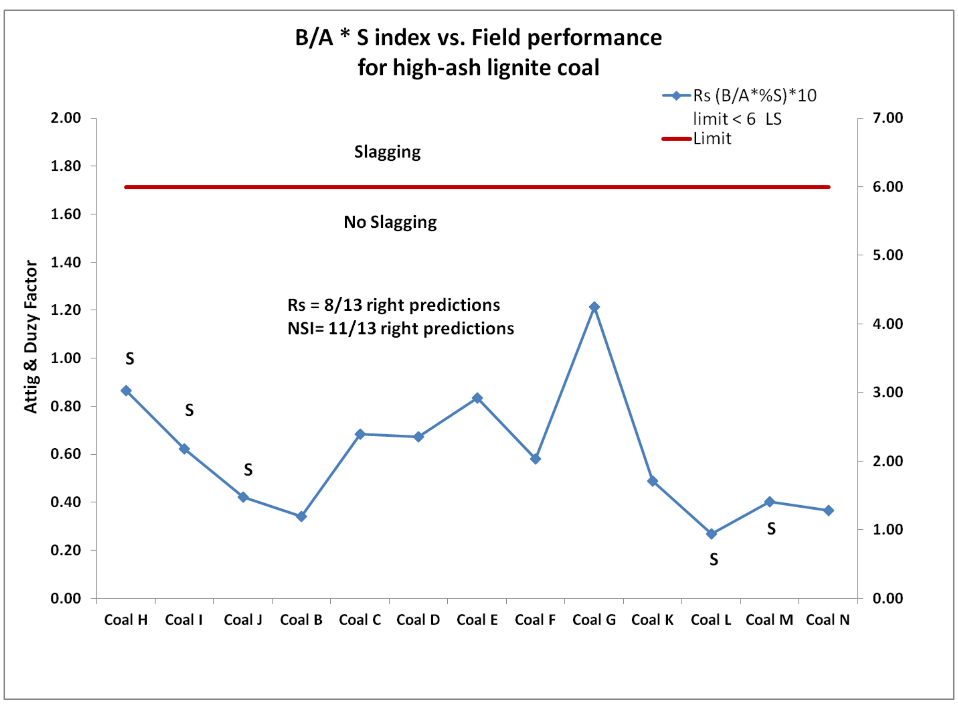

Figure 4-6
Rs Factor vs. Field Performance for High Ash Indian Coals

These results are summarized in Table 4-2.

Table 4-2
Summary of Empirical Indices vs. NSI Performance for the Testing Coals

Empirical Index	Indian High Ash Coals	Sub-Bituminous/Blends
Silica Ratio (SR)	8/13	4/7
% Fe_2O_3 index	6/13	3/7
Rs (B/A × %S) factor	8/13	4/7
NSI index (Sx)	11/13	6/7

The NSI index predictions match field observations better than the conventional indices tested in this study. However, some discrepancies between observed data and NSI values do exist. These discrepancies could be due to external factors involving boiler operation or geometry or due to the empirical constants chosen for some of the equations used in the index. For example; the values of ST calculated using Equation (8) depend on the choice of constants listed in Table 3-1. Secondly, the calculated log(μ) from Equation (4) used in Equation (10) is based on Bomkamp [9] viscosity model. Use of other viscosity models in place of Bomkamp model could result in improved predictions.

Vista Slagging Predictions

Vista offers a predictive slagging tool that is offers some flexibility and utilizes some traditional slagging indices. A study was done with a small sample of the coals tested with the NSI predictor to see how the Vista prediction would compare.

Vista is an EPRI software package that evaluates fuel impacts on total plant operation [10]. Vista quantifies the cost and performance using equipment-specific engineering models. Included in the boiler performance analysis are slagging prediction calculations. Vista models the potential for a particular fuel scenario to cause slagging impacts by a combination of analytical and empirical methods. Using the fuel quality and heat transfer characteristics, the overall slagging potential of the coal is determined by using a number of published indices. A numeric value is assigned and is correlated to the qualitative value. Numeric value ranges from 0 to 9 with the qualitative value ranging from no slagging to very severe slagging.

Results

A total of five coals slagging potential were analyzed with Vista. A previously calibrated model was chosen for the analysis. The model is built and calibrated from actual plant data gathered for a past EPRI analysis. The model is 700 MW Babcock and Wilcox boiler that fires bituminous coal. Vista predicted both sub-bituminous coals to have a medium to high slagging index. It also predicted that the Illinois No.6-2 an Illinois bituminous and the Rochel04 sub-bituminous coal a medium to high slagging index. Lastly the Illinois No.6-1 Illinois bituminous coal was predicted to have a low to medium slagging index. The results of the analysis are summarized along with the field data in Table 4-3.

Table 4-3
Summary of Vista Slagging Predictions and Field Observations

Fuel Description	BTD	BTK	Illinois No. 6 (1)	Illinois No. 6 (2)	Rochel04
Coal Type	Sub. Bit.	Sub. Bit.	IL Bit.	IL Bit.	Sub. Bit.
Vista Slagging Index	Medium/ High	Medium/ High	Low/ Medium	Medium/ High	Medium/ High
Vista Slagging Index (Numeric Values)	4	4	2	4	4
NSI (Sx) Index * 100	0.187	0.154	0.159	0.246	0.141
Field Data	High	Medium/ High	Low	High	Medium
Field Data (Numerically Represented)	0.84	0.66	0.17	0.84	0.5

The results for each fuel type are looked at separately. The Illinois bituminous coals slagging predictions show one with a lower and the other with a higher tendency to slag, the results are shown in Figure 4-7. The NSI and the field data also predict the Illinois No. 6 (1) coal having a considerable lower tendency to slag than Illinois No. 6 (2) coal. Although the actual quantitative difference between each coals affinity to slag cannot be concluded from this data, the trends of the predictors follow that of the field data thus proving these methods to be very encouraging.

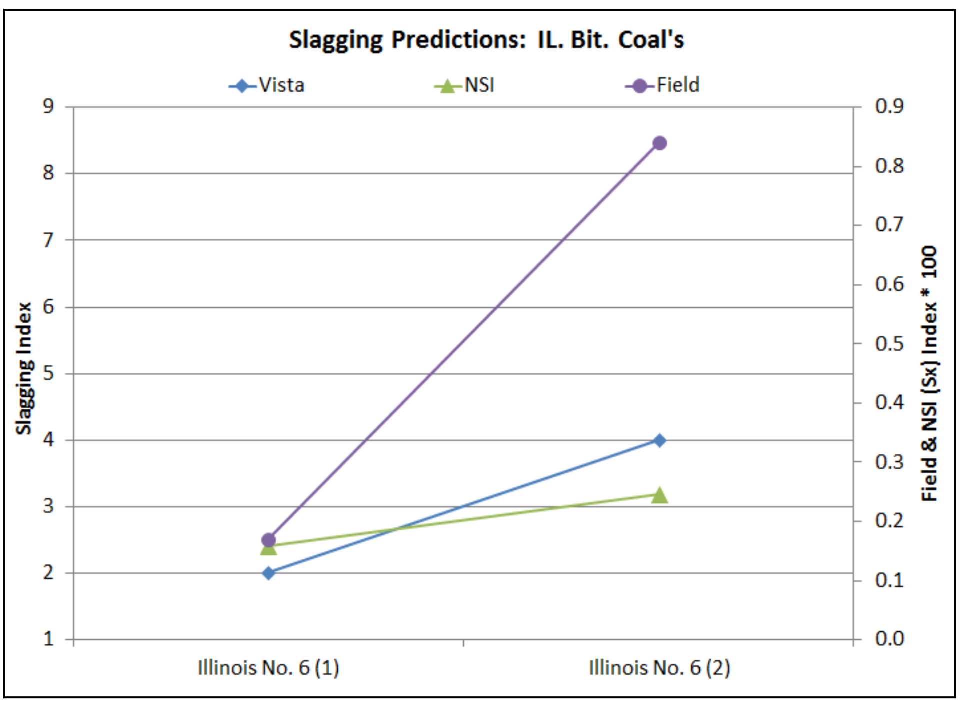

Figure 4-7
Slagging Predictions by Vista for Illinois Bituminous Coal

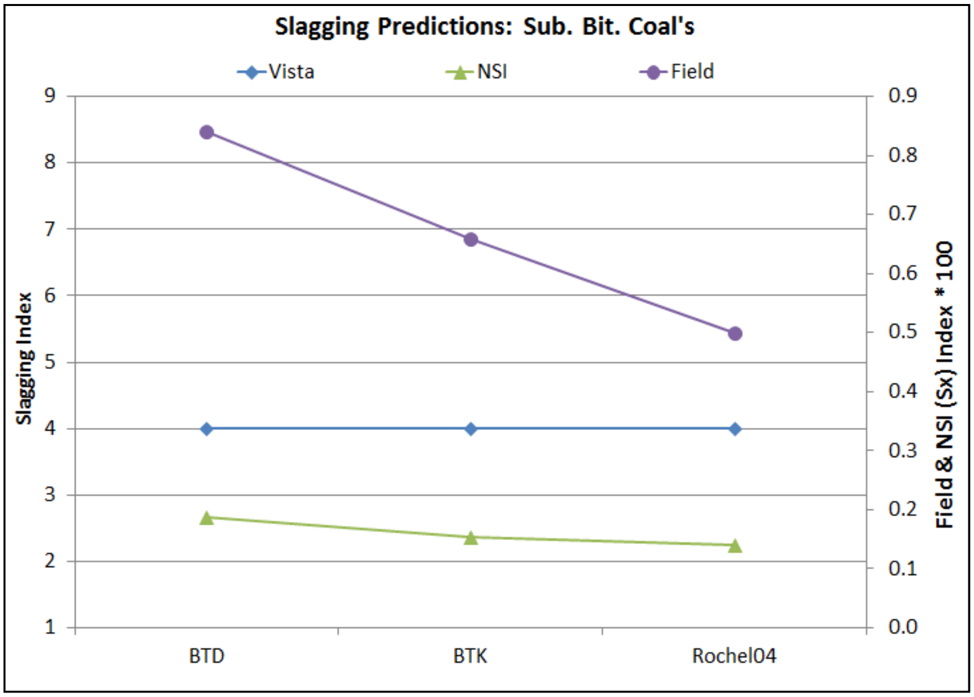

Figure 4-8
Slagging Predictions by Vista for Sub-bituminous Coal

The sub-bituminous coals Vista slagging predictions show all three to have the equal tendency to slag, the results are shown in Figure 4-8. The NSI slagging results have small differences for each coal but for the most part it predicts each coal to have very similar slagging propensity. The field data in this case does not follow the same trend as the Vista or NSI predictors. The field data has the BTD classified as high, the BTK medium/high and the Rochel04 medium.

For both the Illinois and sub-bituminous coals comparing the predictive tools results to the field observations is inherently challenging. Without quantitative data to back up the field observations, which involve a factor of subjectivity by the data collector, of low, medium or high slagging, it is difficult to accurately assess the accuracy of the predictive models. This is one current limitation that requires further development.

5 CONCLUSIONS AND RECOMMENDATIONS

A new Empirical Slagging Index (NSI) based on ash viscosity, ash fusibility and ash loading was developed at the Center for Computational Fluid dynamics at University of Leeds, UK. EPRI evaluated the performance of this predictor against boiler observations for different coal types such as; PRB, Bituminous and Lignite coals and also compared the results to conventional empirical indices. Some of the conclusions drawn from this evaluation and the prospect of using this index as a generic method for predicting pre-combustion slagging behavior of coals is discussed. Lastly, recommendations to improve the model predictions are provided.

Conclusions

1. NSI was successful 11 out of 13 times when compared to field data in ranking the slagging potential of high ash Indian coals tested in this study.
2. For the four bituminous coals tested, the NSI values clearly differentiate between high and low slagging coals based on field observation results.
3. For sub-bituminous coals and blend combinations tested, the NSI values agree well with field observations. Discrepancies exist when comparing performance of a particular coal in different boiler units.
4. For certain cases it was difficult to verify the exact NSI rankings for some coals, since available field observations are not quantitative and had to be numerically represented for the sake of comparison.
5. NSI predictions seem to fail predicting negative Sx values for coals with low SiO_2 (~10 -24%) and high CaO (18-25%) content in ash.
6. Conventional indices like Rs (B/A × %S) factor, % Fe_2O_3 index and Silica ratio (SR) were less effective than NSI in predicting the slagging potentials of the tested coals.
7. Predictions from the Vista model, which also use an extensive collection of published indices commonly used, provided some agreement with the NSI index prediction for bituminous coals but not so well for sub-bituminous coals.

Recommendations

1. NSI index uses empirical constants to calculate the ash softening temperature (ST) used in the overall Sx calculation. These calculated ST values do not match experimental ST measurements to within ±252°F (±140°C) in certain cases. It would, hence, be useful to test the effect of treating this temperature as a variable and re-evaluating NSI performance for some of these coals.
2. The viscosity term in the NSI index is based on the Bomkamp modified viscosity model. It is worthwhile to examine the effect of substituting this estimated viscosity term with other viscosity model correlations like Watt & Fereday, Urbain and Kalmonovitch.

Another approach may involve using a combination of these viscosity models to rule out the extremes and use a conservative middle value.

3. The index, in its current form, can only rank coals based on their slagging potential, but cannot predict the extent of slagging. More field data is needed, to set specific slagging limits (high, low, medium) to the NSI predictions for different coal types and blends.
4. The index does not take into account the effect of boiler geometry, sulfur and other minor alkali elements like K_2O and Na_2O. The incorporated effect of ash loading in NSI's prediction is a unique feature that is missing in all other conventional indices to-date. However, further investigative work is needed to improve the index predictions.
5. The Index can be easily calculated using a spreadsheet program. All required equations to calculate the NSI index are presented in this report. A possible next step is the development a user-friendly spreadsheet tool.
6. Field observations and measurements of slagging propensity from various coals are sought for further validation of this index.

6
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