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Coal Combustion Analysis Tool in Coal Fired Power Plant for Slagging and Fouling Guidelines

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Abstract. Coal remains as one of the major sources of energy in power plant industry. Optimizing the coal combustion in power plant will improve its efficiency and lead to reduction of greenhouse gases in flue gas. One of the main objectives in coal combustion research is the development of techniques to help power plant operators utilize coal cleanly and efficiently. At the same time, power plant operators would like to maintain slagging and fouling inside the boiler to be as minimum as possible to ensure optimize combustion process and maintain its cleanliness. Maximum heat absorption inside the boiler can be achieved through clean boiler tube surface. Slagging and fouling factor for every coal type can be used as an early indication to power plant engineer regarding the overall coal behavior. The slagging and fouling factor are obtained from coal combustion analysis calculation. Coal combustion analysis is a tool to facilitate power plant engineer in predicting the impact of individual or blended coal quality on power plant performance. It will give early prediction on boiler combustion performance related to the coal quality and surely will assist the power plant operators preparing for boiler process control such as soot blower regime, mill outlet temperature setpoint, boiler excess air control and burner control through tilting or auxiliary air dampers adjustment. The boiler process control will ensure the combustion will not have any adverse effect to the boiler. This paper will also discuss about slagging and fouling factor of different coal type which are used as designs for a boiler in one coal fired power plant in Malaysia. Further analysis were also conducted, based on several case studies where different coal types are blended to acquire better slagging and fouling factors compared to individual coal.

INTRODUCTION

The Coal Fired Power Plant Coal Quality Scenario

Over recent years, it has been observed that the quality of coal used at one of the coal fired power plant in Malaysia has vastly deteriorated in terms of its GCV, total moisture and ash content. The GCV level has decreased while the total moisture and ash content have increased. These degradations have significant effects on the overall boiler efficiency. The depletion of fossil fuel reserve, fuel consumption optimisation and production of emission greenhouse gases is the challenge to power plant sector [1-2]. Plant capacity is greatly affected because of the high moisture content where more primary air volume is needed to ensure that the moisture level is controlled to its set value. This will further increase the plant's auxiliary power consumption and reduce the boiler efficiency. Environmentally, the high sulfur content will affect to the FGD performance thus making it difficult for the plant to operate within the specified environmental limit. One of the means to tackle this various coal quality issues is through coal blending process. This option is available to reduce emission from boiler as well as to improve overall boiler performance [3-4].

The capability to handle diverse type of coal will greatly improve the situation. This issue needs to be tackled by considering and implementing suitable solution such as plant improvement initiative for the combustion system. Due to changing market dynamics and deregulation in the power sector, more utilities are now sourcing coal from different mines and suppliers with the goal of minimizing production costs. Such varied

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sourcing obviously leads to varying coal qualities and coal type. Since attributes such as Calorific Value, Ash Content, Volatile Matter, Sulphur Content, Hardgrove Grindability Index (HGI), Moisture Content and etc have a great impact on the combustion process, it is important to monitor and utilise this information in an effort to optimize the combustion (FIGURE 1).

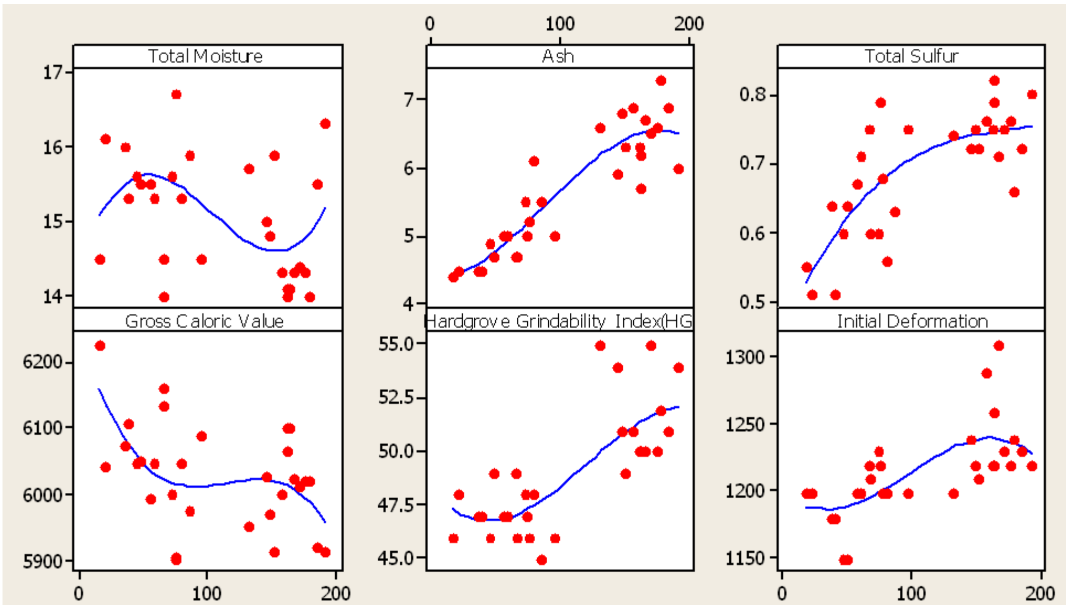

FIGURE 1. Coal quality degradation trending

The Coal Fired Power Plant Background

The coal fired power plant is located in south peninsular Malaysia. The power plant is forced circulation, supercritical boiler, dual fireball with tangential firing. The total capacity is 1,000 MW. The technical data for the power plant is given in the table as follow:

TABLE 1. Design Data

Parameters	Descriptions
Nominal Capocity	1000 MW
Main Steam Pressure	270 Barg
Main Steam Temperature	595 Deg.C
Main Steam Flow	3065 t/h
Boiler Type	Tangential firing with forced circulation, dual fireball boiler

The emission limit is set based on the Environmental Impact Assessment (EIA) prior to the construction of the plant and is given in the figure as follow:

TABLE 2. Power Plant Emissions Limit

Pollutant	Limit Value (mg/Nm^3)
Sox	500
Nox	500
CO	200
Particulate	50

In order to meet the specification, the power plant is equipped with low-NOx burner, fabric filter and FGD. Low-NOx burner is used to reduce NOx level, fabric filter is to reduce particulate while FGD is to reduce SOx.

Pulverized Coal Combustion

The coal combustion process consists of several steps. As the coal particles are heated, moisture is driven off the coal particles. Next, the coal particles undergo de-volatilization and release volatile organic constituents. The volatile matter is combusted in the gas phase and it can occur prior to and simultaneously with combustion of the char particles. Combustion of the char is a surface reaction which is these reactions is for the most part sequential, and the slowest of these will determine the rate of the overall process. The combustion of the volatiles is generally assumed to be homogenous reaction, although the possibility of volatile matter burning heterogeneously. The burning of the volatiles is very fast process that is measured in milliseconds [5].

Char combustion is a much slower process than de-volatilization and therefore determines the times for complete combustion in the furnace. Studies have shown that the combustion of the char begins with chemical sorption of oxygen at active sites on char surface and that the decomposition of the resultant surface oxides mainly generates carbon monoxide (CO)[6]. The CO is then oxidized to CO2 in a gaseous boundary zone around char particle. Fresh reaction sites are continuously exposed as the surface oxides are decomposed. CO2 then either moves off into the gas stream or is reduced to CO if it impinges on the char. The rate of char combustion is a complicated process, as it is influenced by mass transfer by diffusion through the pores and the surface reactions. The diffusion coefficients are strongly dependent on pore diameters and pressure, and the surface reaction s is influenced by the formation of activated absorption complexes and their composition [7].

METHODOLOGY

Coal combustion analysis is a tool for power plant operators to predict the impact of coal quality on power plant performance. This tool can also be used for prediction of milling performance, boiler performance, emission production and etc. The application of the tool is covered for individual coal analysis as well as blended coal.

Coal blending process at coal fired power plant is one of the method to mitigate various coal quality and its effect in the boiler combustion especially slagging and fouling problem in the furnace. Coal blending optimization is widely discussed among the coal fired power plant engineers and researchers [8-12]. The coal combustion analysis software runs in Excel 2010 and has following features:

a) Contains a coal database for all coal received by power plant
b) Calculates coal combustion performance data
c) Calculates optimal blending proportions to utilize coal in the stockpile
d) Accepts standard coal quality parameters and allows conversion between bases on the data input.
e) Present result in summary page for power plant operator guideline.

The effectiveness of this coal combustion analysis has been verified through its application in coal fired power plant.

Slagging and Fouling Indices

When a coal is burned, some portion of ash will result in deposition on boiler tube surfaces after going through chemical reactions and physical forces. There are two types of high temperature ash deposition, namely slagging and fouling. The difference is due to the type of deposition mechanisms involved. Slagging is a formation of molten, partially fused or re-solidified deposits on furnace walls and other tubes surface exposed to radiant heat [13]. Fouling, on the other hand is defined as the formation of high temperature bonded deposits on convective tube surface. Elemental ash analysis is conducted using standard testing (ASTM) which can be used later for calculation on slagging and fouling indices.

Slagging and fouling effect in coal fired power plant are discussed in [14-15]. Slagging indices establish criteria for the furnace and other radiant surface while fouling indices establish criteria for convective surface. Some of the papers discussing on slagging and fouling indices can be found in [16-17]. Practically, coal fired power plant engineer takes into account similar experience when firing identical coal and also result on non-routine test for the coal. The indices also important in evaluating new type of potential coal to be supplied to the boiler to determine the coal slagging and fouling potential. The slagging and fouling indices with its associated aggregate score are given in the Table 3.

Table 3 and 4 describes the slagging indices, the aggregate score related to the severity of each elements as well as the total aggregate score and its overall slagging judgement for the coal type or blended coal composition. Similarly Table 5 and 6 describes the fouling indices together with its individual aggregate score and the overall fouling judgement based on total fouling aggregate score. In summary, for every coal types, the combustion analysis will provide the overall information to the power plant engineer in term of the coal slagging and fouling severity score which is either minimal, moderate or serious. Based on this score overview, the power plant engineer should be able to device overall soot blower operation regime, the mill outlet temperature set point, the excess air flow bias to be applied to the boiler and the burner tilting angle set point for the boiler wind boxes.

TABLE 3. Slagging Indices

Slagging Index	Low Risk	Aggregate Score	Medium Risk	Aggregate Score	High Risk	Aggregate Score
Calc. visc @ 1426 Deg C	> 400	0	NA	NA	< 400	1
T_{250} Temperature (Deg C)	>1275	0	1201<T<1274	0.5	<1200	1
Base Acid Ratio	<0.5	0	0.51<R<0.99	0.5	>1	1
Slagging Factor, B/A*S	<0.6	0	0.61<Slag<0.99	0.5	<2	1
Slagging Factor (AFT)	>1343	0	1150<AFT<1342	0.5	<1149	1
Silica Percentage	>82	0	31<Si<81	0.5	<30	1
Iron/Calcium Ratio	<0.31	0	0.32<R<2.9	0.5	>3	1
Iron + Calcium	<12	0	NA	NA	>12	1
Unsworth Slag Forming Tendency	<10	0	11<Uns<19	0.5	>20	1
Unsworth Sootblower Performance	<5	0	6<SB<14	0.5	>15	1

TABLE 4. Slagging Aggregate Score Judgement

Judgement	Minimal	Moderate	Serious
Total slagging aggregate score	<2	2.1<M<3.9	>4

TABLE 5. Fouling Indices

Fouling Index	Low Risk	Aggregate Score	Medium Risk	Aggregate Score	High Risk	Aggregate Score
Sodium in Ash	<1	0	1.1<Na<4.9	0.5	>5	1
Total Alkalis	<2	0	NA	NA	>2	1
Fouling Factor, B/A*Na	<0.1	0	0.11<Ff<0.49	0.5	>0.5	1

TABLE 6. Fouling Aggregate Score Judgement

Judgement	Minimal	Moderate	Serious
Total fouling aggregate score	<1	1.1<M<1.9	>2

RESULT AND DISCUSSION

The coal fired power plant is designed to fire certain quality of coal. Normally the boiler is set up and tune during commissioning by using one (1) type of coal. However, the other types of coal range which is designed for the boiler need further process adjustment to ensure the boiler can perform and produces the expected steam pressure, temperature and flow and at the same time maintain the operation within the design limit especially the tube material and boiler ancillary equipment.

The coal specification for the power plant is given in the Table 8. Based on the coal specification, the combustion analysis then conducted for each coal and blended between 2 of the coal types and the result in term of slagging and fouling factor is given in the Table 7. Slagging and fouling factor result for the power plant is early indication of the predicted behavior for the coal or the blended coal. Table 7 shows the slagging and fouling factor result based on combustion analysis for all the coal types defines within the coal specification for the boiler. Coal type A to J individual slagging and fouling factor shows mostly serious slagging repercussion and moderate fouling factors. However blending coal type B and C 50%:50% ratio yields serious slagging and minimal fouling factor. In this case, this is better than if the boiler is firing 100% coal type B alone which has moderate fouling factor. However in second case of blending between 50% coal type B and 50% coal type E, the resultant slagging and fouling factor yields the same result as coal type B individual firing which is serious slagging and moderate fouling factor. Thus 50% coal blending between coal B and E is not preferred.

Third case whereby 50% coal B and 50% coal type D blending yields moderate slagging and moderate fouling factors which is better than coal type B individual result. Fourth case where 34% coal type B is blended with 66% coal type F also resulted better slagging and fouling factors which is moderate and minimal. All this 4 cases indicates that the coal blending practices will not result in addition of individual coal type behaviour but depend on the chemical composition in the coal which need to be calculated thoroughly. The cumulative aggregate score for each elementary composition is then translated in the slagging and fouling factor as shown in Table 3, 4, 5, and 6 above. The results also shown that case 4 where the blending of 34% of coal type B and 66% coal type F is giving the best resultant slagging and fouling factor.

Based on the coal specification, the combustion analysis then conducted for each coal or blended between 2 of the coal types and the result in term of slagging and fouling factor is given in the table as follow:

TABLE 7. Slagging and Fouling Factor Result for the Power Plant Coal Types

Coal Brand	Slagging Factor	Fouling Factor
A	Serious	Moderate
B	Serious	Moderate
C	Moderate	Moderate
D	Minimal	Moderate
E	Moderate	Moderate
F	Serious	Moderate
G	Serious	Moderate
H	Serious	Serious
I	Serious	Moderate
J	Serious	Moderate
Blended 50:50 B:C	Serious	Minimal
Blended 50:50 B:E	Serious	Moderate
Blended 50:50 B:D	Moderate	Moderate
Blended 34:66 B:F	Moderate	Minimal

TABLE 8. Coal Specification for the Power Plant

Brand		A	B	C	D	E	F	G	H	I	K
Proximate Analysis											
Inherent Moisture	%ADB	16.18	14.50	15.5	10.05	16.10	10.30	14.20	15.00	15.00	15.00
Ash	%ADB	3.19	2.40	5.2	5.78	4.20	6.58	4.80	4.70	4.50	9.20
Volatile Matter	%ADB	41.07	3.00	37.4	40.59	39.00	40.86	39.70	40.50	38.70	40.20
Total Moisture	%ARB	24.01	28.40	22.9	22.1	26.2	16.8	19.3	22.0	25.0	26.0
Gross Calorific Value	kcal/kg ADE	5552.70	4905.00	5684	6355.00	5929.00	6159.33	5892.00	5780.00	5804.00	5800.00
HGI		54	48	45	55	49	54	47	45	45	48
Ultimate Analysis											
Carbon	%DAF	72.66	73.8	73.57	76.86	76.37	74.62	74.4	76.77	77.07	75.00
Hydrogen	%DAF	5.23	5.2	5.28	5.11	5.66	5.88	5.74	4.4	5.5	5.40
Nitrogen	%DAF	1.03	0.96	1.49	1.21	1.44	1.32	1.57	1.15	1.45	1.40
Sulphur	%DAF	0.12	0.13	0.42	0.94	0.44	0.88	1.2	0.48	0.99	1.29
Ash Fusion Temp											
Reducing Atmosphere											
Initial Deformation	deg.C	1230	1150	1110	1420	1220	1440	1230	1150	1170	1150
Sphere	deg.C										
Hemisphere	deg.C	1250	1170	1200	1490	1270	1480	1180	1200	1230	1250
Flow	deg.C	1260	1180	1260	1500	1320	1500	1210	1250	1270	1300
Ash Analysis											
SiO2	%	27.41	36.19	49.76	51.5	49.24	55.35	42.4	36	41.17	35
Al2O3	%	9.69	14.55	18.83	27.8	26.02	19.27	18.4	17.29	24.43	21
Fe2O3	%	28.57	15.18	11.4	6.53	6.32	12.57	11.5	13	14.84	19
CaO	%	22.42	14.48	5.17	2.79	4.9	3.62	8.81	16	4.97	7
MgO	%	5.14	8.59	2.74	1.56	2.31	1.38	3.44	4	2.29	4
Na2O	%	0.22	0.51	1.31	1.6	3.87	1.09	1.99	2	0.84	1.7
K2O	%	0.25	1.18	1.7	0.54	1.52	0.91	1.37	1.3	1.27	1.8
TiO2	%	0.54	0.76	0.79	0.82	1.22	1.07	0.78	1.8	0.99	1.2
Mn3O4	%	0.19	0.28	0.09	0.073	0.08	0.05	0.05	0.2	0.13	0.5
SO3	%	5.24	7.63	6.76	5.2	2.98	3.69	10.51	6	8.04	6
P2O5	%	0.21	0.28	0.28	0.259	0.52	0.67	0.38	0.2	0.38	0.7
BaO	%					0.32		0.18		0.18	0.1
SrO	%										2
ZnO	%										

CONCLUSION

The coal combustion analysis tool is proven to be one of the most important tool in daily operation for coal fired power plant engineer in providing early indication on the effect of coal burned inside the boiler in term of slagging and fouling factors. This early indication is essential to provide guidelines to the operator in terms of changes need in boiler process control such as soot blower operating regime, the mill outlet temperature setpoint, the excess air flow bias to be applied to the boiler and the burner tilting angle setpoint for the boiler windboxes. The results also shown that case 4 where the blending of 34% of coal type B and 66% coal type F is giving the best resultant slagging and fouling factor.

ABBREVIATIONS

CO_2	Carbon Dioxide
CO	Carbon Monoxide
FF	Fabric Filter
FGD	Flue Gas Desulphurization
GCV	Gross Calorific Value
MW	Mega Watt
NOx	Nitrogen Oxide
SOx	Sulphur Oxide

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