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Investigation of the effects of Sub-bituminous coal with new formulated coal additives using 150 kw combustion test rig

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ABSTRACT

Purpose: Ash deposition from coal combustion has been one of the main operational problems for power plant generation industry. A severe ash deposition in the boiler has led to unschedule outage of the unit. Therefore, there is an urgent need to gain a sound understanding of coal ash deposition behaviour and its relation to the boiler operating conditions. In this study a new formula and improved product of customised coal additive has been developed namely from Dolomite and Kaolin.
Methodology: The characteristic of coal additive and combustion testing has been carried out using TNBR lab and 150kw solid fuel combustion test rig in order to study the effectiveness of the coal additive in reducing slagging and fouling by blending at 3, 5 and 10% ratio with three types of sub-bituminous coal namely CAD (Coal A), CFKP (Coal B) and CAH (Coal C).
Results: The results show significant reduction of Fe_2O_3 content in ash samples, increase in the hemisphere temperature of ash melting point and reduction of Na_2O content in ash composition, which leads to reduction in its fouling propensity. The formulation of Kaolin active compound is found to give the best results that reduces slagging and fouling propensity. The Kaolin formulation at 10% premixed with Coal B shows the best coal additive in reducing slagging propensity at 82.1% and at 10% premixed with Coal C coal shows the best coal additive in reducing fouling propensity at 96.4%
Applications/Originality/Value: In this study a new formula and improved product of customised coal additive has been developed namely from Dolomite (D+ additive) and Kaolin (K+ additive). The new properties of coal additive formulation have been analysed in TNBR combustion and fuel laboratory. The combustion testing of the new formulated coal additives is carried out in using TNBR combustion test-rig facility (CTF).

Key words: Sub-bituminous coal, slagging, fouling, new formula additive, combustion testing

1. INTRODUCTION

Chemical transformation of inorganic constituents from coal play a role in the formation of ash deposits in the radiant section of the furnace. Accumulations of these ash deposits which known as slagging can lead negative effects on the total plant performance, causing extra maintenance cost and lower production capacity. One of the main effects of formation of slagging is reduce the heat transfer process between the fireside and water-steam side therefore resulting in sensible increase of the flue gas temperature, reducing the efficiency of plant and excessive soot blowing operation.

In extreme cases caused unplanned outage of the plant for ash removal or furnace hopper boiler tube burst. However, the claim made for coal additives are rarely backed up by detailed experimented evidence and therefore the main objective of this investigation is to test the effectiveness of the new formulated coal additive on sub-bituminous coal using 150 kw combustion test rig.

Slagging and fouling phenomena are influenced by boiler and firing system design, operation parameters and coal properties. Release of inorganic matters during combustion and their transformation into critical gaseous species and ash particles may substantially affect the boiler efficiency and availability, due to the formation of ash depositions. William [1] and Bilirgen [2] investigated that the ash deposition from coal combustion has been one of the main operational problems for power plant generation industry. Figure 1 and Figure 2 shows slagging and fouling phenomena in coal fire power plant respectively.

Ash deposits in the boiler are complex and heterogeneous materials. The formation process of ash deposits mainly includes diffusion, thermophoresis and inertial impaction was investigated by Bryers [3] and Jackson [4]. Their studies found that the inorganic components and minerals in solid fuel were recognized to be the main source of deposits. The combustion of coal and other solid fuels in a power plant causes build-up of combustion deposits such as soot, ash and slag. The occurrence of slagging if left unchecked and controlled may cause severe disruption to the heat distribution in the boiler and may ultimately disrupt the operation of the plant, Couch [5] and Gul Akar et al [6]. Accumulation of these deposits will lead to negative effects on the plant performance, causing extra maintenance cost and lower production capacity.

In addition, the formation of ash deposits resulting in sensible increase of flue gas temperature, excessive soot blowing operation and in extreme cases caused unplanned outage of the plant for ash removal. Ash deposits in coal-fired boiler are generally classified into two separate modes of occurrence; slagging and fouling. Ash deposition that occurs in the section of boiler at furnace, superheat pendent, reheater pendant where radiant heat transfer is dominant is described as slagging. In coal-fired furnace, slagging is typically caused by the formation of molten ash particles deposited on the upper furnace tube surfaces. Therefore, they are easy to stick to the surface and cause the accumulation of deposits leading to slagging. Depending on the strength and physical characteristic of the deposit, steam or air sootblower may be able to remove most of them. However, the base deposit generally remains attached to the tube, allowing subsequent deposits to accumulate much more rapidly.

Fouling is generally caused by the vaporization of volatile inorganic elements in the coal during combustion. When heat is absorbed and temperatures decrease in the convection area of the boiler, compounds formed by these elements condense on ash particles and heating surface, forming glue which initiate deposition. A severe ash deposition in the boiler has led to unscheduled outage of the unit Su et al. [7-9]. Therefore, there is an urgent need to gain a sound understanding of coal ash deposition behaviour and its relation to the boiler operating conditions.

In order to mitigate these problem and challenges, one of the potential solutions is to develop a coal additive. This project explored potential suitable active compound at several blended ratio of coal additives that reduces the formation of coal ash slagging and fouling and was carried out.

Mishra et al. [10], Luan et al. [11] and Wu et al. [12] conducted few studies in mineral impurities in coal form ash deposits in pulverized coal combustion. Transformation of mineral matter in coals to ash deposit formation was further investigated and the improved knowledge helps better handling of ash-related problems. Few studies have been conducted by other researchers in using coal additive to minimise slagging [13]. However, the corresponding effects to plant operation such as combustion behaviour, reduce ESP efficiency due to low fly ash resistivity and effect on corrosion on boiler tubes are not widely discussed. Chakravarty et al. [14] investigated a correlation of chemical and mineral composition to ash fusion temperature. High viscosity coal was investigated to improve its ash fluidity by blending with low viscosity coal by Liu et al. [15].

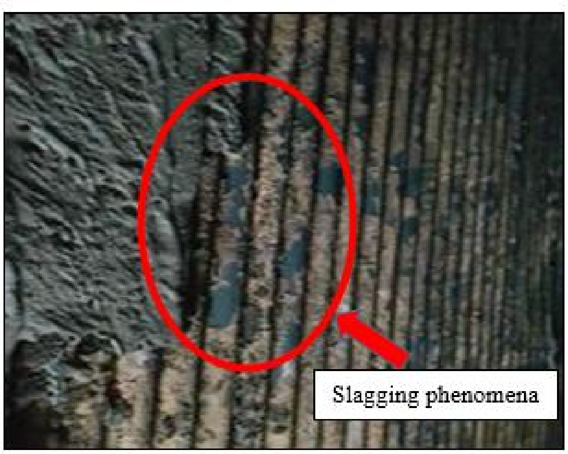

Figure 1: Slagging phenomena in furnace water wall

Therefore, in this study a new formula and improved product of customised coal additive has been developed namely D+ and K+ additive. The new properties of coal additive formulation have been analysed in TNBR combustion and fuel laboratory. The combustion testing of the new formulated coal additives is carried out in using TNBR combustion test-rig facility (CTF). The TNBR combustion test rig facility that is 3.5 m x 1.8 m in length and width, while it is 0.3 m and 9.3 m inner and outer diameter was developed by Hassan et al. [16]. This combustion testing study is to know the effectiveness of coal additive in reducing slagging and fouling by blending at 3%, 5%, and 10% ratio with three types of sub-bituminous coal namely Coal A, Coal B and Coal C.
Some research resources might be relevant and can be considered for advancing the multidisciplinary studies [17-19].

Figure 2: Low temperature fouling at boiler tube

2. EXPERIMENTAL SET-UP AND METHODOLOGY

The project was carried out according to the following methodology:

2.1 Sample preparation

Sample preparation is very critical in ensuring reliability of analytical fuel test results. In sample preparation, several activities such as coal crushing, grinding, sieving and drying has to take place and these activities were conducted according to ASTM standard.

The sample preparation started with the crushing activity followed by grinding and sieving until more than 75% of the sample size of 250 microns or below in diameter is achieved. The sample was then dried in an oven around 40°C until the surface moisture is completely removed.

Throughout this study, three (3) types of coals were obtained from coal fired power station coal stock yard which are Coal A (design coal for particular coal fired power plant), Coal B (slagging propensity coal) and Coal C (fouling propensity coal. Fuel additives are been used to investigate the effect of slagging and fouling.

The development of formulation and characterization of additive from two (2) types of potential coal additive. The fuel additive from base chemical compound namely Dolomite – Ca Mg and Kaolin – $Al_2Si_2O_5$. The additives were blended with treated biomass fuel and blended to 3, 5 and 10%. The additives were name as D+ and K+.

2.2 Combustion testing

Experimental set-up of combustion testing behaviour using 150kW TNBR combustion test rig facility. The combustion testing parameters were focused on ignitibility, furnace temperatures profiles and ash deposition of slagging and fouling.

In Figure 3 show the schematic diagram of 150 kW combustion test rig for solid fuel combustion analysis. Combustion testing is carried out after the analytical testing has been completed. This is because the information from ultimate analysis is required in determining stoichiometry ratio of air and fuel to achieve a complete combustion.

This combustion test rig is equipped with a single swirl burner that has fuel feed capacity of 10 – 40 kg/ hour, slagging and fouling probes, thermocouples as well as flue gas analyser for complete combustion test that enable temperature profile/ flame structure, ash deposition formation and flue gas emission analyses to be performed. This combustor is arranged in an L-shape configuration to mimic a real boiler configuration, whereby the radiation (high temperature furnace/ flame zone) and convection zone could be differentiated.

Starting from the beginning of the process, the primary air is used as a medium to flow the solid fuel sample while the oxidizing agent for the combustion is mainly supplied from the secondary air. On the operational procedure, before any coal sample is introduced into the combustor, the furnace is first heated up until the temperature at section 1 (identified as T1 in the above schematic diagram) reaches 750°C using LPG + air flame. This is to ensure the combustor area near the burner contains enough heat for the sample to 'self-ignite'. Once the temperature reaches this value, coal will be then introduced, and until the temperature shows no sign of increment, the measurement will start to take place.

Flame behaviour, such as flame blow-off can be observed visually through quartz glass windows. There are also four thermocouples along the combustor, each at every section for temperature measurement to analyse flame profile/ structure. From this, prediction on flame behaviour such as combustion delay can be determined and compared to the combustibility index determined from thermogravimetry analysis. The temperature data is stored automatically, once every 10 second for further analysis.

Finally, the investigation of deposit formation is based primarily on deposits collected on temperature-controlled probes. There are two types of probes were used for sampling of deposits, slagging and fouling probes. The ash deposited on the slagging probe due to heat exposure to radiation and on the fouling probe due to heat convection near the heat exchanger area will be then collected for evaluation. In addition, the deposits were collected after combustion testing completed and cool down. Basic analysis such as deposited ash weighting as well as detailed analysis on elemental/ compound using EDX will then be performed

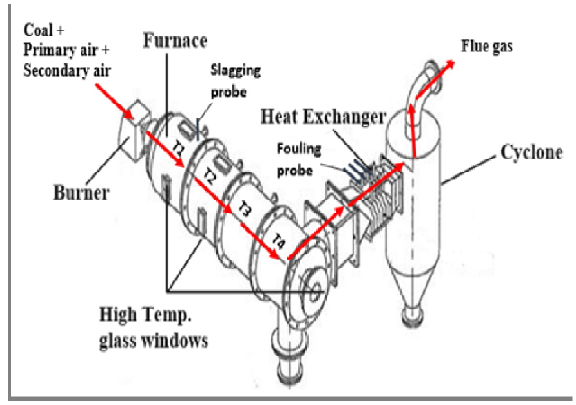

Figure 3: Schematic Diagram of a Combustion Test Rig

2.3 Ash composition

Ashing

Ashing is used to analyse the ash by heating of a coal samples until only non-combustible ash left. The ash left than is analysed its elemental composition. The blended fuel samples were prepared inside a muffle furnace according to ASTM D1875. The blended fuel samples were spread onto crucibles and heated in muffle furnace in air at temperature of 550ºC for 10 hours and increase temperature to 815ºC for 2 hours. The chosen temperature is selected to reduce the evaporation of alkali metals during ashing.

Ash composition

The prepared ash samples from blended fuel were analysed for determining the properties of ash which included 10 elements that is expected to be found in the ash samples. The elements of ash composition are SiO2, Al_2O_3, Fe_2O_3, CaO, MgO, Na_2O, K_2O, TiO_2, Mn_3O_4, SO_3, BaO and P_2O_5. In this paper, the analysis will be focused to Fe_2O_3 and Na_2O element only. The determination of ash constituents is important to be able to predict the behaviour of the ashes and slags in the boiler walls of real working coal fired power plants. The standard test method for determining particulates composition was used using ASTM D 6349.

Ash melting temperature using Ash Fusion

There are four different temperatures captured in this analysis to indicate the phase change of ash for each sample, i.e. Initial Deformation Temperature (IDT), Softening Temperature (ST), Hemispherical Temperature (HT) and Flow Temperature (FT). The analysis was conducted in oxidizing and reducing environment to cover a reasonable range found in a real application. Note that the slagging or fouling propensity is usually estimated based on the initial deformation temperature (IDT) in reducing environment.

The EDX Analysis

The EDX analysis was carried simultaneously or right after SEM analysis completed. The mode to analyse EDX data was controlled by using the SEM computer software and switch to EDX mode function application. The EDX analysis enables the user to get a sample composition at the microscopy level. The EDX will be pointed at multiple zone on the fuel samples to get accurate results. The magnification for EDX analysis will also to be varied so that more area analysis of sample can be covered. Semiquantitative information of organic matters using Electron Dispersion X-ray (EDX) to determine: Silica, Aluminium, Ferus, Sodium, Potassium, Titanium, Sulphur, Magnesium and Calcium.

2.4. Result validation and analysis

Results validation and analysis of new formulated coal additive based on:
i. Effect of Fe_2O_3 element to ash melting temperature
ii. Effect of Fe2O3 element to slagging propensity
iii. Effect of Na2O element to fouling propensity
iv. Combustion behaviour of new formulated coal additive
v. Determination of the optimum blended ratio of new formulated D+ and K+ additive.

Table 1: Coal A, B and C fuel characteristic

Proximate Analysis (ADB)	Coal A	Coal B	Coal C
Inherent Moisture	14.4	9.88	11.42
Volatile Matters	42.3	37.3	39.36
Fixed Carbon	39.6	41.25	42.31
Ash	3.7	11.57	6.91
Fuel Ratio (FC/VM)	0.94	1.11	1.07
Calorific value Gross (ARB) Kcal/kg	4870	5649	5287
ASH FUSION			
DT	1118	1269	1106
ST	1170	1325	1124
HT	1176	1335	1140
FT	1183	1348	1154
Ash Composition (DB)			
Fe2O3	12.66	12.87	6.45
CaO	16.3	5.91	14.48
MgO	7.39	1.85	5.14
Na2O	1.17	0.54	7.09
K2O	1.46	2.37	0.63
SiO2	30.88	46.11	30.48
Al2O3	18.13	26.67	18.86
TiO2	0.86	0.72	1.22
SO3	7.91	2.26	10.2

3. RESULTS AND DISCUSSION

Results and discussion from the research project are as described below:
Amount of nine (9) deposit samples from slagging probe and nine (9) from fouling probe were collected after combustion testing at 3, 5 and 10% ratio with three (3) types of sub-bituminous coal namely CAD (Coal A), CFKP (Coal B) and CAH (Coal C) coal blended with new formulated D+ and K+ additive. Table 1, show the Coal A, Coal B and Coal C fuel characteristic.

3.1 Reduction of slagging propensity

The newly developed formulations of coal additive show significant reduction of Fe_2O_3 content in ash and increased the hemisphere temperature (HT) of coal ash fusion. As a result, it reduces the slagging propensity of coal.

Figure 4 and Figure 5 shows the effect of Fe_2O_3 element in coal ash composition and hemisphere temperature (HT) of coal ash fusion with D+ additive respectively. Whereas Figure 6 and Figure 7 shows the effect of Fe_2O_3 element in coal ash composition and hemisphere temperature (HT) of coal ash fusion with K+ additive respectively.

In this investigation shows the new formulated coal additive of D+ significantly reduction of Fe_2O_3 contents in Coal A and Coal C at premixed of 3%, 5% and 10% respectively except for Coal B coal at 3%. Subsequently improved the hemisphere temperature (HT) of ash deposition of Coal A and Coal C. Whereas the new formulated coal additive of K+ shows significantly reduction of Fe_2O_3 contents in Coal A, Coal B and Coal C coal at premixed of 3%, 5% and 10% respectively. Subsequently improved the hemisphere temperature (HT) of ash deposition of Coal A, Coal B and Coal C.

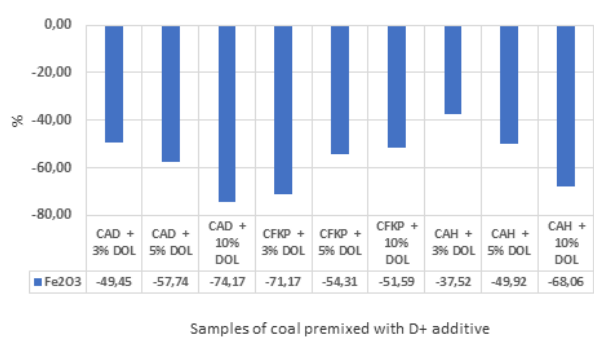

Figure 4: Effect of Fe_2O_3 element in coal ash composition with D+ additive

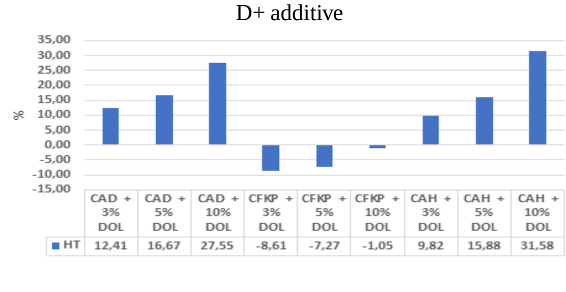

Figure 5: Effect of HT of coal ash fusion with D+ additive

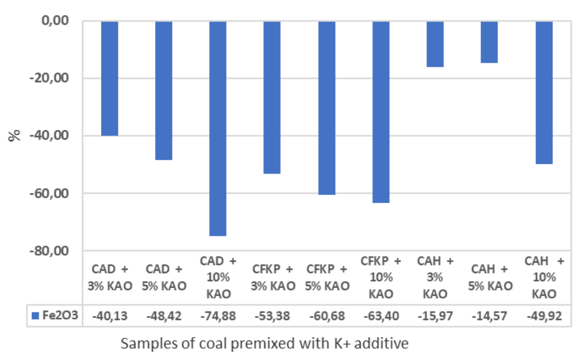

Figure 6: The effect of Fe_2O_3 element in coal ash with K+ additive

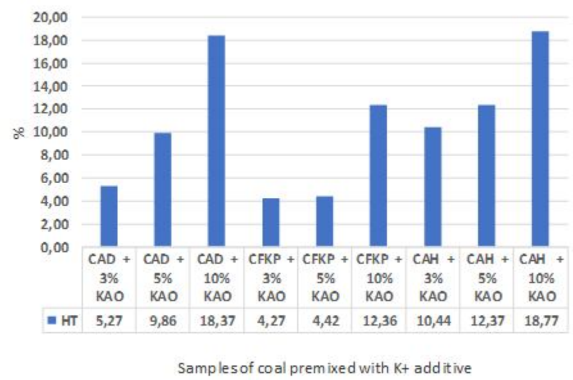

Figure 7: The effect of HT of coal ash fusion with K+ additive.

3.2 Reduction of fouling propensity

As being mentioned in the introduction, the inorganic components of coal are responsible for serious fouling problems associated with certain combustion process. For example, the alkali metal of Sodium (Na_2O) are commonly associated with fouling deposits phenomena. Laboratory tests have been used to evaluate the potential combination coal additive to reduce fouling before investigation of combustion behaviour to be carried out. The newly developed formulations of coal additives of D+ and K+ show significant reduction of Na_2O element content in ash composition. As a result, it reduces the fouling propensity of coal.

Figure 8 and Figure 9 shows the effect of Na_2O element in coal ash composition with new formulated coal additive D+ and K+ respectively. The effect of Na_2O element in coal ash composition are more significant dan dominants in using K+ coal additive compared to D+ additive. As shown in the Figure 9, the effect of Na_2O element of premixed K+ coal additive with Coal A, Coal B and Coal C tremendously reduced at ratio 3%, 5% and 10% respectively. Whereas, the effect of Na2O element in coal ash composition with Dolomite additive shows dominantly reduced for Coal A. However, the reduction trending of Na_2O element shows significantly at 10% premixed of D+ additive with Coal A, Coal B and Coal C.

In addition, the effect of Na2O element in coal ash composition of Coal A, Coal B and Coal C with D+ additive shows significantly reduced at 10% ratio. The results suggest that the both D+ and K+ additive shows reduction of Na2O element in coal ash composition at premixed 10% ratio.

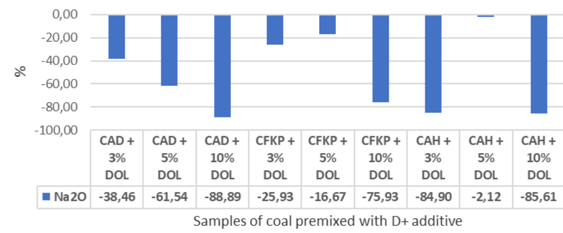

Figure 8: Effect of Na_2O element in coal ash composition with D+ additive

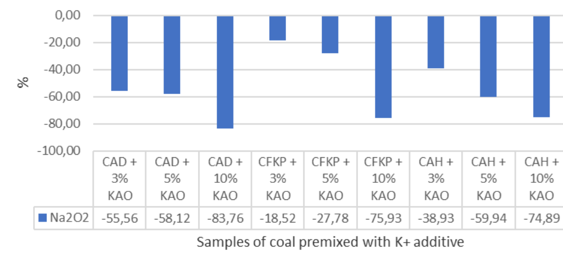

Figure 9: Effect of Na_2O element in coal ash composition with K+ additive.

3.3 Influence of Basic composition on coal ash melting point temperature.

Components of coal ash can be divided to Basic which contents of CaO, Fe_2O_3, MgO, K_2O and Na_2O elements whereas Acidic contents of Si_2O, Al_2O_3 and TiO elements. The reduction of Fe_2O_3 element in Basic components show influences of coal ash melting temperature on hemisphere temperature (HT) of coal ash fusion

Subsequently, HT decreases with an increase in Basic components, when Basic components is less than 40%, but the tendency is opposite when Basic components is larger than 40% as shown in Figure 10.

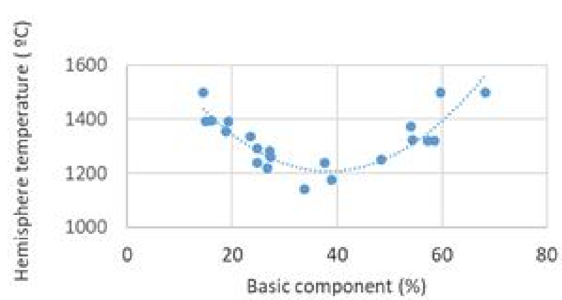

Figure 10: Influence of Basic composition on Hemisphere Temperature (HT) of coal ash fusion

3.4. Combustion testing analysis - Improves furnace temperature profiles, ignitibility and flame stability.

The analysis of coal samples properties, shows that volatiles matters increases when 10% premixed of D+ and K+ additive as shown in Figure 11. The increased of volatiles matter (VM) of the coal samples could improves the furnace temperature of the combustion test rig, easier to ignite and stable flame propagation.

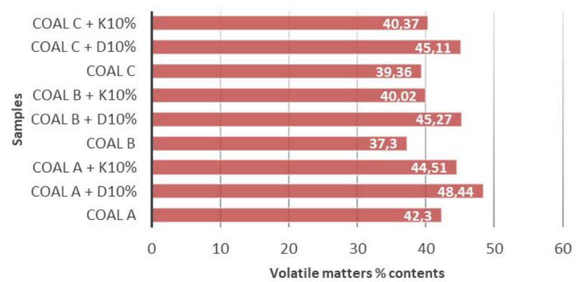

Figure 11: Volatiles matters (VM) of coal samples premixed with 10% D+ and K+ additive.

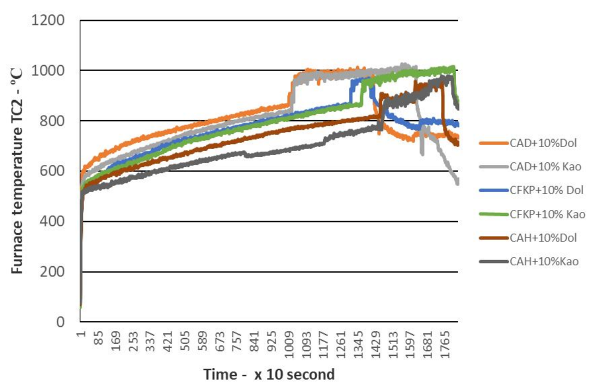

Figure 12: Furnace temperature profiles of coal premixed with 10% D+ and K+ Additives.

In this investigation and to ensure the combustion testing results are meaningful and comparable, the fuel feed rate and air fuel ratio (A/F) for each test was maintained at 10kg/hr and 10% of excess air respectively. In addition, the premixed of 10% ratio new formulated K+ additive with Coal C has much longer flame profile compared to other samples as shown in the Figure 12.

3.5. Reduction of Ferrous element (Fe) in ash slag deposits

The evaluation of ash deposition propensity was first made using the initial deformation temperature from ash fusion analysis. In combustion testing, the ash deposition would be more reliable and quantitative analysis is possible as it takes into consideration of flame dynamic (though do not truly resembling the dynamics of real furnace).

Energy Dispersion X-ray (EDX) analysis of slag samples after combustion test shows significant reduction of Fe element. Table 2 and Table 3 shows the EDX analysis of slag coal samples at 10% premixed with new formulated D+ and K+ additives respectively.

Table 2: EDX analysis of slag samples with 10% premixed of new formulated D+ additive.

	Energy Dispersion X-ray (EDX) - Slagging samples							
Samples	Si	Al	Fe	Ca	K	Mg	Ti	Na
Coal A	14.43	9.60	8.85	11.65	1.21	4.46	0.51	0.87
Coal B	21.55	13.22	9.01	4.23	1.96	1.11	0.58	0.40
Coal C	14.25	9.98	4.51	10.35	0.53	3.10	0.73	5.26
Coal A + D10%	3.94	2.11	8.13	21.99	0.20	6.81	0.06	0.27
Coal B + D10%	2.84	3.35	3.98	15.36	0.20	3.11	0.11	0.17
Coal C + D10%	4.68	3.93	1.08	14.78	0.24	4.36	0.11	0.58

Table 3: EDX analysis of slag samples with 10% premixed of new formulated K+ additive.

	Energy Dispersion X-ray (EDX) - Slagging samples							
Samples	Si	Al	Fe	Ca	K	Mg	Ti	Na
Coal A	14.43	9.60	8.85	11.65	1.21	4.46	0.51	0.87
Coal B	21.55	13.22	9.01	4.23	1.96	1.11	0.58	0.40
Coal C	14.25	9.98	4.51	10.35	0.53	3.10	0.73	5.26
Coal A + K10%	8.45	7.15	1.85	3.41	0.99	1.57	0.16	0.21
Coal B + K10%	7.61	7.26	1.62	1.67	0.48	0.59	0.24	0.21
Coal C + K10%	19.52	18.61	1.45	1.92	1.18	0.92	0.85	0.51

The evaluation of the analysed coal samples were made by comparing to Fe contents in the samples. Energy Dispersion X-ray (EDX) analysis of slag samples after combustion test shows significant and moderate reduction of Fe element as shown in Figure 13. In addition, the K+ formulation at 10% premixed with Coal B show the best coal additive in reducing slagging propensity at 82.1%.

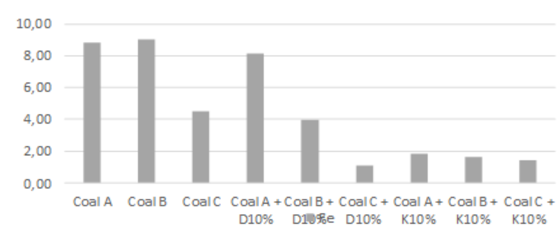

Figure 13: EDX analysis of slagging samples from Coal A, B and Coal C with premixed 10% D+ and K+ additive after combustion testing – Fe contents

3.6. Reduction of Sodium element (Na) in ash fouling deposits

Energy Dispersion X-ray (EDX) analysis of fouling samples after combustion test shows significant reduction of Na element. Table 4 and Table 5 shows the EDX analysis of fouling coal samples at 10% premixed with new formulated D+ and K+ additives respectively.

Table 4: EDX analysis of fouling samples with 10% premixed of new formulated D+ additive.

	Energy Dispersion X-ray (EDX) - Fouling samples							
Samples	Si	Al	Fe	Ca	K	Mg	Ti	Na
Coal A	14.43	9.60	8.85	11.65	1.21	4.46	0.51	0.87
Coal B	21.55	13.22	9.01	4.23	1.96	1.11	0.58	0.40
Coal C	14.25	9.98	4.51	10.35	0.53	3.10	0.73	5.26
Coal A + D10%	6.18	3.33	3.51	25.39	0.43	7.35	0.25	0.34
Coal B + D10%	1.11	3.43	2.85	27.08	0.18	7.12	0.17	0.30
Coal C + D10%	1.67	1.49	1.93	11.95	0.16	3.46	0.05	0.17

Table 5: EDX analysis of fouling samples with 10% premixed of new formulated K+ additive.

Energy Dispersion X-ray (EDX) - Fouling samples								
Samples	Si	Al	Fe	Ca	K	Mg	Ti	Na
Coal A	14.43	9.60	8.85	11.65	1.21	4.46	0.51	0.87
Coal B	21.55	13.22	9.01	4.23	1.96	1.11	0.58	0.40
Coal C	14.25	9.98	4.51	10.35	0.53	3.10	0.73	5.26
Coal A + K10%	7.63	14.79	3.30	4.80	2.05	1.88	0.34	0.36
Coal B + K10%	8.71	16.07	4.77	1.90	1.95	0.79	0.52	0.19
Coal C + K10%	18.38	16.84	1.75	4.49	2.12	1.13	0.40	0.19

As expected, the premixed of new formulated D+ and K+ additive with 3 types of coal shows an improvement compared to single coal on fouling propensity. The Energy Dispersion X-ray (EDX) analysis of slag samples after combustion test shows significant reduction of Na element as show in Figure 14. In addition, the new formulated K+ at 10% premixed with Coal C shows the best coal additive in reducing fouling propensity at 96.4%.

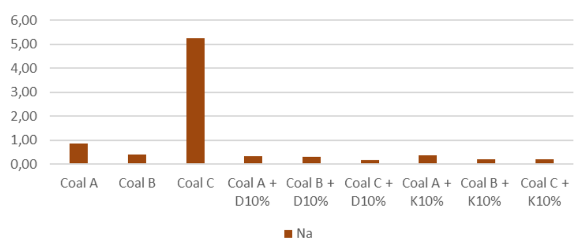

Figure 14: EDX analysis of slagging samples from Coal A, B and Coal C with premixed 10% D+ and K+ additive after combustion testing – Na contents

4. CONCLUSION

A detailed understanding of ash depositions as well as their behaviour in 150kw thermal combustion test rig has successfully achieved to increase ash melting point, thus mitigating the formation of slagging and fouling. High flame temperature at upstream region of the combustion rig further promotes the formation. Premixed of new formulated coal additive however improves the ash deposition propensity as compared to single coal combustion.

The outputs from the project are:
The combustion testing facility of 150 kw is an ideal tool to simulate solid fuel combustion and related phenomena at meaningful scale. Furthermore, can improving the level of understanding on combustion behavior, environmental issues and formation of ash depositions such as slagging and fouling.

Significant reduction of Fe_2O_3 content in ash samples and increases the hemisphere temperature of ash melting point for all coal when premixed with new formulated D+ and K+ additives at 3, 5 and 10% ratio respectively. However, the new formulated K+ additive at 10% premixed with Coal B show the best coal additive in reducing slagging propensity at 82.1%.

Significant reduction of Na element for all coal when premixed with new formulated D+ and K+ additive at 3, 5 and 10% ratio respectively. However, the new formulated K+ formulation at 10% premixed with (CAH) show the best coal additive in reducing fouling propensity at 96.4%.
New formulated K+ additive is found to give the best results that reduces slagging and fouling propensity

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