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Effect of Ash fusion temperature to sub-bituminous coal blends with new formulated D and K additives in 150kWth combustion test rig

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Abstract

Chemical transformation of inorganic constituents from coal play a role in the formation of ash deposits in the furnace. Slagging and fouling phenomena are influenced by boiler and firing system design, operation parameters and coal properties Accumulations of these ash deposits can lead negative effects on the total plant performance, causing extra maintenance cost and lower production capacity. 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 new formulated D and K additive to ash fusion temperature in 150 kw combustion test rig. The Coal A, Coal B and Coal C blends with D and K additives shows consistence finding of the effects of Fe2O3 mineral versus ash fusion temperature. As a result, the reduction of Fe2O3 and Na2O element in basic components show influences of increases of coal ash fusion temperature on hemisphere temperature (HT). However, the CaO and MgO element in basic components increase for blends with D additive and decrease for blends with K additive respectively. Whereas, the reduction of SiO2 and Al2O3 element in acidic components show influences of increases of coal ash fusion temperature on hemisphere temperature (HT).

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Keywords: *Slagging, Fouling, Ash fusion temperature, Additive, Mineral, Acid, Basic*

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 t

he 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 new formulated D and K additive to ash fusion temperature in150 kw combustion test rig. [1]

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. The investigated that the ash deposition from coal combustion has been one of the main operational problems for power plant generation industry. [2],[3]

The coal ash fusion temperature (AFT) is an influential parameter on coal ash fouling and slagging properties stated. [4]. Although some short- comings exists, the Ash Fusion Temperature test is still a sufficient approach to predict coal slagging tendency during its conversion. The low AFTs can cause slag foaming and expansion. The same researcher reported that the AFT variation is manly dependent on mineral composition and its transformation. [5], [6]. The AFT of mixed ashes is mainly dependent on mineral composition and their transformations. The ash fusion temperature will be decrease when the calcium and iron evolve into eutectic and amorphous matter, this phenomenon happen in coal blending. The ash fusion temperature test determines the behavior of coal ash in the processes of coal combustion study. [7],[8]. Increasing of CaO and MgO contents will cause the AFTs of coal ash samples first decrease until reach a minimum value, before increasing once more. [9]. Increasing S/A ratios, will always increase the AFT. [9]. On the other hand, stated that decreasing silica-to-alumina (S/A) ratio will be increasing the AFT.[6]

There are two methods are generally used to decrease coal AFT, which is flux addition and coal blending, Li *et al* (2016). Coal blending contribute a great combustion process because of there is no gain in ash content and oxygen consumption. However, it was discovered from the industrial gasification operation that for some coals, despite the FT lower than the gasification temperature, their slags had a poor flowing stability, Liu *et al* (2017).

The fusion temperatures and the temperature of critical viscosity (Tcv) of ash are constantly higher than that of slag and increasing CaO content on the Chinese coal will decrease the temperature. [10], [11]. Addition of CaO, Na_2O and MgO content will cause the ash fusion decrease.[10]. The coal ash at a temperature below its flow temperature (FT) in the boiler can still have a relatively strong deposition tendency, the high-viscosity ash fouls before its slags on the heat transfer surface. [12].

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 additives. The fuel additive from base chemical compound namely D compound – Ca and Mg base and K compound – Al and Si base. The additives were blended with sub-bituminous coal, Coal A, Coal B and Coal C at 3, 5 and 10% ratio.

2.2 Methodology

Ash fusion determinator is used to measure ash fusion temperature as shown in Figure 2.1. The ash fusion test is an empirical procedure which provides information about the fusion behaviour of an ash in term of four characteristic temperatures. The procedure involves the preparation of test piece, the shape of a pyramid from the ash. The test piece is heated under standard conditions and observed continuously using high speed video camera.

Figure 3.4: Ash fusion determinator

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) – the temperature at which the first signs of rounding, due to melting of the tip or edge of the test piece occur, Softening Temperature (ST) – the temperature at which the height of the test piece is equal to width of the base, Hemispherical Temperature (HT) – the temperature at which the test piece form approximately a hemisphere, ie when the height becomes equal to half the base diameter and Flow Temperature (FT) – the temperature at which the ash is spread out over the supporting tile in a layer and the height of which is one-third of the height of the test piece at hemisphere temperature.

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. Figure 2.2 illustrates the changes of shape throughout the AFT test which is used in the post-processing activity to determine the temperature at every phase change.

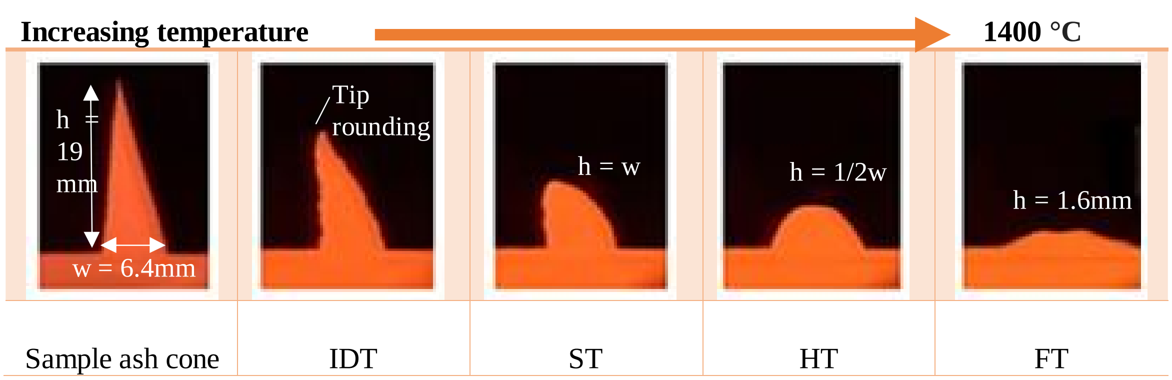

Figure 2.2: Ash Fusion Temperature

3. Results and discussion

3.1 Introduction

The results of ash fusion temperature and its effect to sub-bituminous coal shows significantly increases when blends with new formulated D and K additives at various ratio. The characteristic of ash fusion temperature effect of DT, ST, HT and FT for all blends samples which have been studied are produced in Figure 4.7 to Figure 4.19. The results are discussed comprehensively in sub-chapter under effect of Fe2O3 vs ash fusion, effect of Na2O vs ash fusion and influences of basic components.

3.2 Effect of Fe2O3 versus Ash fusion temperature

The results of the experimental data presented that the ash fusion temperature behaviour of coal A, Coal B, Coal C and its blends are quite complex in nature.

The effect of Fe2O3 versus ash fusion temperature of Coal A, Coal B and Coal C blends with D and K additives at various ratio are shown in Figure 3.1 to Figure 3.3. The results of experiment data presented, show significant correlation of reduction of Fe2O3 could improve the ash fusion temperature, especially the hemisphere temperature (HT) zone.

The Coal A, Coal B and Coal C blends with K additives at various ratio shows consistence finding of the effects of Fe2O3 mineral versus ash fusion temperature. The K additive could reduce the mineral of Fe2O2 and therefore increases and improve ash fusion temperatures of ID, ST, HT and FT.

However, the Coal C blends with D additives at various ratio show convincing result as K additives blends samples. The reduction of Fe2O3 mineral contents increases and improve ash fusion temperatures.

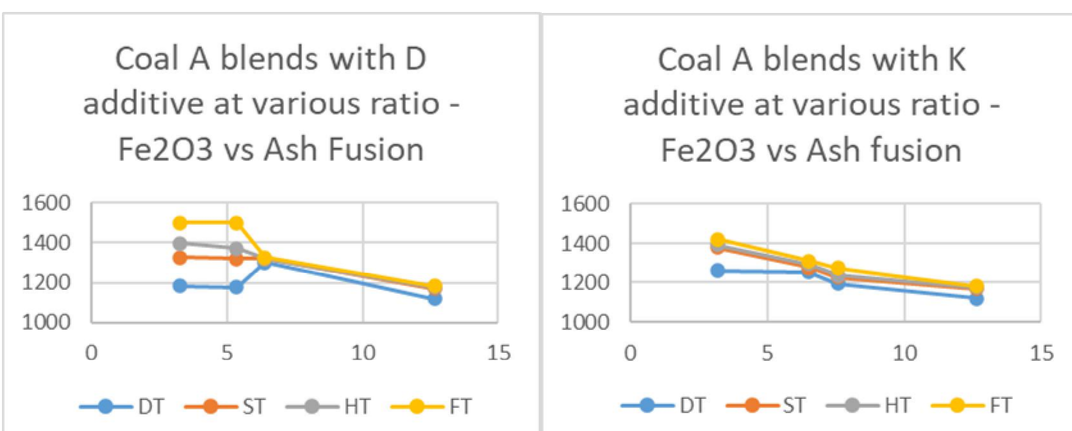

Figure 3.1: Coal A blends with D and K additive at various ratio – Fe2O3 vs ash fusion

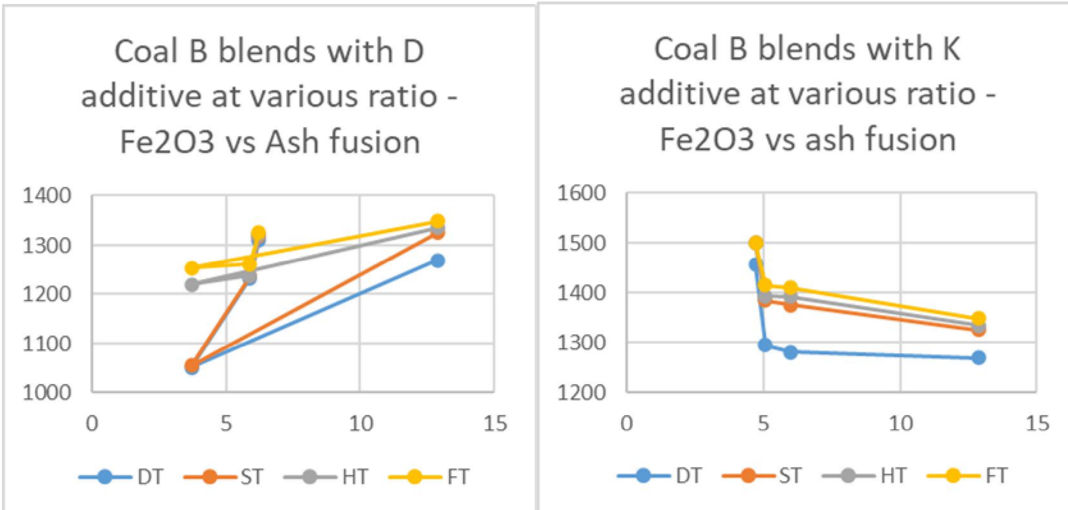

Figure 3.2: Coal B blends with D and K additive at various ratio – Fe2O3 vs ash fusion

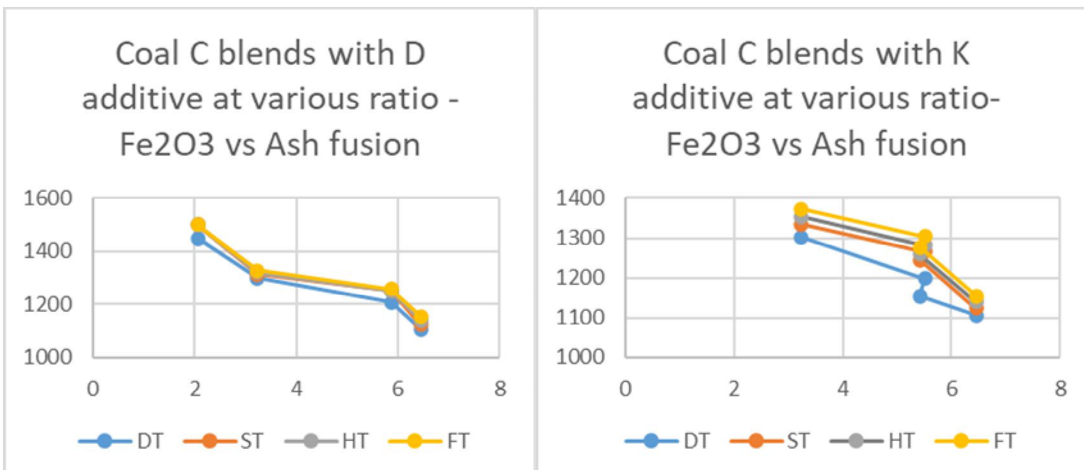

Figure 3.3: Coal C blends with D and K additive at various ratio – Fe2O3 vs ash fusion

3.3 Effect of Na2O versus Ash Fusion temperature

The effect of Na2O versus ash fusion temperature of Coal A, Coal B and Coal C blends with D and K additives at various ratio are shown in Figure 3.4 to Figure 3.6. The results of experiment data presented, also show significant correlation of reduction of Na2O could improve the ash fusion temperature, especially the hemisphere temperature (HT) zone.

The Coal A, Coal B and Coal C blends with K additives at various ratio shows consistence finding of the effects of Na2O mineral versus ash fusion temperature. The K additive could reduce the mineral of Na2O and therefore increases and improve ash fusion temperatures of ID, ST, HT and FT tremendously.

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The Figure 3.4, also show, the Coal C blends with D additives at various ratio show convincing result as K additives blends samples. The reduction of Na2O mineral contents increases and improve ash fusion temperatures.

As in the literature reviews by many researchers, the Na2O mineral contents play a big role in the combustion behaviour, the low contents of Na2O could increases the ash fusion and therefore reduces the ash deposits fouling propensity.

Similar finding was also found in the effects of Fe2O3 versus ash fusion temperature, where the results show the reduces of Fe2O3 mineral content could increases and improve ash fusion temperature. The D and K additives gives good indication to mitigate the ash deposition of slagging and fouling propensity.

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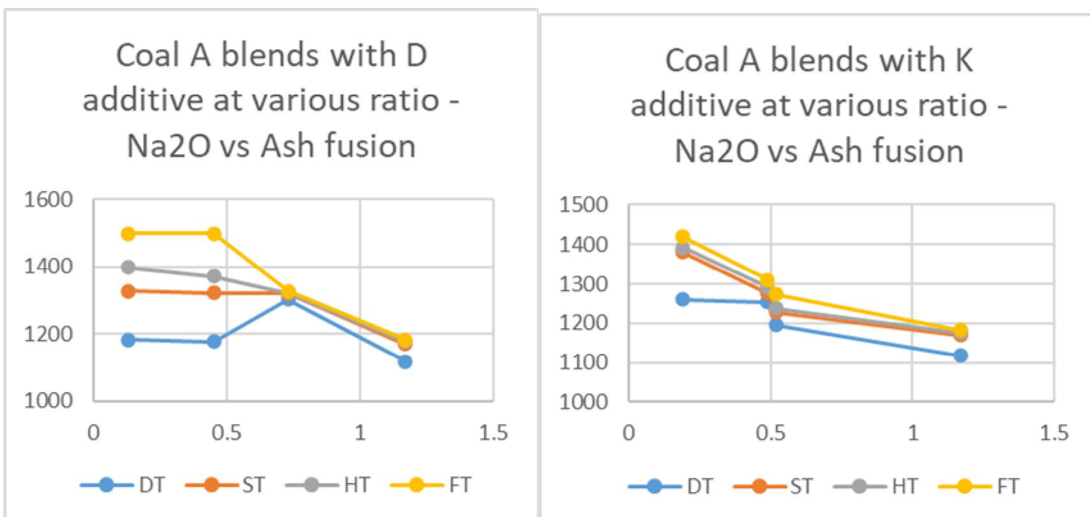

Figure 3.4: Coal A blends with D and K additive at various ratio – Na2O vs ash fusion

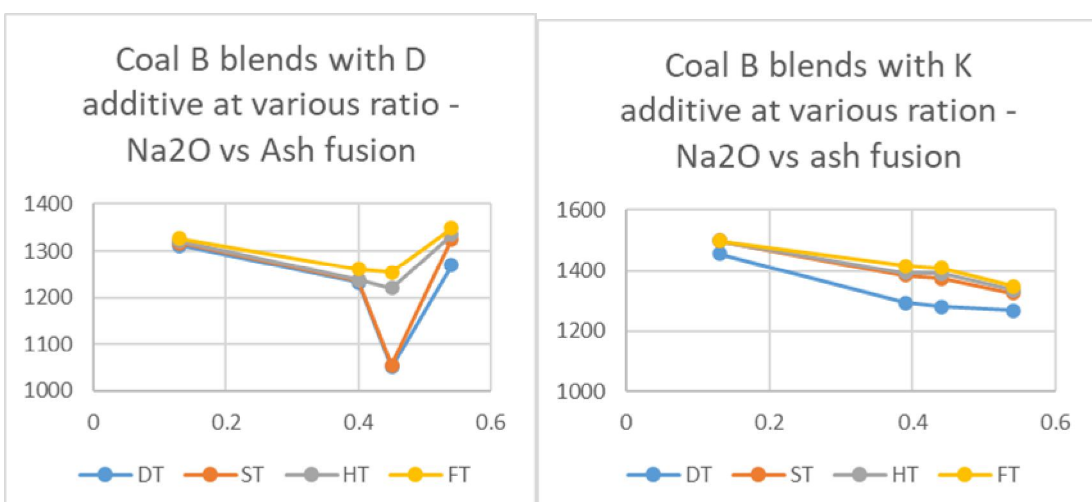

Figure 3.5: Coal B blends with D and K additive at various ratio – Na2O vs ash fusion

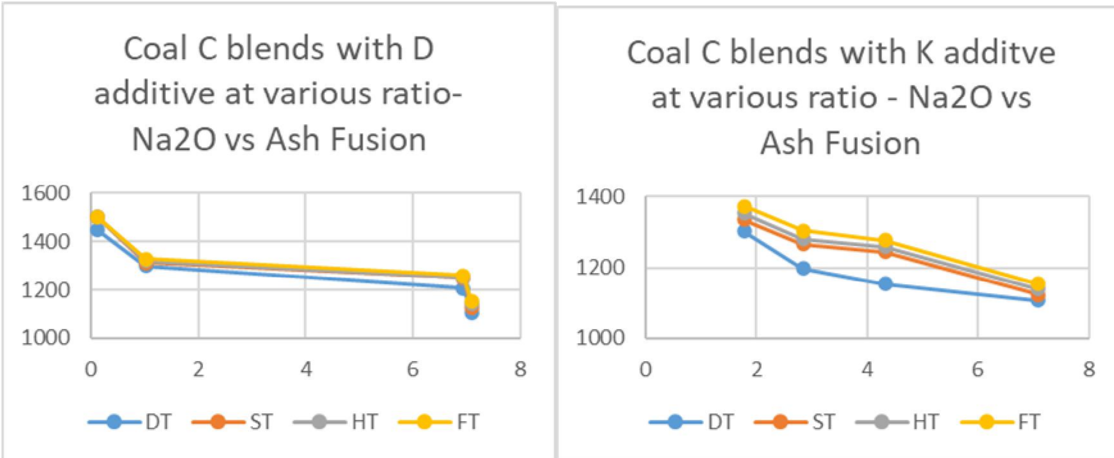

Figure 3.6: Coal C blends with D and K additive at various ratio – Na2O vs ash fusion

3.4 Correlation of ash fusion temperature (DT, ST, HT and FT) with sub-bituminous coal blends

The correlation of ash fusion temperature of Coal A, Coal B and Coal C blends with D and K additives at various ratio are shown in Figure 3.7 to 3.9 respectively. Almost all results and trending of ash fusion temperature of DT, ST, HT and FT increases when Coal A, Coal B and Coal C blends with D and K additives at various ratio.

The correlation of ash fusion temperature of ST, HT and FT Coal A and Coal C blends with D additive increases maximum temperature to 1500 ºC. Whereas the correlation of ash fusion of ST, HT and FT Coal B blends with K additive increase to maximum temperature to 1500 ºC.

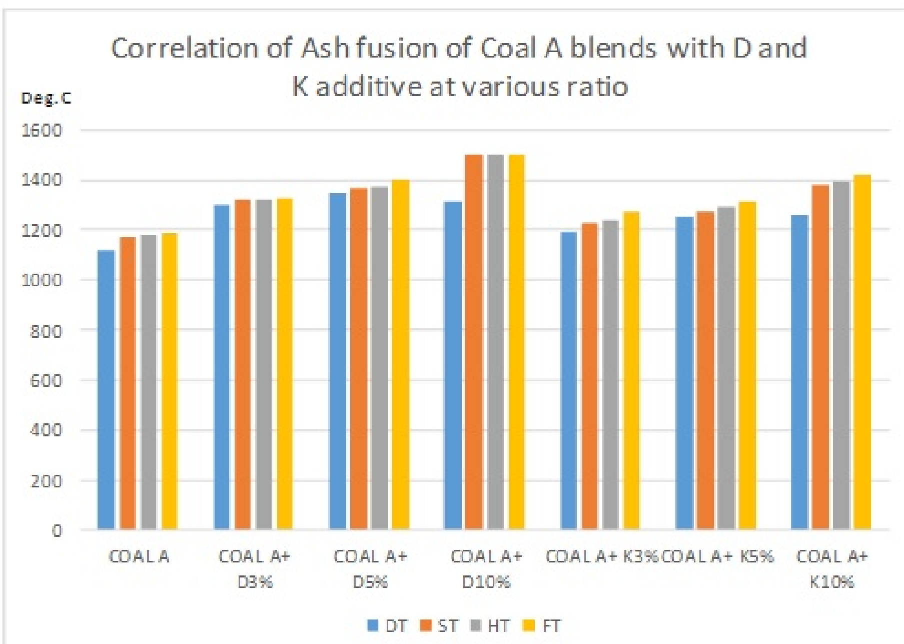

Figure 3.7: Correlation of ash fusion of Coal A blends with D and K additive at various ratio

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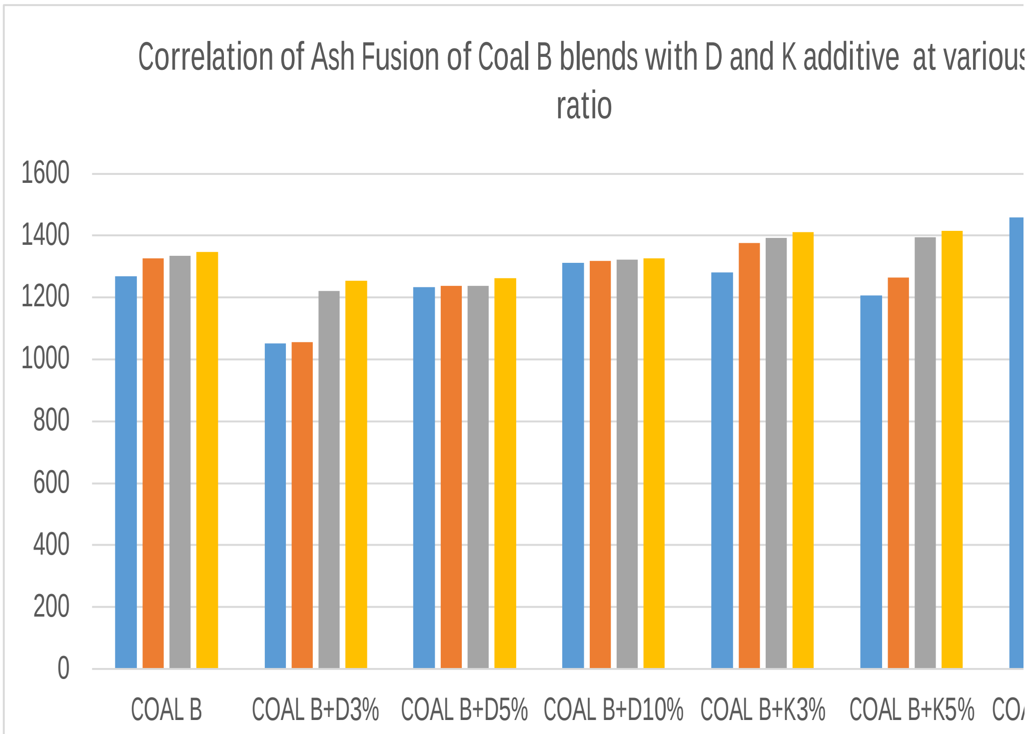

Figure 3.8: Correlation of ash fusion of Coal B blends with D and K additive at various ratio

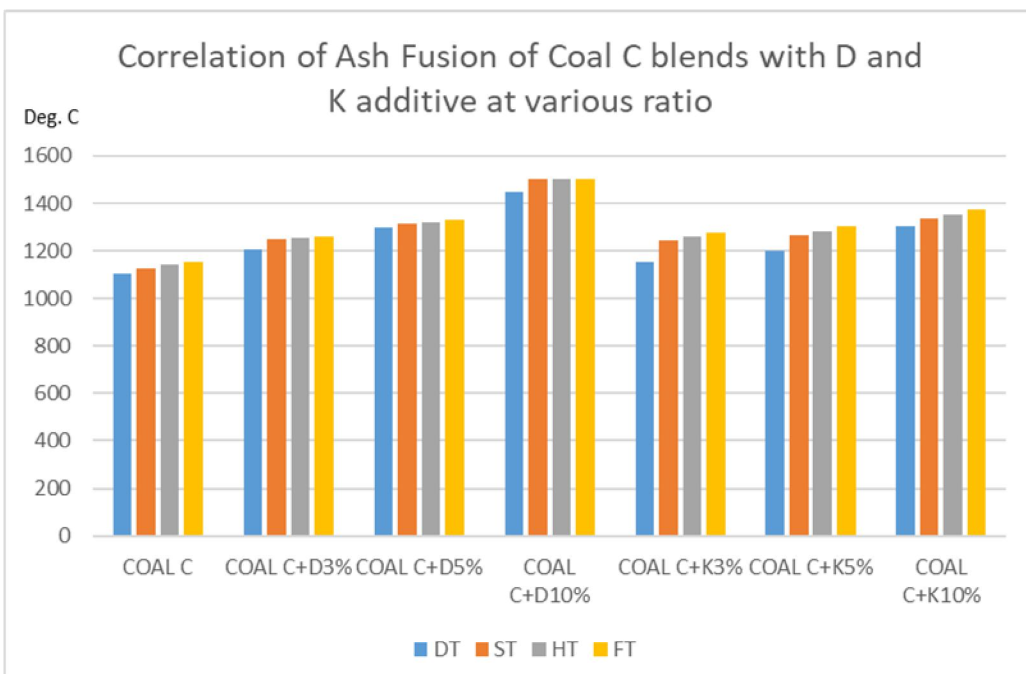

Figure 3.9: Correlation of ash fusion of Coal C blends with D and K additive at various ratio

3.5 Influence of Basic components on ash fusion temperature

Further investigations are carried out to study the influence of basic and acidic components on coal ash fusion temperature. The Components of coal ash can be divided to Basic component which contents of CaO, Fe2O3, MgO, K2O and Na2O elements. The Acidic components contents of SiO2, Al2O3 and TiO elements.

The relation between basic components and hemisphere temperature (HT) of ash deposit blends fuel samples with D and K additives is plotted in Figure 3.10. The solid points shown in the Figure 4.16 are obtained from the experimental and the actual line was the polynomial regressive curve. As can be seen from the Figure 4.26, two points which are Coal A and Coal C are below 1200 ºC. Base from the regressive curve, it was also found that the HT increases when the basic components of Coal A, Coal B and Coal C blends with D additive larger than 40%. Subsequently, the HT increases when basic components of Coal A, Coal B and Coal C blends with K additive less than 40%.

Details investigation of the relation between individual basic component and hemisphere temperature of the blends D and K additives are carried out. Generally, the reduction of Fe2O3 and Na2O element in basic components show influences of increases of coal ash fusion temperature on hemisphere temperature (HT). However, the CaO and MgO element in basic components increase for blends with D additive and decrease for blends with K additive respectively.

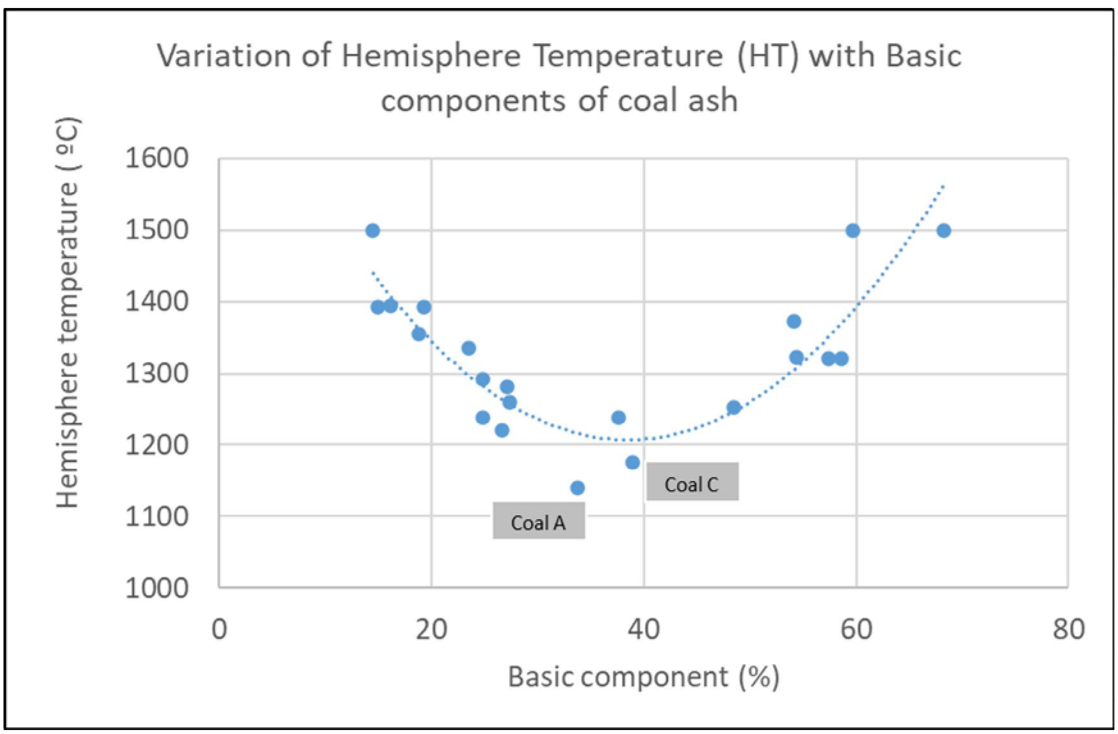

Figure 3.10: Variation of Hemisphere temperature with basic components of coal ash

3.6 Influence of Acidic components on ash fusion temperature

The Acidic components contents of SiO2, Al2O3 and TiO elements.

The relation between acidic components and hemisphere temperature (HT) of ash deposit blends fuel samples with D and K additives is plotted in Figure 3.11. The solid points shown in the Figure 3.11 are obtained from the experimental and the actual line was the polynomial regressive curve. As can be seen from the Figure 3.11, there are two points which are Coal A and Coal C are below 1200 ºC. Base from the regressive curve, it was also found that the HT increases when the acidic components of Coal A, Coal B and Coal C blends with D additive larger than 40%. Subsequently, the HT increases when basic components of Coal A, Coal B and Coal C blends with K additive less than 50%.

Details investigation of the relation between individual acidic component and hemisphere temperature of the blends D and K additives are similarly carried out. Generally, the reduction of SiO2 and Al2O3 element in acidic components show influences of increases of coal ash fusion temperature on hemisphere temperature (HT).

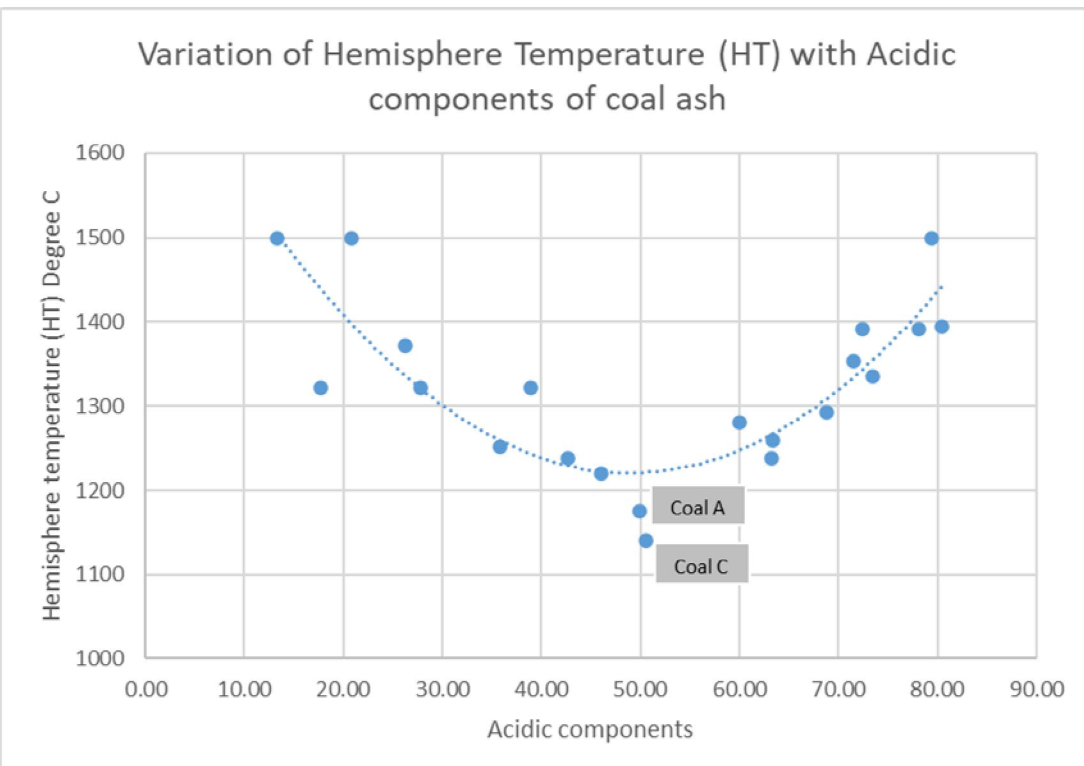

Figure 3.11: Variation of hemisphere temperature with acidic components of coal ash

4. Conclusions

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. Blending of new formulated coal additive however improves the ash deposition propensity as compared to single coal combustion.

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.

Finally, the hypothesis of investigation with regards to effect of ash fusion temperature, it can be emphasised that the new formulated D additive which consists of Calcium (Ca) and Magnesium (Mg) base compounds could increase the CaO and MgO elements in the ash composition and subsequently could reduce the Fe3O2 element. As a result, show increase of the ash fusion temperature and therefore it reduces slagging propensity significantly.

Whereas for the new formulated K additive which consists of Silica and Alumina base compounds could increase the SiO and Al3O2 elements in the ash composition and subsequently could reduce the Na2 element contents. As also as a result, increase the ash fusion temperature and therefore reduce the Na2O element contents and therefore it reduces the fouling propensity.

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