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COMPARISON OF BIOMASS ASH AND COAL ASH SAMPLES USING ASH FUSION TESTING

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Abstract
An ash fusion test was conducted to determine the four temperatures for biomass (miscanthus) ash and coal (UK 15) ash samples. The coal ash sample had higher deformation temperatures than the biomass ash sample. The EDX profile of biomass ash displayed high peak intensity of O, Si, and K; low peak intensity for Fe, S, P, Na, Cl, and Ca. The EDX profile for the coal ash sample showed high peak intensity of O, Al, and Si elements and low peak intensity of Cl, K, Mg, S, and Fe elements. The high presence of reactive elements in the coal ash sample remains a reason for causing ash deposition, high-temperature corrosion, and slagging in power stations; thus, the need to switch to biomass is highly favoured because of the low presence of volatile elements. Biomass is also preferred over coal because of the use of the lower temperature of heating than coal. The ash fusion testing experiment displayed the four temperatures of initial deformation temperature, softening temperature, hemispherical temperature, and fluid temperature. Coal ash sample temperatures were higher than biomass ash sample for the four temperatures.
Keywords: ash fusion testing, biomass ash, coal ash

1. Introduction

The continuous global temperature rise and climate change have become of great concern to developed countries and developing countries. These problems can be attributed to the constant emission of greenhouse gases into the atmosphere from major power stations and gas flaring worldwide. Researchers are looking for means to reduce greenhouse gas emissions by exploring technologies such as carbon capture and storage (CCS), which comprises pre-combustion capture, oxy-fuel combustion capture, and post-combustion capture [11, 16].

Power stations using coal or biomass face various problems such as ash deposition, slagging, and high-temperature corrosion. This affects the power station's overall operational performance, causing loss of man-hours due to downtime used for maintenance purposes of the facility. This maintenance mostly is to either replace corroded parts of the power plant and are quite expensive. Considering the alternative to switch from non-renewable energy sources (coal, NG, Petroleum) to renewable energy sources (Biomass, Solar, Wind) will significantly reduce the number of greenhouse gases being emitted to the atmosphere. The Paris climate agreement between different countries signed is geared towards reducing the amount of GHG's emitted per country [18]. Developed countries that have exceeded their carbon emissions quota are expected to deliberate with other undeveloped countries to reduce their emission rates to enable them to continue emitting theirs. Although, this is not turning out as expected for many developed countries who have threatened to pull out from the agreement to continue emitting the GHG's. With the current situation in the world, that we are having increases in sea levels, bleaching of coral reefs caused by the rise in seas, and ocean temperatures, yearly global 2^{o}C temperature increase, climate change, and global warming; without a rapid collaborative response from both the developing and under-developed countries to tackle this situation, all humanity, and nature stand to be affected [20].

Biomass is a resourceful renewable energy source that is currently being explored as fuel for replacing coal in many developed countries [3]. Improving the biomass's quality as fuel in these power stations is necessary as the biomass can be torrefied to reduce the moisture content and pelletized to increase its energy content value. Coal is from beneath the earth and cannot be considered clean fuel because it is formed over long years of accumulation of decomposed plants and animals [8]. Although various research has been conducted to determine that the carbon content within coal is higher than that found in biomass, coal is not still a preferred fuel because of the presence of increased levels of volatile matter. Biomass mostly contains increased moisture content, less volatile matter, and an appreciable amount of carbon content. Hence, it is most preferred because biomass is expected to have absorbed a certain amount of CO2 from the atmosphere during its lifetime. Once combusted, it will only replace the exact amount of CO_2 it has absorbed back into the ecosystem [4].

2. Material and Methods

2.1 Coal Ash Preparation

The coal sample used for the determination of ash is a general analysis sample. It is UK 15 obtained from Drax located in Selby. This is high ash coal that is normally mixed with better quality coal such as Colombian Rl Cerejon, which has about 3% ash. The coal is first grounded into small fine particles, and then it is passed through a sieve of 22-micrometer aperture. The coal sample is exposed in a thin layer for a minimum time required for the moisture content to attain approximate equilibrium with the laboratory atmosphere. Porcelain crucibles are used, but they are first washed and dried and weighed empty on a digital electronic scale. One gram of the coal sample is placed in the Porcelain crucible and weighed afterward. It is placed in the oven (Muffler Furnace) at a temperature of 105-110^{o}C for 1 hour, and this makes the coal loses its moisture content. Still, it retains its volatile matter, fixed carbon, and ash content. One gram of the finely sieved coal particles is put into the Porcelain crucibles and weighed again, and the weights are recorded. The weight of the crucible with its lid cover is retaken.

The closed crucible with the coal sample inside is placed in the furnace at a temperature of 900^{o}C for 7 minutes. After that, the crucible is brought out of the furnace and allowed to cool on a metal surface before it is placed on the electronic scale, weighed, and recorded. The cola sample has lost both the volatile matter and the moisture content at this stage, but it still contains its fixed carbon and ash content. Finally, the coal sample without the lid on the porcelain crucible is put in the furnace. The temperature of the furnace is gradually raised after every 10 minutes by 85^{o}C till the temperature of the furnace gets to 500^{o}C. At 500^{o}C, the sample is left in the furnace for an hour. Then it is brought out of the furnace and allowed to cool on a metal surface, weighed on an electronic scale, results recorded. The coal sample is put back into the furnace, and the temperature of the furnace is raised to 850^{o}C. It is left for an hour, brought out of the furnace, cool on a metal surface, and weighed. This process is repeated for every one hour at 850^{o}C till a constant reading is achieved where there is little change in the weight of the sample. Here, combustion occurs, and the moisture, volatiles, and fixed carbon are lost, and the sample is converted to ash.

2.2 Biomass Ash Preparation

The biomass is also got from Drax is miscanthus; it is first dried at 105^{o}C in an oven (Muffler furnace) for 1 hour to remove the moisture content. It is weighed and transferred to the furnace. The furnace temperature is raised to 250^{o}C over 50 minutes and left at the temperature for 60 minutes to allow the volatiles to leave the sample before ignition. The furnace temperature is further raised evenly to 550^{o}C over 1 hour and left at this temperature for 2 hours. Finally, the sample is taken out of the furnace and allowed to cool for 5 to 10 minutes, then transferred to a desiccator without desiccant to allow to cool to ambient temperature, weighing the ash and the dish to the nearest 0.1mg as soon as the ambient temperature is reached and the mass was recorded.

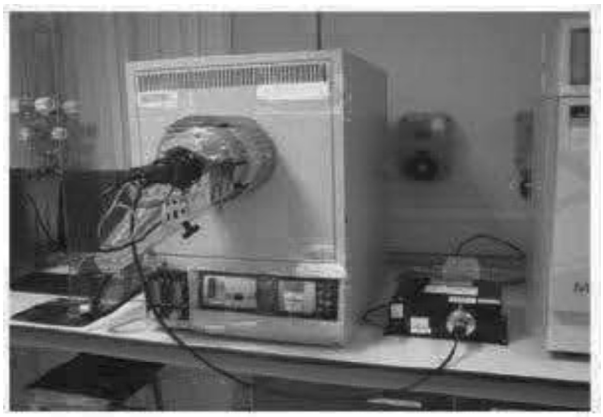

Fig. 1: Ash Fusion Furnace (12)

3 Results and Discussion

3.1 Characterization of Biomass/Coal Ash

Utilizing a Carl Zeiss EVOMA 15 VP Scanning Electron Microscope to determine the surface morphology, EDX profile, and semi-quantitative analysis of the biomass ash sample and coal ash sample. Fig. 2. below shows the surface morphology of SEM images of the biomass ash sample.

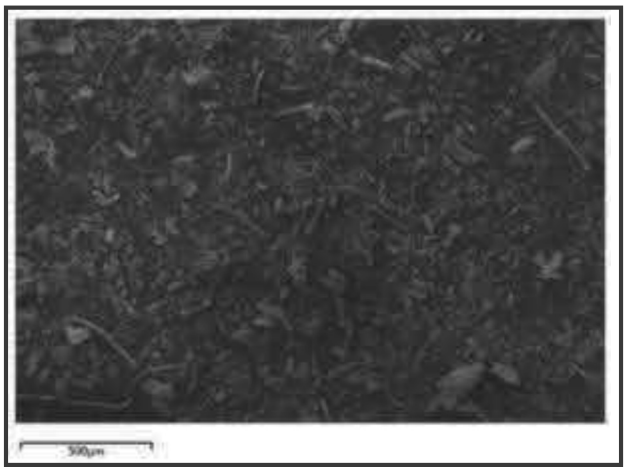

Fig. 2: SEM images of Biomass (Miscanthus) Ash Sample

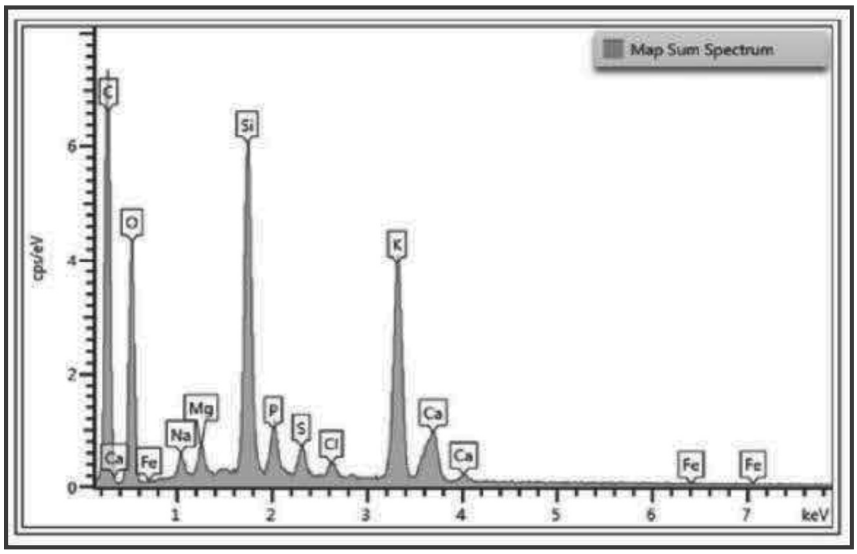

Fig. 3: EDX profile of Biomass Ash Sample

While Fig. 3 below shows an EDX profile of the Biomass sample indicating the various elements with higher concentration than those with lower concentration.

Table 1 below shows the semi-quantitative analysis of biomass ash sample, giving the various weight percentage of the elements determined within the sample. O element having the highest weight percentage of 51.69% and Cl element with the lowest of 1.01%.

Table 1: Semi-quantitative analysis of Biomass Ash Sample

Element	Wt%
O	51.69
Na	1.81
Mg	1.64
Si	16.09
P	2.98
S	1.91
Cl	1.01
K	17.97
Ca	4.69
Fe	0.22
Total	100

Fig 4 shows the SEM image of the coal ash sample. Unlike the biomass ash sample, the particles of the coal ash sample are compacted with larger chunks spaced out within.

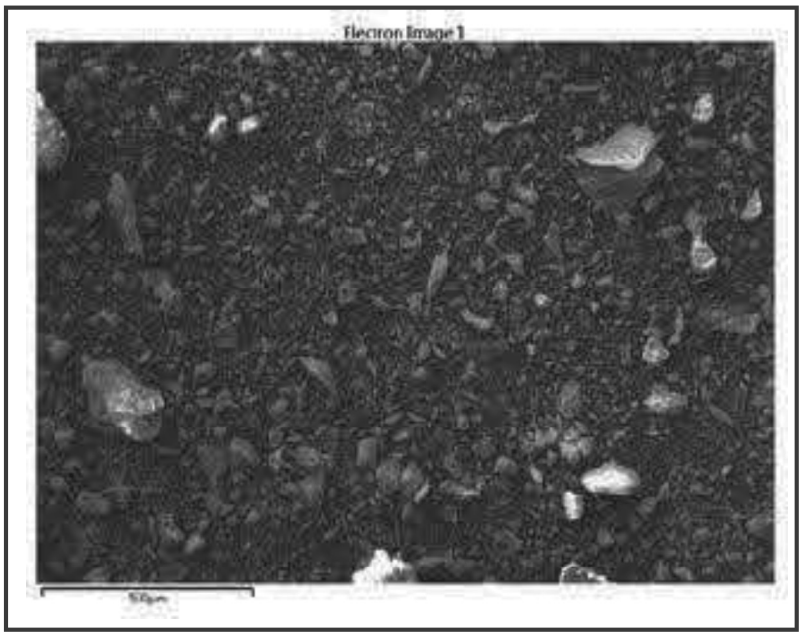

Fig. 4: SEM image of Coal Ash Sample

Fig 5 shows the EDX profile of the coal ash sample with O, Al, and Si exhibiting the highest concentration while K, S, and Cl showing lower concentration. This may not be the case in other coal samples from a different location in the world.

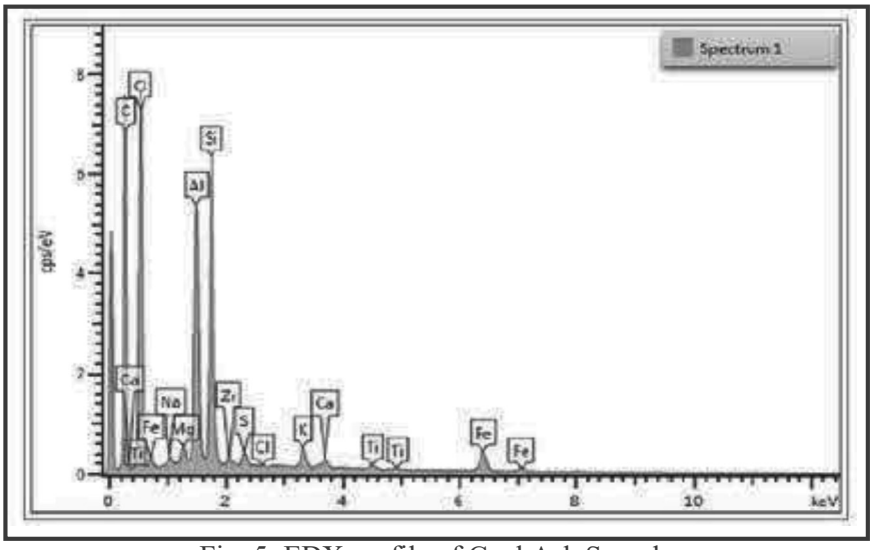

Fig. 5: EDX profile of Coal Ash Sample

Table 2 below shows the semi-quantitative analysis of the coal ash sample giving the various weight percentage of the elements determined within the sample. O element having the highest weight percentage of 53.09%, and Cl having the lowest 0.07%.

Table 2: Semi-quantitative analysis of coal ash sample

Element	Wt%
O	53.09
Na	0.41
Mg	1.07
Al	14.9
Si	19.62
S	1.09
Cl	0.07
K	1.71
Ca	0.66
Ti	0.72
Fe	5.78
Zr	0.87
Total	100

Comparing the semi-quantitative analysis of both samples from the table above shows that the coal ash sample has a higher percentage concentration of O. In contrast, the Biomass ash sample has the lowest Fe concentration. The coal ash sample also exhibited two elements not found in the biomass ash sample, and these are Ti and Zr.

The four different temperatures for Ash fusion testing are

IDT – Initial Deformation temperature

ST – Softening temperature

HT – Hemispherical temperature

FT – Fluid temperature

These temperatures were identified from the ash fusion experiment conducted in a laboratory for coal ash and biomass ash using an ash fusion furnace.

Table 3: Comparison of semi-quantitative analysis of biomass ash sample and coal sample

Semi-quantitative Analysis			
Biomass Ash Sample		Coal Ash Sample	
O	51.69	O	53.09
Na	1.81	Na	0.41
Mg	1.64	Mg	1.07
Si	16.09	Al	14.9
P	2.98	Si	19.62
S	1.91	S	1.09
Cl	1.01	Cl	0.07
K	17.97	K	1.71
Ca	4.69	Ca	0.65
Fe	0.22	Fe	5.78
		Ti	0.72
		Zr	0.87
Total	100	Total	100

3.1.1 Initial Deformation temperature

The initial deformation temperature is when the cone begins to round, and from the experiment conducted for biomass and coal ash, it was around 820^{o}C and 1165^{o}C, respectively. This is indicated from the images which were produced from the experiment. The image in fig 6 shows that the top left corner as the biomass ash sample begins to form a round shape. In contrast, Fig 7 shows at the top right corner, the coal ash sample begins to take a round shape. Tabulated in Table 4 are the ash fusion temperatures for biomass and coal ash, respectively.

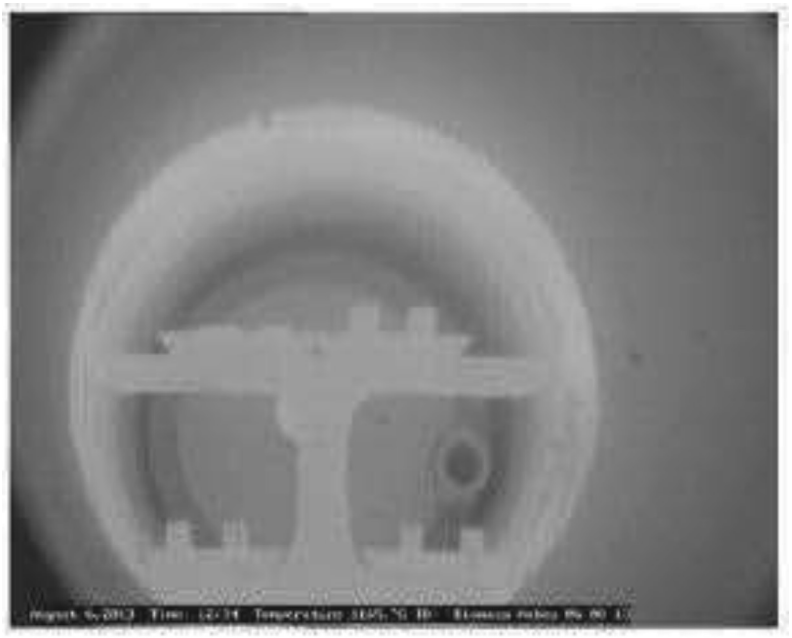

Fig. 6: Ash Fusion Test Result for Coal Ash Sample (Initial Deformation Temperature)

3.1.2 Softening temperature

The softening temperature occurs when the cone of the sample is equal to its height. Unfortunately, this was not adequately captured because of the swelling of the sample, causing them to form irregular shapes. Although the softening temperatures for biomass are about 890^{o}C, and for coal, it was at 1305^{o}C.

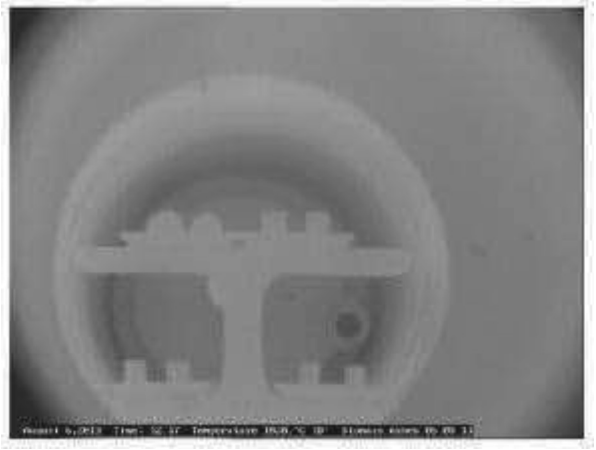

Fig. 7: Ash Fusion Test Result for Biomass Ash Sample (Softening Temperature)

Fig. 8 shows the softening temperature of 1475^{o}C for the coal ash sample, which appears to be losing its shape at the top right corner of the image below

Fig. 8: Ash Fusion Test Result for Coal Ash Sample (Softening Temperature)

3.1.3 Hemispherical temperature

The hemispherical temperature occurs when the base of the cone is twice its height, fig. 7 shows the image of biomass as at 1020^{o}C. This is the sample at the top left corner of the image.

3.1.4 Fluid temperature

The fluid temperature can be identified when the cone has spread to a fused mass no more than 1.6mm in height. Fig. 9 shows the fluid temperature image of the biomass ash sample indicated on the top left corner of the image. This occurs at a temperature of 1040^{o}C while the fluid temperature for the coal ash sample is at 1495oC shows in the top right corner of image Fig. 10. This experiment shows that it takes coal ash longer and higher temperatures than biomass ash for it to attain the various ash fusion deformation stages. Hence Biomass ash will attain its fluid temperature at 1040^{o}C before coal ash does at 1495^{o}C.

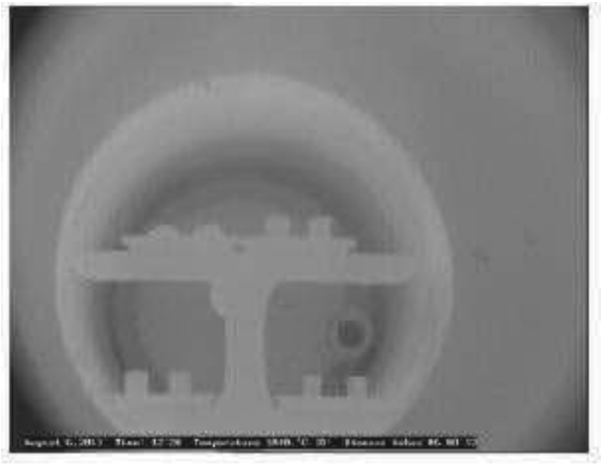

Fig. 9: Ash Fusion Test Result for Biomass Ash Sample (Fluid Temperature)

Fig. 10: Ash fusion Test Result for Coal Ash Sample (Fluid Temperature)

Table 4: Ash Fusion Test Results

	Initial Deformation Temperature (°C)	Softening Temperature (°C)	Hemispherical Temperature (°C)	Fluid Temperature (°C)
Biomass (Miscanthus) Ash	820	895	1020	1040
Coal Ash	1165	1305	1475	1495

Fig. 10 shows a chart comparing biomass ash sample and coal ash sample using the ash fusion testing results. It shows that in all four stages, the coal ash sample has higher temperatures than the biomass ash samples. The initial deformation temperature for biomass ash is 820°C, while for the coal ash sample, it is 1165°C. For the softening temperature, the biomass ash sample is 895°C, while the coal ash sample is 1305°C. The Hemispherical temperature is 1020°C for the biomass ash sample, while the coal ash sample is 1475°C. The fluid temperature for biomass is 1040°C, while the coal ash sample is 1495°C. It is clear that for all four stages, coal requires higher temperatures and biomass lower. Hence the reason by biomass is the most preferred feedstock fuel.

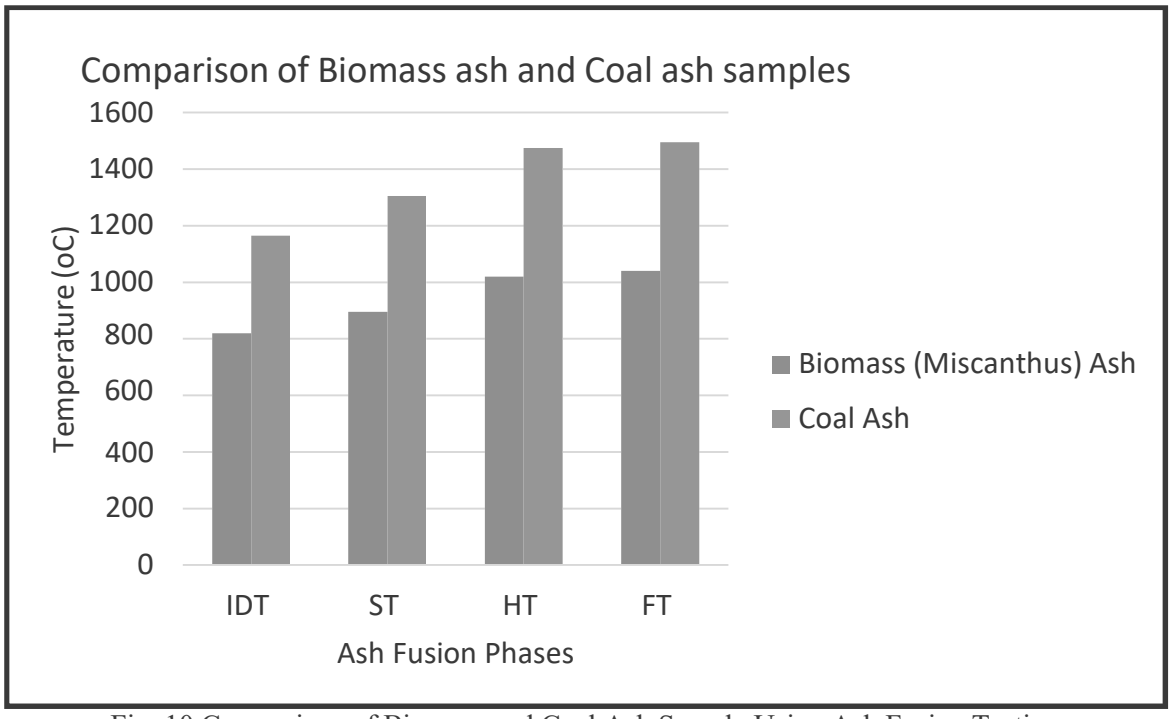

Fig. 10 Comparison of Biomass and Coal Ash Sample Using Ash Fusion Testing

4. Conclusions

The ash fusion testing experiment on biomass ash and coal ash; revealed that biomass ash had lower temperatures than coal ash for the four temperatures phases. This tends to support biomass as feed for power stations in the reduction of greenhouse gases emitted into the atmosphere. The four temperatures attained in the ash fusion testing of both samples are initial deformation temperature, softening temperature, hemispherical temperature, and fluid temperature. The EDX profile and semi-quantitative analysis of biomass and coal ash show that coal has more elements embedded within than biomass. The biomass ash sample has the lowest concentration of Fe. The coal ash sample also exhibited the presence of two elements not found in the biomass ash sample. These are Ti and Zr. This research aims to compare the viability of consideration of biomass over coal through ash fusion testing.

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