PHYSICAL, CHEMICAL AND MINERALOGICAL PROPERTIES OF FLY ASH AND BOTTOM ASH

Ahmad Aiman Azmi and Christina Vargis

Faculty of Chemical Engineering, Universiti Teknologi Mara

Abstract— **The unused fly ash and bottom ash is one of the major problems of all combustion power plants in Malaysia and it brings significant problems to the environment such as the air pollution and groundwater contamination. Having said that, both fly ash and bottom ash have shown suitability in many industrial applications such as cement concrete and agriculture. There is a potential for fly ash and bottom ash to be used as a substitute material in a production. Objectives of this study are to investigate the physical, chemical and mineralogical properties of fly ash and bottom ash taken from the Stesen Janakuasa Elektrik Sultan Abdul Aziz Shah, Kapar, Selangor. Differences in composition is what makes these two ashes differ from each other. Fly ash and bottom ash consist mostly of silicon dioxide. 50% of the diameter particles in the fly ash is between 26.227 µm to 107.731 µm while the other 50% is smaller than 26.227 µm. Meanwhile for bottom ash size distribution analysis, the result shown that 40% is between 18.078 µm to 72.799 µm and remaining 50% of it has diameter between 72.799 µm to 161.071 µm. Mineralogical analysis shows fly ash contains quartz which consist of silicon dioxide, SiO_2. Second mineral detected is Hanjiangite. Another mineral that can be detected is aluminum niobium oxide nitride. In bottom ash analysis, there is a little amount of Berylium Cobalt detected. The presence of Niobium Tantalum Titanium Carbide can be seen. Unburned carbon has been detected in bottom ash during the research.**

Keywords— Fly ash, bottom ash, XRF, XRD, PSA

I. INTRODUCTION

Percentage of minerals possessed by the coal varies by its type and source taken. After the process of incineration takes place, coal ash can be collected along with some of the unburned carbon during the incineration. Combustion with a high level of temperatures and pressures generates by-products which are known as ash [1]. The ash itself can be divided into two categories which are fly ash and bottom ash. The amount of both fly ash and bottom ash produced depends on the combustion condition, amount of mineral matter existing in the coal and volume of coal being burnt at the power plant itself.

Fly ash has a fine, delicate, glassy sphere and very much looks similar in appearance to cement while bottom ash is more to pebbly sandy texture. When it comes to fly ash, it consists of silica, iron, and alumina and it could form a cement with the presence of water [2]. Bottom ash particles are way much rougher than fly ash. It has a scratchy and porous surface texture [3]. Bottom ash is composed of silica, iron, alumina, magnesium, sulfate and a little amount of calcium. Bottom ash typically contain higher amount of carbon compared to fly ash.

As much the danger it has, coal fly ash and bottom ash is also a valuable resource as a replacement of substance in selected productions commonly used in concrete making. Approximately 70% of the fly ash is being taken away to the cement manufacturers and producers. Meanwhile the remaining 30% is thrown away and

deposited into the ash pond because of the quality control procedures [4]. In addition, fly ash can be utilized in agriculture as it acts as a plant nutrient because of the calcium (Ca), magnesium (Mg), potassium (K), sulphur (S), iron (Fe) and zinc (Zn) content [5].

Different amount of fly ash and bottom ash will give different results and its application in industrial might be affected. Standard requirements that has been set must be followed for safety purpose. Appropriate and acceptable reuse of fly ash and bottom ash will provide a one-way solution in reducing the environmental threat. Finally, this research will emerge a new path of finding the suitable key features in fly ash and bottom ash that would be the selling point in increasing the potential of application in industry. Hence this research is to investigate the physical, chemical and mineralogical properties of fly ash and bottom ash.

II. METHODOLOGY

A. Materials

The sample of fly ash and bottom ash is taken from the Stesen Janakuasa Elektrik Sultan Abdul Aziz Shah, Kapar, Selangor. Both ashes are byproducts from coal ash incineration process.

Chemical Composition - The chemical composition of both ashes has been identified by using X-ray Fluorescence (XRF) (*model Axios)*. Boric acid was mixed with both ash in the coin shape crucible before doing the compression. The amount of boric acid placed was 3/4 of the crucible to support the base of the ash during XRF. 1/4 of the crucible was filled with the ash. Next the compression was done carefully until the compression force reached 250 Pa. The coin shape compressed sample was collected from the compression machine. The prepared sample was positioned inside the XRF crucible lead to be analyzed.

Mineralogical Composition – Setup used is X-ray Diffraction (XRD) (*model D/max-2200/PC).* The sample of fly ash didn't have to go through grinding and sieving because its size was already less than 150 µm. For more accurate comparison for both ashes, bottom ash need a size reduction in the size range of less than 150 µm. Hence, bottom ash was grinded using mortar to reduce the particle size. Next the grinded bottom ash was placed into 150 µm sieve sieved for 20 minutes. The bottom ash powder was collected for further. The fly ash and bottom ash were placed on top of sample holder. The sample holder then was placed in the XRD sample stage and the XRD door was locked properly. Cr Kα X radiation, 40kV and 30mA is used. Divergence and anti-scatters slits fixed at 1° (receiving slit 0.2 mm). Scans is done from angular angle of 2° to 60° (2θ) and with the increments of 0.04°. Time of 4 seconds per step was selected and to be counted.

Particle Size Distribution – Size distribution has been measured using Particle Size Analyzer (*model Malvern particle size analyzer 2000*). 700 ml beaker was filled with water and a spatula filled with prepared sample was placed into the beaker. An external ultrasonic bath (35 kHz, 320 W) was used for the de-agglomeration of the particles, increasing the dispersion efficiency. The particle refractive index was set at 1.65. The stirring speed was set between 1700 rpm to 2500 rpm.

III. RESULTS AND DISCUSSION

A. The physical appearance of fly ash and bottom ash

Physical appearance of both sample can be observed in Table 1.

Table 1: Physical appearance of fly ash and bottom ash

Fly ash	Bottom ash
(a) 	(b) 
- Fine, spherical, delicate and greyish.	- Sandy texture, rough, pebbly and dark grey in colour.

B. Chemical composition of fly ash and bottom ash

Chemical composition of the studied fly ash sample in Table 2 is shown below.

Table 2: Chemical composition of fly ash used

Compound	Content, % wt
SiO_2	37.908
Al_2O_3	31.248
Fe_2O_3	21.126
CaO	3.451
MgO	3.129
TiO_2	1.478
K_2O	0.693
Na_2O	0.612
SO_3	0.284
Ga_2O_3	0.070

Fly ash sample studied consists of SiO_2 and Al_2O_3 as the major constituents of 37.908% and 31.248% respectively. Meanwhile Fe_2O_3 serves as the third major constituent with 21.126%.

Table 3 below shown SiO_2, Al_2O_3, Fe_2O_3 are major constituents of bottom ash sample and together represents more than 85 wt%.

Table 3: Chemical composition of bottom ash sample

Compound	Content, % wt
SiO_2	36.474
Al_2O_3	29.380
Fe_2O_3	22.577
MgO	5.110
CaO	2.326
Na_2O	1.245
ZnO	1.001
TiO_2	0.978
K_2O	0.888
SO_3	0.022

Bottom ash sample studied consists of SiO_2 and Al_2O_3 as the major constituents of 36.474% and 29.380% respectively. Meanwhile Fe_2O_3 takes place as the third major constituent with only 22.577%.

Comparison has been made in Figure 1 to show the differences between fly ash and bottom ash.

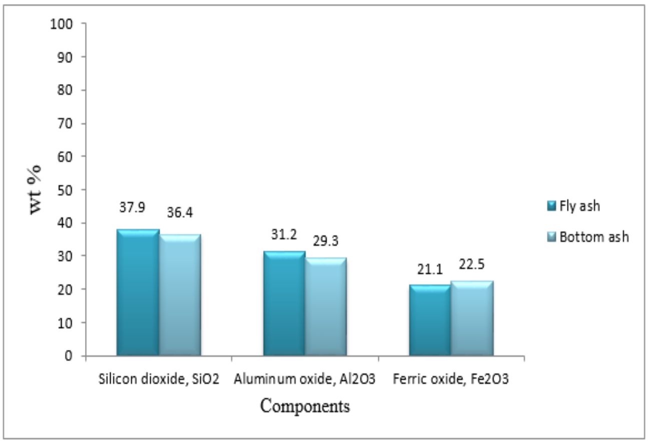

Fig. 1: Major constituents comparison between fly ash and bottom ash

The SiO_2 in fly ash is 1.5 wt% more than in bottom ash. Silicon dioxide also known as silica has been known as the major constituent of sand [6]. Fly ash and bottom ash have been used in cement industry because mixture of cement needs materials that has silica, alumina, iron oxide and calcium compounds. Al_2O_3 in fly ash has surpassed the amount that bottom ash has by 1.9 wt%. However, bottom ash has more 1.4% of Fe_2O_3 compared to fly ash. Note that fly ash has 0.070% of Ga_2O_3 while bottom ash has none of it. Bottom ash has 1.001% of ZnO while fly ash has 0.00% of ZnO in it.

ASTM C168 specifies that the combination of silica, alumina and iron greater than 70% can be used in the industry [7]. From the results obtained, combination of these three major compounds from the sample fly ash and bottom ash has 90.2% and 88.2% respectively which is greater than 70%. Hence both ashes can be used as a replacement in the industry as it meets the ASTM C168 requirements and chemical composition.

There exists a wide variation in elemental composition of fly ash and bottom ash. It usually contains considerable amounts of plant nutrients such as Ca, K, and Mg [8]. Some heavy metals leach out of the ash ponds and contaminate the soil, surface and ground water. These heavy metals have been known to limit the survival and growth of plants and microbial population [9]. Hence these elements make the fly ash and bottom ash suitable to be used in agriculture as plant nutrient. Based on the analysis, both samples don't have heavy metals or toxic such as lead (Pb), nickel (Ni), selenium (Se), and copper (Cu). This means both samples could become a good supplementary material in various industry such as cement and agriculture [10].

Comparison of minor constituents between fly ash and bottom ash has been made. Figure 2 below shows the difference in wt% of minor constituents.

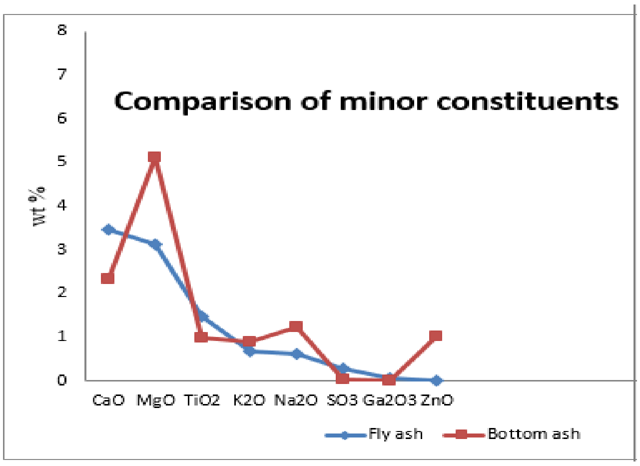

Fig. 2: Minor components comparison between fly ash and bottom ash

There are certain elements that cannot be found in both samples. For example, fly ash has Gallium (III) oxide (Ga_2O_3) while there is none in bottom ash. The same goes for the presence Zinc Oxide (ZnO) in bottom ash that cannot be found in fly ash. From the XRF analysis, the differences in amount of minor constituents between fly ash and bottom ash are slightly similar. Both has CaO, MgO, TiO_2, K_2O, Na_2O, and SO_3. Alas, the wt % of these remainder components barely reach 6.00 wt%. The highest would be MgO of bottom ash with 5.110 wt %. This means the existence of these components somehow can be considered negligible due to the very least amount of it.

C. *Particle size distribution analysis*

Figure 3 shows the size distribution of fly ash.

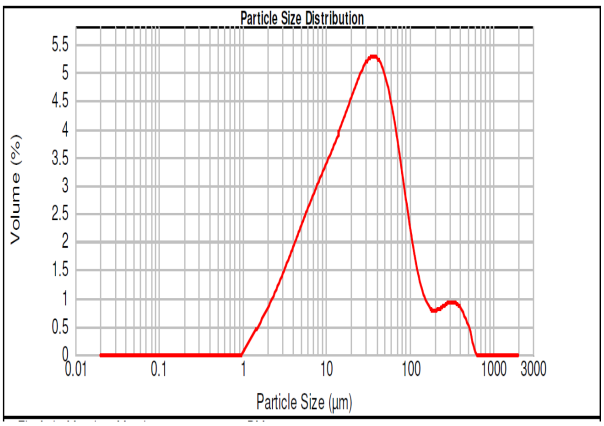

Fig. 3: Fly ash size distribution plot

Table 4 below is generated from the size distribution report.

Table 4: Size distribution data for fly ash

Variable	Result
Particle Refractive index	1.650
Dispersant Name	Water
Dispersant Refractive Index	1.330
Surface Weighted Mean D[3,2]	12.065 µm
Volume Weighted Mean D[4,3]	51.505 µm
Specific Surface Area	0.497 m^2/g
d(0.1)	4.719 µm
d(0.5)	26.227 µm
d(0.9)	107.731 µm

Fly ash particle is in granule size. D[4,3] or known as volume mean diameter of fly ash is 51.505 µm. The surface area of fly ash shown in the results is 0.497 m^2/g. The value d(0.1) equals to 4.719 µm in Table 4 means 10% of the particles sample in the tested sample are smaller than 4.719 µm. The value d(0.5) equals to 26.227 µm

Table 5 below features the summary from the data obtained in the size distribution.

Table 5: Summary of fly ash size distribution

Particle distribution	Less than 4.719 µm	4.719 µm – 26.227 µm	26.227 µm – 107.730 µm
	10%	40%	50%

Figure 4 below shows the cumulative graph that the median diameter is at 26.227 µm. Lastly the d(0.9) of fly ash examined is 107.731 µm. This explains that 90% of the fly ash's diameter is smaller than 107.731 µm.

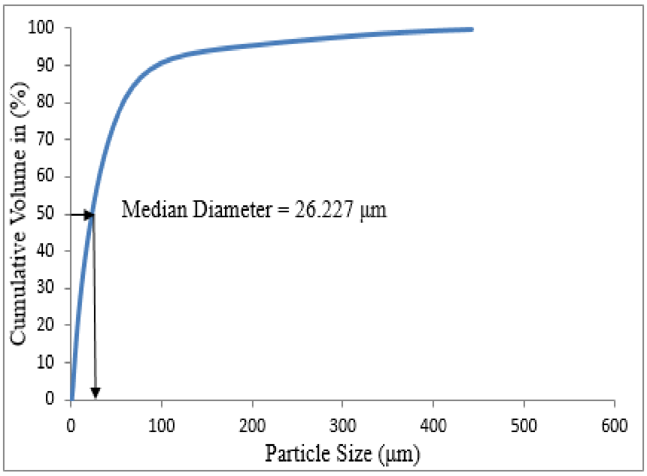

Fig. 4: Cumulative Volume (%) against Particle Size (µm) of fly ash

The bottom ash size distribution is shown in the Figure 5.

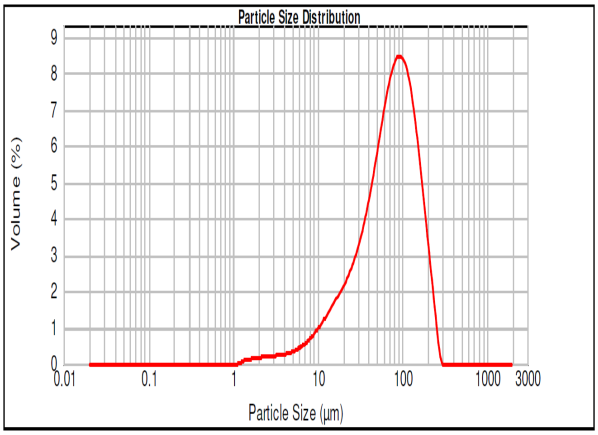

Fig. 5: Bottom ash size distribution plot

Table 6 below is generated from the size distribution report of bottom ash sample.

Table 6: Particle size analyser data for bottom ash

Variable	Result
Particle Refractive index	1.650
Dispersant Name	Water
Dispersant Refractive Index	1.330
Surface Weighted Mean D[3,2]	34.297 µm
Volume Weighted Mean D[4,3]	82.432 µm
Specific Surface Area	0.175 m^2/g
d(0.1)	18.078 µm
d(0.5)	72.799 µm
d(0.9)	161.071 µm

The surface weighted mean, D[3,2] value is 34.297 µm. The value of volume weighted mean, D[4,3] is 82.432 µm. The specific area of tested sample of bottom ash is 0.175 m^2/g. A big difference for bottom ash can be seen when it comes to diameter size. The result shown that 10% of the bottom ash has diameter less than 18.078 µm and 90% of it has diameter less than 161.071 µm. Table 7 and Figure 6 below features summary on bottom ash size distribution and cumulative graph of bottom ash respectively.

Table 7 Summary of bottom ash size distribution

Particle distribution	Less than 18.078 µm	18.078 µm – 72.799 µm	72.799 µm – 161.071 µm
	10%	40%	50%

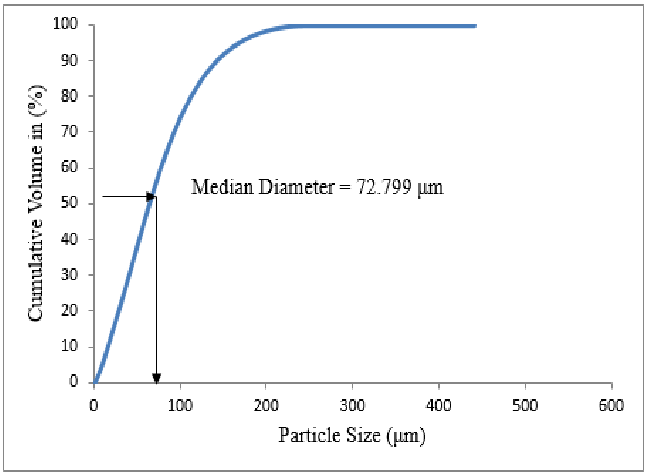

Fig. 6: Cumulative Volume (%) against Particle Size (µm) of bottom ash

The comparison between mean surface and volume diameter between tested sample of fly ash and bottom ash can be illustrated just like in Figure 7.

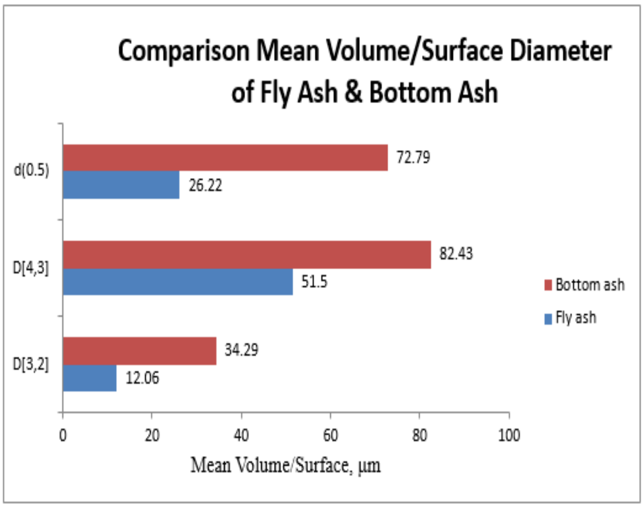

Fig. 7: Comparison of mean surface/volume diameter between fly ash and bottom ash

Mean diameter of bottom ash 72.79 µm obviously is 2.7 times bigger compared to fly ash with a mean diameter of only 26.22 µm. This can be seen from the observation of naked eyes which tells that bottom ash is much bigger and coarser with more sandy texture looking. The D[4,3] value for bottom ash displayed 82.43 µm which is 1.6 times higher compared to fly ash which has 51.5 µm. Bottom ash still dominates in terms of diameter even for the D[3,2] value. Bottom ash shows 34.29 µm in surface weighted mean which is 2.84 times bigger than fly ash which only consists of 12.06 µm.

Size distribution report has shown the specific surface area for both fly ash and bottom ash. The comparison made in Figure 8 between these two samples can enlighten the differences in terms of surface area.

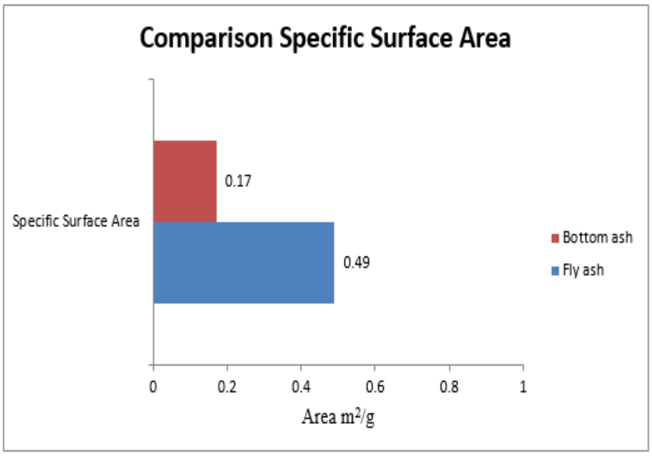

Fig. 8: Comparison specific surface area between fly ash and bottom ash

The smaller the size of the particles, the larger their specific surface area [11]. This hypothesis seems true enough since fly ash is smaller in size compared to bottom ash. Fly ash with a specific surface area of 0.49 m^2/g is 2.8 times bigger than bottom ash with 0.17 m2/g specific surface area.

D. Mineralogical composition of fly ash and bottom ash

In Figure 9, the Integrated X-ray powder diffraction software results has shown a comparison on the existed database library and produced the graph shown below for fly ash sample.

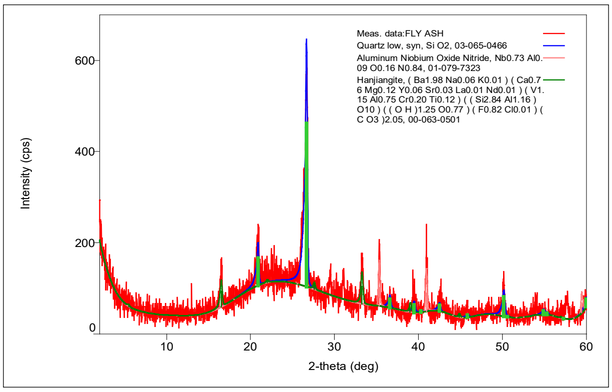

Fig. 9: Qualitative analysis for fly ash sample.

The highest peak intensity shown represents quartz which consist of silicon dioxide, SiO_2. Second mineral noted is Hanjiangite. Another mineral that can be detected is aluminum niobium oxide nitride. There is no unburned carbon detected from the qualitative analysis. This indicates that the fly ash has been burnt completely during the combustion in power plant. Unburned carbon is necessary to be taken seriously because high unburned carbon levels in ash does not only constitute an energy loss during combustion, it can also hinder technological utilization of such ashes [12].

Mineral that have been detected in bottom ash is carbon, berylium cobalt and niobium tantalum titanium carbide shown in Figure 10.

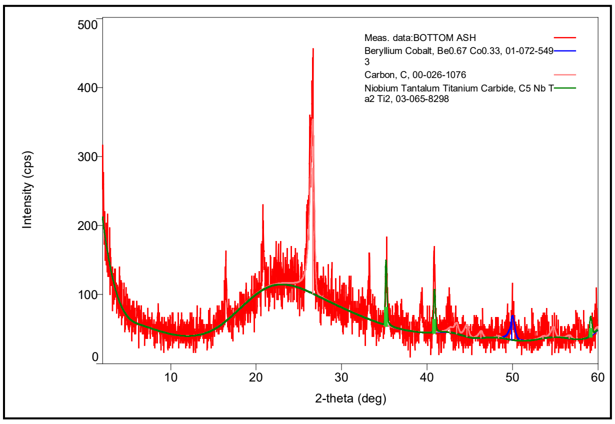

Fig. 10: Qualitative analysis results of bottom ash

Unburned carbon has been detected in bottom ash during the research. This unburned carbon exists due to the incomplete combustion during the combustion at the power plant. The content of unburned carbon is vital because it makes the bottom ash unsuitable for incorporation as aggregate for road construction [13]. It is known that carbon content is closely related to the particle size distribution in ash. The amount of unburned carbon reduces with the increases of fineness of the ash particles. Reliable determination of unburned carbon content in ash provides not only an indicator of the efficiency of the combustion process, but is also a practical indicator for the evaluation of feasible utilization of the ash [14]. This explains bottom ash has more carbon content to its size distribution is more larger and more coarser compared to fly ash.

IV. CONCLUSION

The purposes of coal combustion for power and heat production involves the generation of large quantities of wastes such as fly ash and bottom ash. This research has revealed the physical, chemical and mineralogical properties of both fly ash and bottom ash. Differences exist between these two samples in terms of physical, chemical and mineral aspects. Fly ash is more fineness, spherical in shape and greyish in colour. Bottom ash has more sandy texture, rougher and coarser and looks dark grey in colour. Chemical composition of the studied fly ash sample consists of SiO_2 and Al_2O_3 as the major constituents of 37.908% and 31.248% respectively. Meanwhile Fe_2O_3 serves as the third major constituent with 21.126%. In bottom ash major constituents, 36.474% is from SiO_2, 29.380% is Al_2O_3, and 22.5777% is Fe_2O_3. Together they represent more than 85 wt%. For fly ash size distribution analysis, value d(0.1) equals to 4.719 µm means 10% of the particles sample in the tested sample are smaller than 4.719 µm. The value d(0.5) equals to 26.227 µm and d(0.9) equals to 107.731 µm. This tells 50% of the diameter particles in the fly ash is between 26.227 µm to 107.731 µm while the other 50% is smaller than 26.227 µm. Meanwhile for bottom ash size distribution analysis, the result shown that 10% of the bottom ash has diameter less than 18.078 µm, 40% is between 18.078 µm to 72.799 µm and remaining 50% of it has diameter between 72.799 µm to 161.071 µm. Mineralogical analysis shows that highest peak intensity in fly ash analysis represents quartz which consist of silicon dioxide, SiO_2. Second mineral noted is Hanjiangite. Another mineral that can be detected is aluminum niobium oxide nitride. However, in bottom ash analysis, there is a little amount of Berylium Cobalt detected. The presence of Niobium Tantalum Titanium Carbide can be seen. Unburned carbon has been detected in bottom ash during the research. This unburned carbon exists due to the incomplete combustion during the combustion at the power plant. Several recommendations have been proposed for future project. First is a test on heavy metals traces should be done to ensure fly ash and bottom ash are ready to be used for agriculture and cement industries. Second is more advance XRD software such as crystallinity determination should be used to produce more details analysis on the mineralogical composition of fly ash and bottom ash. Finally is the suggestion to determine the exact amount of unburned carbon levels in fly ash and bottom ash. Creating efficient and economical technique in recycling these power plant by-products will contribute to reserve natural raw materials and reduce the disposal cost of these wastes.

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