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# The potential of cenospheres production from Malaysian coal power plants

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**Abstract.** Coal Combustion Waste (CCW) fly ash, main component of coal ash waste generated at the Coal-Fired Power Plant throughout the year that causes the presents of toxic metals in the ash. Hence, pose significant health threats towards humans and environment. Cenosphere is a coal combustion by-product obtained from fly ash in boilers of coal fired power plants. The properties of cenosphere including spherical, lightweight, good thermal stability, chemical proof, heat resistance making it to have improved insulation. The aim of this research was to investigate the potential of cenospheres production from three different coal fired power plants in Malaysia namely Jimah, Kapar and Manjung. The wet method was used for cenospheres separation from the fly ash. The percentages of cenospheres ranged from 1 to 1.2% of every 1000 gram of fly ash. The mean sizes were 95.86 $\mu$ m, 88.64 $\mu$ m, 49.04 $\mu$ m for Jimah, Kapar and Manjung respectively. Cenosphere evacuated by utilizing water as a medium, it will expend a lot of water and lead to water contamination cause of leaching of toxic material while extracting the cenosphere from fly ash. Nevertheless, any health and environmental impacts from the value-added physical application of cenospheres in civil engineering materials must be screened via strict monitoring and legislated guidelines.

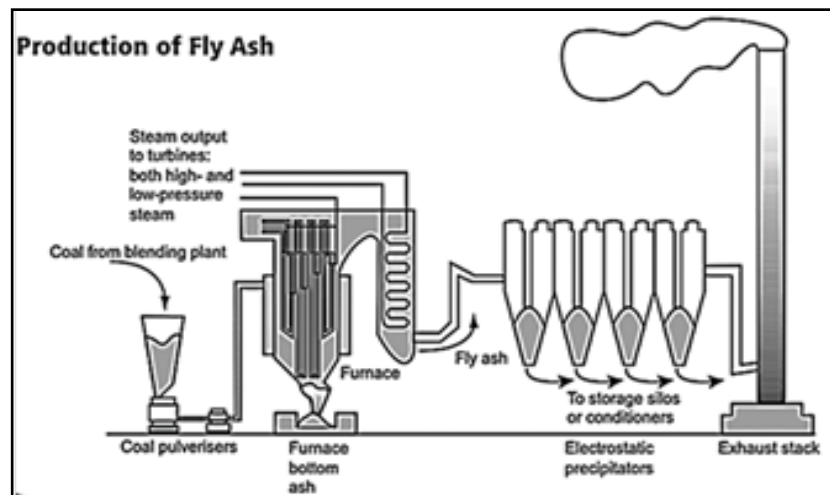
## 1. Introduction

Recently, there have been several studies and research conducted to reuse the waste produced by municipal solid waste [1]. Incineration is a growing form of waste management which is to reuse waste energy to produce electricity. To provide energy recovery, it can reduce the excess mass by 70 percent and the waste volume by 90 percent. Coal dependency in the energy sector is also observed in the Asia Pacific region, where coal has been used to cover more than 45 percent of energy consumption [1].

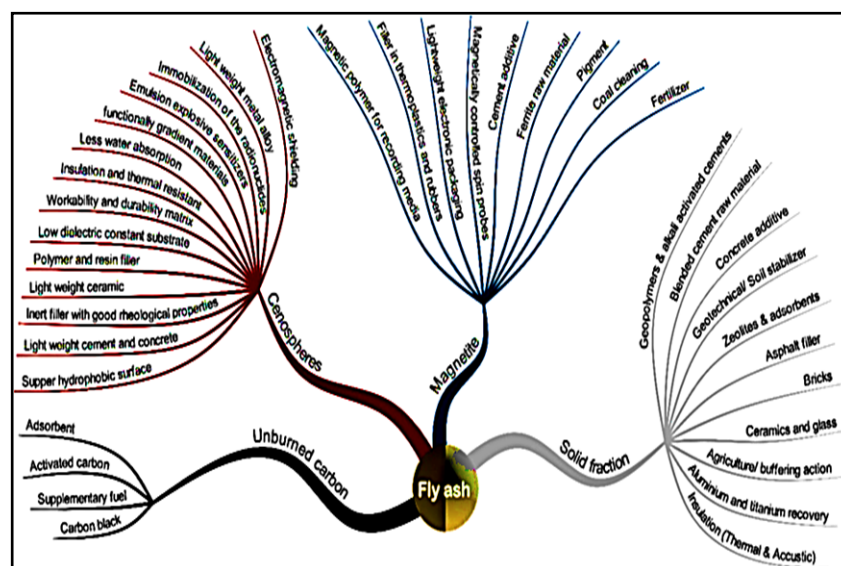
Electricity power is generated by combustion in thermal power plants. Coal combustion by products (CCPs) are commonly known as solid wastes produced during the combustion process. For instance, as fly ash, bottom ash, boiler slag, and flue gas desulphurization materials [2-5].



Figure 1 shows the by-product produced from burning pulverized coal in an electrical generating layout in a station, commonly known as fly ash. It's also gathered by mechanical or electrostatic separators, an incomplete combustion residue, and carried away by flue gases from the burning zone in the boiler [6]. Fly ash was reported to have various value-added applications by previous researchers as proposed in figure 2.



**Figure 1.** Coal-fired electrical generating layout in station [6].



**Figure 2.** Components of fly ash and their potential applications [7].

One part of fly ash is the cenosphere. Along with its unique properties it has immense potential that it would be compatible with a wide variety of industrial applications.

### 1.1 Cenosphere

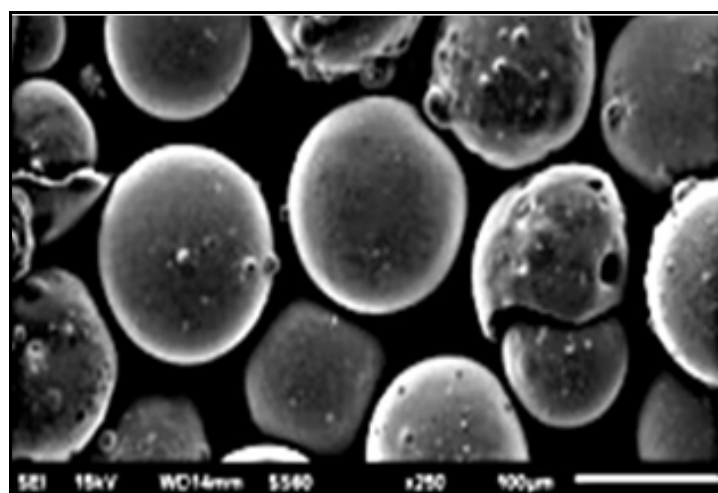
Cenosphere is one of the components that can be extracted from fly ash and has immense potential because of its unique properties including spherical, lightweight, heat resistant, have enhanced insulation, good thermal stability, and chemical inertness. In addition, the cenosphere will be

conformable to a wide range of industrial applications such as, engineering industry, highway engineering, oil, and gas industry, foundry engineering as well as in the chemical industry [7].

There are some factors that lead to an increase in demand for the cenosphere such as, low density, excellent mechanical strength and reasonable cost. A limited study of the cenosphere from the Malaysian sources was found from previous studies [8]. The characteristic of the cenospheres from each coal power plant is slightly different. The formation of the cenosphere is occurred starting from thermochemical results, and phase of the transformations due to mineral coal formed in the combustion. Granulometric, chemical, and phase-mineral compositions of the cenospheres are depending on the composition of the original coal, type of furnaces employed, conditions used for cooling melt droplets, and etcetera [12]. As mentioned earlier, cenosphere means hollow and spherical. These hollows are formed during coal combustion at high temperatures. The larger size of hollow formed by a thin wall size (wall thickness is less than 10 percent of the diameter), and represented about 1-2 percent (weight) of total fly ash, the higher the cenosphere 's ability to float in water [13].

As the sizes of hollow varies, density varies. The density of the cenosphere differs from silica which can be as high as ( $\sim 2600 \text{ kg/m}^3$ ) down to  $200 \text{ kg/m}^3$  and even lower, depending on the size and number of the gas inclusions in each particle [14]. According to Hirajima, the remaining 10% of the cenosphere have diameters lower than  $100 \mu\text{m}$ , while 90 % of the cenosphere have diameters between  $100 - 420 \mu\text{m}$  [15-16]. Several sizes of cenospheres were reported in the previous studies were in the ranges of  $10 \mu\text{m}$  to  $100 \mu\text{m}$  [8],  $1 \mu\text{m}$  to  $300 \mu\text{m}$  [9], and  $1 \mu\text{m}$  to  $600 \mu\text{m}$  [10]. These ranges of sizes can be compared with the size for cenospheres collected from the Malaysia power plants. The particle size of the cenospheres were large compared to the particle size of the fly ash due to the entangled air inside the rigid hollow sphere of the cenospheres [11].

Figure 3 shows spherical shapes of the cenosphere which lead to superior properties include: increasing flow characteristics; chemical inertness; less water absorption; lightweight; good packing factor; enhanced insulation; reduced shrinkage; excellent mechanical strength; good thermal resistance; and good electrical properties. Cenosphere can be used in a wide range of industrial processes to offer product enhancements, significant manufacturing advantages and cost reductions [17]. Due to its significant characteristics like shape, size and density become highly demanded in industrial applications. Unique properties of cenosphere make it suitable for wide range industrial applications [18].

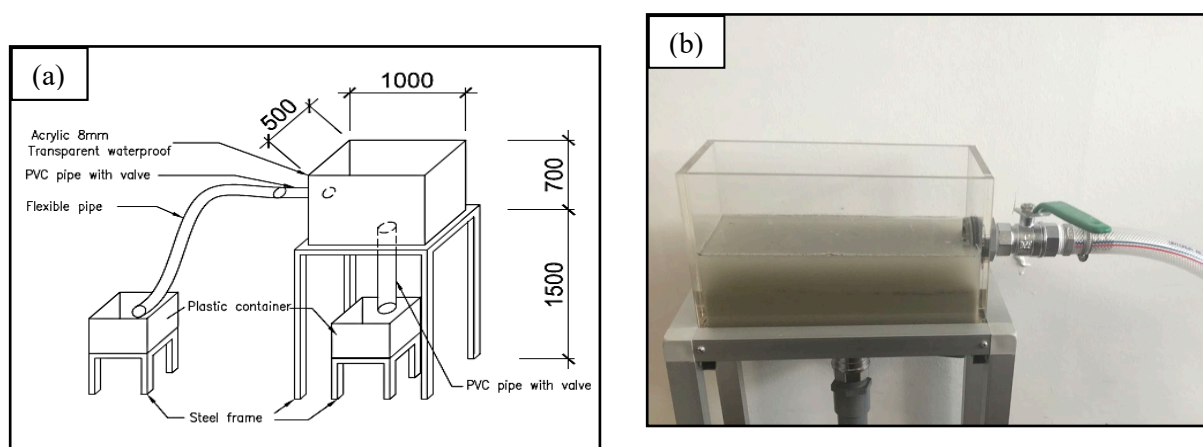


**Figure 3.** Spherical particles shape formation of cenosphere in fly ash [7].

### 1.2 Cenosphere collection

Fly ash is a waste product, produced in large quantities. Cenosphere, one of the materials that has value-added fractions in fly ash, whereas it is already well-known that it is produced as a product of coal combustion at thermal power plants. The cenosphere that is used in this research is extracted from fly ash using the wet method (Floatation / Float and Sink Method).

Briefly, a method involving dispersing the samples of dry fly ash collected from the power plants in water (distilled water or tap water) at room temperature. By the gravity separation processes, the cenosphere is extracted and removed by using water as a medium in the form of a hydraulic separation illustrated in figure 4(b). The full drawing for the wet separation apparatus method can be referred in figure 4(a). by pond skimming. Commonly, several methods are used to distinguish cenospheres from fly ash, including sink-float, centrifugal separation, and hydro- and aero-dynamic separation combination.



**Figure 4.** Full drawing for the wet separation apparatus method in (a) and (b).

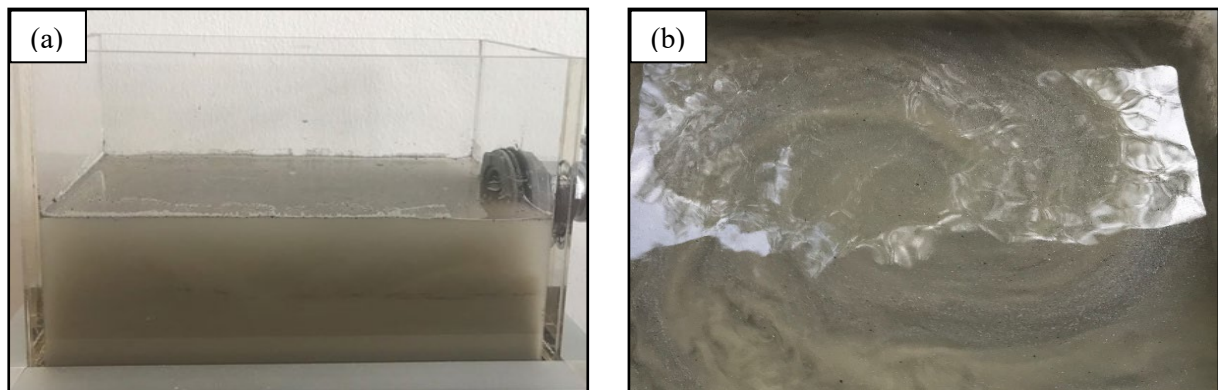
The aim of this research is to investigate the potential of production of cenospheres from existing coal fired power plants in Malaysia. The percentages of cenospheres per fly ash were reported. The particle sizes of cenospheres and fly ash were compared. However, the mobilization of heavy metals fluxes and rich compounds like fly ash are harmful to the environment and health [1]-[4]. As stated by Thomas [5], the leaching properties of Jimah power plant fly ash and bottom ash were in compliance with the allowable limits of metal metal (Lead (Pb) and Arsenic (As)) and industrial effluent (Zinc(Zn) and Copper (Cu)) hazardous waste guidelines.

As cenospheres are part of components from fly ash, the heavy metals fluxes mobilization might probably be similar. However, further studies on leaching properties of cenospheres are highly recommended. Any health and environmental implications from the value-added physical application of cenospheres in civil engineering materials should be strictly monitored according to the legislated guidelines.

## 2. Methodology

In this research, cenospheres were extracted from fly ash using the wet method (floatation / float and sink). This method involved dispersing of dry fly ash samples in distilled water at room temperature. The cenospheres were extracted and removed by using water as a medium in the form of a hydraulic separation method using the gravitational separation processes. Fly ash was sedimented upon continuous stirring leaving floated cenospheres. The cenospheres were collected via decantation followed by the filtration process at figure 5(a) and (b).





**Figure 5.** Cenospheres extraction methods: (a) wet method and (b) filtration method used in this study.

In Peninsular Malaysia, there are four well-known Power Plants, state-owned power companies that are assigned to supply coals shown in figure 6. Figure 7 shows cenosphere extracted from fly ash at Jimah, Kapar and Manjung power plants.



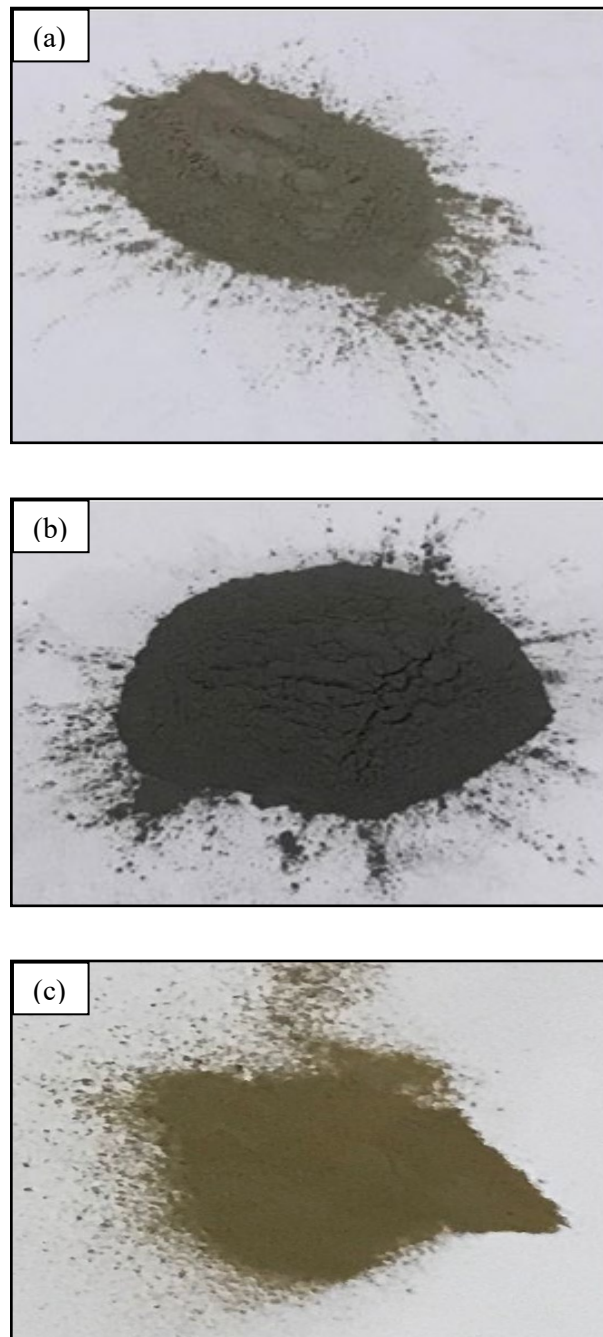
**Figure 6.** Power Plant Locations in Malaysia.

### 3. Result and discussion

Table 1 shows the percentage of cenospheres extracted using wet methods. The percentages of cenosphere were 1.2% (Jimah), 1.1% (Kapar) and 0.9% (Manjung). The percentage of the extracted cenospheres were comparable to previous literatures [14].

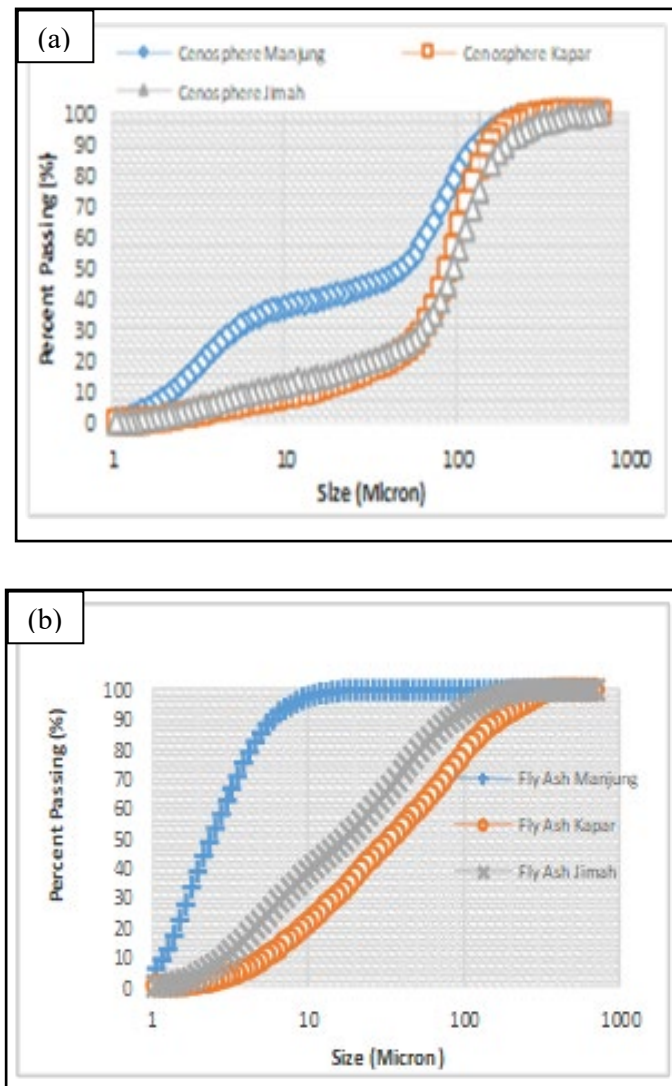
**Table 1** Percentage of Cenosphere extracted using the wet method.

| Power Plants | Mass Fly Ash (g) | Mass Cenosphere (g) | Percentage Cenosphere (%) |
|--------------|------------------|---------------------|---------------------------|
| Jimah        | 1000             | 12                  | 1.2                       |
| Kapar        | 1000             | 11                  | 1.1                       |
| Manjung      | 1000             | 9                   | 0.9                       |



**Figure 7** Cenospheres from (a) Jimah, (b) Kapar and (c) Manjung Power Plant.

Fly ash indicates that the median diameter ( $d_{50}$ ) is in the normal range from different sources between  $2.5\text{ }\mu\text{m}$  and  $40\text{ }\mu\text{m}$  in figure 8 (a). Similar to the extracted cenospheres in figure 8(b), it shows that the  $d_{50}$  ranged between  $40\text{ }\mu\text{m}$  and  $100\text{ }\mu\text{m}$ .



**Figure 8** Particle size distribution of (a) cenospheres and (b) fly ash.

The extracted cenospheres sizes were ranged between 1  $\mu\text{m}$  to 600  $\mu\text{m}$ . However, fly ash of different sources could account for the different sizes of cenospheres. The particle size of the cenosphere is large compared with the particle size of the fly ash [6].

#### 4. Conclusion

This research study is an effort to investigate the potential of cenospheres production from the existing power plants in Malaysia. The percentages of cenospheres production and the particles size of the extracted cenospheres were reported accordingly. The percentage of cenosphere extracted using wet methods for Jimah power plant sources, Kapar Power plant sources and Manjung Power Plant sources. It shows that the percentage of the cenosphere that is extracted for this study was around 1-2 % as stated by the previous researcher.

The percentages of cenospheres production and the particles size of the extracted cenospheres were reported accordingly. Sources from the Kapar power plant were found to have a larger size compared to the Jimah power plant while the finest particle size was observed at the Manjung power plant. The particle size of the cenospheres and fly ash for three separated power plants located in Malaysia



showed that the particle size of the cenospheres was large compared to the particle size of the fly ash due to entangled air inside the cenospheres' rigid sphere hence, raising the diameter.

### Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships which have, or could be perceived to have, influenced the work reported in this article.

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