Particulate Emission Characteristics from Palm Fibre and Shell Combustion with Alumino-Silicate Based Additives

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Abstract. Malaysia is one of the largest palm oil producers in the world with a continuous increment in worldwide demand. The palm oil extraction process leaves palm fibre and shell (F&S) as waste. The palm F&S are biomass fuels that have been utilized in many palm oil mills to generate energy through the combustion process. The release of harmful particulates from the combustion process is the main concern in this research. A few studies had shown that the PM2.5 particulate matters cannot be filtered by the Air Pollution Control System (APCS); thus, it can pollute the environment. In this research, the utilization of additives inside biomass fuels is studied. The effect of additives towards the particulate size of the ashes and determination of the best additive are the two main objectives of this research. The proximate and ultimate analysis was done to determine the combustion profile of the samples. The Scanning Electron Microscopy (SEM) analysis was done to determine the size of particulates inside the ashes.

1. Introduction

Due to its low impact on the environment, sustainable resource and more economical compared to that fossil fuel, biomass fuel has drawn a global interest [1]. To date, biomass ranks at fourth place for the source energy in the world, which is much higher compared to the coal [2]. Palm F&S, rice husk, sawdust and sugarcane bagasse are the examples of biomass fuels that have been used in the industries in Malaysia to produce energy. In the production of the palm oil in the palm oil mill industries, they leave palm fibre (PF), palm shell (PS) and empty fruit bunches (EFB) as wastes.

For energy generation, a boiler is used to utilize the palm wastes. The biomass combustion will produce bottom ash and fly ash. This will result in the release of harmful particulates in the environment. The installation of multi-cyclone as an air pollution control system (APCS) is one of the alternatives to reduce the harmful environmental effect of biomass combustion [3]. It is proven that the existing multi-cyclone has low efficiency in capturing fine particulates with a size of less than 10 µm or also known as PM10. Also, 26% from PM10 mass concentration is represented by PM2.5 emission, which is the finer size fraction [4].

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To date, there are number of studies have been done to solve the problems related to the particulate emission from biomass combustion. One of the solutions for this problem is by the addition of additives. Four mechanisms have been identified by Wang et al. [8] on how the additives can solve the ash related problems from the biomass combustion. First and foremost, by the transformation of low melting temperature elements into high temperature by chemical reaction and through the capture of fine particulate and condensable vapour by the porous additive particles. After that, through the increment of ash’s melting temperature by the presence of more inert materials and elements on the surface of the ash residue. Last but not least, through the dilution and accumulation of the melting ash.

Kaolin is one of the additives that has widely been used to solve the ash problems. Due to its small particle size, which is less than 10µm, Kaolin can provide a large surface area that is suitable for the absorption process [9]. Potassium capture can be achieved effectively at 700 °C and 800 °C by premixing Kaolin with the fuel [6]. Besides, Kaolin is the most efficient for the absorption of alkali metal compound, and it is an effective solvent for the volatile elements under the combustion condition due to the properties of Kaolin itself [6]. PreKot™ can be considered as one of the combustion additive based on its properties, and there is no existing study has been done in evaluating its performance as a combustion additive. PreKot™ is silica-based additive with a large surface area and very low moisture content. Masdiana et al. [10] found that the additive that has a large surface area is good for the purpose of adsorption since it will increase the degree of the contact area between the particles hence, lead to a better adsorption capacity.

2. Experimental

2.1. Proximate Analysis

The proximate analysis consists of the determination of moisture, volatile matter, fixed carbon and ash contents for the palm F&S. The moisture content of the palm F&S will be determined according to the methods specified in ASTM E871-82 (2006) Standard Method for Moisture Analysis of Particulate Wood Fuels. The volatile matter was determined based on ASTM D872 (2013) Standard Test Method for Volatile Matter in the Analysis of Particulate Wood Fuels. ASTM E1755-01 (2007) Standard Test Method for Ash in Biomass was referred to determine the ash content. Fixed carbon will be calculated based on equation 1.

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\text{Fixed Carbon} \% = 100 - (\text{Moisture} \% + \text{Volatile Matter} \% + \text{Ash} \%)
\]

2.2. Ultimate Analysis

The major elements such as Carbon (C), hydrogen (H), nitrogen (N) and sulphur (S) in the raw sample of palm F&S was determined in this analysis. The LECO Elemental Determinator CHN628 was used to determine the mass concentration of each element. A combustion technique was utilized inside this instrument, and the mass concentration for each element was obtained after 4.5 minutes. The system operation and data management were controlled by a custom software operated through an external PC.

2.3. Combustion Process

The palm fibre and palm shell were mixed at the ratio of 70:30 respectively as this ratio was the common ratio that has been practised by many palm oil mills [11], [12] with a total weight of 40 g. Based on the research done by S. Konomboon et al. [13], to retain the potassium completely in the solid phase, 8% of kaolin is sufficient. Thus, 8% of additives were added into the mixture of palm fibre and palm shell. Four samples were prepared which were palm F&S (E1), palm F&S with 8% of Kaolin (E2), palm F&S with 8% of PreKot™ (E3) and palm F&S with 4% of Kaolin and 4% of PreKot™ (E4). The samples composition are shown in table 1. All the samples underwent the combustion process inside the fluidized-bed reactor. All the samples were burned at a temperature of 800 °C for 45 minutes. The airflow was set at 1.24 L/min, and the excess air was 50%. The schematic diagram for the fluidized bed boiler was shown in figure 1. The ash residue for each sample was collected and analyzed.
Table 1. Sample composition

| Samples | Palm Fiber (wt. %) | Palm Shell (wt. %) | Kaolin (wt. %) | PreKot (wt. %) |
|---------|--------------------|--------------------|---------------|---------------|
| E1      | 70                 | 30                 | 0             | 0             |
| E2      | 70                 | 30                 | 8             | 0             |
| E3      | 70                 | 30                 | 0             | 8             |
| E4      | 70                 | 30                 | 4             | 4             |

Figure 1. The schematic diagram of fluidized bed-boiler

2.4. Particulate Size analysis

Scanning Electron Microscopy (SEM) analysis was done to observe the effect of additive towards particulate size. The model for the SEM device was Hitachi SU1510. A morphology image was created as the equipment scanned a focused electron beam over the surface of the samples. The equipment’s software was used to measure the particulate size of the morphology. 3 spots were obtained for each sample.

3. Results and Discussion

3.1. Palm F&S characteristics

The result of the proximate analysis is depicted in Table 2, which shows the mass percentage of moisture content, volatile matter, ash content and fixed carbon of the raw palm F&S. Higher moisture content in solid fuel will result in an increase in the volume of the exhaust gases and lower the temperature for the combustion process [14]. Besides, the lower ash content in the palm F&S indicates the least susceptibility of the slagging problem inside the boiler and lead to a longer period of the ash removal [15]. Based on the literature, the value of ash content was less 5% of the total weight. Volatile matter usually appeared in the form of smoke when the palm F&S combusted under sufficient air, temperature, time, and turbulence condition [16]. Ignition and combustion of palm F&S depend on volatile matter. Based on research done by Miller [17], the fuel was easily ignited as the value of volatile content is high and lead to better carbon burnout. Besides, the value of the volatile matter in palm F&S was more than 80% of the total weight.
The value of Moisture Content of Palm Fiber and Shell is low compared to wood chips [9] and Rice straws [8], which is good for the complete combustion of biomass fuel. Besides, the value of the volatile matter of Palm Fiber and Shell is high compared to rice straws [8] and empty fruit bunch [13], which offers many advantages as a combustion feedstock. Furthermore, the value of fixed carbon of palm fiber and shell is lower than empty fruit bunch [13] and rice straw [8] which is good as it can reduce the ignition and combustion problems. Finally, the value ash content of the palm fibre and shell is low compared to empty fruit bunch [13] and rice straw [8]. The melting point of the dissolved ash can be low, this causes fouling and slagging problems.

The result of the ultimate analysis of palm fibre, palm shell and palm F&S were shown in Table 3. The content of Carbon (C), Hydrogen (H), Nitrogen (N), and Sulphur (S) determines the heating value and the environmental effect after the combustion process [18]. Hydrogen (H) and Carbon (C) were the primary sources for the heating process, and they have a decisive effect on the heating value for solid fuel [5]. Besides, a high value of Nitrogen (N) content can lead to an increase of NOx concentration, thus harm the environment [19]. Furthermore, the high Sulphur (S) content inside the combustion fuel can also pollute the environment and cause corrosion inside the combustor [20].

### Table 2. Proximate analysis of palm fiber, palm shell and palm F&S

| Types of Solid Fuel | Moisture Content (wt. %) | Ash Content (wt. %) | Volatile matter (wt. %) | Fixed Carbon (wt. %) |
|---------------------|--------------------------|---------------------|-------------------------|---------------------|
| Palm Fiber          | 11.40 ± 0.31             | 3.56 ± 0.21         | 84.24 ± 0.42            | 12.20 ± 0.28        |
| Palm Shell          | 11.55 ± 0.14             | 4.88 ± 0.62         | 77.53 ± 0.64            | 17.59 ± 0.14        |
| Palm F&S            | 11.36 ± 1.11             | 2.40 ± 0.69         | 85.51 ± 0.53            | 12.09 ± 1.16        |

3.2. Physical Characteristics of Ash

The ashes for all the samples were compared. Three spots were selected for each sample. Irregular-shaped of fine particulates were observed from SEM results for E1, as shown in Figure 2. It is observed that the size of the particulate was in the range of 186 μm to 430 μm. Figure 3 shows the particulate images of E2 which the particulates is finer and less irregularly shaped due to the presence of additives. Niduangdee & Kuprianov [21] claim that Kaolin can reduce the agglomeration of ash during the combustion process and thus, decreasing the size of particulate for irregular shaped. The range particulates sizes were around 96.7 μm to 272 μm. Spherical shape and porous particulates were observed for E3 ashes. Besides, the addition of PreKot™ to the combustion of palm F&S leads to the formation of pozzolanic-like materials inside the ash with less crystalline particulates. It is formed by the combination of minerals as PreKot™ originated from volcanoes in the form of very finely divided vitreous material. The particulates sizes were in the range of 157 μm to 1450 μm.

The particulates shape E4, which is shown in Figure 5 was quite the same as E3, which were porous and spherical-like. Particulates sizes of ash from the combustion of Palm F&S with Kaolin and PreKot™ additives are in the range between 217 μm to 2290 μm. The range of particulate sizes was compared for all samples in Figure 6, which shows that E4 has the largest size of ash which is 2290 μm. This is due to the large surface area of the additives and the capture of problematic elements. E3 has the second-largest particulate size, which is 1450 μm. Meanwhile, E2 has the smallest particulate size compared to the other samples. The larger the size of particulate indicates that more elements were absorbed by the additives, thus reduces the harmful effects to the environment and the combustor.
Figure 2. SEM images for E1: (a) Spot 1 (b) Spot 2 (c) Spot 3.

Figure 3. SEM images for E2: (a) Spot 1 (b) Spot 2 (c) Spot 3.
Figure 4. SEM images of E3: (a) Spot 1 (b) Spot 2 (c) Spot 3.

Figure 5. SEM images for E4: (a) Spot 1 (b) Spot 2 (c) Spot 3.
4. Conclusion
The combustion of the palm F&S with the addition of PreKot produce larger ash compared to the addition of Kaolin. The combustion of palm F&S with the addition of 4% of Kaolin and 4% of PreKot produce the largest size of particulates. The addition of Kaolin seems to reduce the particulate size of the ash. E4 and E3 are the best combination to produce a larger size of particulate matter inside the ashes.

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