Effect of Additives on the Ash Element from Combustion of Palm Fiber and Shell

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Abstract. Palm fibre and shell (F&S) are commonly used in the combustion process to produce steam and electricity in palm oil mills in Malaysia. Unfortunately, the combustion process releases various types of elements that tends to react with each other contributing to operational and environmental issues. Thus, this motivated, a study to evaluate the concentration of the elements such as C, O, Si, K, and Al in the ash with the presence of two combustion additive which are Kaolin and PreKot^{TM}. The study was performed by simulating the industrial combustion in a laboratory-scale fluidised-bed reactor with addition of the additives at 8% ratio from the 40 g total weight of each sample at 800°C with the supply of 50% excess air at 1.24 L/min air flow. The ash residue were investigated for elemental composition on the ash surface. Interestingly, the study showed that the concentration of the element on the ash surface increased with the addition of additives especially at a 50% ratio of Kaolin and PreKot^{TM}. The higher concentration of the element on the ash surface indicates the reduction of fine particulate. Hence, the study revealed that addition of Kaolin & Prekot^{TM} in combustion process has a promising future not only within palm oil industry but also other industry.

1. Introduction

The combustion of the palm fiber and shell (hereinafter F&S) resulting in the formation of both the organic and inorganic components such as Potassium (K), Carbon (C), Silicon (Si), and Magnesium (Mg). These elements are present in the raw palm F&S which are released either in the vapour phase or retained in the solid phase after combustion. The presence of these elements in the vapour phase contributes to various environmental and operability problems in the combustor due to the tendency of these elements to react with each other [1]. In addition, lower concentration of these elements in the ash increases the release of fine particulate sized less than 2.5 µm (PM$_{2.5}$) to the atmosphere [2]. In return, fine particulate emission will affect the efficiency of the air pollution control system installed

after the combustion process [2]. Moreover, the reaction of these elements with each other forms a low melting temperature compound that contributes to various operational problem such as slagging, eventually reducing the efficiency of the reactor [1]. Therefore, various studies were conducted on the utilizing of the combustion additive such as kaolin, magnesium, and coal to mitigate the problems caused by the release of elements in the vapour state. However, a new material namely, PreKot™ has yet been explored as the combustion additives whereby it has similar physical characteristics as Kaolin. Generally, this study aims to investigate the performance of the additives on the ash element.

2. Methodology
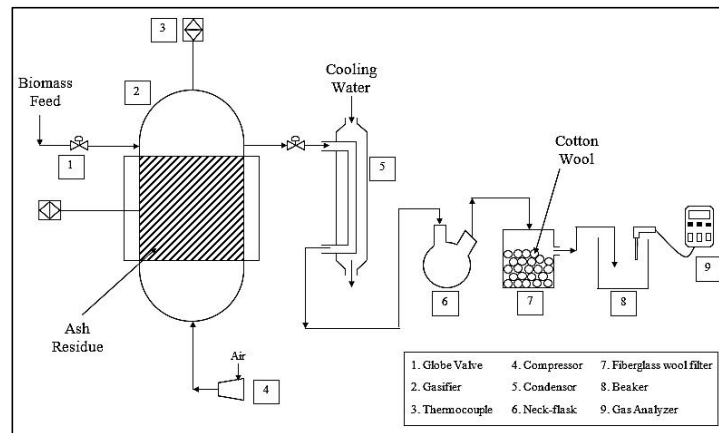
2.1. Characterisation of the Palm F&S
The characteristic of palm F&S was determined based on the proximate and ultimate analysis. The proximate analysis was done to determine the moisture, ash, volatile matter content according to the ASTM D2867-09, ASTM D1102 and ASTM E871, respectively. While the ultimate analysis was done in determining the mass concentration of major elements in the palm F&S such as carbon, hydrogen, nitrogen, and sulphur in was detected using Elemental Determinator (LECO, MODEL: CHN628 Series).

2.2. Combustion of Palm F&S with Additive Using Fluidized Bed Reactor
Table 1 shows four different types of samples with variant composition of fuel and additives used for the combustion process. Figure 1 depicts the schematic diagram of the fluidized-bed reactor, where the sample was combusted at 800°C with 50% excess air at airflow of 1.24 L/min for 45 minutes. The mix ratio of palm F&S was maintained at 70:30 throughout the work, as it is a typical mixing ratio that is used in the palm oil boiler. Upon completion of combustion, the ash sample was collected and analyzed for the elemental content using a Scanning Electron Microscope and Energy-Dispersive X-ray Spectroscopy (SEM-EDX) HITACHI, MODEL: SU1510.

Table 1. Indicator for the types of samples used in the experiment.

Types of sample	Indicators
Palm F&S	EXP 1
Palm F&S with 8% of Kaolin	EXP 2
Palm F&S with 8% of PreKot™	EXP 3
Palm F&S with 4% of Kaolin and 4% PreKot™	EXP 4

Figure 1. Schematic diagram of the Fluidised-Bed Reactor.

3. Results and Discussions

3.1. Palm F&S Characterization

Table 2 depicts the proximate analysis value for palm fibre, palm shell and mixture of palm F&S at mix ratio of 70:30, which showed that the palm shell has higher ash content compared to the palm fibre. This would contribute to more ash generation if palm shell is burned alone.

Table 2. Proximate analysis of the palm fuel (dry basis).

Types of Solid Fuel	Parameters			
	Moisture Content (%)	Ash Content (%)	Volatile Matter (%)	Fixed Carbon (%)
Palm Fibre	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
F&S (70:30)	11.36 ± 1.11	2.40 ± 0.69	85.51 ± 0.53	12.09 ± 1.16

Table 3 depicts the ultimate analysis for the sample of solid fuel, which showed that the highest composition for both sample is carbon. Sulphur content for both fuels is relatively low where the value is 0.14 ± 0.01 wt% and 0.03 ± 0.01wt %, respectively, which indicate that less potential for the fuel to generates sulphuric acid gases. The elemental composition such as Carbon (C), Hydrogen (H), Nitrogen (N) and Sulphur (S) are an important characteristic for any combustible substances. It determines the properties of the substances, especially in terms of their heating values and the effect on the environment after it undergoes the combustion process [3].

**Table 3.** Ultimate analysis of the palm fuel.

Types of Solid Fuel	Component (wt %)			
	C	H	N	S
Palm Fibre	43.38 ± 2.23	6.95 ± 0.24	0.84 ± 0.05	0.14 ± 0.01
Palm Shell	54.04 ± 0.09	8.78 ± 0.55	0.97 ± 0.21	0.03 ± 0.01

3.2. Morphology Analysis of the Ash

Figure 2 depicts the morphology of the ash sample for EXP 1, 2, 3 and 4, which showed that morphology from EXP 1 appeared to be large oblong particles with a smooth surface. The existence of large oblong particles is due to the agglomeration phenomena of nanoparticles at high temperature [4].

In EXP 2, upon addition of Kaolin, ash particle seems to be irregular in shape and have more small coarse dark particles compared to the ash particles in EXP 1, which is not favour in this research. Besides, the surface on the ash particle is rougher compared to the ash particle in EXP 1. Ash particles from EXP 3 seems to appear less irregular and in angular shape with rough external surface. It is anticipated that the rougher surface results in better adsorption capacity of the elements in the ash due to the increasing of the porosity on the external surface of the ash sample.

The structure of the ash from EXP 4 appears to be in a molten state with a highly porous surface on the ash. It is completely different with previous sample of ash from EXP 12 and 3. The increase in porosity of the ash increases the adsorption of the elements which eventually increases the particle size of the ash. Higher porosity on the ash particle lead to the enlarged surface area with higher microspores volume which results to the higher adsorption capacity [5].


(a)

(b)

(c)

(d)
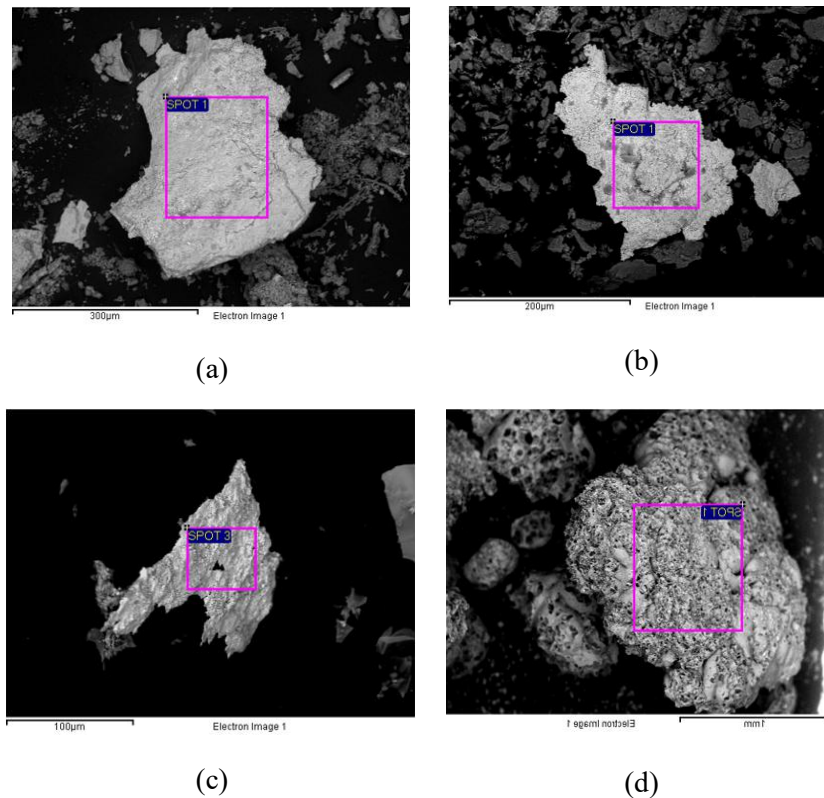
Figure 2. Morphology of the ash sample (a) EXP1 (b) EXP2 (c) EXP3 (d) EXP4.

3.3. Elemental Analysis of the Ash

Figure 3 depicts the summary of selected elemental concentrations from the combustion experiment, which shows that the addition of Kaolin in EXP 2 able to increase the concentration of Si at 1.74% compared to the concentration of Si in the raw ash sample in EXP 1. The addition of Kaolin to the combustion of palm F&S) clearly increases the concentration of Si and Al in the ash composition since it is an aluminosilicate-based additive [3]. Besides, the ash sample in EXP 4 has the highest concentration of Si, K, and Al which is 24.30 wt%, 6.16 wt%, and 5.16 wt% respectively due to the

mixture of Kaolin and PreKotTM additives whereby both additives are silicate-based. Silicates will undergo a chemical reaction with other elements and form a high melting temperature compound such as $KALSiO_4$ (Kalsite) and $KALSi_2O_4$ (Leusite) during the combustion process [1]. It leads to the reduction of operational problems such as ash sintering, fouling, and ash sintering in the reactor. Besides, the submicron particles that are being released to the atmosphere are mainly composed of refractory elements such as Si, K, and Al [2]. Therefore, it is important to trap all of these elements on the surface of ash particles, enlarge the size of particulate after combustion to reduce the emission of fine particulate from the air pollution control system.
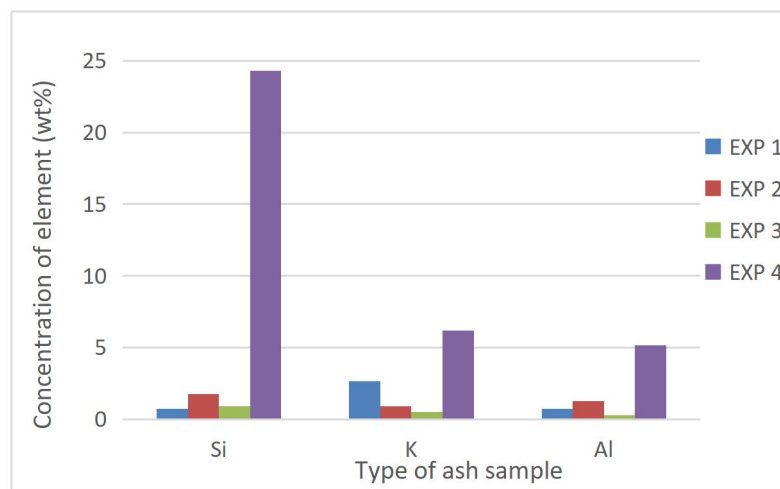
Figure 3.Concentration of Si, K, and Al element on ash surface for various ash sample.

4. Conclusions

In conclusion, it is proven that palm F&S are suitable to be used in the combustion process based on its chemical and physical characteristic where it has lower moisture content, ash content, and fixed carbon content which is < 12%, < 5%, and < 20%, respectively. It is revealed that the ash elemental are significantly affected by the presence of the combustion additive. The mix ratio of Kaolin and PreKot^{TM} additives gives the highest concentration of element on the ash surface, which will lead to the increment of the size of the particulate. This finding serve as a preliminary study on the characterization of the fuel, the additive and the ash which are warrant for future investigations. Results obtained from this study is beneficial to mitigate the problem to reduce fine particulate emission from the air pollution control system in the palm oil mill plant.

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