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EXPERIMENTAL STUDY OF PALM OIL MILL EFFLUENT AND OIL PALM FROND WASTE MIXTURE AS AN ALTERNATIVE BIOMASS FUEL

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Abstract

Palm oil mill effluent (POME) sludge generated from palm oil mill industry and oil palm frond (OPF) from oil palm plantation are considered biomass wastes that can be fully utilized as a renewable energy sources. In this study, an attempt has been made to convert these residues into solid biomass fuel. The study was conducted by developing experimental testing on the POME and OPF mixture. The performance of each sample with different weight percentage was investigated using standard tests. The biomass mixture was converted into compressed form of briquette through a simple process. The properties of the briquettes were observed and compared at different weight percentage following standard testing methods included ultimate and proximate analyses, burning characteristics, dimensional stability and crack analysis. Experimental results showed that POME sludge and OPF mixture is feasible as an alternative biomass fuel, with briquette of 90:10 POME sludge to OPF ratio has a good combination of properties as an overall.

Keywords: Renewable energy, Biomass fuel, Briquette, Oil palm frond, Palm oil effluent.

1. Introduction

Increasing trend in the awareness of biomass potential as an alternative energy source, palm oil mill industry has emerged to be an attractive platform for continuous and large biomass supply. In Malaysia, the oil palm industry has contributed a lot to the country's economic development. In fact, crude palm oil (CPO) production has increased from only 1.3 million tonnes in 1975 to approximately 18.60 million tonnes in 2010. Meanwhile, the total oil palm planted area in the country has increased to 4.85 million hectares in 2010 [1].

Abbreviations	
CPO	Crude palm oil
CV	Calorific value
FFB	Fresh fruit bunches
OPF	Oil palm frond
POME	Palm oil mill effluent

The major products of palm oil processing plant is crude palm oil (CPO) and palm kernel and its biomass waster consists of fiber, shell, empty fruit bunch and palm oil mill effluent, Prasertatsan [2]. In the oil palm plantation, the major biomass waste is trunks and oil palm fronds. In the palm oil processing, it is estimated that for every tonne of CPO produced, 5 to 7.5 tonnes of water are required, and about 3.5 m3 of POME is generated, Parveen et al. [3]. POME also contains substantial quantities of solids which are left after the treatment. These solids are commonly known as POME sludge. Therefore, due to the large quantity of POME production each year, the amount of sludge increases, respectively. This sludge results in bad odors and considered as a pollutant.

On the other hand, with the significantly large plantations areas in Malaysia, a large amount of OPF are pruned regularly during the harvesting of fresh fruit bunches (FFB). It was estimated that for every tonne of CPO processed from FFB, around 6 tonnes of waste of OPF is produced, Sulaiman et al. [4]. The OPF are pruned regularly and left on the ground for natural decomposition which is a slow and uneconomical process. Open burning or simply abandon the waste away is a great loss of energy source since these biomass have significant energy content.

The sludge from POME is a source of pollutant and harmful waste to the environment if discharged untreated, while OPF is usually left on the ground for natural decomposition. Considering their large and consistent supply, POME sludge and OPF mixture could be a promising source of alternative energy.

Considering their large and consistent supply, OPF and POME sludge mixture can be considered as an alternative biomass fuel. Therefore, the feasibility of POME sludge and OPF mixture as an alternative biomass fuel is studied. This was followed by developing experimental testing for these biomass fuels in briquette form. Comprehensive experimental investigations were then performed on each briquette with different weight percentage.

2. Literature Review

2.1. Characteristic of palm oil mill effluent

Characteristics of POME depend on the quality of the raw material and palm oil production processes in palm oil mills. The extraction of CPO from FFB requires huge amount of water. According to Sethupathi [5], POME is mainly generated from sterilization of FFB, clarification of the extracted CPO and hydrocyclone separation of kernel in which large amounts of steam and hot water are used.

POME, when fresh is in the form of thick brownish in colour colloidal slurry of water, oil and fine cellulosic fruit residues. Typically, POME is generated from mill operation at a temperature of between 80°C and 90°C and it is slightly acidic with a pH between 4 to 5, Parveen et al. [3]. POME is a non-toxic waste, as no chemical is added during the oil extraction process, but will pose environmental issues due to large oxygen depleting capability in aquatic system due to organic and nutrient contents.

POME consists of suspended solids and dissolves solids which are left after anaerobic treatment. Therefore, due to the large quantity of POME production each year, the amount of the sludge increases, respectively. It has high amount of moisture content, with pH of 8.4 and enriched with organic matter.

2.2. Characteristic of oil palm fronds

The average density of oil palm fronds is about 700 kg/m3. The weight of each OPF is between 15 and 20 kg depending on the age and condition of the palm tree. The OPF comprises of two main components which are petiole and leaflets. The dry matter weight ratio of petiole to leaflets (including the rachis) is 1.5, Sulaiman et al. [4].

According to Chaney [6], typically, the main biomass composition is carbon. It comprises between 30% to 60% of the dry matter. After that, typically 30% to 40% is oxygen. Hydrogen is the third main constituent making up between about 5–6%. Nitrogen and sulfur (and chlorine) normally make up less than 1% of dry biomass. The OPF has reasonably high carbon content which is 42.65% and the content of nitrogen and sulfur are low. The H:C and O:C ratios are 0.13 and 1.17, respectively.

In terms of energy availability in the fuel, one significant collection of natural fuels shows a linear correlation of the heat of combustion at 400°C with the carbon content of the analysis, Dietenberger [7]. This reveal that OPF could be a good candidate for fuel briquette as high carbon content would be desired since it is an important element in the combustion. A low content of sulfur would be desired as well since its emission could react with water and oxygen to form acidic compound such as acid rain. A comparison of the average carbon content with other types of biomass feed shows that OPF have reasonably high carbon content, which would be considered as competitive with other biomass sources.

3. Experimental Procedure

The POME sludge OPF materials were processed into compact briquettes, through several processes. The procedure suggested by Chin et al. [8] was adopted in the present analysis. The materials were dried, pulverized and finally pressed. The ratios used for POME sludge and OPF were 10:90, 30:70, 50:50, 70:30 and 90:10. A series of tests were performed on the fuel briquettes that divided into two main categories; chemical and mechanical properties tests.

The samples of POME sludge and OPF materials were directly dried in an oven at 105 °C until consistency in the sample’s mass is obtained in order to reduce the moisture content. The other samples were let dry under ambient condition for 24 hours, to reduce their moisture content naturally. In the next step, the mixture of POME and OPF were grinded into powder by using mortar grinder. The grinded sample was then collected and removed from the grinder.

The final process is to compact the POME and OPF mixture by using automatic pellet press. The samples were loaded into a cylindrical mould with an external diameter of 60 mm and a central hole diameter of 40 mm. The briquette produced in this study weighed about 10 g and approximately 7 mm in height.

4. Results and Discussion

The results obtained from comprehensive experimental investigations covered: proximate and ultimate analysis, burning characteristics test, dimensional stability analysis, durability analysis and crack analysis.

4.1. Proximate analysis

The moisture content of POME sludge and OPF mixture that directly dried in the oven were obtained as 10.30% and 3.73%, while samples that dried under ambient condition were recorded as 21.39% and 11.91%, respectively, as shown in the Fig. 1. The calorific value (CV) test result for POME sludge and OPF mixture in an oven dried is presented in Table 1 and Fig. 2, respectively.

Table 1. CV Test Result for Oven Dried Samples.

POME: OPF (%)	Calorific Value (kJ/kg)			
	1	2	3	Mean
10	18710	18547	19031	18763
30	22026	21858	21120	21668
50	23574	23405	24100	23693
70	26053	26550	25600	26068
90	30408	31065	31076	30850

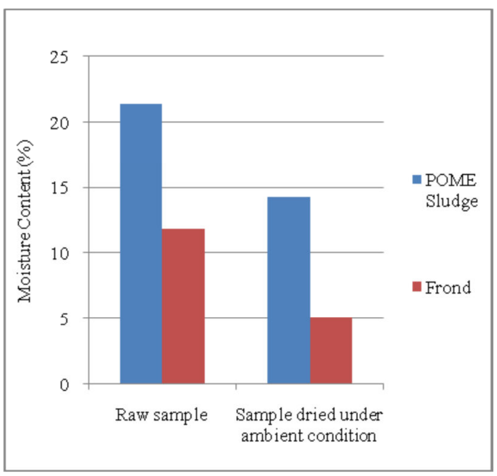

Fig. 1. Moisture Content of POME and OPF.

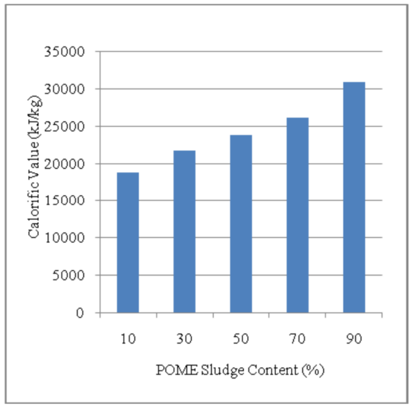

Fig. 2. Average CV for Oven Dried Samples.

Based on the results, it was found that five ratios of POME sludge and OPF mixture show calorific value ranging from 18763 kJ/kg to 30850 kJ/kg. It was noted that the calorific value of the briquette increases with increasing POME sludge content, with the 90:10 POME sludge to OPF showing the highest value. Another set of calorific value test was conducted on the samples that dried under ambient condition is shown in Fig. 3.

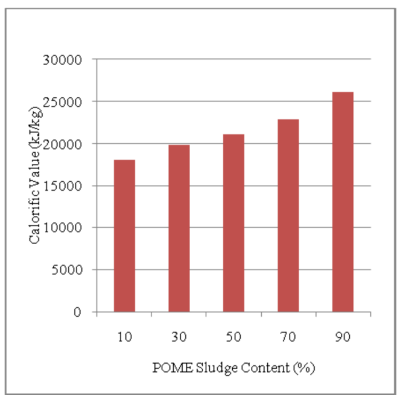

Fig. 3. Average CV for the Sample Dried under Ambient Conditions.

For the five ratios of POME sludge and OPF mixture, the CV ranged from 18099 kJ/kg to 26132 kJ/kg, It was also noted that the calorific value of the briquette increases with increasing POME sludge content, with the 90:10 POME sludge to OPF briquette showing the highest calorific value.

The relationship between the POME sludge content with the average calorific value of the briquette for both experiments is shown in Fig. 4. Samples with oven dried showed higher calorific value than samples dried under ambient condition for all five ratios. Therefore, it can be concluded that the calorific value is limited by biomass moisture content. This is due to the reason that the moisture in the biomass will absorb heat by vaporization and heating of the resulting vapor during combustion in which significantly reduced the heating value of the mixture.

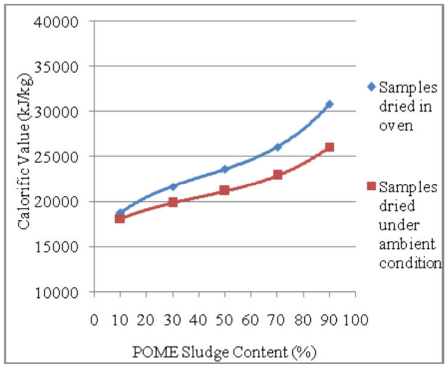

Fig. 4. Calorific Value against POME/OPF Mixing Percent.

4.2. Ultimate analysis

Figures 5, 6, 7, and 8 show the measured composition of carbon, hydrogen, nitrogen and sulfur of 10:90, 30:70, 50:50, 70:30 and 90:10 POME sludge to OPF briquette ratios, respectively. Ultimate analysis result revealed that these mixtures have reasonably high carbon and hydrogen content. A high carbon and hydrogen content means a high calorific value. This is due to the reason that when biomass is combusted, energy is released by breaking of high-energy bonds between carbon and hydrogen.

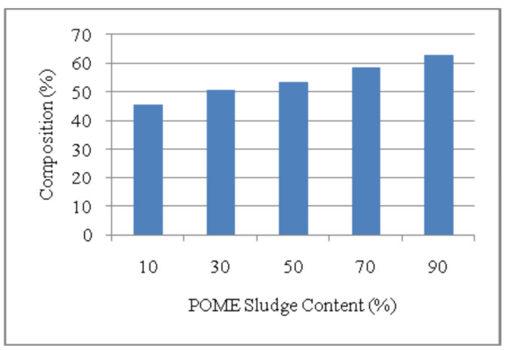

Fig. 5. Carbon Content of Samples.

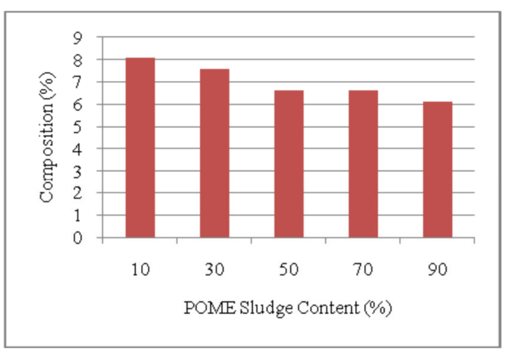

Fig. 6. Hydrogen Content of Samples.

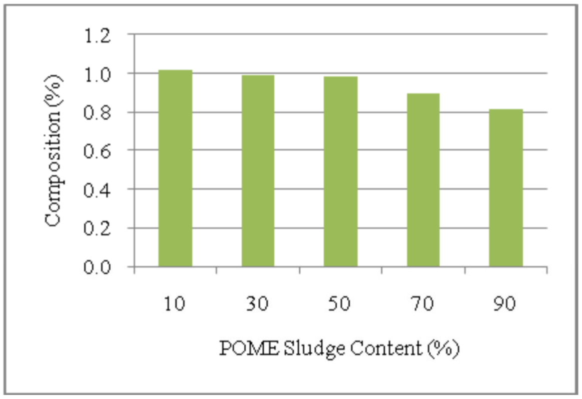

Fig. 7. Nitrogen Content of Samples.

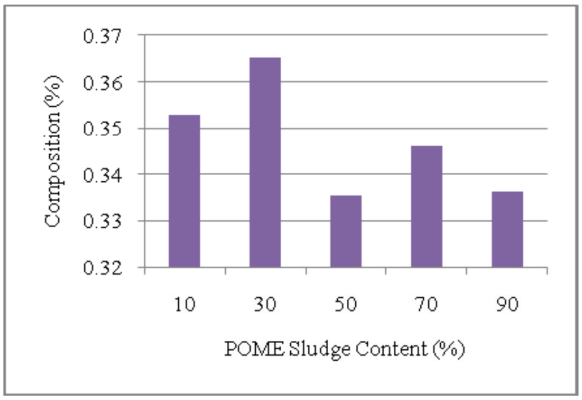

Fig. 8. Sulfur Content of Samples.

Fuel-bound nitrogen is responsible for most nitrogen oxide (NO_x) emissions produced from biomass combustion. Low nitrogen content in this mixture lead to lower NO_x emissions which would bring negative effects to the environment. Sulfur oxides (SO_x) are formed during combustion and contribute significantly to particulate matter pollution and acid rain. Since this mixture has negligible sulfur content with average below 0.4%, its combustion does not contribute significantly to sulfur emissions.

4.3. Burning characteristics test

Figures 9 and 10 show the ignition time against POME sludge content and the time taken to burn to ashes against POME sludge content, respectively. From Fig. 9, the 90:10 POME sludge to OPF briquette has the highest ignition time while the 10:90 POME sludge to OPF briquette has the lowest ignition time. It is observed that ignition time increases with increasing POME sludge content. From Fig. 10, the 90:10 POME sludge to OPF briquette took the longest time to burn into ashes among all the samples. Similar to the previous observation, time taken to burn ashes increases with increasing POME sludge content.

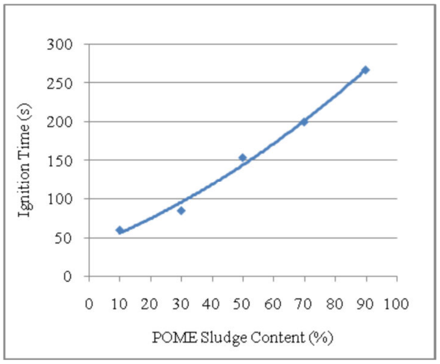

Fig. 9. Ignition Time vs. POME/OPF Mixture.

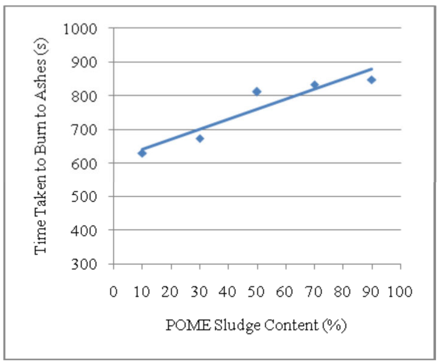

Fig. 10. Time Taken vs. POME/OPF Mixture.

This observation might be due to lower porosity and higher density of the briquettes with high POME sludge content. POME sludge is an oily material and would result in a mixture with low porosity after undergoing compression. Thus, the ignition time and time taken to burn to ashes of the briquettes which contain small percentage of POME becomes shorter. Short ignition time is required in order to ease biomass fuel to start combustion. However, the time taken to burn the briquette into ashes for a good quality biomass briquette should be as long as possible. This is very important as it indicates that the briquettes can supply energy in longer period.

4.4. Dimensional stability analysis

Stability serves as an index of the extent of resistance of briquettes to changes in their initial physical dimensions, Demirbas [9]. The average measured diameter for all the five ratios of POME sludge and OPF mixture is plotted in Fig. 11.

The results reveal that the 10:90 POME sludge to OPF briquette is the least stable, followed by the 30:70 POME sludge to OPF briquette. Generally 50:50, 70:30, 90:10 POME sludge to OPF briquettes are stable and expanded less than 0.5% in the first three weeks. This is contributed by the high POME sludge content that acts as binder which in turn held the briquette firmly together.

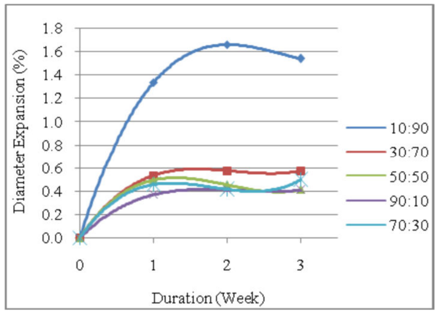

Fig. 11. Diameter Expansion against Duration.

4.5. Crack analysis

In crack analysis, briquette is dropped from 1 m high and any crack in the radial direction was noted and measured. Result from the crack analysis is illustrated in Fig. 12. Crack analysis results show that 10:90 POME sludge to OPF briquette had partially broken into small pieces. Meanwhile, 30:70 POME sludge to OPF briquette shows a very minor crack. Whereas 50:50, 70:30, 90:10 POME sludge to OPF briquettes are strong and free of crack. It can be concluded that the briquettes with low percentage of POME have the tendency to exhibit more cracks. This could be due to the reason that oily material like POME sludge tend to hold briquette tightly together.

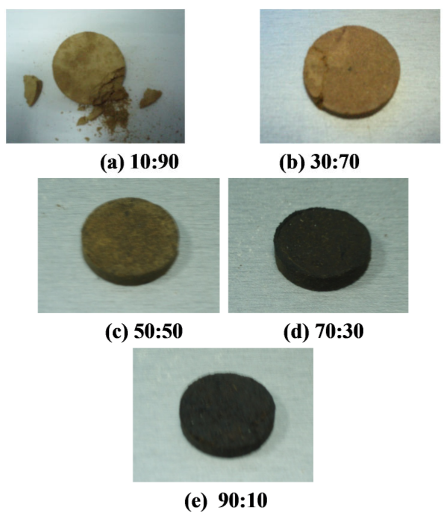

Fig. 12. Crack Analysis Test of Fuel Briquette.

5. Conclusions

The mixture of palm oil mill effluent (POME) sludge and oil palm fronds (OPF) as a solid fuel briquette for alternative biomass fuel were experimentally investigated under various volume ratios. Based on results obtained, the mixture of POME sludge and OPF are feasible as an alternative biomass fuel in terms of solid fuel briquette. Therefore, the main conclusions from this study may be summarized as follows:

- Combination properties of palm oil mill effluent (POME) sludge to oil palm fronds (OPF) briquette resulted in high caloric value for fuel briquette
- Ultimate analysis result reveals that these mixtures have high carbon and hydrogen content, also produces low contents of nitrogen and sulfur. High carbon content would be desired since it is an important element in the combustion.
- POME sludge to OPF briquettes are strong and free of crack based on the results from crack analysis.
- In dimensional stability analysis, the combination of POME sludge to OPF briquettes are found stable and expanded less than 0.5% within 3 weeks

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