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Torrefaction of Oil Palm Fronds for Enhancement of Fuel Quality

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ABSTRACT
In this study, pretreatment of oil palm fronds through torrefaction is studied. The process is carried out using a laboratory reactor. The conditions of torrefaction are varied and properties of the resulting products are observed, such as energy content and energy density. It is found that the calorific value of the torrefied fronds increases by about 50% as compared to those without torrefaction. Furthermore, the weight of the biomass decreases by about 75% due to evaporation of water and volatile matters. The resulting properties would ease transport and logistics and would result in better yields in combustion or gasification.

Key words: Biomass, oil-palm fronds, torrefaction

INTRODUCTION
The use of biomass as energy source is important towards sustainable environment (Okoroigwe, 2007) as it reduces the dependence on the fossil fuels while being available in many parts of the world. To convert biomass into energy source, there are many different conversion methods such as biofuel (Abdeshahian *et al*., 2010; Ibeto *et al*., 2011), direct combustion and gasification (Ahmad *et al*., 2011; Atnaw *et al*., 2011a; Iqbal *et al*., 2010; Mohammed *et al*., 2011; Yusof *et al*., 2008). With global increase in the demand of fossil fuels, efficient biomass conversion technologies such as gasification are becoming more important as a source of competitive renewable energy. Gasification, for example, being one of the attractive conversion methods produces syngas (H_2, CH_4 and CO) by heating biomass particles at temperature 800 and 1000°C (Repellin *et al*., 2010) for combustion in engines or burners.

However, an untreated biomass has a few weaknesses that must be overcome before it can be converted into a useful energy source; these include its low energy density, high moisture content and difficulty to grind into small particles. Problems encountered in the gasification of biomass such as wood are often related to the properties of the fuel or biomass feedstock. The low energy density and high moisture content of biomass can affect the hydrogen production rate during the gasification (Ahmad *et al*., 2011). These properties also make the cost of transporting the biomass to be high. In addition, the wood must be reduced to fine size in order to perform efficient gasification at high temperature (Esteban and Carrasco, 2006). Moreover, formation of tar that cause choking and blockage in the gasifier is due to the thermal instability of wood. It was also has been reported (Schubert and Bernotat, 2004) that grinding of fresh wood would require high amount of energy. In order to increase the efficiency of gasification and to reduce the costs of storage and transportation, biomass can to be treated via drying and mild pyrolysis, a process that is known as torrefaction. The process of torrefaction involves heat treatment at a certain temperature of range for a specific period of time. The process would result in a lower moisture content, increased energy density and ease to grind.

In this study, the effectiveness of pre-treatment of oil palm fronds by torrefaction is studied. The study involves variation of heating temperature and residence time of torrefaction. The parameters of interest include energy density, moisture content and grindability. Oil palm trees are pruned during the harvesting of fresh fruit bunches for the production of oil. It was estimated that 36 million tones of pruned fronds were produced in 2003 (Wanzahari *et al.*, 2003), with an average rate of 24 pieces per year from every oil palm tree, although the biomass has very limited usage. Interest in oil palm fronds are still limited to agriculture (Haniff, 2006; Osemwegie and Okhuoy, 2009; Ramin *et al.*, 2008) until quite recently where a few studies on gasification of the biomass (Atnaw *et al.*, 2011a, b) have been reported.

TORREFACTION OF BIOMASS

Torrefaction is a thermo-chemical method of biomass conversion that is carried out under a temperature range of 220-300°C with an inert atmosphere. The reaction time for torrefaction generally decreased with temperature. The properties of torrefied biomass depend on type of biomass used, temperature and reaction time applied. A study on the impact of torrefaction on syngas production from wood (Couhert *et al.*, 2009) but there has never been any work involving oil palm fronds. Torrefaction allows moisture and low weight organic volatile component of biomass to be removed and thus producing solid product with an increased energy density and brittle structure. Torrefied biomass also has a brown to dark brown a color of which the property is between wood and coal. In a recent work, Uemura *et al.* (2010) was studied the relationship between calorific value and elementary composition of torrefied lignocellulosic biomass and it was proposed that the triangle of carbon, hydrogen and oxygen contents in untreated and pyrolyzed biomass is proposed as an appropriate tool for analysis of biomass decomposition behavior.

There are several advantages of biomass torrefaction. Torrefied biomass is moisture resistant because the material becomes more hydrophobic (Arias *et al.*, 2008). Furthermore, torrefaction greatly enhance grindability and therefore the energy consumption for milling torrefied biomass is three to seven times lower than that of raw materials (Deng *et al.*, 2009). The improved grindability also makes torrefied biomass easier to be shaped into briquettes or pallets. Hence, torrefied biomass is very attractive for combustion and gasification applications. In Fig. 1,

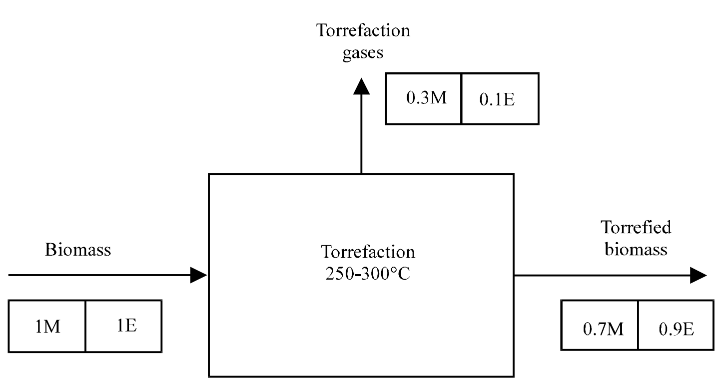

Fig. 1: Typical mass and energy balance of the torrefaction process. Reproduced from Bergman *et al.* (2005)

a typical mass and energy balance of torrefaction is shown. Seventy percent of the mass is usually retained as a solid product, containing 90% of the initial energy content. The remainder 30% of the mass is converted into torrefaction gases, but containing only 10% of the energy content of the biomass.

EXPERIMENT SET UP

The oil palm frond samples were collected from a nearby palm oil estate. The fresh samples were green in color. They were left to dry under the sun for a period of 3 days to ensure a dry sample. The samples were cut to a size of 1-2 inch. Further drying was allowed in an oven at 105°C for 24 h as a pre-treatment process, in which the moisture content in the fronds was completely eliminated. The dried samples were turned into powder by using a granulator and a rock lab grinder.

The biomass was torrefied in Lenton Tube Furnace. The dried samples were divided into three different groups: Sample-1 (46.97 g), Sample-2 (50.66 g) and Sample-3 (44.14 g) and they were torrefied at 230°C for 50 min, 250°C for 30 min and 270°C for 15 min, respectively.

The schematic of the experimental set up is shown in Fig. 2. The bench scale tube furnace unit consisted of a tube that was placed inside an electrical furnace. Figure 3 shows the picture of the

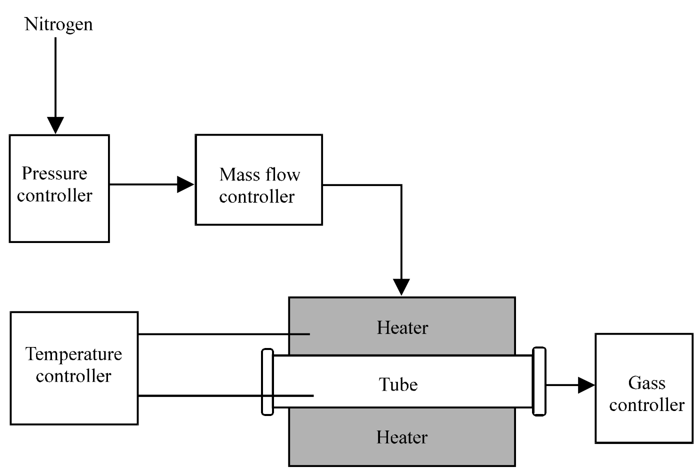

Fig. 2: Schematic representation of the experiment system

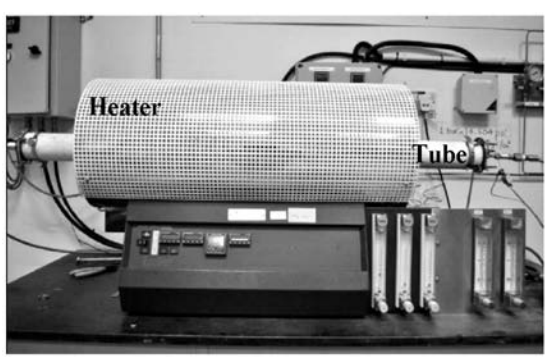

Fig. 3: Bench scale tube furnace

furnace. A continuous flow of Nitrogen was used to keep the system inert and to remove volatile products from the furnace. The flow of Nitrogen was regulated by a mass flow controller. The flow rate of the nitrogen was set to 0.4 L min^{-1} at atmospheric pressure. The temperature of the furnace was measured by thermocouple. A Eurotherm master slave controller was used to regulate the temperature of the furnace. The resulting torrefaction gases were accumulated at the gas collector. Although the gases could be analyzed for the composition and energy content, it was not conducted due to unavailability of appropriate equipment. The thermo-chemical properties of the pre- and post-torrefied samples were measured by calorific test, proximate analysis. Another possible test, the ultimate analysis was not conducted due to unavailability of the equipment during the time of this work.

The calorific test for the samples was performed using a LECO AC-350 bomb calorimeter in accordance to ASTM (2007). Five tests were conducted to determine the average energy value contained in the oil palm fronds.

Proximate analysis was carried out to determine the percentage of moisture, volatile matter, fixed carbon and ashes in the samples. The technique, in which the mass of substance was heated at a controlled rate, used the Perkin Elmer TGA7 Analyzer at an operating temperature range of between the room temperature to 900°C with an accuracy of ±2°C. The resulting mass loss was recorded as a function of time. The tests were conducted in accordance to ASTM (2004). The basic principle of a TGA analysis module involves recording of mass loss with the temperature profile during the programmed time. Changes in mass indicate moisture loss and phase changes which occur at set temperature indicative of the compound.

RESULTS AND DISCUSSION

Color of samples: After being dried for 24 h at 105°C, the samples were torrefied in the tube furnace. In Fig. 4, are pictures of the samples are shown which were treated under different conditions. Figure 4a shows the ground sample prior to torrefaction. In Fig. 4b and c, the torrefied samples at different heating temperature and duration are shown. Clearly, it is shown that the color of the samples change from cream or light brown to dark brown as a result of temperature increase during the torrefaction.

Yield of solid product: In Fig. 5, the variation of solid mass retained in the samples (oil palm fronds or OPF) of the present study with the heating temperature is shown. Also results from other work using willow and straw at various conditions is shown in Fig. 5.

Generally, it is shown in Fig. 5 that the mass retained in any of the samples decreases with temperature. Oil palm frond is shown to have the lowest solid mass retention and this was due to the fact that the samples were ground to fine size as compared to the other samples which were of a maximum diameter of 10 mm.

Calorific value analysis: Bomb calorimeter was used to determine the heating value of the sample material. The test was performed to analyze the calorific value of the samples. In Fig. 6, the distribution of calorific value of oil palm frond samples under different torrefaction condition is shown. The result for non-torrefied samples, for comparison is also shown in Fig. 6. In general in can be concluded that the higher the heating temperature, the greater would be the

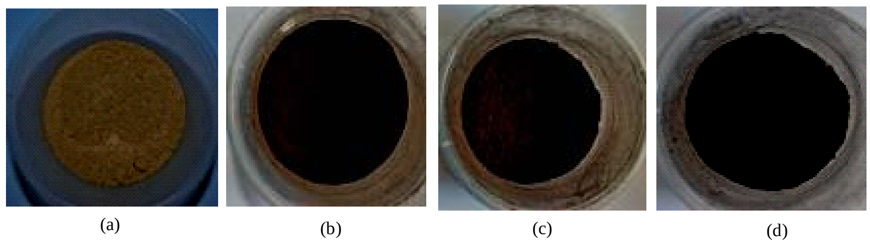

Fig. 4(a-d): Comparison of color of samples in powder form: (a) before torrefaction and with torrefaction at (b) 230°C for 50 min, (c) 250°C for 30 min and (d) 270°C for 15 min

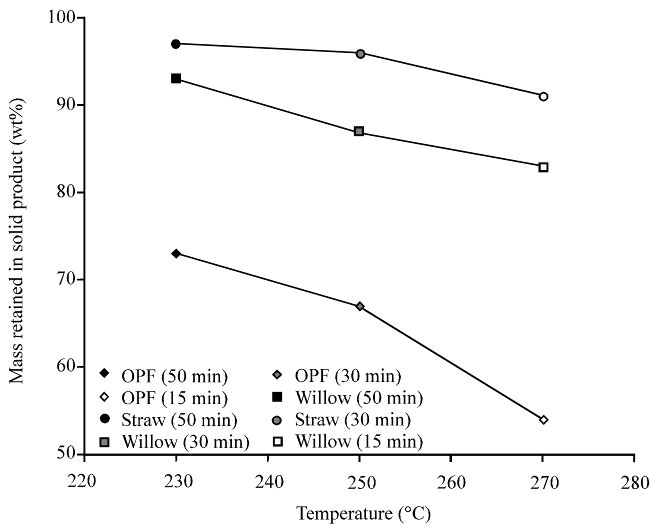

Fig. 5: Variation of the percentage of solid mass retained with the heating temperature for oil palm fronds, as well as willow and straw) at different heating temperature and duration

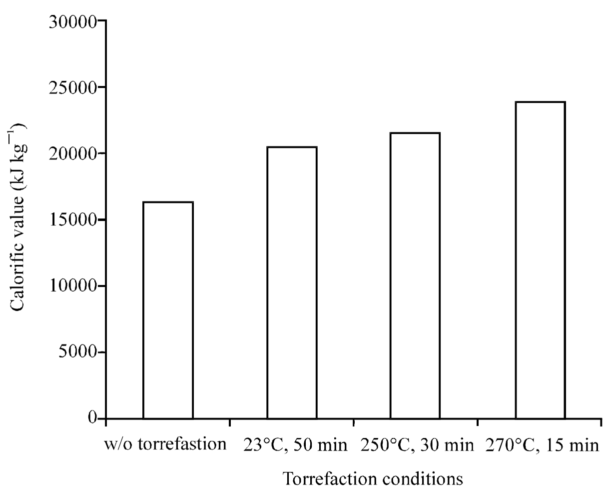

Fig. 6: Variation of calorific value of oil palm frond samples under different torrefaction conditions

Table 1: Calorific values of samples

Sample	Calorific value (kJ g^{-1})	Increase in calorific value (%)
Dried w/o torrefaction	16.3	-
Torrefied (230°C, 50 mins)	20.6	26.4
Torrefied (250°C, 30 mins)	21.5	31.9
Torrefied (270°C, 15 mins)	23.8	46.0

calorific value of the resulting samples. Although, the duration was not fixed to a same value, it is obvious from the figure that fixing the duration would still result in an increasing trend. The effect of residence time is unclear, although from the graph it is probable that it is not that significant. Future investigation will be conducted to confirm this.

An important observation from the result in Fig. 6 is that torrefaction of oil palm fronds increases its energy content. Table 1 shows the actual calorific value and the percentage of increase relative to the non-torrefied samples. The highest increase in energy was 46%; i.e., when torrefied at 270°C for 15 min. Such a result implies significant decrease in the transportation and storage costs.

It would be beneficial to know the actual input energy required for the torrefaction before it can be justified as economical. However, the reactor used in the present study was of a constant electrical power and thus the actual value of the input energy could not be quantified. Further study is required.

CONCLUSIONS

The present research attempts to study the ability and trend of torrefaction of oil palm fronds, which was never attempted elsewhere. From this work, the following conclusions can be drawn:

- The trend of mass retention as a result of torrefaction is similar to that other biomasses; i.e., willow and straw. Thus it can be suggested that the general characteristics of torrefaction of oil palm fronds may be similar to that reported in another work
- Torrefaction increases the calorific value of the oil palm frond samples. In the present work, it is shown that the calorific value can be increased by close to 50%
- In general, the higher the reactor's temperature, the larger would be the resulting calorific value of the sample. The effect of residence time is probably small for the range of conditions tested in the present work. Further test is required in order to determine the suitable duration
- The color of oil palm frond samples gets darker as the heating temperature is increased. From the calorific tests, it can be correlated that darker biomass contains greater energy value

Thus, the present study demonstrates the potential of torrefaction as a potential process for enhancement of biomass fuel. Such feature will provide advantages to the transportation and storage of biomass.

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