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Effect of Torrefaction Condition on the Mass Yield, Elementary Composition and Calorific Value of Empty Fruit Bunches (EFB)

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ABSTRACT

Malaysia has an abundance of oil palm biomass residues which are underutilized. In specific, empty fruit bunches (EFB) are the representative one. EFB has some drawbacks, such as low carbon content and low calorific value, as a solid fuel. A medium temperature treatment called torrefaction can improve these characteristics. If the flue gas in palm oil mills can be utilized as the gas and thermal energy sources of torrefaction, the financial feasibility would be well improved. This study investigated the torrefaction of empty fruit bunches under inert and non-inert atmosphere (oxygen and carbon dioxide). The torrefaction process was conducted at 300˚C for 30 min. The effect of the presence of oxygen, carbon dioxide and mixture of oxygen and carbon dioxide was studied and compared with torrefaction under inert atmosphere. The solid yield of torrefied EFB with the presence of carbon dioxide or oxygen obviously decreased in comparison with inert. Torrefaction under 21% carbon dioxide resulted in better characteristics of solid products in terms of carbon content and calorific value, thus enhancing EFB as a solid fuel. Scanning electron microscopy (SEM) was used to observe the morphology of the untorrefied and torrefied EFB.

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INTRODUCTION

Nowadays, the world is heavily depending on the fossil fuel as the primary source of energy. However, this non-renewable resource is depleting fast as the world's energy consumption is increasing due to rapid growth in human population. There is a noticeable increment in energy consumption throughout Malaysia from 8,993 (2010) to 10,011 (2012) kilo tonnes of oil equivalent (ktoe) of energy (MEIH, 2012).

According to the study conducted by Muda *et al.* (2012), the petroleum reserves can still be used for 13 years (until 2019), whereas natural gas and coal will still be able to last for a period of 51 years (until 2057) and 63 years (until 2069) respectively. This indicates that the world will face severe problem of depletion of fossil fuel energy in the near future. Due to the massive shortage of natural resources, the invention of recent technology and development production of sustainable energy is a must. The alternative energy such as biomass, solar energy and wind power are potentially seen will lessen our dependence on fossil fuels. The biomass may play a significant role because it can be environmentally-friendly as helping to cut down the carbon dioxide emission by partial replacement of coal with biofuels in commercial combustion (Keipi *et al.*, 2014). Oil palm waste biomass has an attracting interest because of their availability. For each 1 kg of palm oil, roughly another 4 kg of dry biomass are produced, approximately a third of which is found in FFB derived wastes (about 1 kg of wet EFB), while the other remaining contributors are represented by trunk and frond material (Sulaiman *et al.*, 2011). In 2012, 351 of Malaysia's palm oil mills produced 30 million tonnes of EFB over 83 million dry tonnes of solid biomass (Chong *et al.*, 2014)

The variations in biomass feedstock properties exhibit certain drawbacks such as lower calorific value, low combustion efficiency and unstable operating condition in a combustor. In order to overcome the limitation of biomass inputs, torrefaction process is required to tackle challenging biomass generation problems. Torrefaction, a biomass thermochemical pretreatment process, has been proved to upgrade biomass combustible properties (Pimchuai *et al.*, 2010 and Bridgeman *et al.*, 2008). Uemura *et al.* (2015) stated that the torrefaction of biomass under carbon dioxide and

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oxygen will provide low-priced pretreatment. The utilization of flue gas from boiler for torrefaction makes the process more financially viable. Thus, in this study, the main objective is to determine the effect of torrefaction condition on the mass yield and the characteristics of torrefied EFB.

MATERIALS AND METHODS

The empty fruit bunches used in the experiment were obtained from a FELCRA Nasaruddin oil palm mill in Bota, Perak. The raw EFB was received from the oil palm mill in very wet conditions. The samples were placed in a drying oven for 24 h at 105˚C. The dried EFB was chopped into smaller size that could be fit into a grinder. Then, the chopped feedstock was grinded and sieved into a particle size range of 250-500 µm.

Torrefaction of empty fruit bunches was conducted in a vertical tubular reactor made of stainless steel with an internal diameter of 0.028 m and a length of 0.56 m. The torrefaction reactor was connected to a condenser which was immersed in ice cubes in order to collect the condensable gas (as shown in Figure 2). The sample was placed in a centre of reactor and was flushed with torrefaction gas (nitrogen, 21% oxygen, 21% carbon dioxide, 9% oxygen + 12% carbon dioxide, and 12% oxygen + 9% carbon dioxide) for 15 min. Then, the temperature of reactor was raised from room temperature to desired temperature (300˚C) using an electric furnace at a rate of 10◦ C/min with 30 mL/min continuous flow of torrefaction gas. Once the desired temperature was reached, the torrefaction temperature was maintained for 30 min. The torrefaction process produces solid, liquid and noncondensable products. The solid torrefied biomass was retrieved later from the reactor after the cooling down and weighed. The vapor phase condensed was collected in a condenser and weighed. The mass of gas product was estimated from the overall material balance. The calorific value and the CHN contents were measured for each torrefied sample.

Fig. 1: Oil palm empty fruit bunches (EFB).

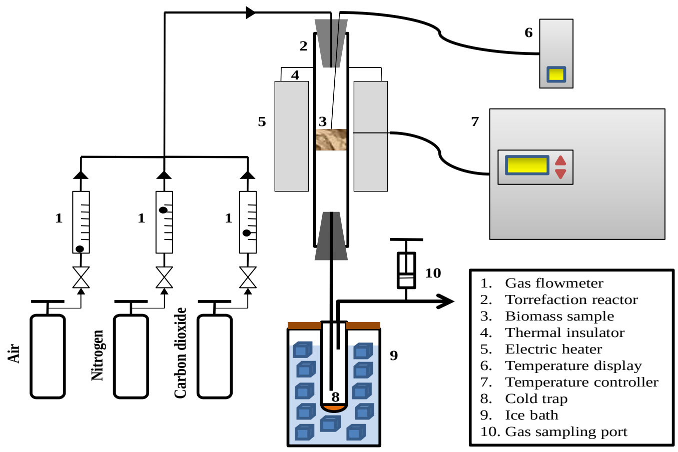

Fig. 2: Schematic diagram of torrefaction reactor.

The untreated and treated samples were further analysed. Perkin Elmer 2400 CHN elemental analyser was used to determine the elemental value of carbon, hydrogen and nitrogen. The calorific values were determined using a bomb calorimeter, model C2000 series manufactured by IKA Werke.

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The obtained calorific value from the bomb calorimeter which included the latent heat of the vapor produced from the sample. The surface morphology of all the samples was examined using scanning electron microscope Model 1430 Germany.

RESULTS AND DISCUSSIONS

Based on the mass balance, the torrefied products of EFB can be expressed in terms of solid, liquid and gas yields. The solid and liquid yield was calculated by the following equation, whereas gas yield is obtained by differences (100%-solid yield-liquid yield).

$Y_m = m_{torrefied} / m_{raw}$

Where $m_{torrefied}$ is the mass of torrefaction products and m_{raw} is the mass of torrefaction reactants.

The torrefaction was carried out at different gas compositions of boiler with the total volume of mixture of oxygen and carbon of 21% to stimulate the composition of flue gas boiler. Figure 3 presents the relationship between mass yield and torrefaction atmosphere. The highest solid mass loss was obtained during 21% oxygen torrefaction, followed by 21% carbon dioxide, the mixture (12% oxygen + 9% carbon dioxide, and 9% oxygen + 12% carbon dioxide) and inert. The order has depicted that an additional reaction occurs when O_2 or CO_2 is added to torrefaction gas. However, the additional reaction by O_2 is more significant than that by CO_2. The presence of oxygen in torrefaction process resulted in higher amounts of mass loss which is comparable with other studies (Uemura *et al*., 2013 and Chen *et al*., 2014). According to Wang *et al*. (2013), this is due to the oxidation of lignocelluloses biomass occurred, thus enhancing the mass loss by triggering the easily degradable components to be degraded. In this work, the mixture of oxygen and carbon dioxide torrefaction did not give same impact as the single gas torrefaction with same total volume. There may be some interactions between the two reactions: the additional reaction in O_2 and that in CO_2. Further investigation is required to elucidate this point.

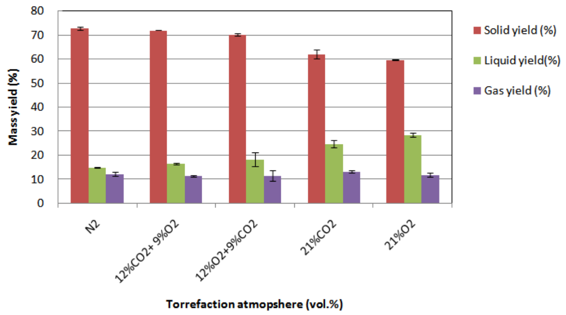

Fig. 3: Effect of torrefaction atmosphere on the solid, liquid and gas yields.

The elementary composition and calorific value of the feedstock and torrefied products are presented in Table 1. Carbon has a significant rise when torrefied in both inert and non-inert condition, while oxygen shows the opposite trend. The carbon content is increased due to the devolatilization of biomass components. Nitrogen shows an increment whereas hydrogen does not show any remarkable changes. Based on the calorific value result, 21% O_2 has as a similar trend with mixtures of O_2 and CO_2, whereas 21% CO_2 has the highest of heating value. This could be correlated to the highest of carbon content was obtained under 21% CO_2 torrefaction.

Table 1: Elementary composition and heating value of raw and torrefied EFB.

Condition	Carbon (wt.%)	Hydrogen (wt.%)	Nitrogen (wt.%)	Oxygen (wt.%)	Calorific value (HHV)(MJ/kg)
Untorrefied	46.95	6.94	0.83	45.28	17.00
N_2	52.75	5.38	2.07	39.81	21.21
$12\%CO_2+9\%O_2$	58.87	6.04	2.58	32.52	23.79
$12\%O_2+9\%CO_2$	59.26	6.44	2.41	31.90	23.69
$21\%CO_2$	62.80	6.49	2.95	27.77	25.06
$21\%O_2$	61.43	4.90	3.01	30.68	23.50

The SEM images of the raw EFB and torrefied EFB are shown in Figure 4. All images are taken at magnification of 1 K. From the cross-sectional view, we found the raw EFB has an almost smooth surface. The uneven structure present in feedstock may be caused by cutting effect. However, the hollow tubular structures are obviously observed in the image of torrefied EFB samples. This is because of the decomposition of hemicellulose and some part of weak lignin. Chen *et al.* (2014) stated that the increasing concentration of oxygen resulted high extent of structure breakage even for the tubular structure.

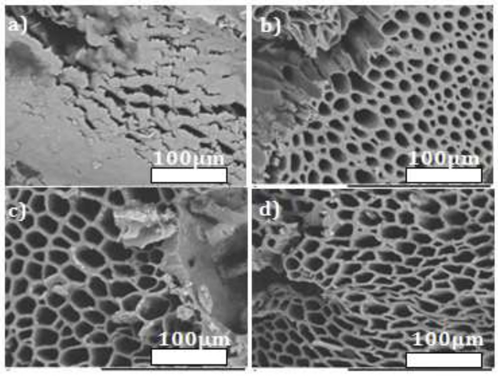

Fig. 4: SEM observation of raw and torrefied EFB (cross-section); (a) untorrefied, (b) torrefied in N_2, (c) torrefied in 21% CO_2 and (d) torrefied in 21% O_2

Conclusion:

In the present study, torrefaction under different torrefaction atmospheres was conducted to investigate the effect of atmosphere on the solid yield, elemental composition and morphology. It was found that the solid mass yield was lowest at 21% oxygen torrefaction. The highest carbon content and energy value was obtained at 21% carbon dioxide torrefaction. From SEM observation, it was found that cross-section of EFB becomes a honeycomb-like structure.

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REFERENCES

Bridgeman, T.G., J.M. Jones, I. Shield and P.T. Williams, 2008.Torrefaction of reed canary grass, wheat straw and willow to enhance solid fuel qualities and combustion properties. Journal of Fuels, 87: 844-856.

Chen, W.H., K.M. Lu, W.J. Lee, S.H. Liu and T.C. Lin, 2014. Non-oxidative and oxidative torrefaction characterization and SEM observations of fibrous and ligneous biomass.Applied Energy, 114: 104-113.

Chong, K.H., P.L. Law, R. Baini, S.F. Saleh and A.R. Henry Rigit, 2014. Performance evaluation of a horizontal air staged inclined biomass-to-heat energy converter for drying paper egg trays. International Journal of Renewable Energy, 4(1): 159-167.

Keipi, T., H. Tolvanen, L. Kokko and R. Raiko, 2014. The effect of torrefaction on the chlorine content and heating value of eight woody biomass samples. Biomass and Bioenergy, 66: 232-239.

Malaysia Energy Information Hub (MEIH), 2012. Electricity-Final Electricity Consumption.

Muda, N. and T.J. Pin, 2012. On prediction of depreciation time of fossil fuel in Malaysia. Journal of Mathematics and Statistics, 8: 136-143.

Pimchuai, A., A. Dutta and P. Basu, 2010. Torrefaction of agricultural residue to enhance combustible properties. Energy Fuel Journal, 24(9): 4638-4645.

Sulaiman, F., N. Abdullah, H. Gerhauser and A. Shariff, 2011. An outlook of Malaysia energy, oil palm industry and its utilization of wastes as useful resources.Biomass and Bioenergy, 35: 3775-3786.

Uemura, Y., S. Saadon, N. Osman, N. Mansor and K. Tanoue, 2015. Torrefaction of oil palm kernel shell in the presence of oxygen and carbon dioxide, Fuel, 104: 171-179.

Uemura, Y., W. Omar, N.A. Othman, S. Yusup and T. Tsutsui, 2013. Torrefaction of oil palm EFB in the presence of oxygen. Fuel, 103: 156-160.

Wang, C., J. Peng, H. Li, X.T. Bi, R. Legros and C.J. Lim, 2013. Oxidative torrefaction of biomass residues and densification of torrefied sawdust to pellets.Bioresources Technology, 127: 318-325.