Technical Report

Special Report: JCREN

小特集: JCREN

Effects of Temperature and Concentration of Oxygen
on Torrefaction of Empty Fruit BunchesSulaiman MOHAMMAD HISHAM^{*1}, Yoshimitsu UEMURA^{*1†}, and Azizan MOHAMMAD TAZLI^{*2}

(Received February 16, 2016)

A huge amount of underutilised empty fruit bunches (EFB) are produced in Malaysia. The abundance of EFB has gained much attention, as they are seen as a potential resource for solid fuel production. However, EFB cannot be directly fed to existing combustion systems due to its undesirable properties. Hence, pre-treatment such as torrefaction is usually conducted to address these limitations. Torrefaction is a thermochemical pre-treatment method that upgrades biomass properties at mild temperatures. The purpose of this study is to investigate the effects of varying oxygen concentrations and temperatures on EFB (0.375 mm particle size) during the torrefaction process. The experiment was conducted at 220 °C, 260 °C, and 300 °C in oxygen concentrations ranging from 0 to 21 vol.% using a vertical tubular reactor. The torrefied EFB was found to turn dark as the torrefaction temperature and oxygen concentration increased. The density of the torrefied EFB was also seen to decrease with increasing temperature. It was also observed that the presence of oxygen lowered the density of the torrefied EFB compared to that of inert conditions. From this work, it was found that solid yield decreased with increasing temperature and oxygen concentration. The solid yield of torrefied EFB ranged from 74-89%, 63-79%, and 51-72% at 220 °C, 260 °C, and 300 °C, respectively, under different oxygen concentrations. The results also reveal an increase in heating values with increasing temperature and oxygen concentrations, ranging from 18.8 to 24.6 MJ/kg. In conclusion, oxygen torrefaction can potentially be a feasible option for biomass pre-treatment.

Key Words

Empty fruit bunches, Torrefaction, Oxidative, Solid yield, Carbon content

1. Introduction

Fossil fuel is the world's primary source of energy, accounting for more than 80% of global energy consumption¹⁾. Overconsumption of this non-renewable energy has resulted in massive greenhouse gas emissions, thus contributing to global warming. The use of fossil fuels has caused serious environmental concerns, motivating people to adopt sustainable practices and increase their use of green technology.

Biomass is widely considered to be a promising alternative energy source. Roughly 90% of biomass is

disposed as waste in palm oil mills²⁾. In 2012, 351 palm oil mills in Malaysia produced 30 million tonnes of empty fruit bunches (EFB) from 83 million dry tonnes of solid biomass³⁾. Hence, there is an abundance of biomass feedstock that is underutilised, and this has attracted growing interest from researchers, especially since it can be used as a potential solid fuel energy resource.

However, biomass feedstock cannot be directly fed into existing combustion systems due to its unfavourable properties such as low calorific value, high moisture content, and lower quality, as a result of biodegradation. Hence, biomass requires prior pre-treatment; for this study, torrefaction was chosen to enhance the quality of biomass as solid fuel. Torrefaction is a lignocellulosic biomass pre-treatment that requires low temperatures between 473 and 573 K and an inert atmosphere. It involves cheap technology but additional operating costs for thermal energy are still needed if nitrogen is used as the carrier gas. However, if

^{*1} Centre for Biofuel and Biochemical Research (CBBR),
Universiti Teknologi PETRONAS
32610 Seri Iskandar, Perak, Malaysia

^{*2} Department of Chemical Engineering,
Universiti Teknologi PETRONAS
32610 Seri Iskandar, Perak, Malaysia

[†] Corresponding author:
yoshimitsu_uemura@petronas.com.my

the torrefaction process was carried out in the presence of oxygen and flue gas from the burners is used instead, operating expenses could be reduced⁴⁾. Therefore, this study aims to investigate the effect of using oxygen in the torrefaction of EFB.

2. Experimental

The biomass residues used in this study were empty fruit bunches (EFB) collected from the Felcra Nasaruddin Oil palm mill in Bota, Perak, Malaysia. Prior to torrefaction, the EFB were first chopped into smaller sizes and dried at 105 °C overnight to remove moisture. Then, the EFB were ground and sieved to obtain uniform particles sizes, ranging from 0.25 to 0.50 mm.

The experimental setup of the torrefaction process consisted of 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, and then immersed in ice cubes to collect the condensable gases (Fig. 1). Next, a sample of 5 g of empty fruit bunches were placed in the centre of the reactor with a glass wool and wire acting as supporter and holder, respectively. Then, the system was flushed with torrefaction gas for 15 minutes at a flowrate of 100 mL/min. After flushing the system, the flowrate of the torrefaction gas was reduced to 30 mL/min and the temperature of the reactor was raised from

room temperature to the desired temperature using an electric furnace at a rate of 10 °C/min. Once the desired temperature was reached, the torrefaction temperature was maintained for 30 minutes. The torrefaction process produces solid, liquid, and non-condensable products. The solid torrefied biomass was later retrieved from the reactor after it had cooled down and been weighed. The condensed vapour was collected in a condenser and also weighed. The solid yield is an important indicator to evaluate the severity of the torrefaction condition on the biomass and can be calculated as per equation (1) below:

$$Y_m = \frac{m_{\text{torrefied}}}{m_{\text{raw}}} \times 100 \% \quad (1)$$

Where Y_m is the solid yield, $m_{\text{torrefied}}$ is the mass of torrefaction products and m_{raw} is the mass of torrefaction reactants. All weights reported are based on dry weights.

The bulk density of the untorrefied and torrefied biomass was determined by measuring the mass of a known volume of EFB sample placed in a measuring cylinder. Then the density is measured based on the known volume and mass obtained.

The calorific values were determined using a bomb calorimeter manufactured by IKA Werke, the C2000 series model. The obtained calorific value from the bomb calorimeter includes the latent heat of the vapour produced from the sample.

Fig. 1 The schematic diagram of torrefaction reactor

3. Results and discussion

3.1 Physical appearance

Figs. 2 and 3 show the physical appearance of the untreated and torrefied empty fruit bunches. An obvious change in colour was observed in the torrefied EFB at different temperatures. The colour of the torrefied EFB turned darker as torrefaction temperature increased. The original colour of untreated EFB is yellow. The torrefied EFB at 220 °C turned brown. The EFB, which were torrefied at 260 °C and 300 °C showed a lot more changes in colour i.e. turning dark brown and black, respectively.

Fig. 2 Comparison of untreated EFB with torrefied EFB; a) raw; b) N₂, 220 °C; c) N₂, 260 °C; d) N₂, 300 °C

Fig. 3 Comparison of untreated EFB with torrefied EFB at 220 °C; a) raw; b) N₂; c) 3 vol.% O₂; d) 9 vol.% O₂; e) 15 vol.% O₂; f) 21 vol.% O₂

However, at different oxygen concentrations, no obvious change in colour was observed for the same temperature except at the low temperature of 220 °C (Figs. 4 and 5). At a higher oxygen concentration, the colour of the torrefied EFB at 220 °C became slightly darker.

3.2 Density

Fig. 6 shows the results of the bulk density of raw and torrefied products for each condition. A net reduction in bulk density was observed after the torrefaction process. Increasing the torrefaction temperature would

Fig. 4 Comparison of untreated EFB with torrefied EFB at 260 °C; a) raw; b) N₂; c) 3 vol.% O₂; d) 9 vol.% O₂; e) 15 vol.% O₂; f) 21 vol.% O₂

Fig. 5 Comparison of untreated EFB with torrefied EFB at 300 °C; a) raw; b) N₂; c) 3 vol.% O₂; d) 9 vol.% O₂; e) 15 vol.% O₂; f) 21 vol.% O₂

Fig. 6 Comparison of bulk density of untoorrefied and torrefied EFB

decrease the density of the torrefied EFB. Basu *et al.* (2013) highlighted that this was because a greater extent of torrefaction severity would result in a greater loss of mass in comparison to volume shrinkage⁵⁾. The density of the torrefied EFB in oxygen was found to be lower compared to the torrefied EFB in inert conditions.

3.3 Solid yield

For the present study, the effect of temperature (220, 260, and 300 °C) on the yields of torrefaction products of EFB was examined. The effect of torrefaction temperature on mass yield is shown in Fig. 7. It was observed that an increase in temperature led to lower solid yield. The decrease in solid yield is attributed to the degradation of major biomass components such as hemicellulose, cellulose, and lignin. For different concentrations of oxygen, it was also observed that the solid yield decreased as the concentration of oxygen increased. The presence of oxygen during torrefaction had degraded the biomass at a faster rate. Additionally, oxidation of hemicellulose also occurred in place of decomposition^{6) 7)}. The presence of oxygen in torrefaction contributes to a higher conversion of biomass into liquid and gas products.

3.4 Calorific value

The torrefaction of EFB at higher temperatures and oxygen concentrations showed a significant increment in calorific value (Fig. 8). The calorific value of torrefied EFB ranged from 18.8 to 24.6 MJ/kg. The highest calorific value of torrefied EFB occurred at a reaction temperature of 300 °C in 21 vol.% oxygen.

4. Conclusion

The torrefaction of empty fruit bunches was carried out at 220 °C, 260 °C, and 300 °C at different oxygen concentrations to investigate these varying temperature effects on physical appearances, density, solid yield, and calorific value of the EFB. The torrefied EFB became darker, as the the torrefaction temperature and oxygen concentration increased. The density of the torrefied EFB decreased with increasing temperature. The oxidative torrefaction could reduce the density of the EFB to a greater extent, as compared to in inert conditions. In addition, the solid yield reduced with increasing temperature and oxygen concentration. Torrefaction in 21 vol.% oxygen at 300 °C resulted in the highest calorific value.

Acknowledgements

This research was carried out with financial support from the Mitsubishi Corporation Education Trust Fund,

Fig. 7 The solid yield of torrefied biomass condition

Fig. 8 The calorific value of torrefied EFB

Japan, and the FRGS grant from the Ministry of Education (MOE), Malaysia.

References

- 1) IEA., World energy outlook, 2013
 - 2) Abdullah, N.; Sulaiman, F.; Aliasak Z., Proceedings of the 2012 National Physic Conference: (PERFIK 2012), AIP Publishing, 331-6 (2013)
 - 3) Chong, K. H.; Law, P. L.; Baini, R.; Saleh, S. F.; Henry Rigit, A. R., *Int. J. Renewable Energy*, **4**, 159-167 (2014)
 - 4) Uemura, Y.; Saadon, S.; Osman, N.; Mansor, N.; Tanoue, K., *Fuel*, **104**, 171-179 (2015)
 - 5) Basu, P.; Rao, S.; Acharya, B.; Dhungana, A., *Can J Chem Eng*, **102**, 827-32 (2013)
 - 6) Wang, C.; Peng, J.; Li, H.; Bi, X. T.; Legros, R.; Lim, C. J., *Bioresources Technol.*, **127**, 318-325 (2013)
 - 7) Chen, W. H.; Lu, K. M.; Lee, W. J.; Liu, S. H.; Lin, T. C., *Appl. Energy*, **114**, 104-113 (2014)
-