Devolatilization Studies of Oil Palm Biomass for Torrefaction Process through Scanning Electron Microscopy

D. Daud, A. Abd. Rahman, A.H. Shamsuddin
Centre for Renewable Energy, Universiti Tenaga Nasional, Putrajaya Campus, Jalan IKRAM-UNITEN, 43000 Kajang, Selangor, Malaysia

E-mail: darsheena@uniten.edu.my

Abstract. In this work, palm oil biomass consisting of empty fruit bunch (EFB), mesocarp fibre and palm kernel shell (PKS) were chosen as raw material for torrefaction process. Torrefaction process was conducted at various temperatures of 240 °C, 270 °C and 300 °C with a residence time of 60 minutes. The morphology of the raw and torrefied biomass was then observed through Scanning Electron Microscopy (SEM) images. Also, through this experiment the correlation between the torrefaction temperatures with the volatile gases released were studied. From the observation, the morphology structure of the biomass exhibited inter-particle gaps due to the release of volatile gases and it is obviously seen more at higher temperatures. Moreover, the change of the biomass structure is influenced by the alteration of the lignocellulose biomass.

1 Introduction

Biomass is widely considered as a very promising alternative source of raw material due to its availability and potential for energy conversion. The main and the most abundant biomass that has been planted in Malaysia came from oil palm. The palm oil industry in Malaysia generates almost 94% of the biomass feedstock of agricultural and forestry sources such as wood residues, rice and sugar-cane contributes the remaining 6% [1]. According to the Malaysian Palm Oil Board (MPOB) it is estimated that the oil palm plantation occupies nearly 4.70 million hectares and produce approximately 77.24 million tonnes (dry) of waste [2].

In order to employ biomass as a primary alternative source, advancement and improvement of technology typically in the power generation sector along with the process selection will play a major role in delivering the activities towards renewable energy. The structure of biomass is mainly fibrous and exhibits low energy density and high moisture content. It also pose difficulty on grindability, handling, transportation and storage when compared to coal [3]. Therefore, torrefaction process has been introduced as a one of the techniques that can convert biomass into better quality solid biofuel. Torrefaction involves heating the biomass in the absence of oxygen to a temperature of typically 200 °C to 300 °C [4]. Torrefaction process is used to enhance the structure of biomass until the physical properties becomes similar to coal. The change of structure can be clearly observed through scanning electron microscopy (SEM) images.

2 Materials and Methods

The waste from the oil palm biomass which consists of empty fruit bunch (EFB), mesocarp fibre and palm kernel shell (PKS) were used for this experiment. It is taken from an oil palm mill in Perak, Malaysia. The raw waste underwent a fuel preparation process in order to ensure the samples are...
monitored especially in term of weight, moisture and particle size before the torrefaction experiment. All samples have prescribed by British standard [5] for moisture content determination. The particle size for all the samples has been processed till the finer size which is 250 µm. Once the samples were ready, it was placed in a vacuum tube furnace with approximately 5 kg per every run for conducting the torrefaction process. The initial temperature was set at ambient temperature, which was 30 °C. The sample was then heated to the drying temperature 105 °C at a rate of 20 °C/min and it was held constant for 10 minutes before proceeding to the next phase. The sample was then heated up again to the desired torrefaction temperature which of 240 °C, 270 °C, and 300 °C and was held constant for 60 minutes of residence time. In order to avoid combustion process from taking place, nitrogen gas was continuously supplied throughout the process. The products of torrefied biomass as well as the raw biomass were then used to observe the pores and surface morphology through the SEM images.

3 Results and Discussion

3.1 SEM images of the raw and torrefied biomass for empty fruit bunch (EFB)

The changes in the morphology structure of raw and torrefied biomass were examined in order to see the correlation between torrefaction temperatures with the volatile gases through the process. The effects of various torrefaction temperatures at 240 °C, 270 °C and 300 °C and a residence time 60 minutes were applied. Figure 1 and Figure 2 shows the SEM images of the raw and torrefied biomass for EFB with magnification of 2000 and 6000 respectively.

From the observation, the SEM images show significant differences between the raw and torrefied biomass. The raw EFB indicated pores which can obviously be seen through a magnification of 6000. According to Sabil et al. (2013) [6] a presence of pores in the surface of EFB verified that EFB is a fibrous material. Furthermore, after the torrefaction process was conducted, the torrefied EFB shows a prominent surface. This may be due to the loss of the moisture and some light organic volatiles under
the pre-treatment process. The process may have affected the hemicellulose structure which started to decompose at a lower temperature of 150 °C. Due to this, the biomass slightly shrank, then exhibited the prominent structure at 240 °C.

The observation continues with SEM images of the torrefied biomass at 270 °C. SEM images of the torrefied biomass samples that have been torrefied at 240 °C and 270 °C show dissimilarities. At 270 °C, the torrefied biomass show increase of inter-particle pores in the cell wall. The observation is in agreement with Tsai & Liu (2013) [7] who studied the effect of temperature on thermochemical property and true density of torrefied coffee residue. The increase of inter-particle pores in the cell wall was found to have been caused by the trapping of volatile gases during the devolatilization stages. These gases are released during the process and at the same time the decomposition of hemicellulose is still taking part. At 300 °C, the surface of the torrefied EFB biomass looks damaged and it seems to have melted under the pre-treatment process. According to Stelt et al. (2011) [8] the cohesive failure is due to the fact that the fibre ends and particles stick out of the surface which causes the voids to appear. In addition, lignin and hemicellulose exceed their glass transition temperatures, thus leading to further cracks and crevices.

3.2 SEM images of the raw and torrefied biomass for mesocarp fibre

Figure 3 and Figure 4 shows the SEM images of the mesocarp fibre with magnification of 2000 and 6000 at the aforementioned parameters. From the observation, the raw mesocarp fibre shows the inter-particle gaps in the surface structure. The images of the surface structure are slightly changed when the torrefaction process was conducted. The influence of the pre-treatment process changed the internal structure and reduced the amount of gaps at which at this stage, the integrated structure was performed. This observation is similar to the Chen et al. (2014) [9].

![Figure 3: SEM images (2000 x) of (a) MF raw, (b) MF torrefied at 240 °C, (c) MF torrefied at 270 °C and (d) MF torrefied at 300 °C](image)

![Figure 4: SEM images (6000 x) of (a) MF raw, (b) MF torrefied at 240 °C, (c) MF torrefied at 270 °C and (d) MF torrefied at 300 °C](image)

Meanwhile, the SEM images of the torrefied biomass at 270 °C start to show the pores and cracks. At this temperature the mesocarp fibre reacted with the heat and rearranged the internal structure by
losing its fibrous nature. Moreover, lignin started to decompose added to the hemicellulose extensive decomposition as xylan-based hemicellulose also generally starts to decompose around 250 °C – 280 °C. Due to the decomposition of lignocellulose it seems to be easier to obtain a structural shrinkage that makes the structure very brittle or friable. The decomposition of lignocellulose continued until the end of the torrefaction temperature at 300 °C.

3.3 SEM images of the raw and torrefied biomass for palm kernel shell (PKS)

The observation continues with SEM images of PKS at magnification 2000 and 6000 in Figure 5 and Figure 6 respectively. The PKS images show different images between the EFB and mesocarp fibre, especially at the beginning of the process. The raw PKS shows the integrated surface and not much prominent surface is observed. This indicates an image that is quite similar with the torrefied PKS at 240°C. Thus, PKS can be considered as a material that affected lesser at the beginning of the torrefaction temperature. It also shows less fibrous material as compared to EFB and mesocarp fibre.

Moreover, in the low to the high selection magnification images show cracks and fissures on the torrefied PKS images at 270 °C. It is also creates a more pores and leaving an empty space in between due to the releasing of volatile gases. The alteration of structure increased when the torrefaction temperature was increased until 300 °C. The pores in the torrefied biomass could increase the potential for lignocellulose cracking and fissures in order to produce char. This result is in agreement with the finding of previous studies by Tsai & Liu (2013) [7].

4 Conclusions

Based on the morphology observation of the raw and torrefied biomass it can be concluded at the higher torrefaction temperatures, the structure of the torrefied biomass become brittle and creates more pores and fissures structure. Moreover, the appearance of the inter-particle gap due to the released of the volatile gases is mostly observed at temperature 270°C and above. From the result obtained, the
overview change of the biomass structure obviously has correlated with the alterations of the lignocellulose of the biomass. This results in a biomass product that is more homogenous in structure and more brittle or friable in all samples, aiding towards improving its grindability and handling.

Acknowledgments
Authors would like to acknowledge for the financial support given: Long Term Research Grant (01201102 LRGS) from Ministry of Higher Education (MOHE) and Universiti Sains Malaysia (USM).

References

[1] Ng, F. Y., Yew, F. K., Basiron, Y., & Sundram, K. (2011). A renewable future driven with Malaysian palm oil-based green technology. *Journal of Oil Palm & The Environment (JOPE)*, 1-7.

[2] *Malaysian Oil Palm Statistics 2009*. (2010). 8-29: Malaysian Palm Oil Board.

[3] Chew, J., & Doshi, V. (2011). Recent advances in biomass pretreatment-Torrefaction fundamentals and technology. *Renewable and sustainable energy reviews*, 4212-4222.

[4] Bergman, P., Boersma, A., Kiel, J., Prins, M., Ptasinski, K., & Janssen, F. (2005). *Torrefaction for entrained-flow gasification of biomass*. Energy Research Centre of the Netherlands (ECN): ECN-C--05-067.

[5] BS EN 14774-2: 2009. *Solid biofuel - Determination of moisture content - Oven dry method*. British Standard. November 2009.

[6] Sabil, K. M., Aziz, M. A., Lal, B., & Uemura, Y. (2013). Effects of torrefaction on the physiochemical properties of oil palm empty fruit bunches, mesocarp fiber and kernel shell. *Biomass and Bioenergy*, 351-360.

[7] Tsai, W. T., & Liu, S. C. (2013). Effect of temperature on thermochemical property and true density of torrefied coffee residue. *Journal of analytical and applied pyrolysis*, 47-52.

[8] Stelt, M. J., Gerhauser, H., Kiel, J. H., & Ptasinski, K. J. (2011). Biomass upgrading by torrefaction for the production of biofuels: A review. *Biomass and Bioenergy*, 3748-3762.

[9] Chen, W. H., Lu, K. M., Lee, W. J., Liu, S. H., & Lin, T. C. (2014). Non-oxidative and oxidative torrefaction characterization and SEM observations of fibrous and ligneous biomass. *Applied Energy*, 104-113.