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Determination of the Equilibrium Moisture Content of Oil Palm Fronds Feedstock for Gasification Process

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ABSTRACT

Malaysia has abundant, but unutilized oil palm fronds waste. The lack of knowledge on the characteristics of biomass is considered as one of the barriers for not utilizing it as a source of energy. Particularly, determining the moisture content of biomass and reducing it to the required level for the use of thermochemical processes, have remained as a major concern. In this study, the hygroscopic nature of oil palm fronds was investigated and the equilibrium moisture content in a specific laboratory room condition (80% relative humidity and 23°C room temperature) was identified. In the investigation the equilibrium moisture content of oil palm fronds was obtained to be 12% on wet basis. The variation of moisture content of different sections of oil palm fronds with particle density was also investigated and it was found that moisture content has positive correlation with density. For the same moisture content the middle part of the frond was found to be denser than the other sections and the hub section was found to be the least. To investigate the relationship of density with porosity, images of different sections of the frond were taken using scanning electron microscope. The image results showed that the porosity of the middle section is lower than the other two sections while that of the hub section is the highest.

Key words: Moisture content, oil palm fronds, gasification, hygroscopic property, porosity

INTRODUCTION

Oil palm frond (OPF) is one of the most abundant, but unutilized biomass wastes in Malaysia. The total amount of OPF generated from pruning and re-plantation activities was estimated to be 97 million tons per year (Vamvuka *et al*., 2009; CBBR, 2010; Atnaw *et al*., 2011a, b; Guangul *et al*., 2011; Lahijani and Zainal, 2011). By using a proper technology like gasification, there is an opportunity for Malaysia to generate considerable amount of energy from OPF waste (Hong *et al*., 2011). The lack of knowledge about the characteristics of biomass is considered as one limitation for not utilizing the resource as a source of energy. Though, type of species is the major factor for the variation of characteristics of biomass, within the same species remarkable difference might be observed from place to place due to the climate and environment change. Hence, to use a specific type of biomass as a feedstock for thermochemical processes or as a raw material in chemical industries, it is essential to know the characteristics of a particular biomass (Bushnell *et al*., 1990).

One of the prominent factors which affect the process of gasification is the moisture content of the feedstock. High moisture content in biomass has adverse impacts on the syngas quality by draining part of the deliverable energy for vaporization of the moisture. In addition, high moisture content reduces the combustion temperature which in turn hinders the efficiency, stability and quality of output syngas (Abdullah and Wu, 2011). Therefore, reducing the moisture of the feedstock to the required level prior to gasification process is essential although, it is challenging as it requires lower humidity and higher temperature environment. Most biomass materials are hygroscopic in nature and are affected by the humidity and temperature of the surrounding during their storage time (Singh, 2004; Hartley and Wood, 2008). As reducing the moisture content of the biomass to the required level is important, maintaining the moisture content after drying is also equally important in order to use it with the required level of moisture for gasification process (Rietz, 1978). In order to design or select the proper storage system and maintain the moisture content of the biomass feedstock, knowledge on the Equilibrium Moisture Content (EMC) of the feedstock is essential (Singh, 2004).

The other challenge of using biomass is the determination of moisture content of the feedstock prior to regular operations like gasification and combustion. The information on moisture content of a feedstock is used for calculating the energy penalty for drying of the feedstock prior to gasification process. In addition, the moisture content information serves as an input for the design of different components of the gasifier system. In downdraft gasifiers, the gasification process will be affected adversely if the moisture content of the feedstock is beyond a certain level and cannot be tolerated when the moisture content is in excess of 20% (Roos, 2008; Gautam, 2010). There are different methods of determining the moisture content (Simpson, 1999; Samuelsson *et al*., 2006). However, most of the methods require either sophisticated equipment or long time to determine the amount.

In this study the hygroscopic property of OPF were investigated. The equilibrium moisture content under a specific laboratory condition and the relationship of the moisture content with particle density was studied. In addition, OPF images were taken using Scanning Electron Microscopy (SEM) and the effect of porosity on the density was investigated.

MATERIALS AND METHODS

Material preparation: To study the hygroscopic nature of OPF, freshly pruned oil palm fronds were collected at Felcra classic oil palm plantation in Bota Kanan, Perak, Malaysia. A single frond, with the leaflets removed, was divided into three sections; tip, middle and hub. In this work the hub section was considered to be approximately the first one-sixth of the full length measured starting from the root of the frond. The middle section was considered to be one-third of the full length measured from the end of the hub and the remaining half part of the full length measured after the end of the middle section was considered as tip section as shown in Fig. 1.

Method for the determination of hygroscopic nature of OPF: To investigate the hygroscopic nature and preserving conditions, samples from different sections of OPF were prepared and dried

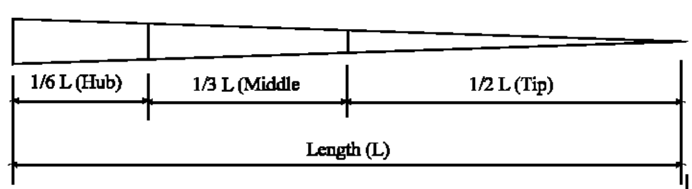

Fig. 1: Sections of a frond

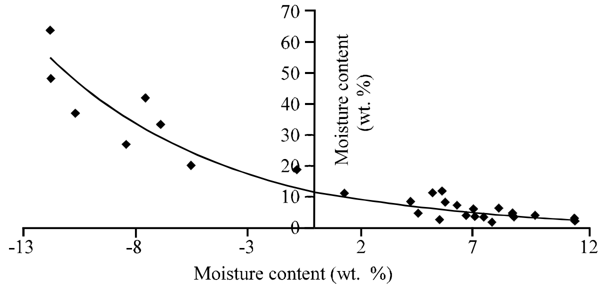

Fig. 2: Moisture Gain/Loss of OPF at different moisture content

in an oven for different time lengths to get different amount of moisture content. Carbolite 450 oven at 105°C was used for drying and the weight measurement was done using Ohaus precision standard weighing balance with an accuracy of 0.01 g. A total of 96 samples (32 from each of the tips, middle and hubs) were prepared and three samples (one from each section of the frond) were kept outside the oven. The remaining 93 samples were kept in the oven and three samples (one from each section of the frond) were withdrawn in every thirty minutes time interval until the 15th hour. Immediately after withdrawal from the oven, weight measurements were taken for all samples. To insure complete removal of the moisture, the last three samples (one from each section of the frond) were kept for twenty four hours in the oven and weight measurements were taken immediately after withdrawal. After this process the samples were preserved in a laboratory room which is used to store OPF feedstock prior to the gasification process. The room has an average temperature and relative humidity of 23°C and 80%, respectively. After preserving the samples for 48 h the loss or gain of weight of each sample was investigated by measuring their weight and subtracting from the weight measurement obtained after withdrawal from the oven. From the result, the variation of moisture gain/loss with moisture content graph was plotted as shown in Fig. 2.

Method for the determination of the relationship of density with moisture content and porosity: Aiming to investigate the relationship of moisture content with density, experimental investigation was also carried out on different sections of OPF. In this case 147 samples (49 from each of the sections) were prepared and weight measurement was taken in three stages. The first weight measurement was taken in a green stage before drying the samples. In order to get samples with different moisture content, the samples were kept for different periods of time in an oven at 105°C. The second stage weight measurement was taken by withdrawing from the oven in every 15 minutes interval for 12 h for a set of samples containing one from each of the sections. The volume of the samples was measured immediately after the second stage weight measurement by using graduated cylinder and a known amount of fine sand. After a sample had been placed in a graduated cylinder, 150 mL sand was added into the cylinder and total volume reading was taken. The volume of each sample was calculated by subtracting 150 mL from the total volume reading. After completing the second stage weight and volume measurement, all samples were taken back to the oven and kept for another twelve hours continuously in order to ensure complete removal of moisture. After twelve hours of the second drying, the weight measurement was taken for the third time. The moisture content of the samples was determined from the weight difference of the second and third stage measurements. Densities of the samples were determined from the volume

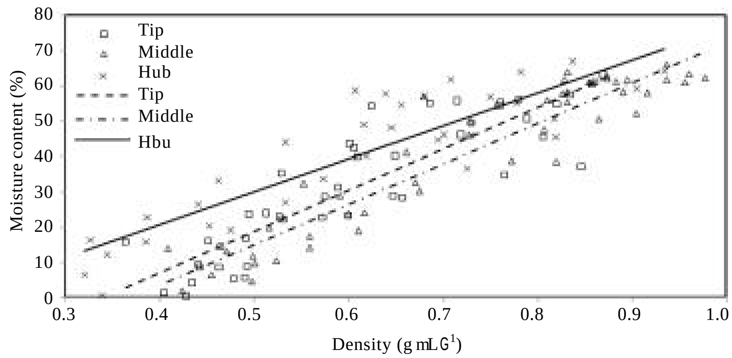

Fig. 3: Variation of moisture content with density of oil palm frond sections

measurements obtained in the above method and the weight measurements obtained in the second stage weight measurement. The variation of moisture content with density is shown in Fig. 3. To investigate the effect of porosity on the density of different sections of OPF, Scanning Electron Microscope (SEM) images were taken for different sections of OPF using LEO 1430VP model scanning electron microscopy.

RESULTS AND DISCUSSION

Hygroscopic nature of OPF: The moisture gain or loss of OPF which was kept for 48 h in a laboratory room at an average temperature and relative humidity of 23°C and 80%, respectively is shown in Fig. 2. As shown in the graph, OPF samples which had moisture content above 12% on wet basis showed weight reduction when it was measured after 48 h. On the contrary, those samples which had moisture content below 12% showed increase in weight when their weight were measured after 48 h. This showed that samples which had moisture content above 12% have absorbed moisture from the surrounding and those samples which had moisture content below 12% have lost their moisture in the surrounding.

Hence, the minimum and ideal moisture content that can be achieved by natural drying under the specified condition is about 12% on wet basis. Drying of OPF feedstock below 12% moisture content will not have advantage as far as the feedstock is kept under the specified condition for more than 48 h. To maintain the moisture content below 12%, OPF feedstock must be stored in a room under conditions of lower humidity level and higher temperature than the above specified conditions.

Variation of density with moisture content and porosity: The graph in Fig. 3 shows a plot of the variation of moisture content with density for the tip, middle and hub sections. From the graph, it can be ascertained that moisture content has positive correlation with density. In the linear regression analysis of moisture content variation with density, the square of correlation coefficient (R^2) values were found to be 0.80, 0.89 and 0.78 for the tip, middle and hub sections, respectively.

For the same moisture content values, the middle section is denser than the other two sections while the hub section has the least density. This variation in density may not be unconnected with the inner morphology of the various sections of OPF, hence SEM investigations were carried out. As the investigation reveals, in the SEM images of Fig. 4, the middle section has smaller pore sizes

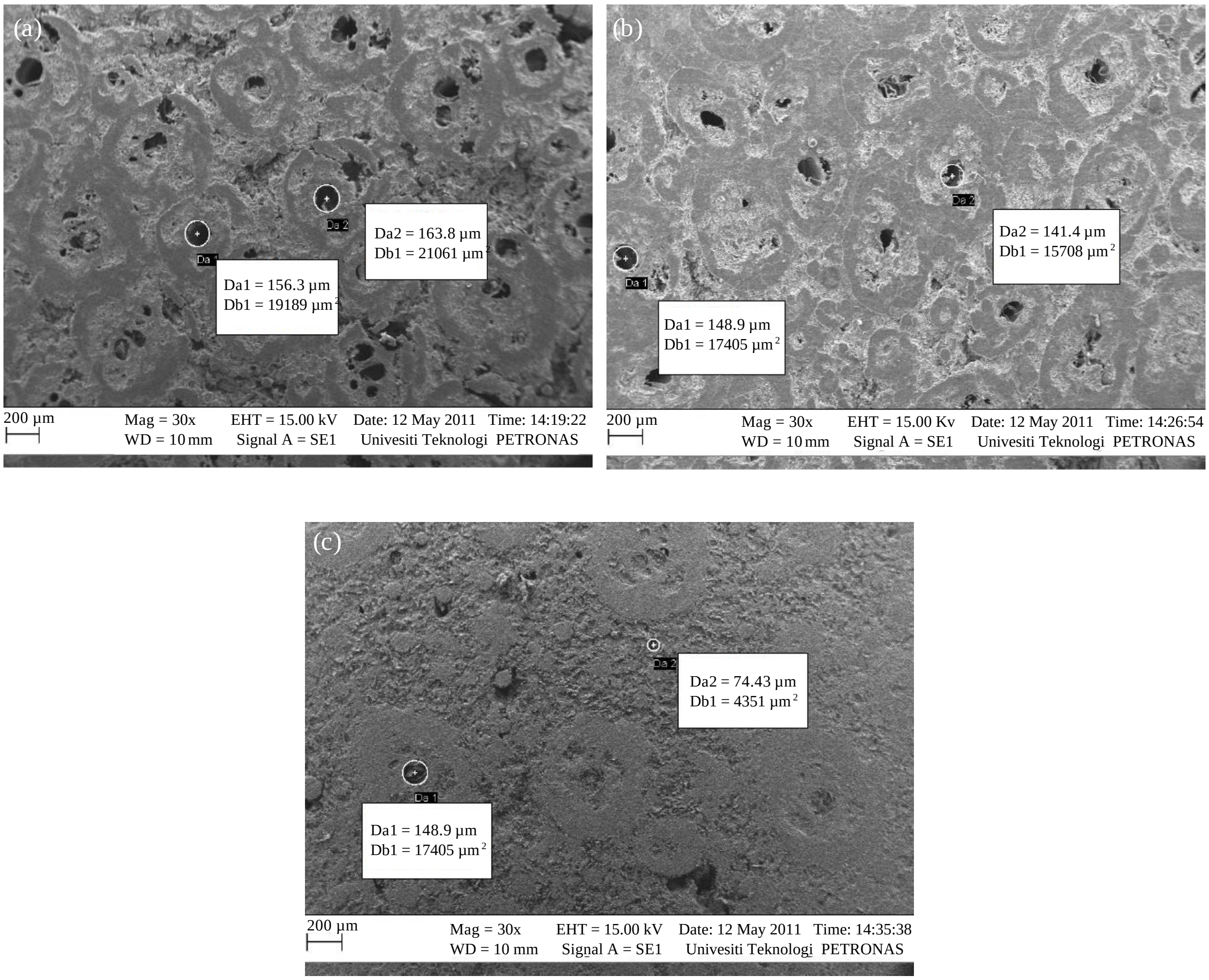

Fig. 4(a-c): SEM images of (a) Tip (b) Middle and (c) Hub with 30x magnification

and lower distribution than the tip section. As the density per unit area and size of the pores affect the particle, the middle section is supposed to have higher density compared to the tip section due to smaller size of pores, resulting in closer packing (more matter per volume). It could be conclusively inferred therefore, that the result of SEM images of the tip and middle sections are in agreement with the density comparison of the two sections of the frond having the same moisture content.

The pores of the hub seem smaller in size compared to the other two sections on the SEM image with 30x magnification in Fig. 4c while, when the SEM image is seen with 300x magnification in Fig. 5c the surface seems very rough and irregular compared to the other sections. Therefore, despite the fact that the hub pores which are smaller in size compared to the other sections, the number of pores per unit area is high which may cause the density to be lower than the other sections. As it can be seen in Fig. 5c the

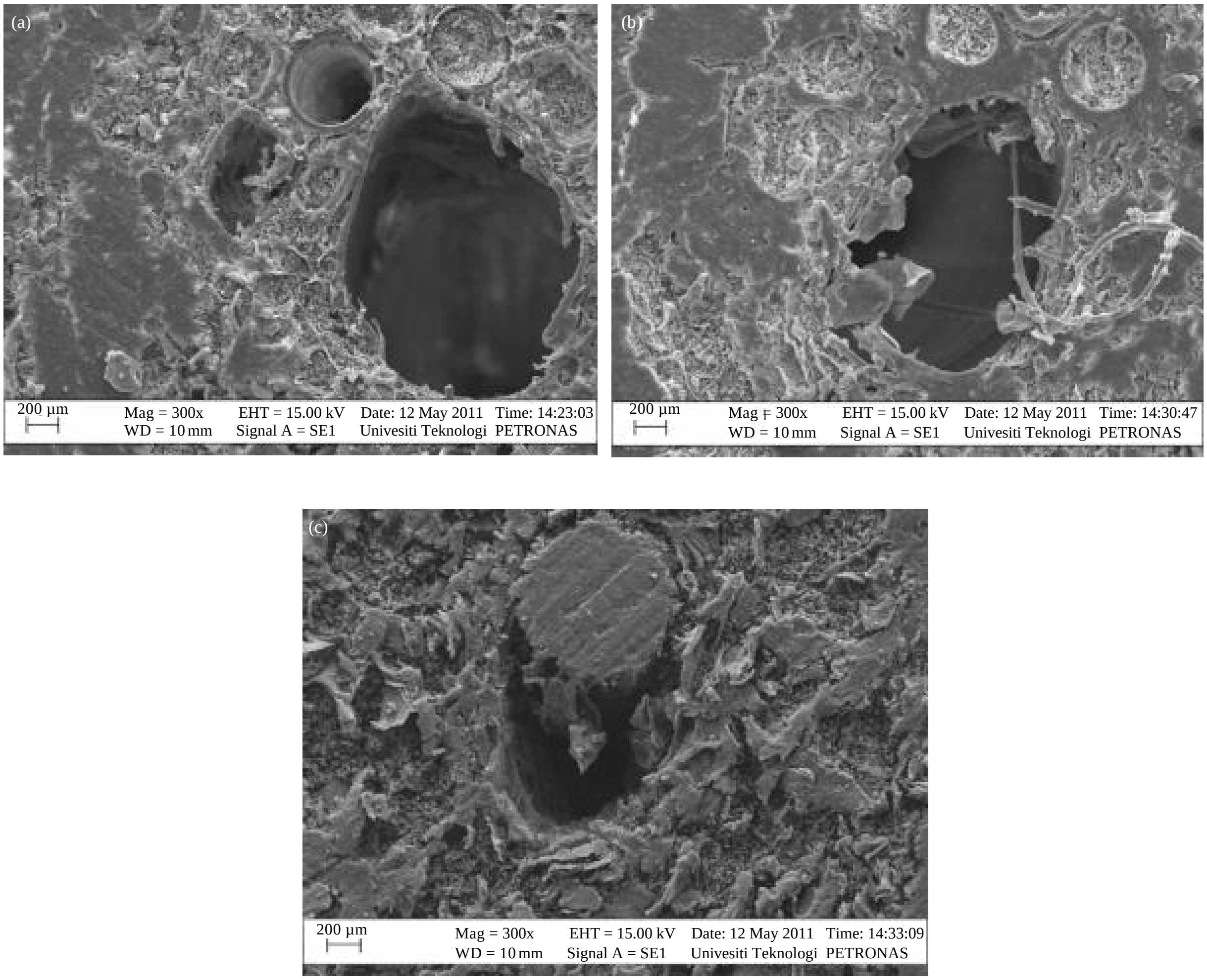

Fig. 5(a-c): EM images of (a) Tip (b) Middle and (c) Hub with 300x magnification

surface also looks uneven and pores are blocked with chips which might happen during sample preparation by polishing using surface grinder.

CONCLUSION

In the investigation of the hygroscopic nature of Oil Palm Fronds (OPF) feedstock, the Equilibrium Moisture Content (EMC) was found to be 12% on wet basis at 23°C and 80% relative humidity conditions. From the investigation it was also ascertained that moisture content of different sections of OPF has positive correlation with its density. In addition, it was observed that the nature of porosity of the feedstock has an effect on its density. The SEM images of OPF showed that the middle section has less pores than the other two sections. As a result, the middle section was found to be denser than the tip and the hub sections while the hub section was the least in density for the same moisture content.

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