Characterization of saw-dust solid waste for its pyrolytic conversion into bio-oil

Mohammad Nurul Islam[1], Farid Nasir Ani[2], Mohammad Hafiz Bakar[1] and Nurhamizah Ahmad[1]

***Abstract*—** Biomass in the form of saw-dust widely available in Brunei Darussalam from different timber industries is characterized in order to be used as feedstock for its conversion into bio-oil by the emerging thermochemical process, known as pyrolysis. It has dual effects. In one way, it reduces too much dependency on fossil fuel sources with a diversion of attention towards renewable sources of energy. On the other hand, it contributes to the reduction of pollution and disposal problems which are at present a major concern of every nation along with the whole world. For this purpose, locally available saw-dust solid waste is collected, prepared and characterized for its thermal behavior by means of thermo-gravimetric analysis (TGA). From the study it is realized that the solid saw-dust particles can be used as a feedstock material for its pyrolytic conversion into bio-oil with sufficient percentage of liquid and solid product yields. The study indicates that the pyrolysis reactor bed temperature should be in the range of 300 to 600 ^{o}C.

***Keywords*— Saw dust; pyrolysis; characterization; biomass; solid wastes.**

I. Introduction

When it comes to renewable energy context, it is to mention that Brunei Darussalam is well known for its conventional, non-renewable energy sources in the form of oil and gas. The country is heavily reliant on oil and gas for its local uses and foreign exports. However, it is a fact that in course of time this organic fossil fuel will deplete gradually when it is used at a faster rate. Besides the environment also gets sufficiently affected as a result of fossil fuel exploration. Fossil fuel combustion is known to create serious environmental problems. Carbon dioxide emission causes greenhouse effect which in turn causes a concern on global warming and climatic change. In Brunei, biomass energy may not be a convenient energy resource at present; however, development of biomass energy can provide solution to disposal problems, generate renewable energy and reduce carbon emission. In this context it is appropriate to mention that biomass solid waste in the form of saw-dust is generated significantly from the timber processing mills in Brunei Darussalam. It is either unused or underutilized with disposal problem. This waste can be a potential candidate to derive renewable energy in the form of bio-oil. For this the newly emerging pyrolysis technology can be utilized. This type of works is in progress in Malaysia, Indonesia, India, Bangladesh, European countries and the USA [1]. In order to proceed for this, the saw-dust solid waste is required to be characterized from the point of view of particle size, bulk density, moisture content, ash content, higher heating value and thermogravimetric analysis (TGA) to check its potential to be used as the feedstock for the purpose. A major part of this characterization study is carried out in the Thermodynamics Laboratory of the Mechanical Engineering Programme Area of Institut Teknologi Brunei (ITB), Brunei Darussalam as reported in the works of Omarali, Bakar and Ahmad and Islam, Yazdani and Omarali [2-4]. This present work focuses on the thermal behavior of saw dust available in Brunei Darussalam to complete the characterization study.

II. Determination of Feedstock Properties

Saw-dust waste is collected locally from Tutong Wood Milling Station, Brunei Darussalam. It is air-dried and subjected to grinding to obtain suitable particle size. Afterwards, the particles are screened into suitable size by means of Mechanical Sieve using dry sieve method. The particles are obtained in size in the range of 63 to 1168 µm. The properties of locally available saw-dust solid waste are presented in Table 1 as reported by Bakar, et al (2014). The bulk density is found to be at around a hundred in kg/m^3. The moisture content and ash content are determined using the standard test procedures. These are found to be 8 percent and 1.55 percent respectively. The higher heating value (HHV) of the saw-dust specimen is determined by means of an oxygen bomb calorimeter adopting the ASTM standard test procedure ASTM D240. This is found to be 21.5 MJ/kg.

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Table 1. Properties of saw-dust solid waste of Brunei Darussalam [5]

Properties	Unit	Value
Particle size	µm	63 - 1180
Moisture content	%	8
Ash content	%	1.5
Bulk density	kg/m^3	94
Higher heating value (HHV)	MJ/kg	21.5

III. Thermal behavior study of saw dust with TGA

A. *TG and DTG plots*

Thermogravimetric analysis is a technique in which the mass of a substance is monitored as a function of temperature or time as the sample specimen is subjected to a controlled temperature program in a controlled atmosphere [6]. Saw-dust samples of size 63-1180 µm were air-dried. During pyrolysis activity, data of about 25 mg of the samples were recorded continuously as a function of temperature and time by a computer connected to the system. The TG curve shows the fractional weight loss of the sample with temperature while the DTG curve shows the percent weight loss of the sample per unit time against temperature. The thermogravimetric (TG) study is carried out at two different heating rates at Universiti Teknologi Malaysia (UTM), Malaysia. From the TGA readings, the TG and DTG plots are obtained. These are presented in Fig. 1 and Fig. 2 at heating rates of 10 ^{o}C/min and 40 ^{o}C/min respectively. From Fig. 1 representing the TG curve at the lower heating rate of 10 ˚C/min, it appears that moisture was initially driven out from the sawdust sample within the temperature of 100 ˚C which represents a 10 % of the total weight loss of the sample. The devolatilization is observed to start at a temperature of 280 ˚C that is almost completed at 580 ˚C. The sample is found to be almost fully volatilized indicating a very high percentage of volatile matter present in the sample that is a very good indication from the point of view of pyrolytic liquid conversion. At the higher heating rate of 40 ˚C/min as presented in Fig. 2, the devolatilization is found to start at a slightly lower temperature of 240˚C and approached the completion at about a same temperature near 600˚C. The volatile yield at 600 ˚C is found to be 70 % by weight. It shows a char residue including ash of 20 % by weight. From Fig. 1 showing the DTG curve, devolatilization appears to occur at two distinct stages of reaction. The first stage devolatilization occurs between 280 ˚ to around 380 ˚C. At the lower heating rate, the peak rate of devolatilization occurs at around 380 ˚C, at a rate of about 12 % weight loss per ˚C.

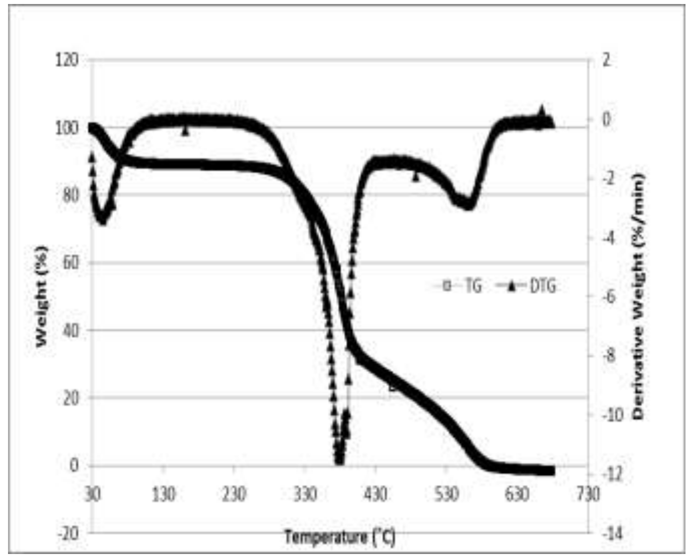

Fig. 1. TG and DTG plot for sawdust at 10˚C/min.

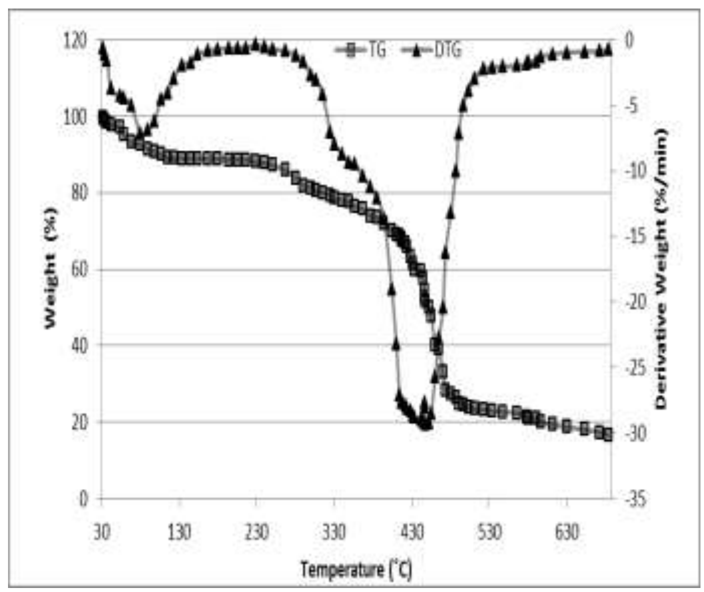

Fig. 2. TG and DTG plot for sawdust at 40˚C/min.

The second stage of devolatilization occurs at a temperature range of 400 to 550 ˚C. From Fig. 2 showing the DTG curve at the higher heating rate, the first stage devolatilization is found to occur between 230 ˚C to 450 ˚C. The peak rate of devolatilization occurs at around 27 % weight loss per ˚C. The second stage occurs between 450˚ to 600 ˚C at a peak rate of 30 % weight loss per ˚C. Shafizadeh in his study found that the decomposition of hemicellulose at the first stage occurs between 220 ˚C and 330 ˚C [7]. Moreover, the decomposition of cellulose at the second stage is found out to occur between 300 ˚C and 380 ˚C and lignin decompose gradually between 180 ˚C and 500˚C [8]. Thus, the results of the study are found to be consistent with the work of Shafizadeh.

B. *Degree of Conversion*

The value obtained from the TG and DTG plots of sawdust is used to determine the degree conversion of selected biomass X in a pyrolysis system that could be derived using Equation (1) [8]. The derivative of conversion can be calculated using Equation (2) [3].

$$X = (W_o - W)/(W_o - W_a) \qquad (1)$$

$$\frac{dX}{dt} = \frac{W_a(W_o - W_a) - (W_o - W)(W_a{}^2)}{(W_o - W_a)^2} \qquad (2)$$

Where, W_o = the initial mass of the sample,
W = the instantaneous mass of the sample, and
W_a = the final mass of the sample.

Fig. 3 gives the conversion plots at the two different heating rates. It clearly has three distinct stages of reaction as can be seen by the characteristics of the curves as presented in Fig. 3. For a given temperature of the sample pyrolysis, the corresponding conversion at lower heating rate (10˚C/min) was slightly more than that at a higher heating rate (40˚C/min). The first stage is the degree of conversion of sawdust that is found to increase by 10 % when the temperature is at 200 ˚C for both the heating rates. This may be related party to the devolatilization of the hemicellulose with a rapid increase of degree of conversion in the second stage which is due to the evolution of the volatile matter of cellulose and hemicellulose of the biomass wastes [9]. The second stage indicates the increase in degree of conversion to 70% within the temperature range of 250 ° to 400 ˚C for the lower heating rate. The degree of conversion increases to 75 % within range of 250 ˚C to 450 ˚C for the higher heating rate. This second stage is mainly attributed to the decomposition of the organic constituents into volatiles and char [10]. The third stage is the degree of conversion after 70 % and 75 % for lower and higher heating rates respectively. At this stage, there are gradual breakdown of lignin into char and gases when the temperature was varied from 500 ° to 600 ˚C. When the temperature exceeded 600 ˚C, the organic materials were almost completely decomposed to carbon and other inorganic compounds [9].

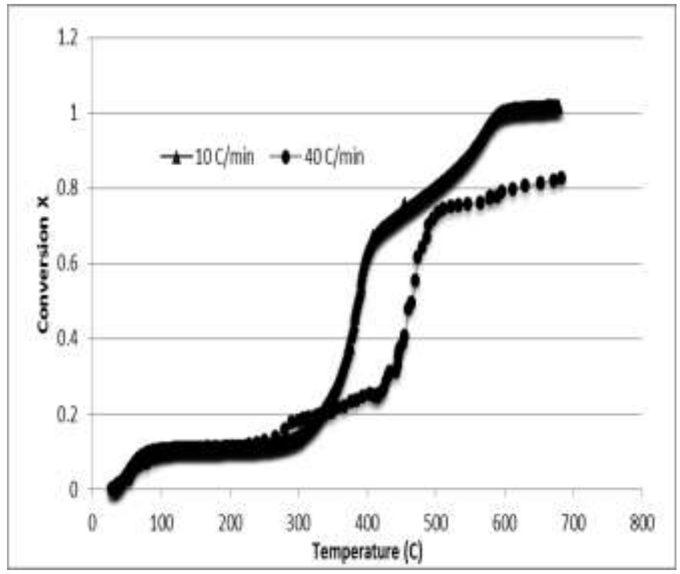

Fig. 3. Effect of heating rates on the pyrolysis conversion of sawdust.

Fig. 4 gives the rate of conversion in the form of derivative of conversion at two different heating rates. It can be found that the plot contains two distinct stages. At the first stage of the lower heating rate, the rate of conversion increases to 0.33 % at 13 ˚C from zero initial. The second stage of the conversion rate occurs at temperature range of 300 to 400 ˚C with a maximum peak rate at a temperature of 350 ^{o}C. The rate gradually falls to zero rates after it reached the highest peak. For the higher heating rate, the rate of conversion increases to 0.1 % at a peak temperature of 80 ˚C. Then the rate of conversion falls to 0 %. The second stage of the conversion rate occurs at temperature range of 300 to 550 ˚C at the peak rate of 2.8 % at a reaction temperature of about 475 ^{o}C. The rate gradually falls to zero rates after it reaches the highest peak.

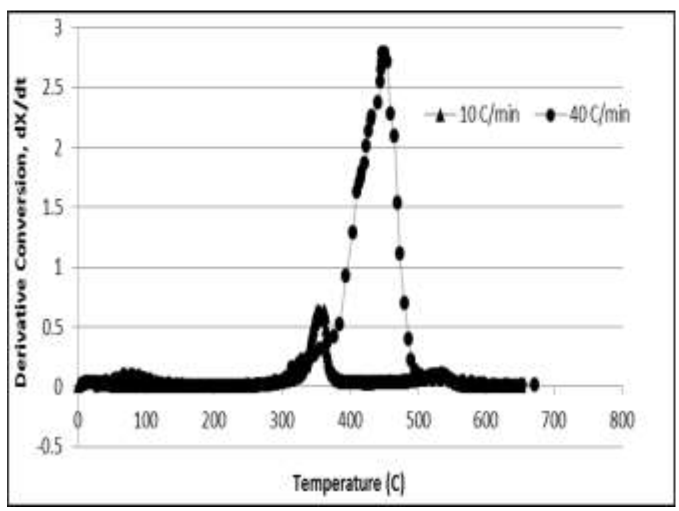

Fig. 4. Effect of heating rates on the derivatives of pyrolysis conversion of sawdust

IV. Conclusions

The saw-dust waste solid waste of Brunei Darussalam is successfully characterized for its thermal behaviour by thermogravimetric analysis (TGA) indicating the fact that saw-dust can be a suitable potential feedstock for its pyrolytic conversion into bio-oil. The characterization data obtained from this study can be used to design the pyrolysis conversion system. The reactor bed temperature for pyrolysis system should be kept in the range of 300 to 600 ^{o}C for pyrolysis reaction to take place so that complete devolatilization takes place rendering maximum percentage of bio-oil yield. The design and fabrication of the pyrolysis system for bio-oil production from the saw-dust feedstock is recommended for further study.

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References

[1] M. N. Islam, Pyrolysis of Biomass Solid Waste and Its Catalytic Treatment with Techono-economic Analysis, A Ph.D. Thesis, Faculty of Mechanical Engineering, Universiti Teknologi Malaysia, (1999).

[2] S. R. B. H. Omarali, Selection and Characterization of Biomass Solid Waste in Brunei Darussalam for Its Pyrolytic Conversion, A B.Engineering Final Year Project Report, Mechanical Engineering Programme, Institut Teknologi Brunei, Brunei Darussalam, (2013).

[3] M. H. Bakar, N. Ahmad, Characterization of Biomass Solid Wastes of Brunei Darussalam for Their Pyrolytic Conversion, A B.Engineering Final Year Project Report, Mechanical Engineering Programme, Institut Teknologi Brunei, Brunei Darussalam, (2014).

[4] Islam, M. N., Yazdani, M. G. & Omarali, S.R., Selection and characterization of biomass solid wastes for its pyrolytic conversion to liquid fuel in Brunei Darussalam, 8th CUTSE International Conference, Sarawak Campus, Miri, Malaysia, December (2013).

[5] Bakar, M. H., Ahmad, N., Islam, M. N. & Ani, F. N., Characterization of biomass solid wastes for its pyrolytic conversion into liquid oil in Brunei Darussalam, 5th BICET International Conference, ITB, Brunei Darussalam, November (2014).

[6] S. Anandhan, Thermal Analysis, Department of Metallurgical and Material Engineering. NITK, http://www.nitk.ac.in/static/assets/files/MetMat/Dr.AS/TGA.pdf (2007).

[7] F. Shafizadeh, Pyrolysis reactions and products of biomass, in: R. P. Overend, T. A. Milne, L. K. Mudge (Eds.) Fundamental of Thermochemical Biomass Conversion, London, Elsevier Applied Science, 183-217 (1985).

[8] T. H. Liou, F. W. Chang, J. J. Lo, Pyrolysis kinetics of acid leached rice husk, Ind. Eng. Chem. Res., 36, 568-573 (1997).

[9] M. R. Islam, M. N. Nabi, M. N. Islam, Characterization of biomass solid Wastes for liquid fuel production, 4th International Conference on Mechanical Engineering, December 26-28, Dhaka, Bangladesh, I77-182, (2001).

[10] M. N. Islam, F. N. Nasir, Thermal characteristic of Malaysian rice husk, Jurnal Teknologi, 30, 39-50 (1997).