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Characterization of Sawdust Residues for Cyclone Gasifier

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Abstract: This study presents, the characterization of sawdust residues from Malaysian furniture industries for cyclone gasifier. The characterization of sawdust has been studied and evaluated to determine its potential utilization as a biomass fuel for cyclone gasifier. The raw sawdust was produced by cutter, sawing, sieve and sanding. The types of species of wood sawn timber used by the factory were Meranti (dark red, light red and red). The raw sawdust was pre-treated throughout a grinding process into smaller sizes of particles and sieve with three different mesh sizes (3.5, 1.2 and 0.6 mm). The sample of ground sawdust was analyzed for its biomass fuel characteristics. The results of proximate analysis shows that the ground sawdust with moisture content of 8.25% (wet basis) contains 14.04% of fixed carbon, 76.23% of volatile matter and 1.49% of ash on dry basis. The High Heating Value (HHV) of sawdust was found to be about 18.23 MJ kg^{-1} while the Low Heating Value (LHV) was about 16.54 MJ kg^{-1}. The result of ultimate analysis validates both ash and moisture content which are found to be 1.49 and 8.25%, respectively. Other elemental compositions determined by the ultimate analysis are carbon (42.38%), hydrogen (5.27%), nitrogen (0.14%) and oxygen (42.41%). There is no sulphur detected in the sawdust. The study has identified that the sawdust from local furniture industries is comparable with other types of biomass and therefore, making it very potential as a source of fuel for the cyclone gasification system.

Key words: Biomass, sawdust, fuel characteristics, gasification, cyclone gasifier, characterization

INTRODUCTION

Cyclone is the most widely used separation technique to clean gas stream from solid or liquid particles and extensive works have been reported on this separating technique. Furthermore, the used of cyclone as a combustor system is well known and there are many types of commercialize cyclone combustor available in the market. However, the use of cyclone combustor is generally limited to burn liquid and gaseous fuel. In addition, they are also cyclone combustor designed to burn pulverized coal. Hence, the idea of using cyclone to gasify biomass fuels was first studied by Kjellstrom at the Royal Institute of Technology in Stockholm. Since, then only few studies including practical work have been reported in the literature on using cyclone as a gasifier (Fredriksson, 1999; Gabra *et al*., 1998, 2001a-c; Syred *et al*., 2004).

A cyclone gasifier is newly developed at School of Mechanical Engineering, Universiti Sains Malaysia to gasify fine biomass material such as sawdust for the purpose of power generation. Sawdust is chosen as the biomass fuel in this study because compared to other materials sawdust is easily and abundantly available as waste and generally disposed in landfill areas, since this is a cheapest way to manage it. In addition, it is locally available at the surrounding areas of the university especially at the Furniture Industrial Area, Sungai Baong, Jawi, Pulau Pinang. Sawdust is readily available in dry pulverized form which can be used directly with some pretreatment process.

The goal of this study was to characterized the pre-treat sawdust residues from Malaysian furniture industries mainly *Meranti* species and determine its potential use as biomass fuel for a newly developed cyclone gasifier at Universiti Sains Malaysia. The sawdust will be characterized by using sieve shaker, PE 2400 Elemental Analyzer, TGA7 together with TG controller and bomb calorimeter. Testing results are discussed and characterization of the sawdust is presented.

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MATERIALS AND METHODS

The study was conducted at the School of Mechanical Engineering, Universiti Sains Malaysia from 1 January 2008 to 31 December 2008, where the sample sawdust residues were collected from local furniture industries. The characteristics of the biomass fuel have a significant effect on the performance and key design parameters when selecting the gasifier system. However, all the gasifier will operate satisfactory within the range of fuel properties, which the most important parameters are particle size distribution, biomass fuel composition, moisture content, volatile matter, ash content and heating value.

Particle size distribution: The particle size of biomass fuel and the size distribution affects the pressure drop across the gasifier and power output produced from the gasification process. Large pressure drops reduces the particle separation in the cyclone gasifier, resulting in low temperature inside the gasifier chamber. Excessively large sizes of particles reduce reactivity of fuel, causing start-up problem and poor gas quality. Theoretically, the smaller biomass fuel the faster is the gasification reaction. For example, fluidized bed gasifiers accept size in the range of 1 mm diameter while fixed bed gasifiers accept in the range of 100 mm diameter. Thus for pulverized biomass fuel, with particle size below 1 mm, cyclone gasifier is introduced which utilizes cyclonic motion concept to suspend the particles for initiating the gasification process occurred in the chamber.

The size distribution of sawdust is a very important parameter because it affects the flow of particles in the downcomer, the injector and in the cyclone chamber. The low bulk density and cohesive characteristics of sawdust can cause accumulation of fuel in the feeding system, creating the difficulties to flow towards the cyclone chamber. The build up amount of sawdust along the flow channel can break off the fuel flow, thus compacted into a solid structure and leads to a blockage in the discharge. Furthermore, the size distributions determine the time required for initiating and maintains gasification process and determine amount of particles carried out of the cyclone gasifier chamber with the producer gas.

The raw saw dust was characterized using sieve shaker and pre-treated using a disk mill. The disk mill is capable of grinding and sieve with three different mesh sizes (3.5, 1.2 and 0.6 mm). The size distribution was determined by automatic sieve shaker.

Biomass fuel composition: Biomass fuels are characterized using the ultimate and proximate analysis. The ultimate analysis gives the composition of the biomass in weight percentage of carbon, hydrogen and oxygen as well as sulfur and nitrogen. This analysis will show the elemental composition differences between sawdust and other biomass fuels. The composition variations among biomass fuels are large, but as a class, biomass has substantially more oxygen and less carbon than other fuels. Less obviously, nitrogen, chlorine and ash vary significantly among biomass fuels. Generally, biomass has relatively low sulfur compared to other fuels.

The proximate analysis gives the moisture, the volatiles, the fixed carbon and the ash contents in the biomass fuel. From the analysis, the quality of biomass fuel for usage in the gasifier is determined. The significance of the volatiles and fixed carbon is that they provide a measure of the ease with which the biomass can be ignited and subsequently gasified or oxidized, depending on how the biomass is to be utilized as an energy source. For example, a volatile content of the wood of about 80% is higher compared to a charcoal with volatile content of only 30%. This is good for initiating the combustion in the oxidation zone but too high means creating problems associated with tar formation because the formation of tar is proportional to the volatile content.

High volatile matter in biomass generally increases tar content of the producer gas. Volatile matter and inherently bound water in the fuel are released in the pyrolysis zone at the temperatures of 100-150°C forming a vapour consisting of water, tar, oils and gases. Fuel with high volatile matter content produces more tar, causes problems and should be removed before it is fed to internal combustion engine. The gasifier must be designed to crack tars and the heavy hydrocarbons released during the pyrolysis stage of the gasification process. According to Turare (1997), volatile matters in the fuel determine the design of gasifier for removal of tar. Compared to other biomass materials the amount of volatiles is as follows: crop residue: 63-80%, wood: 72-78%, peat: 70%, coal: up to 40% and charcoal contains least percentage of volatile matter (3-30%).

The moisture content of biomass fuel affects the heating value of producer gas. In thermal conversion processes, it is necessary to reduce the moisture content of biomass fuel. High moisture contents contribute to low gas heating value. This is because, dry biomass burns at higher temperature and thermal efficiency than wet biomass. High moisture contents will reduce the thermal efficiency since the heat is used for drying purposes. Besides, flame temperature is directly related to the amount of heat necessary to evaporate the moisture contained in the biomass fuel. The concentration of CO reduces with increase of moisture (reaction between CO and steam) while the concentration of CO_2 increases. In addition, the reaction between carbon and hydrogen will increase the concentration of CH_4. Moisture Content (MC) can be determined on a dry basis as well as on a wet basis. Moisture content is defined as:

$$MC_{dry\ basis} = \frac{Wet\ weight - Dry\ weight}{Dry\ weight} \times 100 \quad (1)$$

Alternatively, the moisture content on a wet basis is defined as:

$$MC_{wet\ basis} = \frac{Wet\ weight - Dry\ weight}{Wet\ weight} \times 100 \quad (2)$$

The accepted value of moisture content of the fuel in the biomass combustion system is between 20-55 (wt.%) (Jean and Donald, 1988). However, Mckendry (2002a, b) reported that biomass fuel with moisture content above 30% is difficult to ignite and reduces the heating value of the product gas due to the need to evaporate the additional moisture before combustion/gasification process can take place. Gabra *et al*. (2001b) used bagasse in cyclone gasifier with the moisture content of 5.90 (wt.%). Therefore, the moisture content of sawdust should be selected to be in the range of 5 to 20% (wt.%).

Ash is defined as mineral contents in the fuel, which remains in oxidized form after combustion of fuel. In practice, ash also contains some of unburned fuel. Ash content and composition have an impact on smooth running of gasifier. High mineral content makes gasification impossible. Therefore, the lower ash content the better the fuel is. The oxidation temperature is often above the melting point of the biomass ash, leading to clinkering/slagging problem in the hearth and subsequent feed blockages. If no measures are taken, slagging or clinker formations lead to excessive tar formation or complete blockage of reactor. In general, no slagging occurs with fuel having ash content below 5%. Ash content varies from fuel to fuel. Wood chips contain 0.1% ash, while rice husk contains high amount of ash 16-23% (Turare, 1997).

The ultimate analysis was conducted on the sample ground sawdust in order to determine its chemical composition using PE 2400 Elemental Analyzer located at School of Chemical Engineering, Universiti Sains Malaysia. Proximate analysis was carried out using TGA7 together with TG controller. The TGA system interfaced to a microcomputer for data acquisition and control task.

Heating value: The heating value (or calorific value) is defined as the amount of heat released during the combustion of a fuel. It is measured in units of energy per amount of material. Commonly, heating value is determined by using the adiabatic bomb calorimeter which measures the enthalpy change between the reactants and the products at 25°C. The quantity known as higher heating value or net calorific value or gross energy (HHV) represents the heat of combustion relative to liquid water as the product while the quantity known as lower heating value or net calorific value (LHV) represents gaseous water as a product in the combustion. The difference is the value of latent heat of water of combustion. Heating value is commonly quoted on dry basis where the biomass fuel is dried and all moisture contents are removed before it is used. HHV on dry basis is:

$$HHV = LHV + W\lambda \quad (3)$$

In addition, the HHV can be quoted on wet basis. The HHV on wet basis is given by:

$$HHV\ (dry\ basis) = \frac{100 - MC}{100} \times HHV\ (wet\ basis) \quad (4)$$

Otherwise, simple Eq. 5 can be used to calculate high heating value of biomass (Jean and Donald, 1988)

$$HHV\ (dry\ basis) = 0.4571\ (\%\ C\ on\ dry\ basis) - 2.70 \quad (5)$$

It is found that Eq. 5 fitted the experimental data with an average error of 1.45%, a typical error in most measurements. This equation permits using heat values in calculations and models of biomass processes. Table 1 shows the HHV for various types of wood (Jean and Donald, 1988).

The heating value for various types of wood is only slightly different, less than 2 MJ. Therefore, the average heating value of sawdust is acceptable without considering the type of wood. Syred *et al*. (2004) used commercial Austrian sawdust and Swedish wood powder produced from various type of wood. Gabra *et al*. (2001b) used bagasse as a fuel with HHV (dry basis) of 18.2 MJ and LHV (dry basis) 17.02 MJ. Furthermore, Gabra *et al*. (2001c) used sugar cane trash with HHV (dry basis) 17.84 MJ and LHV (dry basis) of 16.67 MJ. As a result, the

Table 1: High heating values of different wood

Name of wood	Types	Moisture range (wt.%)	High heating value (MJ dry kg^{-1})
Black alder	Hardwood	30-60	20.1
Cotton wood	Hardwood	30-60	19.5
Eucalyptus	Hardwood	30-60	18.7
Hybrid poplar	Hardwood	30-60	19.5
Redwood	Hardwood	30-60	21.0
Sycamore	Hardwood	30-60	19.4
Loblolly pine	Softwood	30-60	20.3

heating value of sawdust that will be used in this study should be determined first, in order to obtain appropriate results on gasification process.

Bomb calorimeter was used to determine the heating value of the sawdust. The test was done at Thermodynamic Lab, School of Mechanical Engineering, Universiti Sains Malaysia. The sample was wrapped and tied up using a nickel wire and it was placed in the crucible. Then, the crucible with the sample was placed in the bomb filled with oxygen. Then, the bomb was immersed in water. The outer jacket was kept at a constant temperature while the temperature of the water inside the vessel was varied. The changes were measured until it stops. The experiment was done in almost 15 min.

RESULTS AND DISCUSSION

Particle size distribution: The raw sawdust from local furniture industry was pre-treat by grinding in a disk mill (Fig. 1a, b). The type of species of sawn timber used by the factory was Meranti (dark red, light red and red).

The particle size distribution was investigated using three different type of disk mill meshing size. In particular, the raw sawdust were ground, sieved and classified to obtain fraction of uniform particle size. The conditions of the test were stated in Table 2 while the result of the size distributions of raw sawdust and ground sawdust from the sieving process are as shown in Fig. 2.

From the results, fuel A and B consist of about 80% for size more than 1 mm while fuel C consist of about 50% in the same region. In addition, for size ranging from 0.25-1.0 mm, fuel C and D consist of about 40 and 80%, respectively. From earlier study, Fredriksson (1999)

Table 2: The conditions of sieve test

Type of fuel	Sources	Grinder	Meshing size
A	Furniture industries	Raw	N/A
B	Furniture industries	Disk mill	3.5 mm
C	Furniture industries	Disk mill	1.2 mm
D	Furniture industries	Disk mill	0.6 mm

N/A: Not available

Fig. 1: (a) Raw sawdust and (b) ground sawdust

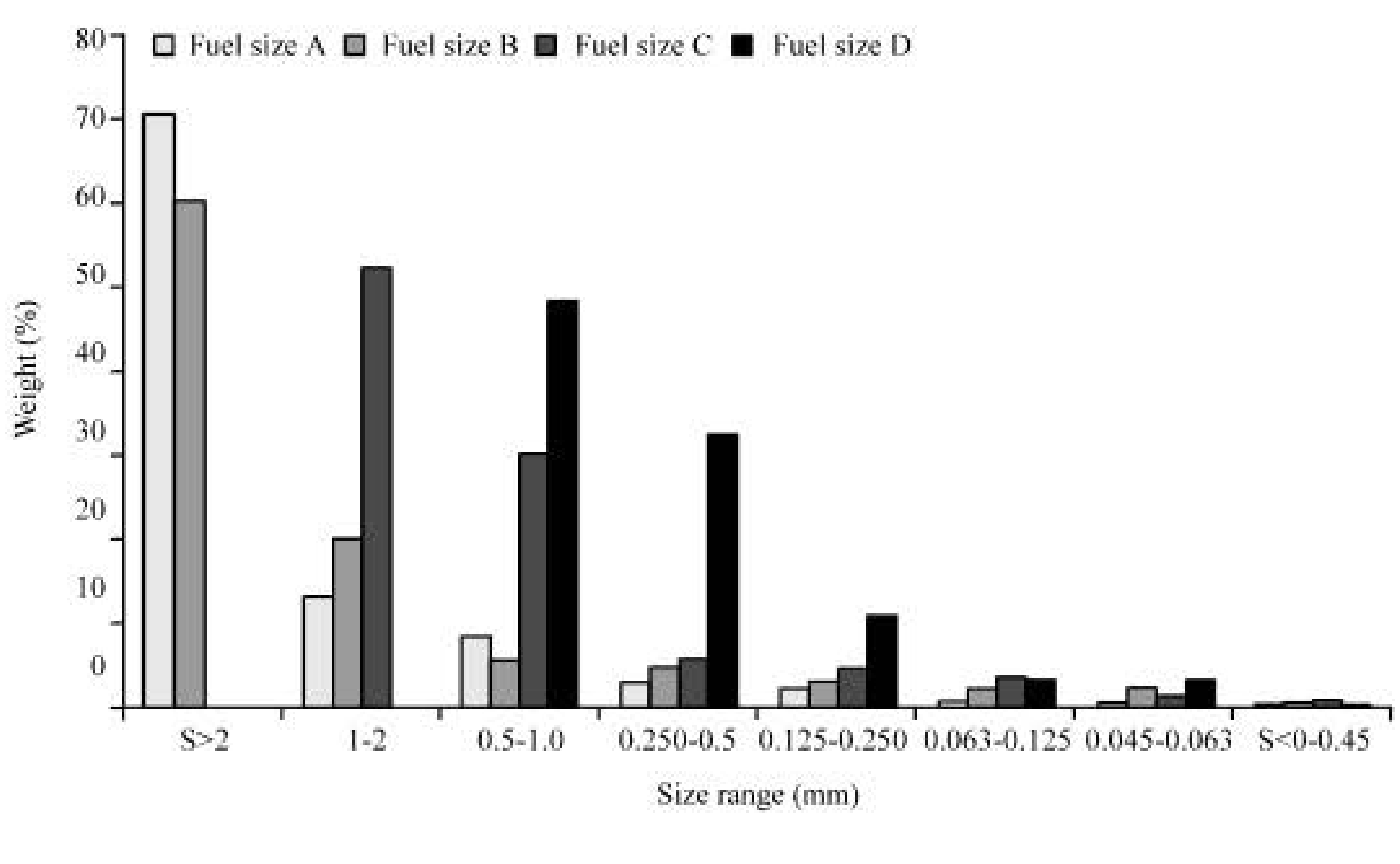

Fig. 2: Size distributions of sawdust

using commercialize Swedish wood powder, the largest percentage of size distribution is in the range of 0.25-0.5 mm, which is about 38%. Gabra *et al*. (2001c) using different types of sugar cane residue and the largest percentage of size distributions is in the range of 0.25-1 mm, which is about 50 to 70%. Therefore, the ranges of size distributions were comparable with other researchers.

Biomass fuel composition: The ultimate analysis determines the weight percentage of carbon, hydrogen, nitrogen, oxygen and sulphur (dry basis). The results of the ultimate analysis are shown in Table 3.

The results are consistent with typical wood analysis reported by Fredriksson (1999). However, the percentage of nitrogen and carbon of the sawdust used are relatively lower compared to processed biomass materials such as plywood which normally gives higher carbon and nitrogen value at above 48 and 1%, respectively (Reed, 1998). The low nitrogen and carbon value is nevertheless consistent with the analysis obtained for unprocessed wood. This may reflect the quality of the sawdust obtained from the local furniture industry, which is comparable to the unprocessed wood. The results are also comparable with baggasse (Gabra *et al*., 2001a).

From the results shown earlier (Table 4), the fixed carbon content is 14.04%, the volatile content is 76.23% and the ash content is 1.49%. The amount of ash content is much lower compared to rice husk, another potential biomass fuel for application in a cyclone gasifier, which has the typical ash content at about 18% (Yusof *et al*., 2008). The selection of sawdust as the biomass fuel appear to be the right choice since ash content is very important parameter affecting the composition and calorific value of producer gas. The lower the amount of ash content the better the fuel.

According to the above proximate analysis, moisture content of sawdust is around 8.25%, a typical value for sawdust. This moisture content is relatively higher compared to other types of biomass fuel used by other researchers using cyclone gasification technique. Table 5 shows the moisture content of various type biomass fuels used in similar cyclone gasifier. Other researchers agreed that the moisture content will affect the performance of the gasifier and thus they adopt a pre-treatment process to reduce the moisture content of

Table 3: Ultimate analysis of the sawdust in different elements

Elements	Dry weight (%)
C	42.38
H	5.27
N	0.14
O	42.41
S	0.00

Table 4: Proximate analysis of the sawdust

Proximate analysis	Dry weight (%)
Moisture content	8.25
Volatile matter	76.23
Fixed carbon content	14.04
Ash content	1.49

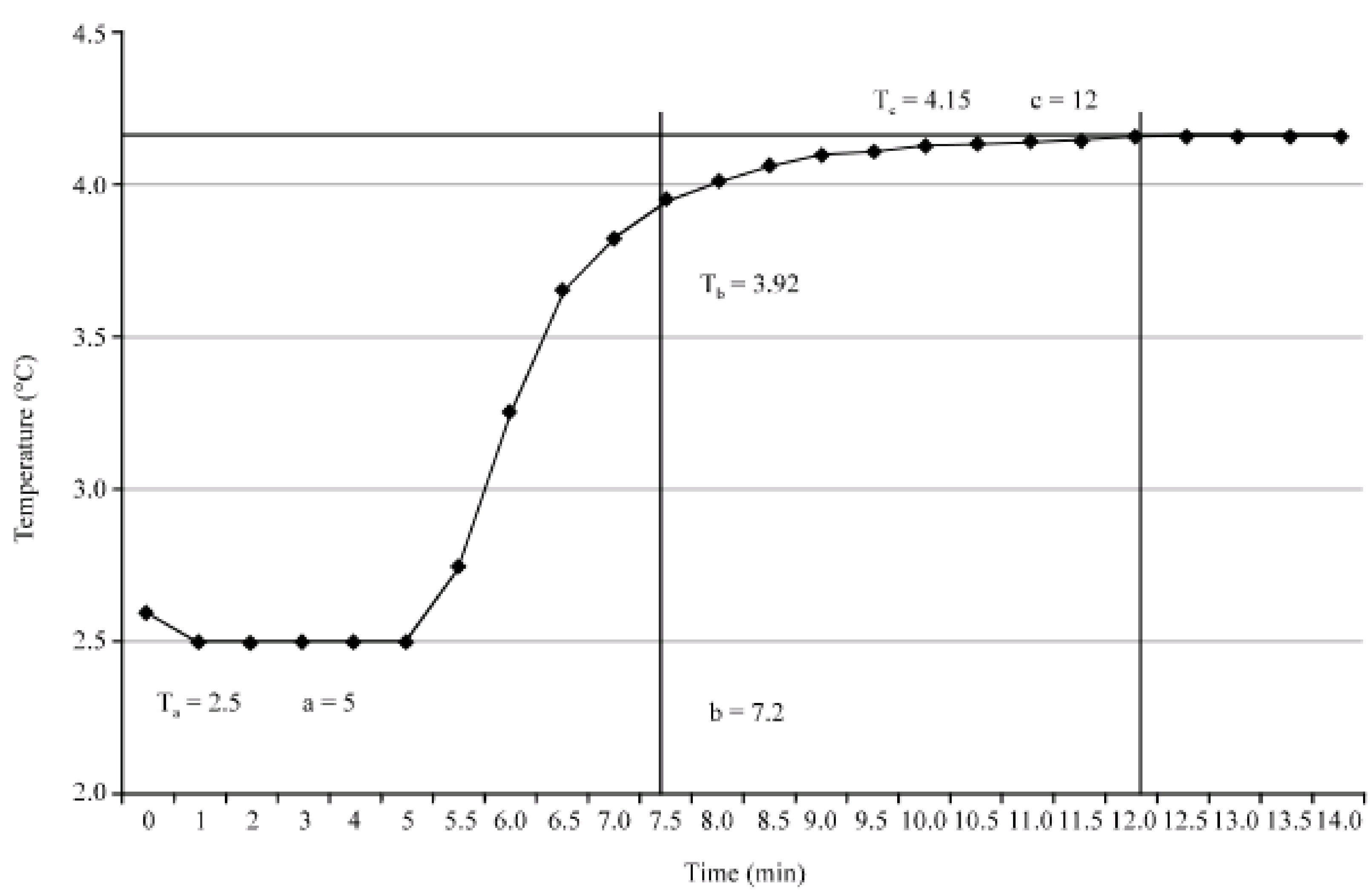

Fig. 3: Water temperature versus time

Table 5: Comparison of biomass fuel moisture content

Researchers	Biomass fuel	Type of gasifier	Moisture content (dry basis %)
Gabra *et al*. (2001b)	Ground bagasse	Cyclone gasifier	5.9
Gabra *et al*. (2001c)	Sugar cane trash	Cyclone gasifier	6.0
Fredriksson (1999)	Commercialize wood powder	Cyclone gasifier	5.6

their biomass fuel to give the optimum operating condition. The typical maximum amount of moisture content of wood acceptable for gasification process is in the range of 30 to 60% depending on types of gasifier design. However, the effect of different moisture content of sawdust and other biomass fuels on the cyclone gasifier are beyond the scope of this study since assumption has been made that any extra pre-treatment process on the sawdust will render the cyclone gasifier to be impractical and uneconomical and direct use of the sawdust with the typical moisture content is still within acceptable value for smooth operation. Extra caution has been made for the sawdust used in this study to be in the dry condition as-it-is basis.

Heating value: The calorific value of the test sample can be determined using the following expression:

$$HHV_{wood} = (m_{ECW} + m_{WC}) \times \frac{T_{Corr}}{m_S} \times Cp_W \times 4.1868 \qquad (6)$$

$$T_{corr} = T_c + r_2\,(c\text{-}b) - [T_a + r_1\,(b-a)] \qquad (7)$$

A High Heating Value (HHV) of sawdust was found to be about 18.23 MJ kg^{-1} using a Bomb Calorimeter (Fig. 3) with moisture content 8.25%. A low heating value (LHV) was about 16.54 MJ kg^{-1}. Low Heating Value (LHV) is used in the calculation for gasification rather than High Heating Value (HHV) because the final product from the gasifier is in the gaseous form.

CONCLUSION

The pretreatment process of raw sawdust residues from local furniture industry mainly from Meranti species helps to improve its fuel characteristics especially for the potential use as a biomass fuel in the cyclone gasification system. In addition, the ranges of size distributions were comparable with other researchers. The results of proximate analysis shows that the ground sawdust with moisture content of 8.25% (wet basis) contains 14.04% of fixed carbon, 76.23% of volatile matter and 1.49% of ash on dry basis. The High Heating Value (HHV) of sawdust was found to be about 18.23 MJ kg^{-1} while the Low Heating Value (LHV) was about 16.54 MJ kg^{-1}. The result of ultimate analysis validates both ash and moisture content which are found to be 1.49 and 8.25%, respectively. Other elemental compositions determined by the ultimate analysis are carbon (42.38%), hydrogen (5.27%), nitrogen (0.14%) and oxygen (42.41%). There is no sulphur detected in the sawdust. The study has identified that the sawdust from local furniture industries is comparable with other types of biomass and therefore, making it very potential as a source of fuel for the cyclone gasification system.

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NOMENCLATURE

T_{corr} = Correction temperature (°C)
T_a = Temperature at igniting (°C)
T_b = Temperature at b time (°C)
T_c = Temperature at the maximum (°C)
a = Time at igniting (min)
b = Time at 6/10 from maximum temperature (min)
c = Time to reach the maximum temperature (min)
r_1 = Temperature rate 5 min before igniting (°C min^{-1})
r_2 = Temperature rate 5 min after maximum temperature (°C min^{-1})
HHV = Higher heating value (MJ kg^{-1})
m_{WEC} = Mass water in equivalent calorimeter (g)
m_{WC} = Mass water in cylinder (g)
m_S = Mass of sample (g)
Cp_W = Specific heat of water (cal/g°C)
λ = Latent heat of vaporization (kJ kg^{-1})

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