Penerbit Akademia Baru

Journal of Advanced Research in Engineering Knowledge

Journal homepage: www.akademiabaru.com/arek.html
ISSN: 2600-8440

Chemical Properties of Torrefied and Raw Sawdust

Open Access

Alina Rahayu Mohamed[1,*], Nur Nadhirah Ahmad Nordin[1], Noor Hasyierah Mohd Salleh[1]

[1,] Department of Chemical Engineering Technology, Faculty of Engineering Technology, Universiti Malaysia Perlis, UnMAP Campus Unicity Alam, 02100 Padang Besar, Perlis, Malaysia

ARTICLE INFO

Article history:
Received 1 January 2019
Received in revised form 22 February 2019
Accepted 25 February 2019
Available online 31 March 2019

ABSTRACT

Torrefaction of sawdust was performed in a fixed bed reactor under nitrogen flowrate of 150 ml/min from room temperature to torrefaction temperature of 200-300°C at holding time of 20, 40 and 60 minutes. The proximate analysis and predicted carbon (C), hydrogen (H) and oxygen (O) as well as predicted high heating values were performed on raw and torrefied sawdust. It was determined that from proximate analysis, the moisture content and volatile matter decreased upon increasing torrefaction temperature. The predicted elemental analysis showed that the C content increased but H and O content decreased upon increasing torrefaction temperature. The predicted high heating value of torrefied sawdust also increased with increasing torrefaction temperature. During torrefaction process, several deoxygenation reactions such as decarboxylation, decarbonylation and dexydroxylation occured for successive expulsion of volatile gaseous products. Torrefaction process had reduced the moisture content and improved heating value of sawdust.

Keywords:
Sawdust, torrefaction, proximate analysis

1. Introduction

Utilization of non-renewable energy such as fossil fuels and coal continuously is expected to result in its depletion as well as contributed to severe environmental pollution. Therefore, it is necessary to search for sustainable source of energy which is non-exhaustive and does not contribute to environmental pollution. Biomass is a sustainable energy source and it is environmentally friendly.

Malaysian timber industry has generated approximately 3.4 million m^3 of yearly wood wastes in terms of sawdust, wood chips and others [1]. This huge amount of solid waste especially sawdust is viewed as a possible source of energy. However, biomass such as sawdust has low energy density and high moisture content that hindered its utilization as energy source [2]. Torrefaction is thermochemical pretreatment on biomass that allows expulsion of water and oxygenated compounds from biomass. The torrefaction process forms a brown to black uniform solid product that is also called torrefied biomass that low moisture contents and high caloric values [3]. Torrefaction process involves heating of biomass in an inert environment at temperatures between

* *Corresponding author.*
E-mail address: alina@unimap.edu.mu (Alina Rahayu Mohamed)

200 to 300ºC and heating rate must be under 50ºC/min [4]. Typically, 70% of the feed mass is retained after torrefaction as solid products (torrefied biomass) which contained 90% of initial energy [3]. Torrefaction is advantageous towards biomass or wood in such a way it increased grindability and hydrophobicity characters via elimination of an extensive amounts of hydroxyl functional groups [5]. Torrefaction of Douglas fir sawdust pellet in a thermogravimetric analyzer under nitrogen environment at torrefaction temperatures of 250, 275, and 30^{o}C and its related kinetics parameters were evaluated. It was stated that the sample mass loss during torrefaction process was correlated strongly to the torrefaction temperature [6]. The torrefaction of empty fruit bunches with particle size of 250-500 µm was carried out in a vertical tubular reactor from torrefaction temperature of 220-300˚C at a constant heating rate of 10˚C/min and the holding time was varied at 30, 60 and 90 mins. It was reported that the higher torrefaction temperature had resulted in higher heating value which mainly due to the enrichment of C content [7]. The effects of torrefaction on the basic characteristics of corn stalks was reported [8]. Corn stalks were torrefied in a horizontal tubular reactor at torrefaction temperature from 150°C to 400°C at residence time from 0-50 mins. Analysis on the torrefied corn stalk products were conducted such as its elemental composition, energy yield, ash content and volatile fraction. The energy and mass yield were found to decrease with an increase in torrefaction temperature, whereas the higher heating value (HHV) increased. The expulsion of oxygenated compounds was achieved at the temperatures of 290–330°C [8]. Torrefaction of sawdust and rice husk at three different temperature levels of 200-220, 240-260 and 280-300^{o}C were performed in a modified muffle oven where nitrogen was purged to ensure complete inert environment [9]. They reported that the C and O content of torrefied sawdust decreased significantly upon increasing torrefaction levels [9].

Based on the reported studies, several research has been done on biomass torrefaction especially sawdust. However, the information regarding the evaluation of predicted elemental content of raw and torrefied sawdust as well as comparison with elemental analysis of non-renewable energy source is scarce. Therefore, this paper is aimed towards reporting the evaluation of predicted elemental content of raw and torrefied sawdust upon comparison with non-renewable energy source

2. Methodology

2.1 Sample Preparation

The sawdust was obtained from small, medium industry in furniture located in Perlis, Malaysia. The sawdust was dried in an oven at 80ºC for 24 hours to remove the moisture as well as to make the grinding process easier. The particle size of the sample was ≤ 1000 µm.

2.2 Torrefaction of Sawdust

Torrefaction of sawdust was conducted in a fixed-bed reactor as shown in Figure 1. Approximately 10.0 g of sawdust was placed in a reactor. Then, the nitrogen was purged into the reactor for 10 mins to ensure an inert environment. The torrefaction temperature was varied from 200-300^{o}C and the holding time was varied from 20-60 mins at a ramp rate of 20°C/min. After the reaction was completed, the reactor was cooled down at room temperature under the stream of nitrogen [10]. The colour changes of the torrefied sawdust during the process was recorded and evaluated.

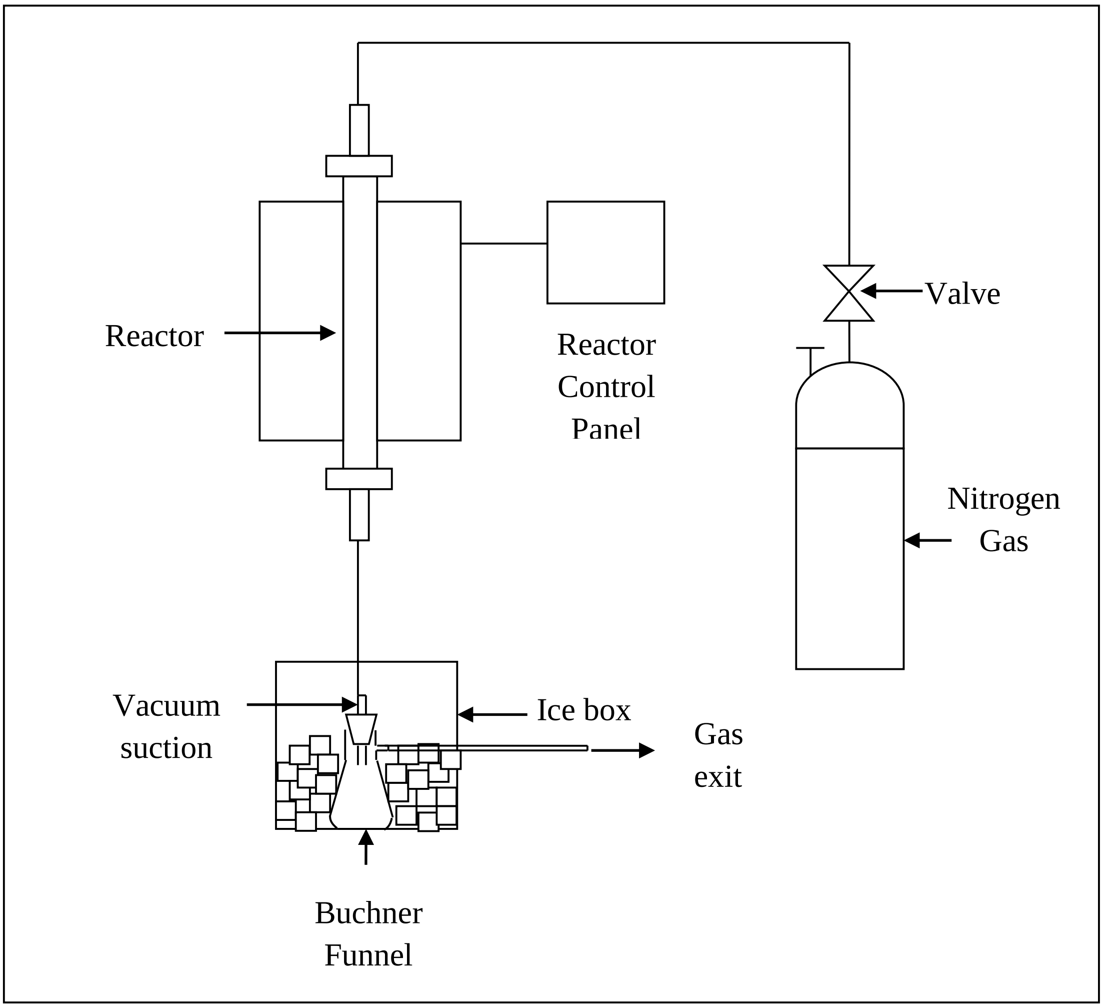

Fig. 1. Schematic diagram of torrefaction of sawdust in a fixed bed reactor

2.3 Proximate Analysis

The proximate analysis of raw and torrefied sawdust was conducted according to American Standard of Testing Material (ASTM) method. The moisture content was determined following the ASTM E871-82, the volatile matter and ash content were evaluated based on ASTM E872-82 and ASTM D1102-84 respectively. The fixed carbon content was calculated by difference.

2.4 Predicted Ultimate Analysis

For elemental analysis, the component of Carbon (C), Hydrogen (H) and Oxygen (O) were determined by using correlation based on the Equation 1, 2 and 3 [5].

$$C = -35.9972 + 0.7698VM + 1.3269FC + 0.3250ASH \quad (1)$$

$$H = 55.3678 - 0.4830VM - 0.5319FC - 0.5600ASH \quad (2)$$

$$O = 223.6805 - 1.7226VM - 2.2296FC - 2.2463ASH \quad (3)$$

The value of volatile matter (VM), fixed carbon (FC) and ash (ASH) were taken from the proximate analysis.

2.5 Predicted High Heating Value

The heating value also known as calorific value and it was calculated based on the correlation in Equation 4 [11].

$$HHV = 0.3536FC + 0.1559VM - 0.0078ASH \quad (4)$$

The value of fixed carbon (FC), volatile matter (VM) and ash (ASH) were taken from the proximate analysis.

3. Results

3.1 Proximate Analysis of Raw Sawdust

The raw sawdust possessed low moisture content and reasonable amount of volatile matter that contributed to prominent reactivity of saw dust as shown in Table 1. The experimental data are in good agreement with the reported studies [9,12,13].

Table 1
The proximate analysis of raw saw dust

Moisture Content (%)	Volatile Matter (%)	Ash Content (%)	Fixed Carbon Content (%)	Reference
4.52	81.79	1.58	12.11	This study
8.31	80.74	1.42	17.84	[9]
6.40	74.30	3.30	16.0	[13]
5.00	80.90	2.00	12.10	[12]

The physical features of raw and torrefied sawdust are presented in Table 2. It can be visualized that upon increasing the torrefaction temperature and holding time from 200 to 300°C and 20 to 60 mins, the colour of raw sawdust had changed from yellow brownish to brownish and finally dark colour. At torrefaction temperature of 300°C and holding times of 60 mins, the torrefied sawdust was the most intensified black colour. Black color indicated higher fixed carbon content [9]. Thus, it can be seen that torrefaction improved the quality of sawdust by upgrading the carbon content of sawdust. This results were in good agreement with reported studies [9,14].

3.1 Predicted Ultimate Analysis of Raw and Torrefied Sawdust

Table 3 shows the proximate and predicted ultimate analysis of raw and torrefied sawdust at different torrefaction temperature of 200-300°C and at holding time of 20 mins. This set of sample was selected that represented the whole three series of experiments. Based on the result, moisture content and volatile matter decreased from 4.25 to 0.07% and 81.79 to 60.05% respectively with increasing torrefaction temperature from 200-300°C. It is evident that increasing the torrefaction temperature had significantly reduced the volatile matter of sawdust from 80.05% to 60.05% for torrefaction temperature of 200 and 300°C respectively. This could be due to the contribution of expulsion of oxygenated compounds via several deoxygenation reactions which occur simultaneously. The removal of oxygen from the hemicellulosic fractions of sawdust through decarboxylation, decarbonylation and dehydroxylation reactions produced carbon dioxide (CO_2), carbon monoxide (CO) and H_2O. Removal of CO_2 and CO are entropically favoured since gaseous products possessed higher entropy. Fixed carbon and ash content of the torrefied sawdust increased in parallel pattern with torrefaction temperature from 12.11 to 35.79% and 1.58 to 4.09% respectively. This results were in good agreement with reported study [15]. Torrefaction increased the high heating value (HHV) of sawdust markedly because of the carbon removal from hemicellulosic fraction of sawdust. After the torrefaction at temperature 200 - 300°C, HHV of the sawdust increased from 17.51 MJ/kg to 21.99 MJ/kg. These calculated results are in good agreement with reported study Ren *et al.*, [9] that stated the HHV of sawdust was 25.68 MJ/kg when torrefied at 300°C.

Table 2
Observations of raw sawdust and torrefied sawdust at different torrefaction temperature and holding time

Torrefaction tempertaure	20 mins	40 mins	60 mins
Raw			
200°C			
220°C			
240°C			

260°C			
280°C			
300°C			

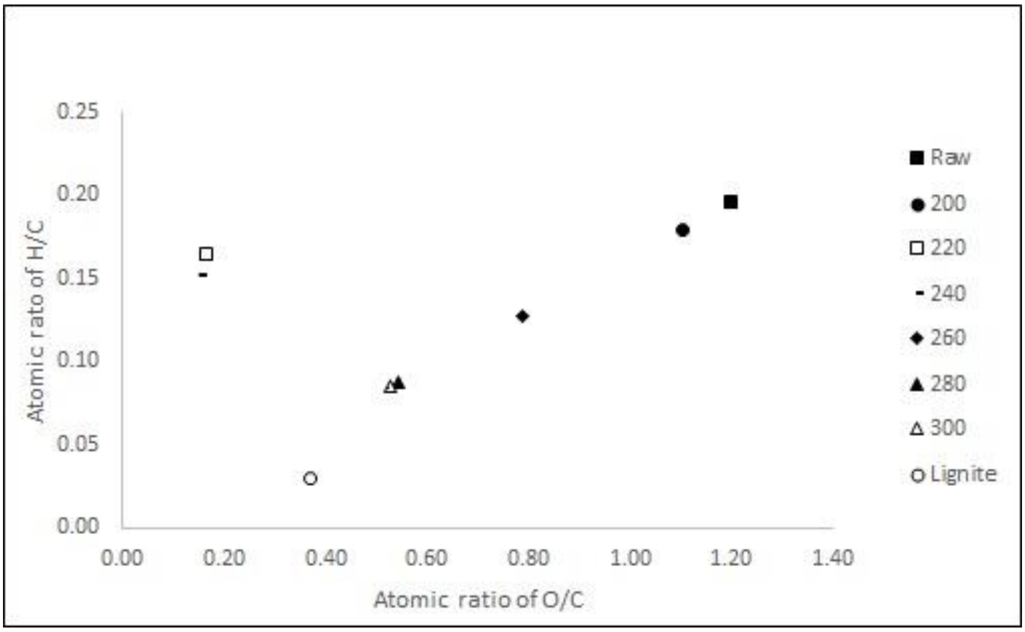

Fig. 2. Atomic ratio of H/C and O/C plot of raw and torrefied sawdust

Table 3
Proximate and predicted ultimate analysis of raw materials and torrefied sawdust

	Proximate Analysis				Ultimate analysis					
	Moisture (%)	Volatile Matter (%)	Ash Content (%)	Fixed Carbon (%)	C	H	O	H/C	O/C	HHV (MJ/kg)
Raw	4.52	81.79	1.58	12.11	43.55	8.54	52.24	0.20	1.20	17.02
200	3.83	80.05	1.85	14.27	45.16	8.08	49.81	0.18	1.10	17.51
220	3.14	78.80	2.30	15.76	46.32	7.64	47.63	0.16	1.03	17.84
240	2.58	76.78	2.95	17.69	47.54	7.22	45.35	0.15	0.95	18.20
260	1.98	70.08	3.50	24.44	51.52	6.56	40.61	0.13	0.79	19.54
280	0.31	60.51	3.72	35.46	58.84	5.20	32.03	0.09	0.54	21.94
300	0.07	60.05	4.09	35.79	59.05	5.04	31.25	0.09	0.53	21.99

4. Conclusions

As a conclusion, torrefaction of sawdust was successively conducted in a fixed bed reactor under nitrogen environment. The proximate analysis of raw and torrefied sawdust at different torrefaction temperature of 200-300^{o}C were analysed. It was identified that the moisture content and volatile matter decreased significantly with increasing torrefaction temperature. The predicted high heating values of raw and torrefied sawdust were evaluated and it was determined that the HHV content of torrefied sawdust also increased with increasing torrefaction temperature. Therefore, torrefaction process had reduced the moisture content and improved the HHV content of sawdust. The atomic behavior of torrefied sawdust approached that of lignite.

Acknowledgement
The authors would like to express their gratitude to the Department of Chemical Engineering Technology, Faculty of Engineering Technology, University Malaysia Perlis (UniMAP) for the utilization of laboratory equipment and facility during conducting the experimental works.

References
[1] Syafie, S. M., Othman, Z., and Hami, N. “Potential utilisation of wood residue in Kedah: a preliminary study”. *Journal of Technology and Operations Management*, (2017), 60-69.
[2] Lela, Branimir, Marin Barišić, and Sandro Nižetić. "Cardboard/sawdust briquettes as biomass fuel: Physical–mechanical and thermal characteristics." *Waste management*47 (2016): 236-245.
[3] Luo, Xun. "Torrefaction of biomass; a comparative and kinetic study of thermal decomposition for Norway spruce stump, poplar and fuel tree chips." *SLU, Swedish University of Agricultural Sciences, Faculty of Natural Resources and Agricultural* (2011).
[4] Wang, Ziliang, C. Jim Lim, John R. Grace, Hui Li, and Maria Regina Parise. "Effects of temperature and particle size on biomass torrefaction in a slot-rectangular spouted bed reactor." *Bioresource technology* 244 (2017): 281-288.
[5] Nhuchhen, Daya Ram. "Prediction of carbon, hydrogen, and oxygen compositions of raw and torrefied biomass using proximate analysis." *Fuel* 180 (2016): 348-356.
[6] Ren, Shoujie, Hanwu Lei, Lu Wang, Quan Bu, Shulin Chen, and Joan Wu. "Thermal behaviour and kinetic study for

woody biomass torrefaction and torrefied biomass pyrolysis by TGA." *Biosystems engineering* 116, no. 4 (2013): 420-426.

[7] Sulaiman, Mohammad Hisham, Yoshimitsu Uemura, and Mohammad Tazli Azizan. "Torrefaction of empty fruit bunches in inert condition at various temperature and time." *Procedia engineering* 148 (2016): 573-579.

[8] Poudel, Jeeban, and Sea Oh. "Effect of torrefaction on the properties of corn stalk to enhance solid fuel qualities." *Energies* 7, no. 9 (2014): 5586-5600.

[9] Cai, Wenfei, Antzela Fivga, Ossi Kaario, and Ronghou Liu. "Effects of torrefaction on the physicochemical characteristics of sawdust and rice husk and their pyrolysis behavior by thermogravimetric analysis and pyrolysis–gas chromatography/mass spectrometry." *Energy & Fuels* 31, no. 2 (2017): 1544-1554.

[10] Uemura, Yoshimitsu, Wissam N. Omar, Toshio Tsutsui, and Suzana Bt Yusup. "Torrefaction of oil palm wastes." *Fuel* 90, no. 8 (2011): 2585-2591.

[11] Parikh, Jigisha, S. A. Channiwala, and G. K. Ghosal. "A correlation for calculating HHV from proximate analysis of solid fuels." *Fuel* 84, no. 5 (2005): 487-494.

[12] Bhatti, B., and Chouhan, A. P. S. Thermo-gravimetric analysis of wood saw dust for evaluation of kinetics parameter. *Indian Journal of Science and Technology*, (2016), 9(44).

[13] Suranani, Srinath, and Venkat Reddy Goli. "Combustion characteristics of sawdust in a bubbling fluidized bed." In *2011 International Conference on Chemistry and Chemical Process, IPCBEE*, vol. 10, pp. 167-172. 2011.

[14] Yoo, Ho Seong, and Hang Seok Choi. "A study on torrefaction characteristics of waste sawdust in an auger type pyrolyzer." *Journal of Material Cycles and Waste Management* 18, no. 3 (2016): 460-468.

[15] Pepejal, Bakar. "Physico-chemical characterizations of sawdust-derived biochar as potential solid fuels." *Malaysian Journal of Analytical Sciences* 18, no. 3 (2014): 724-729.

[16] Liu, Zhengang, and Guanghua Han. "Production of solid fuel biochar from waste biomass by low temperature pyrolysis." *Fuel* 158 (2015): 159-165.