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ScienceDirect

Energy Procedia 138 (2017) 313–318

Energy Procedia

www.elsevier.com/locate/procedia

2017 International Conference on Alternative Energy in Developing Countries and Emerging Economies
2017 AEDCEE, 25 ‐ 26 May 2017, Bangkok, Thailand

Torrefaction of Municipal Solid Waste in Malaysia

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Abstract

Municipal solid waste (MSW) disposal is one of the main issues towards sustainable development in Malaysia. Current practices for MSW disposal such as landfilling and incineration poses a serious problems on the environment and health. Therefore a significant efforts have been made to utilize MSW for energy source by employing gasification process. However, the MSW is characterized by its high moisture content and low high heating value (HHV) which lowering the energy efficiency. In order to overcome this problems, torrefaction can be used as pretreatment method to remove the moisture content and upgrading MSW properties. The objective of this work is to study the effects of torrefaction temperatures ranging from 240 to 330°C for residence time of 30 minutes on two types of MSW namely food waste and wood waste. The torrefied MSWs are characterized in terms of ultimate analysis, proximate analysis and HHV. The mass and energy yields are also performed for both MSW. Based on the torrefaction, it was found that both food waste and wood waste show an increment on the weight percentage of C contents and decrement on the weight percentage of H and O content which resulting into reduce O/C ratio as the temperature is increased. The HHV for both food waste and wood waste are also increased after torrefaction between 240 and 330°C. The mass yield and energy yield were found to decrease with an increase in the torrefaction temperature. This suggests that torrefaction can be used as an effective MSW pretreatment and the torrefied MSW is more suitable to be used as fuel in gasification process.

Keywords: Torrefaction; Municipal solid waste; Food waste; Wood waste; Ultimate analysis; Proximate analysis

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10.1016/j.egypro.2017.10.106

1. Introduction

The Malaysian population has been increasing from 23.49 to 30.65 million between 2000 and 2015 [1]. In line with the rapid population growth, the generation of municipal solid waste (MSW) also increases. Based on MSW generation study conducted in Malaysia, the total daily MSW generation was 29,711 tonne/day in 2012 and an overall of 36,165 tonne/day of MSW has been projected to be hit by 2020 [2]. Due to the tremendous MSW generation rate, the MSW disposal becomes one of the main issues affecting environmental and sustainable development. Current practice exploits landfilling as the most common method for MSW disposal and most of the landfill sites in Malaysia are open dumping areas which pose serious environmental threats such as a large scale contamination of soil, water and air. Another common practice to dispose MSW is by using incineration technology. Theoretically incineration technology is the controlled combustion of waste with the recovery of heat to produce steam that in turn produces power through steam turbines. However emissions from incinerator can produce a wide variety of pollutants such as heavy metal, dioxins and furans which are detrimental to human health [3].

Alternatively gasification process can be adopted to overcome MSW disposal problem. Gasification involves partial combustion or oxidation of biomass to produce synthesis gas and ash at high temperatures (>800°C) in the presence of gasifying agent such as air or steam. The synthesis gas consists of hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2) and methane (CH_4) and after cleaning up can be used for heat and gas providing, electricity generation and chemical synthesis [3]. The MSW utilization using gasification will reduce significant amount of waste, preserve landfill space and an alternative for advanced thermal treatment application. Many attempts have been made to investigate the production of synthesis gas from various types of biomass [4-5]. Although hydrogen gas can be produced from those gasifiers, there is a concern on the low energy efficiency and low fuel quality [4]. This is due to the fact that raw biomass contains high moisture content between 40 – 80%, low bulk density, high O/C ratio and relatively low calorific value. Due to the high moisture content, the raw biomass is classified as hygroscopic in nature because moisture can be absorbed into the cell walls and hydrogen bonded to the hydroxyl groups of the cell wall components. Due to the hygroscopic nature of raw biomass, the gasification rate become slow and as consequence the conversion efficiency become low. As consequence, high energy is needed to remove the moisture content due to the drying during gasification process and in the end high consumption of energy is required. In addition, due to the low carbon content (high O/C ratio) and low calorific value, the amounts of synthesis gas production particularly hydrogen gas is relatively low which contributing to the low cold gas energy and exergy efficiencies [5].

One of the ways to improve the fuel quality is by using torrefaction method. Torrefaction is a pretreatment method to upgrade raw biomass to a refined fuel with improved properties such as higher heating value and carbon content [6-8]. Torrefaction is usually carried out at temperature in the range of 200-300 °C for residence time between 30-60 min in an inert environment at atmospheric pressure [6]. As a result of torrefaction, biomass exhibits brittle behaviour and a reduction in mechanical strength thus eliminating poor grindability problem of raw biomass. Besides, torrefaction increase energy yield of torrefied biomass due to the increase of carbon contain. It also reduces the moisture content and hemicellulose content in biomass so that the shelf life of biomass is increased as no biodegradation occur during the storage [6]. Because of these improved properties, the value in terms of carbon content and heating value of the torrified biomass as a fuel is significantly higher than the raw biomass. Therefore the objective of this work is to perform torrefaction experiment using MSW at various temperatures between 240-330 °C under a nitrogen atmosphere for 30 min. In this study two main types of MSW are used namely food waste and wood waste considering both wastes are non-recyclable and the main contributor of the MSW in Malaysia. The ultimate analysis, proximate analysis and high heating value (HHV) are also measured and compared for raw and torrefied MSW. The effect of different torrefaction temperature on the mass yield and energy yield is also investigated.

2. Experimental

2.1. Materials

In this study the MSW samples used were collected from Sungai Ikan Landfill Terengganu in Malaysia where only two different types of MSW were utilized which consists of food waste and wood waste. The raw MSW were dried in the oven at temperature of 105°C for 24 hours. The samples are then transferred into the air-tight containers until the torrefaction experiments were performed.

2.2. Torrefaction experiment and samples analysis

The torrefaction experiment was carried out in the vertical tubular reactor with 39.7 cm long and 1.9 cm internal diameter as shown in Fig. 1. The biomass is weighed approximately 2-3 gram and then is inserted into the reactor. The reactor was flushed with 10mL/min nitrogen for 5 minutes to ensure an inert condition is obtained. Next, the MSW sample was torrefied at temperatures of 240, 270, 300 and 330 °C for residence times of 30 minutes by an electric furnace. The residence times of 30 minutes is selected because there was little improvement in biomass properties if torrefaction residence time was longer than 30 minutes [7]. The reactor is then cooled to room temperature before the torrefied MSW sample is taken out and weighed. In order to avoid contamination of the torrefied MSW sample before the analysis, it is transferred to air-tight containers. The experiment is then repeated for 3 times and the average of the reading is presented in this study.

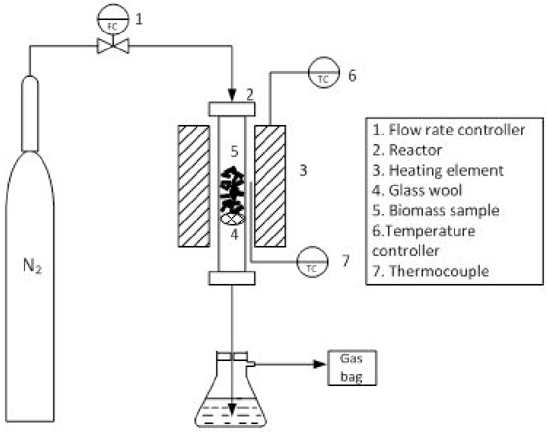

Fig. 1. Schematic diagram of the vertical tubular reactor.

The analysis for the raw and torrefied biomass includes the ultimate, proximate and calorific analysis. The proximate analysis is conducted according to ASTM E871, E872 and E1755 standards in order to determine the moisture content (MC), volatile matter (VM) and ash content. Based on the analysis, it was found that the MC for food waste and wood waste is 79% and 66% respectively. The content of fixed carbon (FC) is obtained by subtracting the value of 100% with MC, VM and ash content. The C, H, N, O and S contents for ultimate analysis were measured using CHNS analyser. The calorific analysis was measured using bomb calorimeter. The mass yield and energy yield are calculated by using Eqs. (1) and (2) respectively.

$$\text{Mass yield}(\%) = \frac{\text{mass of torrefied MSW}}{\text{mass of raw MSW}} \times 100\% \tag{1}$$

$$\text{Energy yield}\,(\%) = \text{Mass yield} \times \frac{\text{HHV of torrefied MSW}}{\text{HHV of raw MSW}} \times 100\% \tag{2}$$

3. Results and Discussion

3.1. Ultimate analysis, proximate analysis and HHV

The results of ultimate analysis, proximate analysis and high heating value (HHV) for raw and torrefied MSW are shown in Table 1. For both food waste and wood waste, the weight percentage of C content is increased with an increase in the torrefaction temperature. On the contrary, the weight percentage of H and O are decreased steadily. This is due to the effects of dehydration and de-carbon dioxide which occur during torrefaction of biomass [8]. As the torrefaction temperature is increased, more generation of volatiles such as carbon monoxide (CO), carbon dioxide (CO_2) and water (H_2O) are expected and thus resulting into the decrease in the H and O contents for both MSW. Meanwhile the N and Cl content for both MSW are increased slightly but the S contents did not suffer significant changes when the torrefaction temperature is increased. It is important to note that the weight percentages of N and Cl in food waste are higher than wood waste. This is due to the presence of protein and salt in the food waste. However the low weight percentages of N, S and Cl are not desirable for solid fuels and thus usually are neglected. In terms of proximate analysis, the ash content and fixed carbon (FC) are increased while the volatile matter (VM) is decreased when the raw MSW is torrefied from temperature of 240 to 330°C for both food waste and wood waste. When the waste is torrefied at higher temperature, more volatiles are released and low mass yield in the form of solid is obtained. Thus the solid waste usually contains more ash and FC but less VM due to the mass loss during torrefaction. In terms of HHV, Table 1 shows the raw food waste contains 17.45 MJ/kg and increased to 28.42 MJ/kg when torrefied at temperature of 330°C. Meanwhile the HHV of raw wood waste initially at 19.27 MJ/kg and then increased steadily to 31.09 MJ/kg during torrefaction which is higher than torrefied food waste. Based on Table 1, wood waste have a higher weight percentage of carbon content than food waste and thus increases the heat in combustion which translating into high heating value of wood waste.

Table 1. Ultimate analysis, proximate analysis and HHV of raw and torrefied MSW.

Components	Torrefaction Temperature	Ultimate analysis (dry wt%)						Proximate analysis (dry wt%)			HHV (MJ/kg)
		C	H	N	O	S	Cl	Ash	VM	FC	
Food waste	Raw	47.39	6.90	3.32	38.67	0.27	3.45	16.89	75.92	7.19	17.45
	240°C	49.07	6.63	3.55	36.32	0.28	4.16	18.96	64.86	16.18	21.53
	270°C	50.52	6.39	3.95	34.10	0.29	4.75	21.03	53.96	25.01	23.87
	300°C	52.43	6.11	4.32	31.69	0.31	5.14	23.09	42.55	34.36	26.11
	330°C	54.30	5.69	4.67	29.19	0.33	5.82	25.16	31.68	43.16	28.42
Wood waste	Raw	52.62	6.85	1.88	38.24	0.16	0.25	7.37	73.54	19.09	19.27
	240°C	54.56	6.45	2.22	35.67	0.18	0.92	11.64	62.17	26.19	23.55
	270°C	56.88	6.02	2.56	33.29	0.21	1.04	14.64	51.94	33.42	26.13
	300°C	59.21	5.69	2.89	30.62	0.23	1.36	16.71	42.72	40.57	28.66
	330°C	61.15	5.32	3.23	28.43	0.26	1.61	18.90	33.45	47.65	31.09

The changes of H/C molar ratio and O/C molar ratio under different torrefaction temperature for food waste and wood waste is shown in Fig. 2. As shown in Fig. 2, the H/C molar ratio and O/C molar ratio show decreasing trends for both MSW. As the torrefaction temperature is increased from 240 to 330°C, the food waste and the wood waste are decreased steadily in terms of H/C molar ratio from 1.62 and 1.42 to 1.26 and 1.04 respectively. At the same temperature ranges, the food waste and the wood waste initially at 0.55 and 0.49 are declined gradually until it reaches 0.40 for food waste and 0.35 for wood waste respectively. During the torrefaction, as the temperature is increased the weight percentage of C content is increased but the weight percentage of H and O are decreased which explains the decrease in the H/C and O/C ratios. In addition, the lower O/C ratio is usually favorable because the HHV tends to increase.

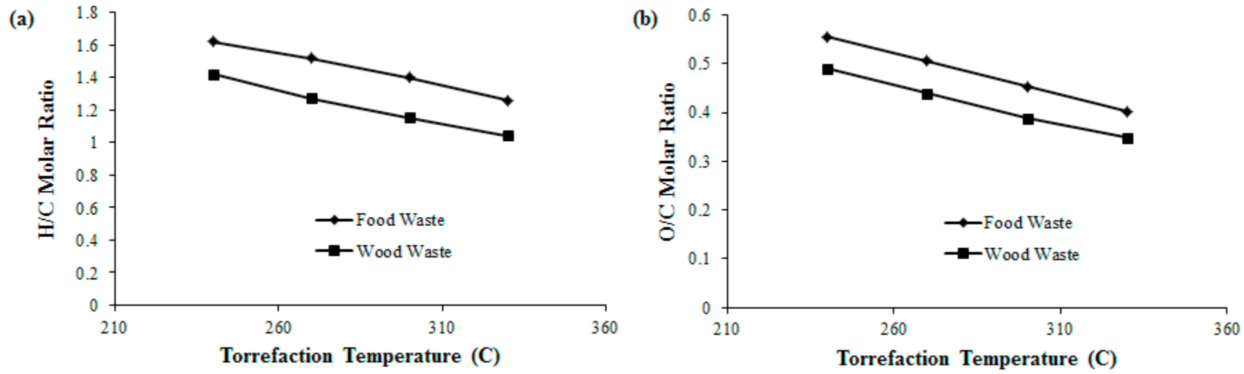

Fig. 2. (a) Changes of H/C molar ratio; (b) Changes of O/C molar ratio for food waste and yard waste

3.2. Mass yield and energy yield

The influence of torrefaction temperature on the mass and energy yields is shown in Fig. 3 for food waste and wood waste. In Fig. 3(a) and (b), the mass and energy yields are decreased linearly for both wastes with an increase in torrefaction temperature from 240 to 330°C. Fig. 3(a) shows the mass yield for food waste is decreased from 81% to 48% and the mass yield for wood waste initially at 77% is decreased to 46% in Fig. 3(b). This is mainly due to the loss of moisture content as the torrefaction temperature is increased which contributing to the decrease in mass yield. In addition more volatile gaseous products such as carbon monoxide (CO), carbon dioxide (CO_2), acetic acid and other organics are released at higher torrefaction temperature above 300°C which explains more mass loss at higher temperature compare to lower temperature [7,8]. Meanwhile the energy yield is decreased steadily from 93% to 78% for food waste and 95% to 74% for wood waste respectively when the torrefaction temperature is increased. Here the energy yield is decreased at the slower rate compare to the mass yield. As shown in Eq. (2), the energy yield is depending on the mass yield and the HHV ratio of torrefied MSW and raw MSW. Although the HHV ratio of torrefied MSW and raw MSW is increased in line with the increase of torrefaction temperature but the mass yield is decreased significantly which explain the slower rate of decrease in energy yield [9].

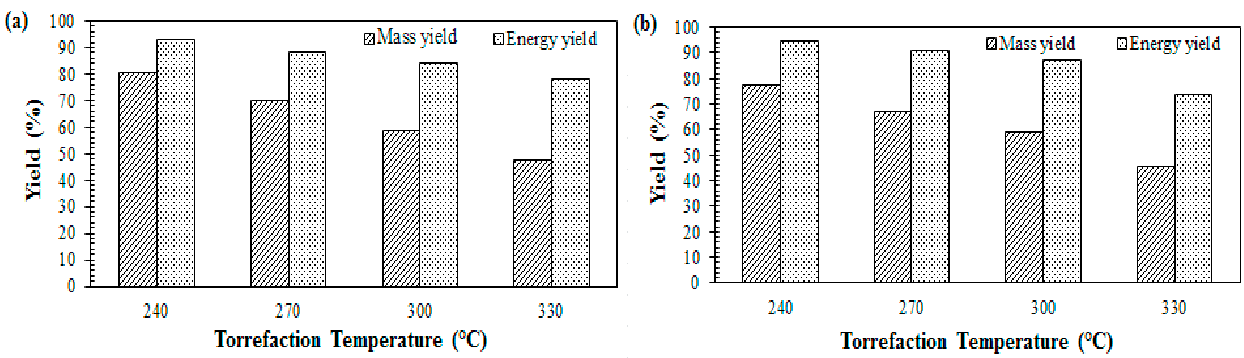

Fig. 3. Mass and energy yields for (a) food waste; (b) wood waste.

4. Conclusions

This study shows the application of torrefaction as pre-treatment method for MSW. Two types of MSW are selected namely food waste and wood waste. Four torrefaction temperature ranging from 240 to 330°C at the fixed residence time of 30 minutes are used in order to study the effects of temperature on the fuel characteristics of food waste and wood waste. From this study, the ultimate analysis shows that the weight percentage of C contents in the food waste and wood waste are increased but the weight percentage of H and O content show the opposite trend. This results into decreasing trend of H/C and O/C molar ratios for both food waste and wood waste. The proximate analysis shows the decreasing patterns for ash and FC but the HHV tends to increase when the torrefaction temperature is increased. It was also found that the mass and energy yields are decreased with an increase in the torrefaction temperature for both food waste and wood waste. Finally it can be concluded that the torrefaction as pre-treatment method is indeed able to upgrade solid fuel qualities of both food waste and wood waste by having a low O/C ratio and the increase of HHV which is suitable to be used as a fuel for further application such as gasification or co-firing process.

Acknowledgements

This work was financially supported by Internal Grant entitled Influence of torrefaction on the synthesis gas production from gasification of municipal solid waste under Universiti Malaysia Pahang.

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