Syngas Production from Microwave Gasification of Oil Palm Biochars

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Abstract. Gasification is a reaction process between solid or liquid carbonaceous materials with some gasifying agent to produce gaseous fuel. In this study, a microwave gasification test rig is designed to produce syngas from oil palm biochars. Carbon dioxide is used as the gasifying agent. Oil palm empty fruit bunch (EFB) and oil palm shell (OPS) biochars are used as the carbonaceous materials. The effects of CO_2 flow rates on the type of biochars to the syngas produced are investigated. The optimum CO_2 flow rate for EFB biochar gasification is 3 lpm where the gas compositions are 0.52% CH_4, 50.52% CO_2, 26.1% CO, and 22.86% H_2. For OPS biochar, the optimum CO_2 flowrate is 2 lpm that produce 6.92% CH_4, 57.19% CO_2, 10.98% CO, and 24.92% H_2. For EFB biochar gasification, the specific volume of gas yield is from 1.22 to 1.51 m^3/kg while for OPS biochar yields higher specific gas volume, ranging from 2.62 to 7.88 m^3/kg. The highest carbon conversion efficiency and gas heating value for EFB biochar is 75.07% and 12.84 MJ/kg at 3 lpm respectively and 66.83%, 13.03 MJ/kg at 2 lpm for OPS biochar respectively . This concludes that EFB biochar produced higher quality syngas than OPS biochar because of the higher volume of CO and H_2 content in the syngas produced at the higher carbon conversion efficiency with specific gas volume of 1.22 m^3/kg.

Introduction

Solid waste management is often fragmented and lacks coherence for countries and cities across the globe. Even at present, the system has been often negligence to basic environmental preservation and have serious environmental risks. In Malaysia about 50 million tons of palm oil mill effluents (POME) and about 40 million tons of oil palm biomass are generated from the palm oil industries every year. The current management practice poses significant environmental problems as much of the waste is disposed by biomass burning of end product emit greenhouse gas into the atmosphere and leave high organic content on the grounds [1]. Gasification is a clean energy technology that generates syngas consists of hydrogen and carbon monoxide through the partial oxidation of a fuel source [2]. However, the conventional gasification process has many arising problem. As an alternative, this study chooses to focus on the microwave induced thermal process. For start, it consumes less power than conventional electrical thermal arc. It is also capable of turning biomass waste into useful materials and energy such as syngas and slag [3]. As supported by Kim, Song, Chun and Lee [4], microwave plasma can operate without electrode and the lower temperature of non-thermal process results in lower energy consumption in sustaining the discharge. Thus, concluding the general advantage of selecting the microwave thermal process for this study.

Research Methodology

Materials. Biochars that are used in this research are empty fruit bunch (EFB) and oil palm shell (OPS) biochars. The waste biomass are obtained from Federal Land Development Authority (FELDA) oil palm mill in Kulai, Johor and undergo pyrolysis in a conventional oven at 650°C to produce biochar. EFB and OPS are grinded and sieved to 1.18 to 2.00 mm before the pyrolysis process. Table 1 shows the Ultimate analysis of EFB and OPS biochars.

Table 1. Ultimate analysis of EFB and OPS Biochars

Type	EFB Biochar [wt%]	OPS Biochar [wt%]
Carbon (C)	64.93	79.40
Hydrogen (H)	2.55	3.18
Nitrogen(N)	1.12	0.82
Oxygen(O)	31.40	16.60

Experiment Setup and Procedures. The microwave gasification system is modified from a domestic microwave oven. Fig. 1 shows microwave gasification rig in details.

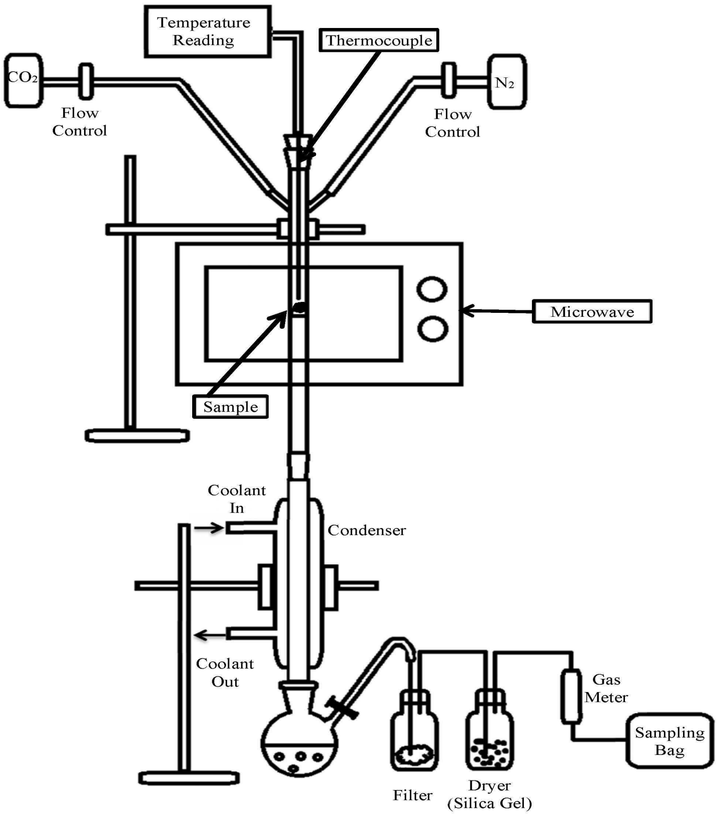

Fig. 1. Microwave thermal gasification rig

A quartz reactor of 600 mm length and 20 mm internal diameter is designed as the gasification reactor. The heat that is generated inside the reactor is stabilized by flowing the CO_2 and N_2 gas in a swirl from both the right and left side of the reactor. Flow rate of CO_2 is varied from 1 to 4 lpm. The microwave output power is supplied continuously at 800 W for 5 min. The syngas from the gasification flow down to the condenser for cooling, through the gas filter, drier, gas meter, and lastly are collected by a gas sampling bag. The solid residue left in the reactor is carefully collected and weighed. The syngas collected are analysed on gas chromatography (GC) Agilent 6890 fitted with packed column, thermal conductivity detector (TCD), and, capillary column for measuring volumetric concentration of CH_4, CO_2, CO, and H_2. Inert argon gas at the flow rate of 10ml/min and TCD with front detector temperature of 473K was applied to operate GC. Standard gas mixtures is used for quantitative calibration.

Data Analysis. Specific gas yield (SGY) is calculated using Eq. 1:

$$\text{SGY (m}^3\text{/kg)} = \frac{V_{gas}}{W_{Sample\ Before} - W_{Sample\ After}} \quad (1)$$

Where, V_{gas} is the volume of gas produced (m^3), W is the weight of sample before and after gasification (kg). Carbon conversion efficiency (η) is defined as a ratio between carbon produced and carbon supplied. Eq. 2 shows the calculation for carbon conversion efficiency:

$$\eta = \frac{V_{gas} \times \sum x_i \times (\frac{MW_C}{V_{STP}})}{W_{Sample\,Before} \times x_c} \times 100\% \qquad (2)$$

Where, x_i is the volume fraction of component of product gas (vol%), MWc is the molecular weight of carbon (12 kg/kmol), V_{STP} is the volume of 1 mol of ideal gas at STP (22.4 m^3), and x_c is the carbon content in biochar (wt%). Gas heating value, HV (kJ/kg) is calculated using Eq. 3:

$$HV = \sum x_i (HV_i) \qquad (3)$$

Where, HVi is the corresponding heating values of the gas component.

Results and Discussions

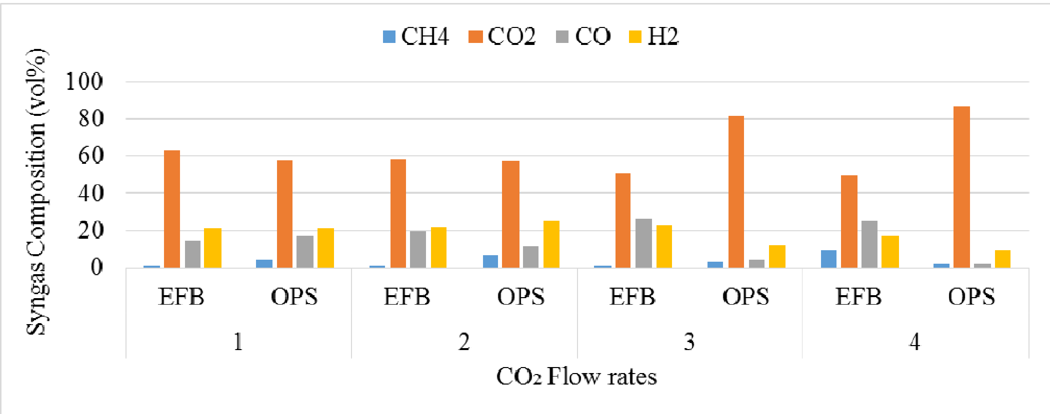

Fig. 2. Syngas composition (vol%) for gasification of EFB and OPS biochars

Table 2. Specific gas yield (m3/kg), carbon conversion (%), and heating value (MJ/kg)

CO_2 Flow rates (lpm)	Biochar	SGY (m^3/kg)	Carbon conversion (%)	HV (MJ/kg)
1	EFB	1.51	67.87	11.01
	OPS	3.05	56.29	11.89
2	EFB	1.41	69.97	11.09
	OPS	2.62	66.83	13.03
3	EFB	1.22	75.07	12.84
	OPS	6.03	62.10	10.33
4	EFB	1.33	70.20	11.39
	OPS	7.88	59.59	9.91

Fig. 2 shows the syngas composition (vol%) of CH_4, CO_2, CO, and H_2 for gasification of EFB and OPS biochars. The highest CO produced in EFB gasification is 26.10 vol% at 3 lpm. For OPS, the maximum CO composition is at 1 lpm with 16.73 vol%, lower than EFB. Further increase in the CO_2 flow rates resulted in a massive decrease of CO production. The low conversion rate of CO_2 resulted from the low surface area of OPS biochar and high residence time [5]. Also, due to dielectric properties of EFB and OPS, it absorb less microwave irradiation, thus the lowering the temperature of OPS [6, 7, 8, 9]; this contributes to the high percentage of CO_2 volume in the gas produced. The rate of H_2 production in EFB gasification varies between from 16.61-22.86 vol%. The production of CH_4 is very low as compared to the main gasification reaction. Yoon and Lee [2] argues that the low concentration of CH_4 is typical for a high temperature plasma gasification. Table 2 shows specific gas yield (m^3/kg), carbon conversion (%), and heating value (MJ/kg) of the syngas produced. For EFB biochar gasification, the specific volume of gas yield is from 1.22 to 1.51 m^3/kg while for OPS biochar yields higher specific gas volume, ranging from 2.62 to 7.88 m^3/kg. The highest carbon conversion efficiency and gas heating value for EFB biochar is 75.07% and 13.03 MJ/kg at 3 lpm and 66.83%, 13.03 MJ/kg at 2 lpm for OPS biochar.

Summary

In this study, microwave thermal gasification of oil palm biochars is investigated. The experimental runs are carried with 800W microwave power and various CO_2 flow rates. The optimum CO_2 flow rate for EFB biochar gasification is 3 lpm where the gas compositions are 0.52% CH_4, 50.52% CO_2, 26.1% CO, and 22.86% H_2. For OPS biochar, the optimum CO_2 flowrate is 2 lpm that produce 6.92% CH_4, 57.19% CO_2, 10.98% CO, and 24.92% H_2. For EFB biochar gasification, the specific volume of gas yield is from 1.22 to 1.51 m^3/kg while for OPS biochar yields higher specific gas volume, ranging from 2.62 to 7.88 m^3/kg. The highest carbon conversion efficiency and gas heating value for EFB biochar is 75.07% and 12.84 MJ/kg at 3 lpm and 66.83%, 13.03 MJ/kg at 2 lpm for OPS biochar. This concludes that EFB biochar produces higher quality syngas than OPS biochar because of the higher volume of CO and H_2 content in the syngas produced at the higher carbon conversion efficiency with specific gas volume of 1.22 m^3/kg. This study is an alternative for solid waste treatment that uses less energy, time, and cost.

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