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PERFORMANCE AND CARBON EFFICIENCY ANALYSIS OF BIOMASS VIA STRATIFIED GASIFIER

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ABSTRACT

Recent concerns on environment, fuel price and scarcity of its supply have promoted interest in the development of renewable sources as a replacement. This paper aims to show the gasifier experimental finding based on performance and process efficiency. Wood chip was fed in stratified downdraft gasifier with air as gasifying agent. The biomass feeding rate varied from 3 to 4.5 kg/hr with an output of various high heating values (HHV) of producer gas. The study provides a clearer picture of the result obtained from the equivalence ratio (ER) which improvises the gas composition, HHV and carbon conversion efficiency.

Keywords: downdraft gasifier; biomass, gasification, carbon conversion efficiency.

INTRODUCTION

Rapid development of modern industry has greatly increased the demand for the energy in recent years. The growing demand for clean renewable energy and less dependency on fossil fuels promote the research for development environmentally technologies, as well as drive the biomass fuel to become one of securing energy source.

Biomass with a component of lignin, cellulose and hemicelluloses is as a promising future energy crop because of its high growth rate plus a number of major fuel characteristics such as low ash content and high heating value. In view of wood wastes quantity, it is an opportunity to be utilized as one of energy to fulfill the domestic demand. Although it was reported by several studies, commercialization of research findings has not been fully undertaken on a large scale [1].

Biomass gasification is proved to be a promising strategy to convert biomass into biofuel and bioenergy. Gasification is a thermo chemical conversion process with limited supply of air as gasifying agent. Biomass gasification was accomplished by drying, pyrolisis, oxidation and gasification processes. Then, gasification process takes place where char is converted into combustible gases with a heating value of 4-5MJ/m^3. Researchers have reported varying temperature of gasification zone, ranging from 600 °C to 950 °C [2].

Typically, gasifiers can be broadly classified as fixed bed: updraft and downdraft gasifier, and fluidized bed gasifier: bubbling fluidized bed gasifier (BFBG) and circulating fluidized bed gasifier (CFBG) Fixed bed gasifiers have been widely used in the energy conversion due to their cheapest method and can produce the producer gas with less tar content [3].

To take advantage of the versatility of the fixed bed gasifier and low tar production, it is desirable to carry gasification studies on woodchip to address related issues regarding performance and analysis. In this paper, we present our recent work on the parameter of equivalence ratio (ER), carbon conversion efficiency and gasifier temperature affect from ER. The results obtained from the gasification of wood chip in term of high heating values (HHV) of producer gas were considered for further exploitations such as a compression ignition engine and steam boiler.

METHODOLOGY

Biomass material and characterization

Wood chip from rubber wood was obtained from the sawmill factory. Fresh feedstock with higher moisture content was sun dried for a full day in an open air. The dried wood was chipped into nongranular size; 20-40 mm with a mean length with calculated in average bulk density 609.8 kg/m^3. The characteristic of biomass feedstock was first investigated in TGA analyzer (Perkin Elmer TGA7) to have compositions of fixed carbon, volatile matter and ash. In contrast Element Analyzer (Perkin Elmer 2400) was used to obtain the composition of carbon, hydrogen, oxygen and sulfur. Meanwhile, low heating values (LHV) were measured by using Bomb calorimeter (Yoshida Seisakusho 1013B).

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Gasification setup

An atmospheric stratified downdraft gasifier with a height of 1.11 and 0.46 m in diameter was used in the experiment. Feedstock was fed through the top opening cap, while the material will hold on the steel grate in 42 cm diameter at the bottom. The air was flowing into the gasifier via throated holes into the gasification area. The gasifier was built with throated refractory as it to improve movement of the feedstock according gravitational. The temperature of different zones of gasifier, gas stream and cooling and cleaning (CC) system was monitored by several Type K thermocouples. The producer gas was induced out via 520 L/min blower with varying flow rate by using the Siemens inverter from 15 Hz to 50 Hz with an increment of 5 Hz. An orifice meter was installed to measure the producer gas flow rate. The setup of this experiment has been published in previous articles.

At startup, the gasifier was heated up by using liquid petroleum gas (LPG) with initial fed up 0.5 kg of biomass feedstock for 20 mins until the bed temperature reaches 400 °C. Then, biomass is continuously fed periodically at the top of the gasifier while weighing over a period of time. In order to prevent bridging or clogging situation, biomass were fed in average 1~ 1.5 kg every 20 mins in each feeding process. The char was collected in the lower cylinder bin.

Gas sampling and analysis method

In order to have a clean producer gas before it is being used in any energy conversion medium such internal combustion engine or steam boiler, gas was flowing through the cooling and cleaning (CC) system after the blower. The hot producer gas was flared before it enters the cyclone separator. Char and ash were removed from the producer gas in cyclone separator, and sent it to pre-cooler. The amount of ash and condensate were weighted while part of it was sent to gas sampling bags for gas chromatograph (GC) analysis. The clean gas collected in sampling bags was injected into a gas chromatograph (Agilent module 4890 GC) with thermal conductivity detector (TCD) to sense the substance. The carbon conversion efficiency presents the amount of carbon in the biomass material which converted into gases as shown in the Equation. (1), where m_{char} is the amount of char remaining in the ash bin and $m_{biomass}$ is the amount of biomass used in the experiment. The carbon percentage (%C) in wood was measured separately for ultimate analysis. The carbon conversion efficiency for each run was calculated as follows:

$$\left[1-\frac{m_{char}}{m_{biomass}\, x\%C}\right] x100\% \qquad (1)$$

RESULTS AND DISCUSSIONS

Biomass properties

From TGA and Elemental Analyzer (EA) tests, the wood chip composition obtained are presented in Table-1. Results obtained from TGA and EA of wood chip was compared to rice husk due locally obtained. Moisture content of woodchip was beyond rice husk with 14.9%, explained the dependent on the humidity where the biomass were stored. Ash content for rice husk was recorded 23.5%, higher than those found in woody biomass materials. The volatiles matters are up to 75 %. Higher heating value of wood shows a correlation to its chemical composition. Higher value of ash in rice husk as an inert composition would attribute a lower value in HHV [4]. Higher ash content could lead significantly corrosion phenomenon in the gasifier or boiler.

Table-1. Ultimate and proximate analysis of biomass feedstock.

Proximate analysis (wt. %)	**Wood chip**	**Rice husk [**10**]**
Moisture	14.9	11.2
Fixed carbon	11.36	18.4
Volatiles	78.12	81.6
Ash	0.22	23.5
Ultimate analysis (wt.%)		
Carbon	43.9	38.9
Hydrogen	4.94	5.1
Nitrogen	0.09	0.6
Oxygen (by diff.)	51.07	55.4
Density (kg/m3)	609.8	617
HHV (MJ/kg)	18.5	15.29

Gasification performance

The average flow rate of producer gas is shown in Table-2. To guide the selection of gasification conditions, suction blower frequency is limited to the 35 and 40 Hz due to stability flare observed at flare stack compared to another frequency. The biomass feed rate is associated with the suction blower frequency. Due to non-granular shaped, biomass feed rate seems inconsistence and might attribute bridging. Other studies show particle size and shape of biomass affect gasification rate, to turn volatile matter into gas [3]. ER of the experiment was calculated varying between 0.27-0.32. For fixed bed gasifier, in [6] calculated the ER for gasification to be about 0.2-0.43.

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Table-2. Biomass gasification experimental run details.

Blower frequency (Hz)	**Average producer gas flow rate** (kg/hr)	**Air flow rate** (kg/hr)	**Biomass feed rate** (kg/hr)	**ER**	**Cold gas efficiency** (%)
35	11	6.27	3.4	0.29	76.6
35	11	6.27	3.1	0.32	84
35	11	6.27	3.7	0.27	70.4
40	13.7	7.8	4.1	0.31	79.1

Figure-1 mentioned temperatures in the gasification zone are linked to the suction blower frequency. The average gasification temperatures are ranging from 700-725 °C and 750-775 °C respectively to 35 and 40 Hz. Similar results also reported [5, 7] the temperature profile on fixed bed gasifier (throat type). The significance of bed temperature is associated with the feeding rate with the rapidity of decomposition of hemicelluloses fractions. Performance of gasifier was determined by using cold gas efficiency. Cold gas efficiency is the fraction of power output of producer of the power input from biomass, so the higher value could explain better biomass conversion into gas. In this study, cold gas efficiency is found to be an average of 77.5 % with a maximum of 84 %.

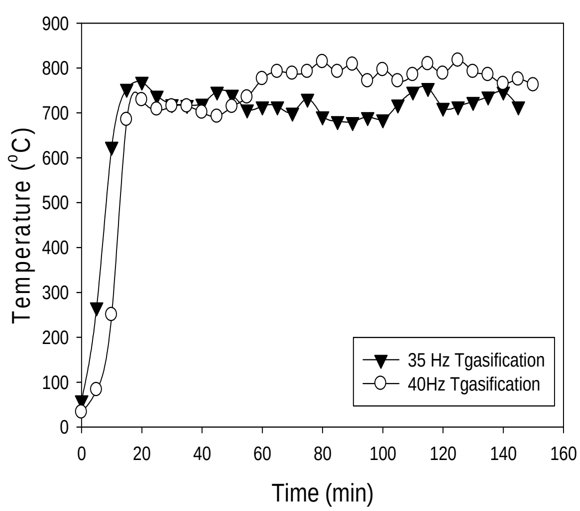

Figure-1. Stratified downdraft gasifier temperature profile at 35 and 40 Hz blower frequencies.

The effectiveness of the gasification process was also evaluated in terms of HHV of dry gas. The HHV of the dry gas was determined considering the volumetric percentage of hydrogen (H_2), carbon monoxide (CO) and methane (CH_4) in the flue gas by the following Equation. (2) [8]:

HHV: (H_2% x 30.52 + CO% x 30.18 + CH_4 % x 95) x 4.1868 (MJ/m^3)) (2)

Figure-2 shows the variation of the producer gas composition with respect to ER. To study the effect of ER on gasification performance, this parameter was varied in the range of 0.27-0.32 while the bed temperature was around 770±40 °C. As observed, increasing of ER to 0.29, the HHV of gas reaches maximum value of 4.77 MJ/m^3 with cold gas efficiency 76.6 %. It would explain the improved of CO, CH_4 and CO_2 level in a producer gas while increased of ER to 0.32 lead to further increase of CO_2 hindered CO, CH_4 production. At high ER, more air was inducted into the gasifier and high degree of combustion occurs that improves char burning to CO_2. Other researchers observed the trends of both components decrease start at ER 0.388 and HHV of gas is acceptable for use further application in CI engine [4; 6].

Figure-3 presents the effect of ER on the producer gas HHV. As expected, the maximum HHV of 4.53 was achieved at ER of 0.21 which corresponds to the high content of CH4. CH_4 was a main content for the producer as it forms as combustible gas. Increasing the ER to beyond 0.29 was disadvantageous for gas HHV due to the dilution of the producer gas by N_2 as the air flow rate increased in the gasification process. This will turn the HHV results in low energy content.

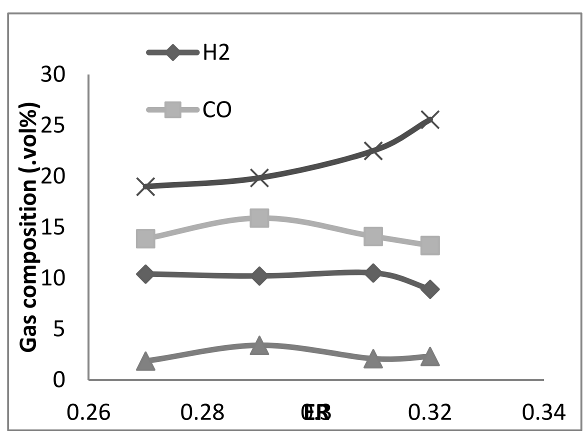

Figure-2. Effect of ER on producer gas composition of wood chip.

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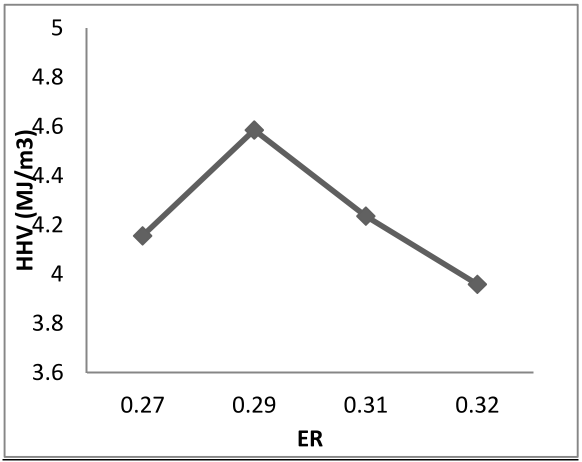

Figure-3. Effect of ER on HHV for wood chip.

Figure-4 shows the biomass-gas conversion in the gasification process. The result obtained shows an average of carbon conversion efficiency lied in 89.6%. Size and shape of biomass feedstock would affect volatile release rate inclusive with gasification temperature. The higher reaction could explain the optimized of char as it converts into CO_2 with improvement of combustion. When ER was at 0.32, the biomass-gas conversion achieve as high 92.6 %. As ER decrease, carbon conversion also decreases due to lack of oxygen to enhance the gasification process. The average efficiency compares well with [9], obtained 87-98 % for fixed bed gasifier.

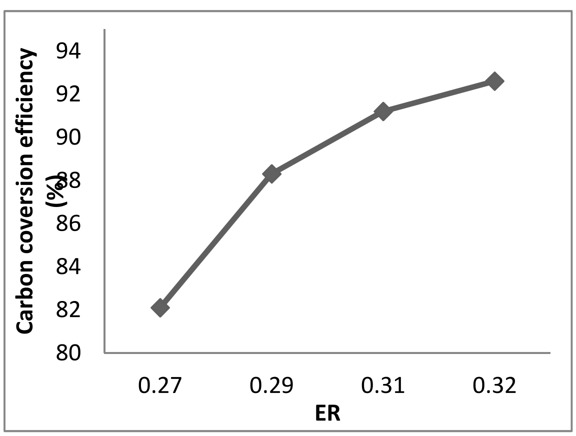

Figure-4. Effect of ER on carbon conversion efficiency of wood chip.

Product distribution and mass balance

Mass balance on the stratified suction gasifier system was carried out to determine the thermal efficiency of the gasification system. The processed input consisted of air (gasifying agent), biomass feedstock (fuel) and water (moisture) which naturally presented in biomass. The output from the process as shown in Figure-4 such dry gas, condensate water, tar and char (mainly derived as non-combustible product) were measured. The total product distribution varied from 95.3 to 97.4 % at a function of ER 0.27-0.32. Mass loss could probably from tar which was deposited in the pipes. However, if moisture in wood chips increases, the mass balance dramatically increases and hence encountered difficulties in maintaining the producer gas quality.

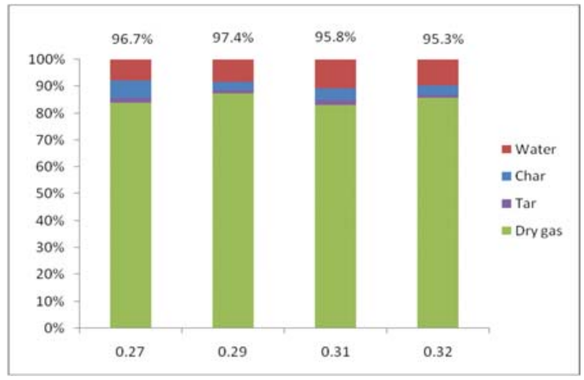

Figure-5. Effect of ER on product distribution for wood chip.

CONCLUSIONS

Wood chip gasification was conducted in the stratified downdraft gasifier. The above studied showed that the woods were excellent feedstock for gasification purpose. All stable experiments of suction biomass gasifier have established under various operating conditions. The optimum value of ER is 0.29 at cold gas efficiency of 76.6 %. The consistent production of good quality gas is satisfied with optimum conditions could lead HHV as high 4.5 MJ/m^3 with potential to become as one alternative fuel in bioenergy production plant.

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REFERENCES

[1] A. M. Iqbal, Z. A. Zainal, M. Mazlan, A. M. M. Al-Bakri and M. S. Salim. 2013. Performance and emission characteristics of diesel engine running on blended palm oil. Advanced Materials Research. 795: 164-169.

[2] M. I. Ahmad, Z. A. Z. Alauddin, S. N. M. Soid, M. Mohamed and M. H. Yusoff. 2013. Experimental of wood gasification in suction biomass gasifier. Advanced Materials Research. 626: 1020-1026.

[3] P. N. Sheth and B. V. Babu. 2009. Experimental studies on producer gas generation from wood waste in a downdraft biomass gasifier. Bioresource Technology. 100(12): 3127-3133.

[4] M. Mohamed, M. I. Ahmad, Z. A. Zainal, A. M. M. Al Bakri and M. S. A. Aziz. 2013. Renewable energy from biomass-A potential contribution and energy analysis. Australian Journal of Basic and Applied Sciences. 7(5): 213-219.

[5] T. Yamashita, Y. Fujii, Y. Morozumi, H. Aoki and T. Miura. 2006. Modeling of gasification and fragmentation behavior of char particles having complicated structures. Combustion and Flame. 146(1): 85-94.

[6] Z. A. Zainal, A. Rifau, G. A. Quadir and K. N. Seetharamu. 2002. Experimental investigation of a downdraft biomass gasifier. Biomass and Bioenergy. 23(4): 283-289.

[7] B. S. Pathak, S. R. Patel, A. G. Bhave, P. R. Bhoi, A. M. Sharma and N. P. Shah. 2008. Performance evaluation of an agricultural residue-based modular throat-type down-draft gasifier for thermal application. Biomass and Bioenergy. 32(1): 72-77.

[8] R. Xiao, M. Zhang, B. Jin, Y. Huang and H. Zhou. 2006. High-temperature air/steam blown gasification of coal in a pressurized spout-fluid bed. Energy Fuels. 20(2): 715-720.

[9] Y. Cao, Y. Wang, T. R. John and W. P. Pan. 2006. A novel biomass air gasification process for producing tar-free higher heating value fuel gas. Fuel Processing Technology. 87(4): 343-353.

[10] V. Kirubakaran, V. Sivaramakrishnan, R. Nalini, T. Sekar, M. Premalatha and P. Subramanian. 2009. A review on gasification of biomass. Renewable and Sustainable Energy Reviews. 13(1): 179-186.