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Effect of Blending Ratio on Quality of Producer Gas From Co-Gasification of Wood and Coconut Residual

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Abstract. Biomass gasification often encounters the shortage of biomass supply for continuous operation. Co-gasification of different biomass materials is a promising solution that can address the shortage of biomass supply for the continuous gasification process. However, the effectiveness of co-gasification is not well understood. Furthermore, there is nearly no reported work of co-gasification of two or more biomass materials. In this study, two Malaysian local biomass materials, wood residual and coconut shells were co-gasified in a 33.6 kW thermal capacity downdraft gasifier to investigate the effect of blending ratio the on quality of the producer gas. The results show that producer gas composition increased as coconut shells proportion increased in blends of up to 60%. A blend of 40:60 W/CS results in a synergetic effect as compared to discrete gasification of both feedstock. The maximum H_2 and CO were obtained as; 11.46 vol.% and 23.99 vol.% respectively at 40:60 W/CS blending ratio. The results achieved from 40:60 W/CS blend were 16.70% and 10.96% higher as compared to pure wood gasification for H_2 and CO respectively. It is concluded that coconut shells can be utilized a substitute of wood residual in form of blends or as discrete feedstock for the continuous gasification process without the change in gasifier geometry.

1 Introduction

The world projected to face energy shortage and global environmental issues related to the emission of conventional fossil fuel. In the meantime, modern lifestyle utilizes a high amount of energy that comes from petroleum energy sources [1]. The utilization of biomass is considered a promising renewable energy source that could be a substitution of fossil fuels via gasification. Malaysia is bestowed with verities of biomass resources due to its tropical weather and its location near the equator. The main areas, which contribute to the streamline of the biomass energy supply, are forestry (30.56%) and agricultural sector. In 2010, 12 million m^3 of timber logs were produced from the Malaysian forest area [2]. The wood waste generated during the logging operation is 5.1 million m^3 in form of stumps, branches, bark, tops, broken logs, defective logs and injured standing trees, all these are 43% of total

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volume of the tree [3]. In addition, Malaysian agricultural crops contributed as; oil palm (43.67%), rubber (30.56%), rice (12.68%), cocoa (6.75%) and coconut (6.34%) [4, 5]. Coconut is another industrial crop in Malaysia, which is the third biggest in plantation area size. In 2009, the total domestic coconut production was about 459,000 tons. From coconut processing, coconut husk (0.166 Mton), coconut shell (0.735 Mton), coconut frond (0.103 Mton) and coconut empty bunches (0.022 Mton) are obtained as by-products. In terms of total energy supply, it contributed 6 PJ (1×10^{15}) in 2009 [2].

Although biomass can be gasified to mitigate the issues associated with fossil fuels depletion and emission [6, 7]. However, dependence on discrete biomass feedstock could be problematic for continuous gasification operation. The operation often encounters a problem of unsteady supply of feedstock throughout the year and can be affected by factors like drought and heavy rain. In additions, some biomass materials are available in limited quantity, not sufficient to support continuous biomass gasification. The pre-mentioned issues related to biomass supply can be mitigated by mixing of different biomass materials to ensure uninterrupted biomass gasification [8]. Therefore, the wood and coconut shells base lignocellulosic biomass materials are considered as a potential source of energy, which could be exploited by using a co-gasification process [2]. Recently, co-gasification of different biomass is the emerging interest of many researchers [9-19].

In this study, wood residual (W) and coconut shells (CS) co-gasified in downdraft gasifier to investigate the coconut shells as a wood substitute. Furthermore, the effect of blending ratio was investigated on producer gas quality. The quality of producer gas is described in terms of gas composition. The quality of producer gas is important to decide its final utilization for energy explication. The composition of producer gas consists of combustible gases, for instance; CO, H_2, and CH_4 and non-combustible gases CO_2 and N_2 [20].

2 Materials and methods

2.1 Experimental setup and procedure

The wood residual and CS were the potential feedstock for the current study. Wood logs were collected from the landscape of the Universiti Teknologi PETRONAS, Malaysia during tree trimming activities. Coconut shells were obtained from local coconut market at Batu Gajah, Perak, Malaysia. Both feedstocks were chopped using a shredding machine at a timber factory, located at Ayer Tawar, Perak, Malaysia, and sieve it. Feedstocks were dried at 105°C for 24 hours using an electric oven as per ASTM E871-82 standard method [21]. The proximate analysis, ultimate analysis, and higher heating value (HHV) of feedstocks samples were performed as per ASTM E1755-01 in a STA 6000 TGA analyzer, ASTM D3176-09 in Leco CHNS-932 analyzer, and ASTM D4809-00 in Leco AC-350 automatic bomb calorimeter respectively, the results are shown in Table 1 [22-24]. A 33.6 kW (thermal) pilot-scale batch feed downdraft gasification system designed and devolved by Guangul et al.,2012 [25] was used in this study as shown in Fig. 1. The system consisted of a gasifier, air blower, rotameter, Type-K thermocouples (T_1-T_7), cyclone and gas filtering, gas cleaning and cooling, and gas analyzer.

As producer gas left the outlet of the gasifier, it passed through the cyclone where particulates in gas were removed. Next, it passed through a filter, which removed tar and moisture from producer gas. Producer gas was sampled after leaving the first stage of gas cooling and filtering system. For more cleaning and cooling of the sample, gas passed through a mechanical cooling and cleaning system. The cooling and cleaning system consisted of a gas cooler, pump, rotameter, 4 μm ceramic filter, and gas flow control valve. The gas was cooled down to 5°C in the gas cooler and condensate was removed from the cooler using two integrated peristaltic pumps. Moisture free producer gas was pumped to the ceramic filter for further particulate removal. Clean and cool producer gas was pumped into an online analyzer through rotameter at control flow rate of 1.0 L/min. Emerson made X2GP-Stream (≤ 1%) online gas analyzer used to measure the volumetric gas composition of producer gas. Gas analyzer displayed the concentration of four gases, namely CO, H_2, CH_4 and CO_2 on its LCD screen. Each experiment was repeated three times and average values are presented in results and discussion section.

2.2 Data analysis method

The average gas composition of H_2, CO, CH_4, and CO_2 was calculated by:

$$Gas\ composition_{Average} = \frac{1}{n}\sum_{i=1}^{n} x_i \quad (1)$$

Where n is the number of gas samples and x_i is the concentration of any component of producer gas.

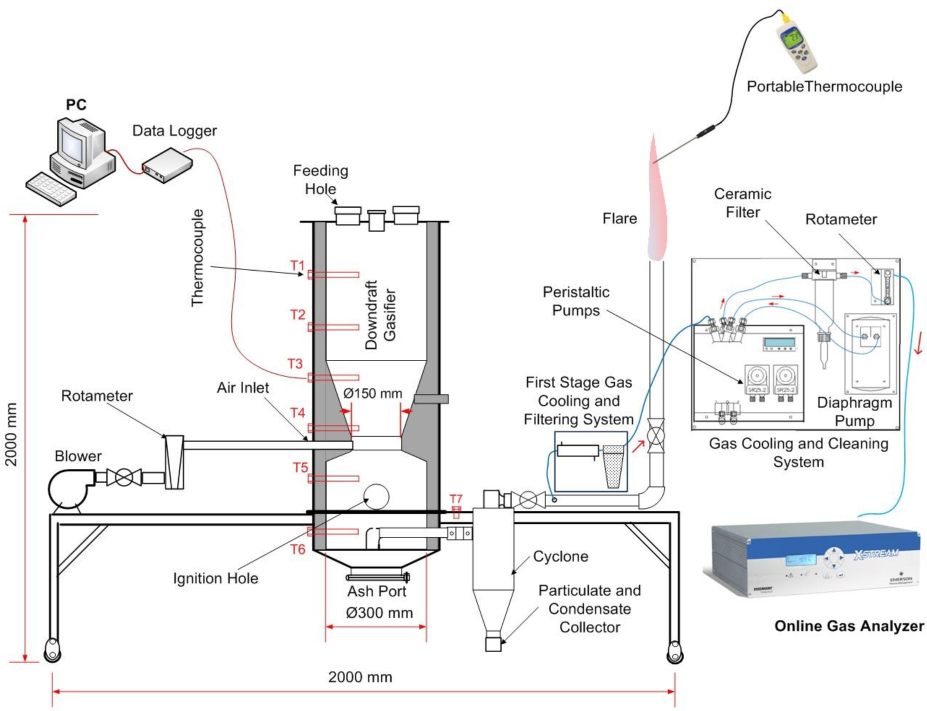

Fig. 1. Downdraft gasification system.

3 Results and discussion

Table 1. Characteristics of processed wood residual and coconut shells

Biomass	Ultimate Analysis (wt. %)					Proximate Analysis (wt. %)				HHV
	C	H	O*	N	S	MC	VM	FC*	Ash	MJ/kg
W	43.54	3.59	51.70	1.00	0.16	4.25	88.07	10.61	1.32	17.53
CS	46.93	3.96	48.21	0.71	0.19	2.29	81.67	17.50	0.83	19.43

W; Wood residual (*acacia mangium*), CS; Coconut shells, on difference basis*

3.1 Effect of blending ratio on producer gas during W/CS co-gasification

The variation in the producer gas composition as blending ratio varied from 0 to 100 for W/CS and vice-versa is shown in Fig. 2. The results show that concentration of CO in producer gas was higher as compared to the other gas contents of H_2, CH_4, and CO_2. The CO ranges between 15.2-24.0%, a reason for high CO content was high oxygen content in biomass [26]. CO concentration showe a fluctuated decreasing trend as the CS ratio increased in blends. The co-gasification of W/CS at ratios of 60/40 and 20/80 have low concentrations of CO contents than the value of CO obtained from the gasification of pure wood and CS. The reason of low CO content was high moisture content of the wood feedstock for both blends, which was 15% and 14% by weight (on the wet basis) for 60/40 and 20/80 W/CS blends respectively. As the result of a high moisture content of wood consequently, a low pyrolysis temperature was achieved, which caused poor boudouard ($C + CO_2 \rightarrow 2CO$) and dominated water-gas shift reaction ($CO + H_2O \leftrightarrow CO_2 + H_2$) that result in low CO and high H_2 and CO_2 of producer gas. However, a blend of 40/60 has a high concentration of CO content, which was 11% higher than wood residual and CS gasification results. The co-gasification of 40/60 blend of W/CS has a high concentration of CO and low CO_2, which implies a strong dominance of boudouard reaction.

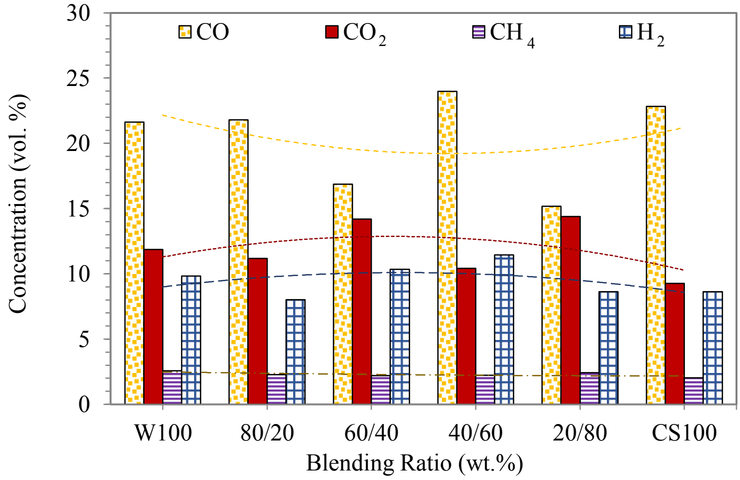

Fig. 2. Variation of producer gas composition at different W/CS blending ratios**.**

In producer gas, H_2 is the main constituent of combustible gases, it varies from 8.01 to 11.46 vol.% during the co-gasification of W/CS blends. As shown in Fig. 2, H_2 concentration in producer gas has increasing trend for co-gasification of 80/20, 60/40 and 40/60 W/CS blends as compared to the gasification results of pure CS. On the other hand, a slight decrease was observed in H_2 during co-gasification of 20/80 W/CS blend as compared to gasification of 100% CS. A high concentration of H_2 was due to high hydrogen content of raw wood residual and CS blends itself, which were 3.66%, 3.74%, and 3.81% by weight in 80/20, 60/40 and 40/60 blending ratios, respectively. The high H_2 content 11.30 vol.% obtained from co-gasification of W/CS at a ratio of 40/60, which is 33% higher as compared to the gasification 100% CS. At low moisture content (5%) of the blend, a fast pyrolysis was observed at the comparative high oxidation and pyrolysis zone temperature of 614°C and 426°C, respectively. The splashes of pyrolysis oil come out from the flare, the initial heat of combustion zone was utilized in pyrolysis zone that causes fast pyrolysis.

The CO_2 concentration varied from 10.41 to 14.39 vol.% during the co-gasification of W/CS. The CO_2 and CO were increasing and decreasing vice versa for W/CS blends as clearly shown in Fig. 2. The W/CS blends at ratios of 60/40 and 20/80 have high CO_2 contents and low CO contents as compared to gasification results of 100% wood residual and CS as mentioned before. On the contrary, 40/60 blend of W/CS has low CO_2 value and high CO contents, which was due to high oxidation zone temperature causing the consumption of CO_2 via boudouard reaction ($C + CO_2 \rightarrow 2CO$), thereby increasing the yield of CO in producer gas.

Producer gas has low CH_4 values in most of the literature as during the co-gasification of hardwood and glycerol gasification [27]. In the present co-gasification study of W/CS blends, the CH_4 concentration varied between 2.04 to 2.57 vol.%. There was no significant effect of blending ratio on CH_4 concentration. The almost similarly values of CH_4 were obtained from all co-gasification experiments. Overall, 40/60 W/CS blend has a good producer gas composition among other blends. It has high H_2 and CO contents, low CO_2, and moderate value of CH_4 contents. In the present study, the CO_2 proportion in producer gas was noted as lower than the literature [28]. The overall process shows that add of CS in wood residual improved the gas composition and both feedstocks can be used as a substitute for each other. Furthermore, the co-gasification process has more flexibility over the utilization of feedstock.

4 Conclusions

The co-gasification of W/CS at various blends ratios successfully carried out in downdraft gasifier without a change in gasifier geometry. CS feedstock can be used as a substitute for wood residual in blend form in the co-gasification process. The blending ratio may vary depending on the supply of biomass materials or the desired quality of producer gas. All gaseous components of producer gas improved as the proportion of CS increased in blend up to 60%, however, CO have a contrary trend.

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