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Study on gasification of multi-air-stage downdraft reactor using pelletized biomass

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Abstract:
The downdraft gasification technology has been well known among researchers as the most promising biomass utilization method. Common downdraft gasifier generally consist only single stage air supply. This study developed the design of downdraft gasifier to triple air supply stages which can carry up to 50 kWth. The aim of this study is, instead of improving gasifier performance, can improve producer gas quality. Eucalyptus wood pellet was chosen as raw material in consideration of stable dry fuel, more uniform size, increase the energy density and decrease problematic in gasifier. By varying two different air flow feed (285 L/min and 400 L/min) in each double and triple air supply stages, measuring the CO, H_2, CH_4 and CO_2 gas concentrations, the gas heating value, as well as other performance variables were calculated. There was almost linear relation between air flow feed, a number of stages and producer gas quality: Air flow feed of 400 L/min showed a better syngas quality than 285 L/min with CO, CH_4 and H_2 concentrations of 12.6, 0.88 and 8.80% v.

Keywords: *Gasification; Multi-air-stage; Downdraft; Eucalyptus wood pellet*

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1. Introduction

Gasification as energy conversion technology has been numerously studied to solve environmental issues. Gasification allows the production of combustible gas component (CO, H_2 and CH_4), small quantities of char, ash and condensable compounds (tar and oil) from incomplete combustion with thermal decomposition. Oxygen, steam or air is limitedly supplied to the reaction as a gasifying medium. Producer gas or syngas is main product of gasification not only has more value but also a marketable fuel. The typical biomass gasification process consists of some stages (Basu,2010): drying where in this stage the moisture content of biomass is reduced, thermal decomposition process in the absence of oxygen or gasifying medium where in the low temperature biomass converted into volatile gas, char and liquid tar, partial oxidation process which is developed with less oxygen than the stoichiometric, and reduction stage where the un-burnt char is gasified here and converted into volatile gas which has higher composition of combustible gas (CO, H_2 and CH_4). This gas is called producer gas. Downdraft fixed bed gasifiers are widely used for its simple design and better producer gas quality because the gas move downward pass a higher temperature zone in gasifier. The hot gas product of pyrolysis and oxidation flow downward over the remaining hot char, where the gasification takes place, turn out to more combustible gases with a low energy content. This basis underlies some researchers to modify a downdraft gasifier. Bhattacharya (2001) studied on a multi-stage hybrid biomass-charcoal gasification. Jaojaruek (2011) has proved that thermal utilization concept can increase temperature zone in the reactor and also improve HHV gas up to 6.5 MJ/Nm^3 by created an innovative two stage air and premixed air/gas supply. The more stage air supply, the higher residence time for gases to elevated temperatures, thus increasing producer gas quality. At the same time, biomass factor also take place in a successful gasification. Its carbon neutral has made biomass to be the most widely used especially in downdraft gasification. However, this biomass would better be conditioned before being processed in downdraft gasifier. High moisture content, dissimilar structure, high of small particle, and other problems could be done by pelletized the biomass (Erlich and Fransson, 2011; Lickrastina et al., 2011; Simone et al., 2012). The current study is aimed to convert pelletized biomass into a gaseous fuel considering the effect of air flow feed and a number of air supply stages in downdraft gasifier.

2. Material and methods

2.1. Material

Pellet made of eucalyptus wood was selected as raw material for this study. It has cylindrical shape with diameter range 6–9 mm and length 30-70 mm. The moisture content was around 10%. The ultimate and proximate properties are reported in Table 1.

Table 1 Properties of eucalyptus wood pellet

Ultimate analysis (wt.% dry)				Proximate analysis (wt.% dry)			LHV (MJ/kg)
C	H	O	N	V	FC	Ash	13.46
37.78	4.73	35.42	0.51	66.37	6.03	21.56	

2.2. Equipment

The downdraft gasifier with some cleaning system used for the experiments. It is a close top design with a total height of 2100 mm and internal diameter of 150 mm. It is built with an internal coating of refractory material to properly keep the heat inside gasifier. The top zone of gasifier is a feedstock hopper, the bottom is ash chamber zone separated by the grate to support the bed and in the middle is the main part of gasification which has 3 stage of air injection. The purpose of 3 air stage supply is considered as primary method to improve the quality of syngas. The syngas is cleaned using cyclone to remove impurities such as fly ash and particles. Heat exchanger of shell and tube type is used to cool down the syngas. Fine particles will be removed using bag house filter before the syngas sucked by suction blower to a flare. Fig. 1 presents a simple schematic of downdraft gasification system.

2.3. Experimental procedure

The eucalyptus wood pellet was loaded 19 kg into the gasifier at feed stock hopper. Ignition started at ignition port using gasoline. At the beginning, suction blower was used to supply air for ignition. When combustion developed, ignition port was closed and ring blower operated to reach the amount of air supply needed. For the double stage, air was supplied only at first and second air stage while for the triple stage all stage of air supply opened. The air supply rate obtained through an orifice and the values were measured by rotameter in each pipe. Temperature profile was read by 7 K-type thermocouples along the gasifier. Thermocouples were set up only until inner gasifier wall. Although it will not show reliable temperature but it prevents biomass flowing problem, chanelling and bridging. To investigate the effect of air flow rate and air supply stages on gasifier performance, thus gasifier was tested for 285 L/min and 400 L/min for each double and triple air supply stage. After reaching the steady state of operating condition, combustible gases could be seen by igniting the fire in flare. Since the fire obtained in flare, gas samples taken henceforward analyzed using micro gas chromatography (Micro GC Agilent 490).

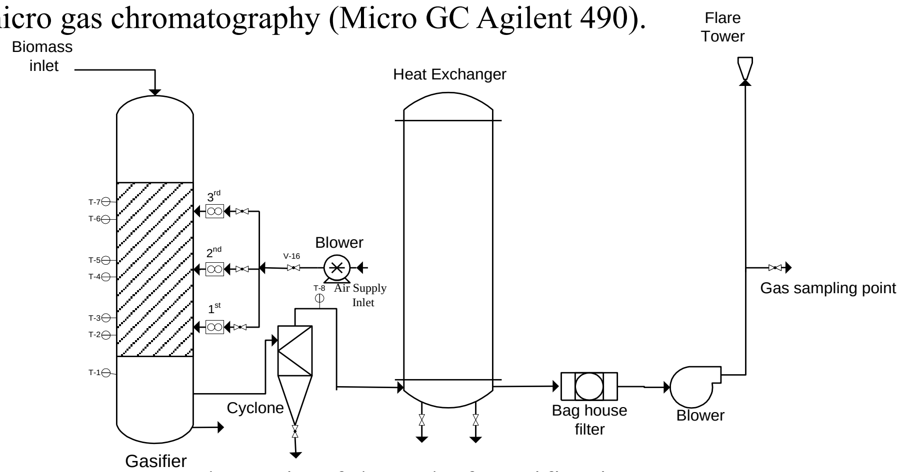


Fig.1 Schematic of downdraft gasification system.

3. Results and discussion

3.1. Temperature profiles on gasification of multi-air-stage downdraft gasifier

Temperature profiles of multi-air-stage gasification are presented in Fig.2. This temperature profiles are read from data logger which is connected to 7 thermocouple type K along the gasifier. The thermocouples are projected up to the inner wall of the gasifier in order to prevent the biggest moving bed gasifier problems which are channeling and bridging of the biomass, so this might not show the real gasification temperature.

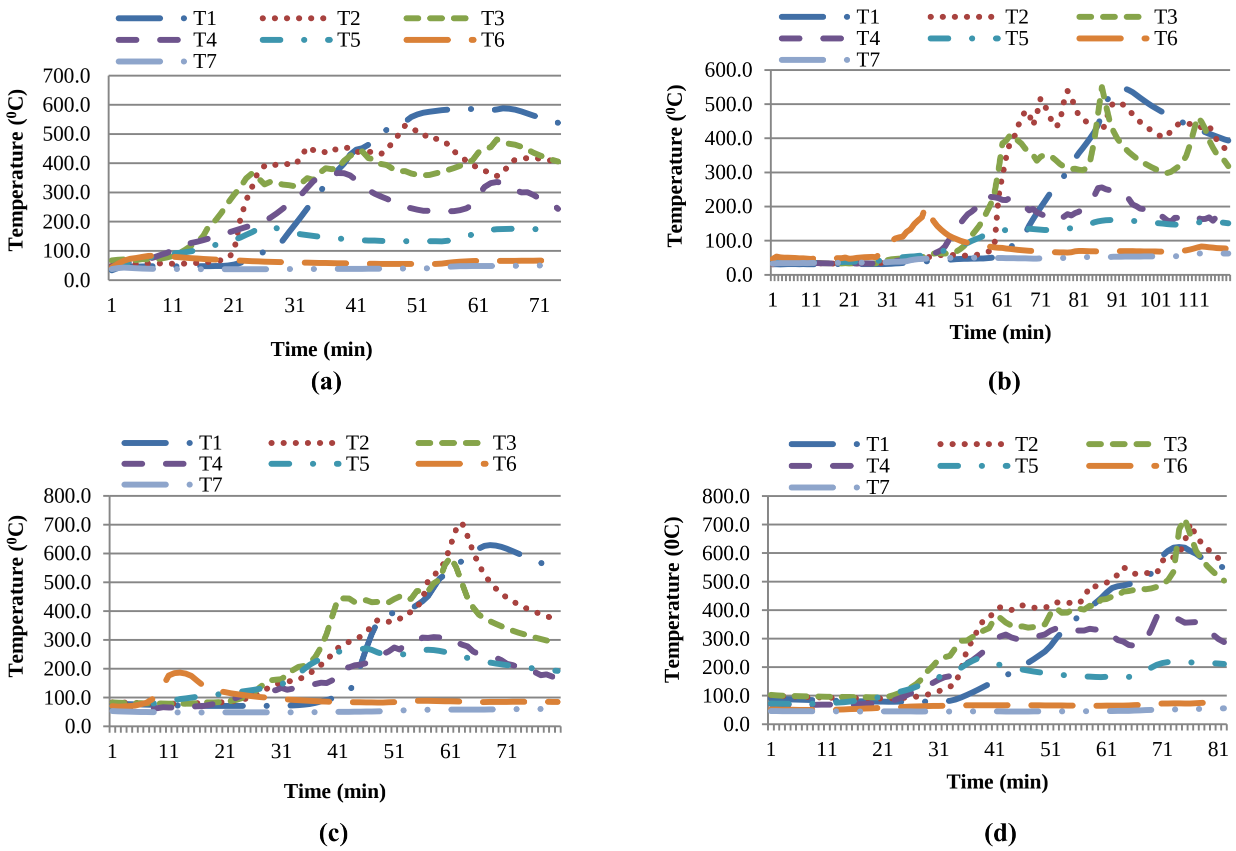
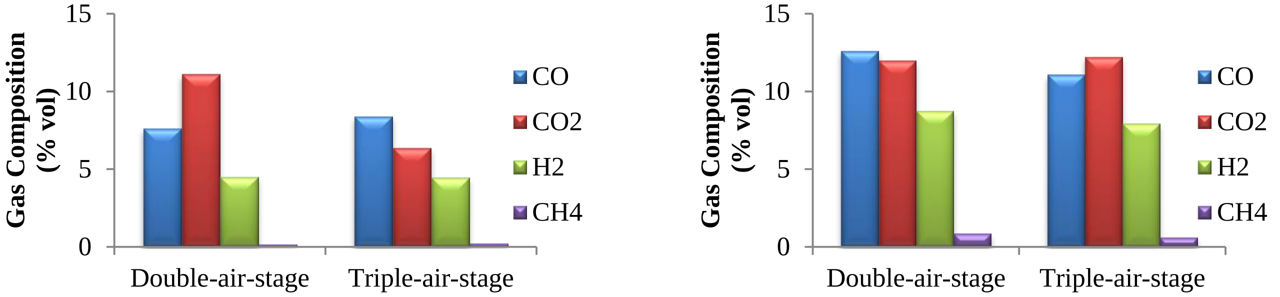


Fig. 2 Gasification temperature profile. (a) double air supply stage, 285 L/min; (b) triple air supply stage, 285 L/min; (c) double air supply stage, 400 L/min; (d) triple air supply stage, 400 L/min.

The most noticeable temperature profiles shown by T1, T2 and T3 as it was the oxidation zone and reduction zone. Temperature is closely related to changes of air supply rate. Pellets were ignited at the ignition port near Thermocouple 6. After about 15 until 30 minute, heat built up and the flaming oxidation zone was formed. Triple air supply at feed rate 285 L/min took the longest propagation time because the air supply was divided into three pipe lines. Even it took longer propagation time, it showed better air supply distribution than the same air supply rate at double air stage. As shown in Fig. (c) and (d), propagation took less time as it was supplied higher air feed rate. It also verified that the higher air supply is fed, the higher temperature is reached. Higher temperature in gasifier could help more CO_2 to react to form CO. Char from pyrolysis could be cracked by higher temperature in oxidation and reduction zone to form more combustible gases. Compared to 285 L/min air supply, at 400 L/min the oxidation zone could reach 700°C. During the gasification process, eucalyptus wood pellet consumed and formed a very high temperature of bed 300 mm above the grate. As this eucalyptus wood pellet has high ash composition, slag problem occurred. Slag is formed when the ash melted. It was a big, hard, mixture of melted ash which blocked the grate and made the fuel above it could not flow down smoothly. At this state, quality and quantity of syngas began to decrease.

3.2. Syngas composition and heating value

Fig. 3 reports the syngas composition during four tests. Syngas was mainly composed of carbon monoxide, hydrogen, carbon dioxide, methane, nitrogen; ethane and ethylene were detected but in very low concentration. Since air is used as gasifying medium in the gasifier, so the concentration of syngas dominated by nitrogen. The nitrogen in it greatly dilutes the product and affects to lower heating value of syngas (Basu, 2010)



(a) **(b)**

Fig. 3 Syngas composition. Air flow rate of 285 L/min (a) and (b) air flow rate of 400 L/min.

In this case, it was found that gas composition was better at higher air flow rate. It got better when the higher air flow rate distributed well by all air stages. The amount of carbon was converted to CO and H_2 through Boudouard and Water Gas reaction. The CO concentration was in the range 8-13% relatively low due to lack carbon conversion efficiency. The best gasification performance was double air stage at flow rate 400 L/min with LHV, HHV and carbon coversion efficiency of 2.86 MJ/m^3, 3.07 MJ/m^3 and 34.35% respectively. Other tests performance are presented in Table 2. The lower fuel conversion of fuel either a bad fluid-dynamic in the gasifier or due to high ash content of fuel affect to lower H_2, CO_2 as well as CO (Simone et al., 2012).

Table 2 Comparison of gasification performance

Gasification approach	Air flow rate (L/min)	LHV (MJ/m^3)	HHV (MJ/m^3)	Carbon conversion efficiency (%)
Double air stage	285	1.52	1.62	21.94
Triple air stage	285	1.63	1.72	17.25
Double air stage	400	2.86	3.07	34.35
Triple air stage	400	2.49	2.67	31.13

4. Conclusion

Four tests were analysed and compared at different air feed rate and air supply stages. A good temperature distribution due to more air supply stages had an effect on the quality and quantity of syngas. Double air stage gasification showed the best CO, H_2, and CH_4 concentrations of 12.6, 8.80 and 0.88% v. The effect that ash had on gasification process led to higher bed temperature which in its turn to ash melting.

5. Acknowledgement

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