August 2013. Vol. 4, No. 2 ISSN2305-8269

International Journal of Engineering and Applied Sciences

www.eaas-journal.org

INFLUENCE AIR FACTOR AGAINST OPERATING PARAMETERS OF BIOMASS FLUIDIZED–BED GASIFIER

Bambang Suwondo Rahardjo

Pusat Teknologi Pengembangan Sumberdaya Energi (PTPSE), Deputi Bidang Teknologi Informasi Energi dan Material (TIEM) BPP Teknologi
Email: bamsr52@yahoo.co.id

ABSTRACT

Research and development on fluidized-bed gasification of biomass has been initiated by Yayasan Dian Desa collaboration with NEDO (New Energy and Industrial Technology Development Organization of Japan) starting from small scale (2000–2003), bench–scale tests (2004–2005) and pilot–plant (2006–2009). Since 2006, a cooperative research and development on fluidized–bed gasification of biomass established and agreed between the BPP Teknologi, Yayasan Dian Desa and NEDO to investigate the influence of the air factor on other gasifier operation parameters: bed temperature, gas calorific value and gasifier cold efficiency. The experiments were carried out with the following kinds of biomass: rice husk, sawdust, sugarcane bagasse and spent coffee grounds. The relationship between the gasifier cold efficiency and air factor shows that the curves for rice husk and sawdust have a maximum; for bagasse the relationship is decreasing because of intensive elutriation; for spent coffee grounds due to feeder limitations, it was not possible to feed the biomass flow corresponding to air factor values greater than 0.2. The low efficiency values are a consequence of the lack of thermal insulation in the gasifier freeboard zone.

Keywords : Fluidized–bed, gasification, biomassa

1. INTRODUCTION

NEDO (New Energy and Industrial Technology Development Organization of Japan) and Dian Desa Society has been conducting research and development of biomass fluidized-bed gasification starting from small scale (2000-2003), bench-scale test (2004-2005) and pilot-plant (2006-2009) [10]. In addition, Dian Desa Society and NEDO also conducts research and development simultaneously bagasse pyrolysis [11] by using the supporting research and development facility owned, ie:

- Mini fluidized–bed reactor ∅ = 8 cm, for experiment devolatilization [3], [4].
- Continuous fluidized–bed reactor ∅ = 20 cm for biomass gasification experiment [5].

Since 2006, a cooperative research and development of biomass fluidized-bed gasification started braided and agreed between BPP Technologi, Dian Desa Society and NEDO. So far, the research and development phase on biomass fluidized-bed gasification that has been done is the effect of operating parameters and fuel characteristics against the devolatilization process using rice husk and bagasse.

2. LITERATURE REVIEW

Gasification is the process of converting carbon containing materials by partial oxidation at high temperatures into gas. The resulting gas is called producer gas containing gas CO, H_2, dan CH_4. Biomass gasification is more profitable than direct combustion, because the gas is more flexible product that can be directed into gas fuel or feedstock for the chemical industry has a higher sale value. Gasification generally consists of 4 (four) processes, namely drying (>150°C), pyrolysis (150°C<T<700°C), oxidation (700°C<T<1500°C), and reduction (800°C<T<1000°C).

International Journal of Engineering and Applied Sciences

www.eaas-journal.org

Pyrolysis or devolatilization is a series of physical and chemical processes occurring slowly at temperatures <350°C and rapidly at temperatures >700°C. Product composition arranged is a function of temperature, pressure, and gas composition during pyrolysis takes place. Pyrolysis process starts at temperatures around 230°C, when the component thermally unstable, such as lignin broke and evaporate along with other components. Vaporized liquid product containing tar and PAHs (polyaromatic hydrocarbons). Pyrolysis products are generally composed of light gases (H_2, CO, CO_2, H_2O, CH_4), tar, and char.

Oxidation is the most important reactions occurring in the gasifier which provide all the heat energy needed on the endothermic reaction. Oxygen is supplied to the gasifier reacts with combustible material. The reaction products were CO_2 and H_2O which subsequently reduced when in contact with the char produced on pyrolysis.

$$C + O_2 \rightarrow CO_2 + \ 393{,}77 \ ^{kJ}/_{mol\ C}$$

Another combustion reactions take place is the oxidation of hydrogen contained in the carbon material to form steam.

$$H_2 + \frac{1}{2} O_2 \rightarrow H_2O + \ 742 \ ^{kJ}/_{mol\ H_2}$$

Reduction or gasification includes a series endothermic reaction that supported by the heat produced from the combustion reaction. The resulting product is a fuel gas, such as H_2, CO, and CH_4. There are four (4) common reactions related to gasification process, i.e.:

- Water-gas reaction is a partial oxidation reaction of carbon by steam which can be derived from the pyrolysis of solid fuels itself and of the water vapor is mixed with air and steam produced from water evaporation.

$$C + H_2O \rightarrow H_2 + CO \ - 131{,}38 \ ^{kJ}/_{mol\ C}$$

- Boudouard reaction is the reaction between CO_2 that occur in the gasifier with char to produce CO.

$$C + CO_2 \rightarrow 2\ CO - 172{,}58 \ ^{kJ}/_{mol\ C}$$

- Shift conversion is the CO_2 reduction reaction by steam to produce H_2. This reaction is known as the water-gas shift which results in an increase on ratio of H_2/CO_2 gas producer to manufacture synthetic gas.

$$CO + H_2O \rightarrow CO_2 + H_2 - 41{,}98 \ ^{kJ}/_{mol}$$

- Methanation is a gas–forming reaction CH_4.

$$C + 2H_2 \rightarrow CH_4 + 74{,}90 \ ^{kJ}/_{mol\ C}$$

Fluidized–bed gasification is gasification process with a moving bed of material resembling fluid and gas flow rate between 1~12 m/sec. Based on the speed of the flow bed movement, fluidized-bed gasification systems can be divided into circulating fluidized-bed and bubbling fluidized-bed, as shown in Figure 1.

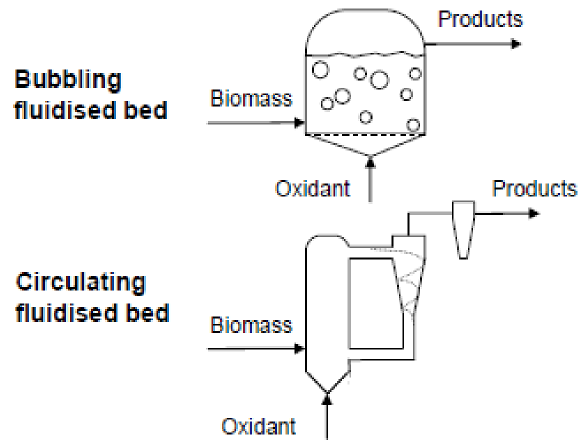


Figure 1. Differences in stream bed movement on fluidized-bed gasification system

3. RESEARCH

The purpose of research is to conduct biomass gasification experiments to determine the effect of air factor against gasifier operating parameters, such as: temperature base–bed, the oxygen content in the fluidizing gas, gas calorific value, biomass composition granulometric [3], [4] and gasifier efficiency.

3.1. Materials

International Journal of Engineering and Applied Sciences

www.eaas-journal.org

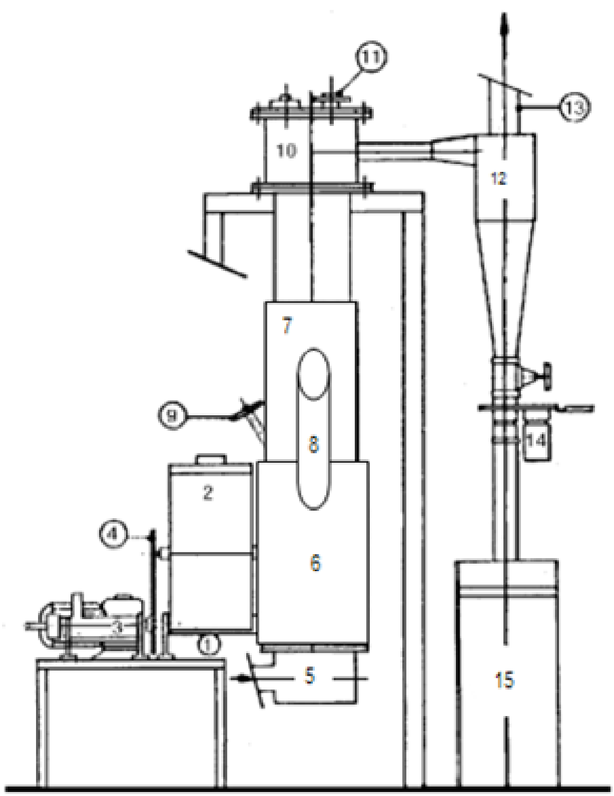
Table 1 shows the characteristics of the biomass type used as feedstock gasification: rice husk, sawdust, bagasse and bark coffee [12].

Table 1. Proximate analysis and calorific value of biomass

Biomassa	Proximate Analysis				HHV MJ/kg dry
	Fixed Carbon %dry	Volatile Matter %dry	Ash %dry	H_2O %wet	
Rice husk	12.0	72.2	15.8	10.0	15.6
Bagasse	9.2	86.4	4.4	6.4	16.7
Sawdust,	15.2	84.2	0.6	12.9	18.0
Bark coffee	13.9	83.5	2.6	5.7	21.8

3.2. Equipments

- Fluidized–bed gasifier (Figure 2) in the form of tube outer diameter 25 cm is made of 316 stainless steel and coated with a layer of 2.5 cm thick fire bricks. Gasifier 20 cm inside diameter with a total height of 200 cm. At the base–bed zone, gasifier insulated with mineral wool. Gasifier temperature measurement points located along the top and separated from each other ± 15 cm. Base–bed of inert material is white aluminum oxide (alumina).
- Root compressor (Omel SR–07–12HP) equipped with orifice flowmeter for measuring the air flow rate.
- Screw conveyors are used to carry–out biomass to the gasifier through the hopper.



1. Biomass feeding system
2. Biomass hopper
3. Reducer
4. Chain
5. Plenum
6. Reactor body
7. Freeboard zone
8. Duct for alumina feeding
9. Observation glass
10. Reactor gas exit section
11. Security seal
12. Cyclone
13. Gas exit
14. Ash sample system
15. Ash hopper

Figure 2. Experiment set–up for the biomass fluidized-bed gasifier

International Journal of Engineering and Applied Sciences

www.eaas-journal.org

3.3. Metodology

- To operate gasifier for tar-cracking on *base*–bed operating temperature interval 600-800ºC with a superficial gas velocity of 0.75 m/sec.
- To inject air as the gasifying agent into the gasifier using root compressor. Air distribution on base–bed through 2,000 distribution plate hole diameter 1.3 mm.
- To feed biomass on the base–bed gasifier through the hopper and screw conveyor. Feed slot is located 5 cm above the distribution plate. The feed is cooled internally by water and its speed controlled by a reducer.
- To measure the parameters of air flow rate (f_a), flow rate of biomass (m_c), elutriated powder flow rate (m_f), temperature base–bed at various points (T_{BI}), gas temperature (T_{gi}), entrance and exit gas temperature cyclone (T_{CI} and T_{CO}), composition of the gases (CO, H_2, CH_4), carbon content in the powder (% C_{in}).

Table 2. Operating condition and design parameters of *gasifier*

Parameters		Rice husk		Sawdust		Bark Coffee		Bagasse	
		(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
AF	-	0.55		0.25		0.22		0.16	
T_b	^oC	759		777		780		740	
CO	%	11.7	15.0	14.5	15.3	13.5	14.8	11.5	13.0
H_2	%	4.3	6.0	8.2	8.9	7.0	7.4	4.5	5.4
CH_4	%	2.8	3.7	4.1	4.3	4.0	4.1	2.9	3.3
LHV_g	MJ/Nm^3	2.9	4.0	3.8	4.3	2.9	4.0	2.7	3.3
η_{min}	%	43.0	53.9	35.0	41.0	20.0	25.5	15.5	18.0
η_{mak}	%	60.0	65.0	47.0	52.0	28.0	33.6	22.0	24.0
$R_{g/b}$	m^3/kg	1.2		1.3		1.6		0.8	
Q_{vg}	MW/m^3	1.4		1.8		2.0		1.3	
V_{vb}	t/m^3hour	1.0		1.25		1.4		2.0	

- To calculate the ratio of air / fuel (a/f), air factor (AF), low calorific value gas recovery (LHVg), minimum efficiency gasifier (η_{min}) and maximum efficiency gasifier (η_{mak}). Air factor (AF) is the volume fraction of air stoichiometry (basis 1 kg of fuel) which supplied into the gasifier. Air factor is the main parameters of gasifier operating that determine base–bed temperature and efficiency. Common values range of air factor for biomass gasifier 0,2–0,4.

.

4. RESULT AND DISCUSSION

The test results of filter granulometric show that the bagasse powder has the largest fraction, followed by sawdust, bark coffee and rice husk [5], [6], [7], [8].

4.1. Result

Table 2 shows the gasifier operating conditions and design parameters for the overall parameters are adjusted according to the value of the data polynomial order 2 and the maximum value observed.

International Journal of Engineering and Applied Sciences

www.eaas-journal.org

(1) : Setting value (2) : Maximum value observed

AF	:	Air Factor	
T_b	:	Base–bed temperature	^oC
LHV_g	:	Lowest calorific value gas	MJ/Nm^3
η_{min}	:	Minimum efficiency *gasifier*	%
η_{mak}	:	Maximum efficiency *gasifier*	%
$R_{g/b}$	:	Gas recovery volume per 1 kg biomassa	m^3/kg
Q_{vg}	:	Volumetric power of recovery gas per 1 m^3 base–bed	MW/m^3
V_{vb}	:	Biomass feeding rate per 1 m^3 base–bed	ton/m^3hour

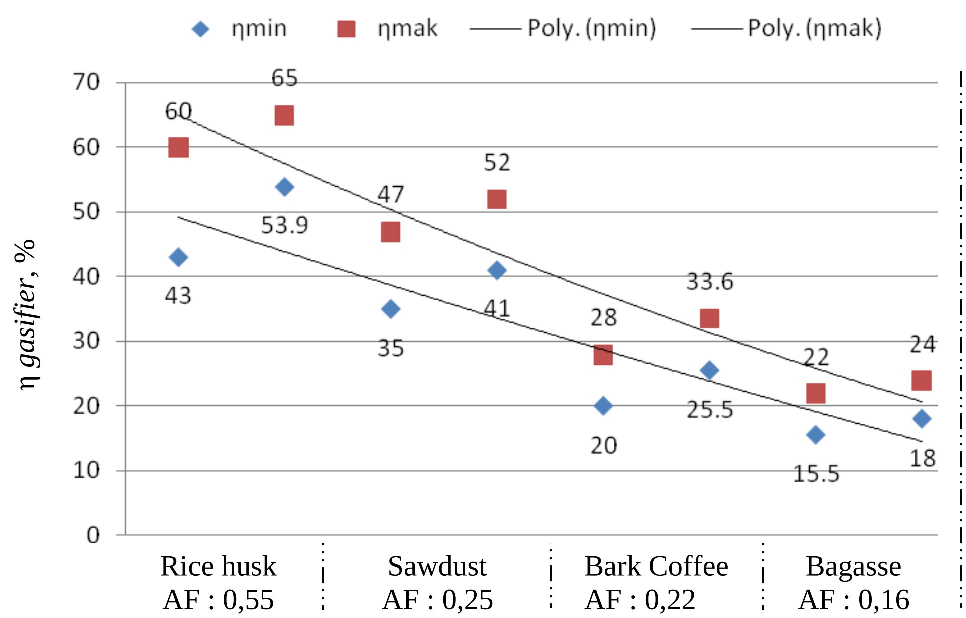


Figure 3. Correlation efficiency (η) gasifier and air factor (AF)

Figure 3 shows the curve of the relationship between gasifier efficiency and maximum air factor for rice husk and sawdust, while the curves for bagasse decreased due to intensive elutriation.

4.2. Discussion

Increase in base–bed temperature of 740^{o}C to 850^{o}C causes 3-5 times reduction of tar content in the gas recovery [2], [1]. However, some types of biomass residues with high ash content and low melting point, can resulted agglomeration of inert base–bed material and fluidization collapse [9]. During static testing of base–bed has a limited height 37-48 cm corresponding rise as high as 600-710 mm.

ISSN2305-8269
International Journal of Engineering and Applied Sciences

www.eaas-journal.org

Design parameter is the volume of gas recovery 1 kg of biomass ($R_{g/b}$, m^3/kg), volumetric power gas recovery (Q_{vg}, MJ for 1 m^3 base–bed volume), biomass feeding rate (V_{vb},, ton/m^3hour).

Temperature conditions of base–bed that operated to achieve gasifier efficiency, respectively 780°C (bark coffee), 777°C (sawdust), 759°C (rice husk), 740°C (bagasse), this means that the higher base–bed operating temperature, gasifier walls lack insulation.

From the observations show that the higher operating temperature of base–bed, the greater biomass flow rate (V_{vb}, ton/hour) dan volumetric power recovery gas (Q_{vg}, MW) per m^3 base–bed, as well as recovery gas volume ($R_{g/b}$, m^3) per kg greater biomass.

Considering the limitations of bark coffee feeding, thus not allowing the feeding rate in accordance with the air factor value greater than 0.2, so the efficiency is low as a consequence of the lack of thermal insulation in the gasifier wall zone.

5. CONCLUSSION

- Operation using bagasse powder granulometric gasifier efficiency leads to a lower value due to the intensive elutriation, but this can be overcome by operating higher base–bed.
- The lack problems of reliability, streams stability and feeder capacity of fibrous biomass to be solved for the practical application of bagasse gasification on an industrial scale capacity.
- The obtained results can be used for preliminary calculations relating to the biomass fluidized-bed gasifier industrial scale.

References

[1].Bilodeau, J.F. and Chornet, E. (1993), *Gasification of Residual Biomass via the Bio–syn Fluidized–bed Technology*, Proceedings of Advances in Thermochemical Processing of Biomass, Interlaken, Elsevier Pub.

[2].Czernik, S., Koeberle, P.G., Jollez, P. (1992), *Gasification of Residual Biomass via the Bio–syn Fluidized–bed Technology*, Proceedings of Advances in Thermochemical Processing of Biomass, Interlaken, Elsevier Pub.

[3].Sanchez, C.G., Peel, R.B., Santos, F.J. (1990), *Research on biomass devolatilization rates in fixed and fluidized–beds*, The 3rd Brazilian Thermal Science Meeting Proceedings: 789~792.

[4].Sanchez, C.G., Silva, E.L., Santos F.J. (1993), *Experimental research on the sugarcane bagasse and rice husk devolatilization process*, XII Brazilian Congress of Mechanical Engineering Proceedings: 545~548.

[5].Sanchez, C.G. (1994), *Research on Biomass Fluidized Bed Devolatilization and Gasification*; Ph.D. thesis, UNICAMP.

[6].Sanchez, C.G., Silva, E.L. (1994), *Rice–husk Fluidized–bed Gasification*, Presented at the 5th Brazilian Thermal Sciences Meeting, São Paulo.

[7].Silva, E.L., Sanchez, C.G. (1994), *Bagasse Gasification*, Presented at the International Seminar on Commercial Energy Generation in the Cane Agro–Industry, 15–l8 June, Guatemala City, Guatemala.

[8].Silva, E.L., Shestakov, S.M., Beatón, P.S., Recio, A., Malajaev, P.A., *Sugar–cane Bagasse Pyrolysis Characteristics*; Jimia Drevesiny No. 3: 103–106.

[9].Salour, D., Jenkins, B.M., Vafaei, M., Kayhanian, M. (1989); *Combustion of rice straw and straw wood fuel blends in a fluidized–bed reactor*; American Society of Agricultural Engineers, Paper No. 89–6574.

[10].Tanaka N., Herman S. (2000–2003), *R&D on Small Scale Test of Fluidized–bed Biomass Combustion and Gasification*, Japan.

[11].Tanaka, N., Herman S. (2004–2005), *R&D on Bench Scale Test of Fluidized–bed Biomass Combustion and Gasification*, Japan.

[12].Tanaka N. (2006), *R&D on Pilot Plant of Fluidized–bed Biomass Combustion and Gasification*, Indo