Jurnal Teknologi

Full paper

Effect of Biomass Feed Size and Air Flow Rate on the Pressure Drop of Gasification Reactor

Wusana Agung Wibowo*, Sunu Herwi Pranolo, Juli Novianto Sunarno, Doyok Purwadi

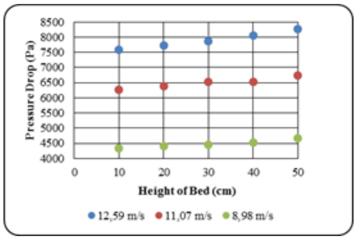
Department of Chemical Engineering, Faculty of Engineering, Universitas Sebelas Maret, 36126 Surakarta, Indonesia

*Corresponding author: wusana_son@yahoo.com

Article history

Received :1 January 2014
Received in revised form :
15 February 2014
Accepted :18 March 2014

Graphical abstract



Abstract

The present work investigates feed size characteristics of the biomass on pressure drop for prediction of gasification reactor performance. Bed of biomass in the reactor resulted pressure drop causes the increase of energy for supplying gasifying agent, thereby reducing the net energy gain. Biomass used in this study are sawdust, rice husk, wood charcoal, coconut shells, peanut shells, corn cobs and leaf litter. Pressure drop test were performed under turbulent condition (Reynolds: 63000; 78000, and 88000) and five bed height variations (0.1, 0.2, 0.3, 0.4, and 0.5 m). It had been found that the higher Reynolds and bed of biomass as well as the smaller particle size of the biomass resulted greater pressure drop. Moreover, the shape characteristic of biomass also affected pressure drop. The study yield correlations of pressure drop, fluid velocity and height of bed for each biomass. The obtained pressure drops are analyzed by Bernoulli equations for investigation of power prediction. The highest power requirement was achieved for saw dust (P= 47.84 W) with Reynolds 88000 and height of 0.5 m. In contrast, the lowest power requirement was achieved for corn cobs (P=11.257 W) with Reynolds 63000 and height of 0.1 m.

Keywords: Biomass characteristic; biomass bed; gasification; pressure drop; blower power

■1.0 INTRODUCTION AND BACKGROUND

Biomass is organic matter derived from biological matter. The energy from biomass is sustainable without any risk of deficiency as its abundance source [1]. Biomass is renewable alternative energy and it has huge potency of development as new energy resource particularly in Indonesia. The advantage of utilizing biomass as source energy are to recycle CO_2, thus CO_2 emissions into the atmosphere as a net amount to zero, and as a means of utilization of industrial wastes especially agricultural waste.

Gasification is, occasionally, maintained as a means of energy conversion of biomass. This reaction conducted in gasification reactor called gasifier. The performance of reactor requires an excess energy as hindrance effect of biomass bed inside the reactor. It affects pressure drop as well as energy requirement for jetting process of gasifying agent, which in this work was air. Pressure drop may be defined as the pressure difference between two analysis spot in fluid system. The loss of pressure relies on fluid characteristic run through the device. Pressure drop in fluid system are consist of reversible pressure drop and irreversible pressure drop. Conversions of mechanic energy to heat energy or friction loss are classified as irreversible pressure drop [2].

Spherecity and size of biomass particle may cause hindrance of gas flow. Bed of biomass inside the reactor may raise pressure drop, thereby increased the required energy of blower to transpor the gasifying agent. The high energy requirements of gasification unit can reduce the net energy gain. This hindrance is rarely happen if the size and shape of particle is uniform [3]. Therefore, initial treatment such as drying and cutting is necessarily needed prior entering the reactor.

Studies have shown that pressure drop through the bed is affected by fluid velocity, physical properties of fluid (viscosity and density), porosity of bed, bed arrangement, size and shape of bed particle, ratio of diameter particle per diameter reactor (l/d) [4-5]. As mentioned previously, the pressure drop through the bed of reactor is affected by bed porosity. This porosity depend on feed particle shape. Wide distribution of particle shape create higher value of porosity, thereby influenced the reactor pressure drop. Radom bed porosity variously range from 0.45 to 0.55. The value of 0.45 creates pressure drop 2 until 3 time higher with value of 0.55 in comparison [6].

Each gasification unit has different characteristics. These characteristics depend on biomass feed in which affect the performance of reactor. Therefore, the investigation is required in order to optimize the reactor performance in various conditions.

The aim of this study was to investigate the effect of biomass feed size and gasifying agent flow rate on pressure drop to predict required blower power. This work generates equations to predict pressure drop which correlate the height of bed in the reactor and gasifying agent flow rate which is then used to calculate the blower power

2.0 METHODOLOGY

The materials used for sample were saw dust, Rice husk, corn cobs, coconut shel, wood charcoal, peanut shell and leaf litter. All materials were cut, dried and classified by its size (see Table 1).

Table 1 Material classification

Material	Size
Saw dust	30% size 0.5 mm or less
Rice hust	4 mm < l average < 7 mm
Corn cobs	l=d l=2d l=3d
Coconut shell	De=2.5 cm De=5.5 cm De=8.5 cm
Wood charcoal	1 cm x 1 cm x 1 cm 3 cm x 3 cm x 3 cm 6 cm x 6 cm x 6 cm
Peanut shell	3 cm
Leaf litter	-

Term index:
$l_{average}$: Height average
l : length
d : diameter
De : equivalent diameter

Fixed bed reactor was utilized for pressure drop test. All treated sample above were stacked inside the reactor. Air was introduced inside the reactor by ring blower and controlled by valve to get the desired flow rate. Three manometers were used to measure the entering air flow rate, the pressure drop inside the reactor and the exit air flow rate (see Figure 1).

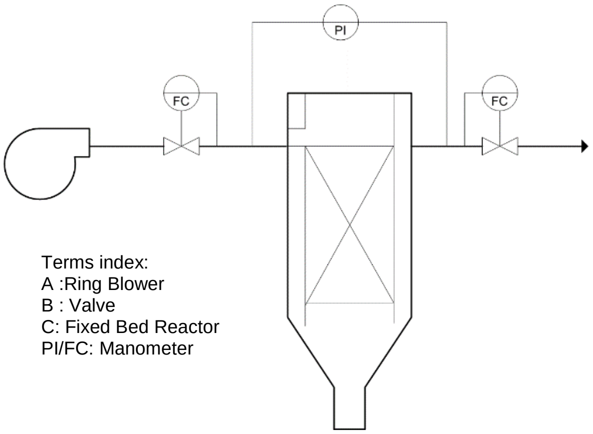


Figure 1 Pressure drop test apparatus

Pressure drop tests were done in three Reynolds conditions i.e. 12.59 m/s (Re: 63000), 11.07 m/s (Re: 78000), 8.98 m/s (Re: 88000). The Reynolds number calculated were based on pipe diameter as diameter parameter in equation, which mean these Reynolds number represent the Reynolds of air entering the reactor. The airflow rate through the inlet pipe was measured by manometer. Prior to pressure drop test, inlet manometer calibration was conducted by correlating height difference in manometer to air flow rate measured by anemometer. Pressure test of empty bed reactor also conducted as comparison for obtained data.

Stated previously that manometer was used as indicator by measuring height difference in order to obtain pressure and flow rate values. From hydrodynamic correlation, we might obtain the pressure drop inside the reactor by knowing the density of fluid in manometer and gas flow through the reactor.

$$\Delta p = \Delta h(\rho_{Hg} - \rho_{gas})g \qquad (1)$$

Where Δp is pressure drop through the reactor (Pascal), Δh is the difference in fluid height in a liquid column manometer (m), ρ is fluid density inside the column (Kg/m^3) and g is gravitational constant (m/s^2).

Void fraction in packed bed link to particle sphericity. In small diameter vessel, wall friction effect is significantly important as wall friction is function of ratio of height and diameter of tube. When diameter is small, the ratio will increase thereby giving significant additional value to the total pressure drop, but when the ratio is small (larger diameter of tube), the value of head loss will reduce to the extent of zero which means no friction loss caused by wall effect. Several investigations in fluid behavior were conducted. One of the most prominent was Ergun and the correlations.

$$\frac{\Delta p}{L} gc = 150 \frac{(1-\epsilon_m)^2}{\epsilon_m^3} \frac{\mu u_0}{(\Phi_s d_p)^2} + 1,75 \frac{1-\epsilon_m}{\epsilon_m^3} \frac{\rho_g u_0^2}{\Phi_s d_p} \qquad (2)$$

Where L is the length of the bed (m), dp is s the equivalent spherical diameter of the packing (m), ρ is density of fluid (kg/m^3), Єm is the void fraction of the bed (bed porosity at any time), μ is dynamic viscosity of fluid (Pa.s), ϕ is particle sphericity and u_0 is the superficial velocity (i.e. the velocity that the fluid would have through the empty tube at the same volumetric flow rate).

In this work, we limited under several assumption. The first assumption was no channeling effect in the packed bed but channeling effect only occurred through the specific pores in the packed bed. Second, feed diameter was so small compared with reactor diameter. And the last was the air flow rate, particle diameter, and void fractions were considered similar in every volume element, thus we able to use average value during data computation.

Pressure drop in Ergun correlation represent viscosity factor and kinetic energy loss. In case higher Reynolds number, viscosity factor contribution is lower than kinetic energy factor. Therefore, the loss of kinetic energy needs to be taken into account and viscosity fator is neglected. Then The Ergun's equation simplifies to:

$$\frac{\Delta p}{L} gc = 1,75 \frac{1-\epsilon_m}{\epsilon_m^3} \frac{\rho_g u_0^2}{\Phi_s d_p} \qquad (3)$$

But at intermediate Reynolds number (Re lesser than 300 or 400), both factor should be used [7]. The relationship between the pressure drop (Δp) with the height of bed and superficial velocity were approximated by Equation (4) which a simplification model of Ergun equation.

$$\Delta p = C_1 h^{C_2} u^{C_3} \qquad (4)$$

Data were analyzed by equation (4) to obtain parameter values C_1, C_2 and C_3. The relationship between the pressure drop and the blower power requirements could be predicted by the Bernoulli equation [8].

$$\frac{p_1}{\rho g}+\frac{u_1^2}{2g}+z_1+q+W=\frac{p_2}{\rho g}+\frac{u_2^2}{2g}+z_2 \tag{5}$$

Where p represents pressure, ρ is density of fluid, u is the velocity of fluid, z is the elevation, g is gravitational acceleration, q is heat and W is work required.

Adams *et al.*, [9] investigated that the distribution of flow velocity in the channel or pipe passes through the cross-section is generally not uniform. This inconsistency resulted in manual calculation using the average velocity (u_1) is smaller than the actual value of the velocity head. Then the required modifications in the form of additional kinetic energy correction coefficient (α) on the Bernoulli equation so the value of W (power value) obtained is close to the actual value. The correction coefficient varies according to Reynolds. For laminar and turbulent flow is, respectively, used α = 2, α = 1.06. Bernoulli equation can be modified into:

$$\frac{p_1}{\rho g}+\alpha_1\frac{u_1^2}{2g}+z_1+q+W=\frac{p_2}{\rho g}+\alpha_2\frac{u_2^2}{2g}+z_2 \tag{6}$$

■3.0 RESULTS AND DISCUSSION

Results of experiments with rice husk biomass showed that greater the flow rate have greater pressure drop. Likewise the higher the biomass bed then pressure drop also greater (see Figure 2). This also applies to experiments using other biomass. The tendency is in accordance with the Ergun equation that missing press is directly proportional to flow rate and height of bed.

Experiments with charcoals that have the same sphericity which is cubed but different sizes indicate that the pressure drop on the reactor is influenced by particle size. Experimental data is shown in Figure 3. It is also in accordance with the Ergun equation that the smaller the particle size the greater the pressure drop. The larger particle size inside the reactor creates greater porosity. Higher porosity shows that the particles have the pore is more than that with the low porosity of particles with the same volume. The hindrance of air inside the reactor is influenced by the number of pore inside the reactor. Low number of pores or the smaller particles size will result in a high pressure drop.

Results of experiments with various kinds of biomass showed that biomass characteristics influence the pressure drop and porosity through the reactor. In Figure 4 it appears that the pressure drop of sawdust is much larger than the other materials as sawdust has a smaller particle size and shape approaching spherical particles (sphericity close to 1) so that it has smaller porosity.

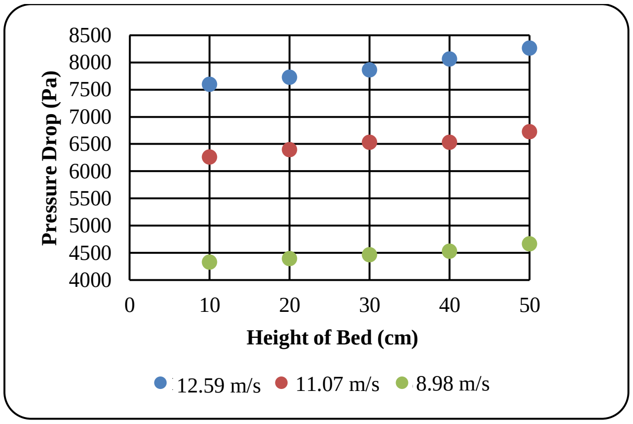


Figure 2 The effect of height of bed on reactor pressure drop (Rice Husk)

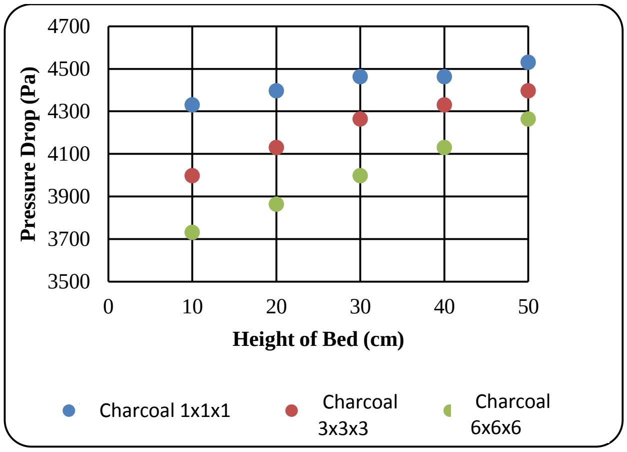


Figure 3 The effect of height of bed on reactor pressure drop in various dimension (material: Wood Charcoal; Re: 63000)

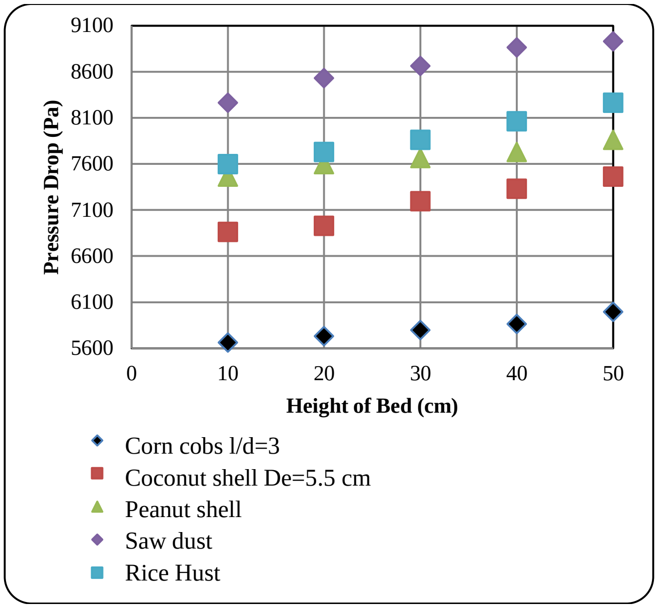


Figure 4 The effect of height of bed various biomass in reactor pressure drop (Re: 88000)

Analysis of the data in this study was approached by the relationship equation between pressure drop (Δp) with the flow rate and bed height. Data were analyzed with reference to equation 5 to obtain the parameter values C1, C2, and C3 (Table 2).

When the reactor is empty (h = 0), the air flow simply obstructed by the reactor. The obstacles also cause a pressure drop in reversible and irreversible. Reversible pressure drops in an empty reactor caused by frictional forces of fluid flow by reactor wall. While the irreversible pressure drop caused by the reactor column height (elevation pressure drop).

Table 2 shows that the characteristics of biomass material which are sphericity and particle size (indicated by the parameters C_1) effect on the pressure drop in the reactor. The smaller the particle size then the biomass bed gets smaller porosity. Characteristics of sawdust particles larger than other materials (C_1 = 145.854).

Effect of bed height on pressure drop is shown by the variable C_2 in Table 2. For the material approximated by a cylinder, corn cobs, are still influenced by height of bed. The higher bed and smaller size of cylinder will generate higher pressure drop.

Characteristics of bed height showed random results. There are other predictable variables affecting the pressure drop in this variable.

The effects of flow rate on pressure drop for various biomasses are indicated by parameter C_3. Flow rate has more influence on fluid characteristic which could be determined by Reynolds number of each particle. The greater particle diameter so the effect of flow rate in pressure drop relatively increase as greater particle diameter gives larger space for fluid to pass and loss its turbulence character. Thus, the Reynolds drop caused by particle hindrance is lower than smaller particle. Equation 5 may be used in pressure drop calculation by means of defined parameter (C1,C2 and C3) on respective biomass listed in Table 1.

Blower power requirement is proportional to pressure drop inside the reactor. The energy requirement can be calculated by Bernoulli equation. Figure 5 shows that higher pressure drop inside the reactor result higher energy requirement. This energy is used for the air to flow through the pore inside the reactor.

Table 2 Parameter value for equation 4

Material	C_1	C_2	C_3
Sawdust	145.8544	0.0608	1.6450
Wood Charcoal 1 cm x 1 cm x 1 cm	127.0759	0.0437	1.6496
Rice husk	116.4009	0.0441	1.6919
Wood Charcoal 3 cm x 3 cm x 3 cm	115.5301	0.0611	1.6761
Peanuts shell	111.6245	0.0405	1.6914
Coconut shell De = 2.5 cm	105.1123	0.0414	1.7111
Coconut shell De = 5.5 cm	101.3786	0.0490	1.7129
Corn cobs l/d=1	98.6742	0.0651	1.7445
Wood Charcoal 6 cm x 6 cm x 6 cm	90.3515	0.0559	1.7565
Coconut shell De = 8.5 cm	84.9590	0.0463	1.7610
Corn cobs l/d=2	68.9954	0.0565	1.8620
Leaves	56.1583	0.0400	1.9400
Corn cobs l/d=3	49.1316	0.0496	1.9121

4.0 CONCLUSION

The experimental studies were performed to examine the effect of biomass feed size and air flow rate on the Pressure Drop of Gasification Reactor. Sphericity and particle size affect in bed porosity inside the reactor. The smaller bed porosity gives higher pressure drop and vice versa. Also, the height of bed inside the reactor has significant influence on pressure drop. For all size of particle, while height of bed is increase, the pressure drop inside the reactor proportionally increase. From obtained data, if random particle were introduce into the reactor as well as higher particle size resulted in an decrease in the reactor pressure drop, and vice versa.

The experiment also yielded parameter C1, C2 and C3. These parameters can be used to predict pressure drop inside the reactor when the reactor start-up. These parameters represent characteristic behavior such as particle size, height of bed and air flow rate. The Highest C1 is saw dust (145.85); The Highest C2 is corn cobs l/d=1 (0.065); the highest C3 is leaves (1.94).

The smallest particle for bed inside the reactor required the highest blower power which in this work was achieved by saw dust with 0.5 m bed under 12.59 m/s (Re: 88000) air flow rate. The pressure drop obtained by this scenario was Δp= 8927.80 by power of 47.840 W. By contrast, corn cobs l/d=3 with 0.1 m height and Re: 63000 gave the lowest power requirement by 11.275 W.

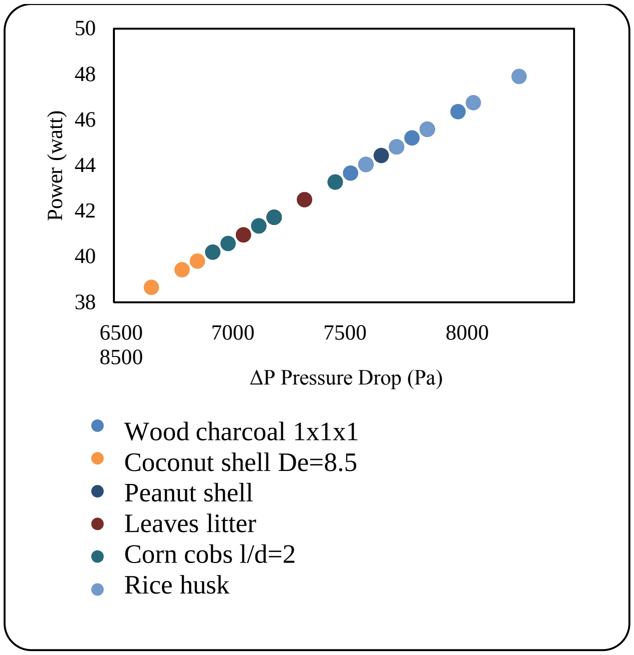


Figure 5 Blower energy requirement (Re= 78000)

References

[1] C. R. Brown. 2003. *Biorenewable Resources*. Iowa State Press.

[2] Gartia. 2007. *Thermo-fluid Dynamics and Pressure Drops in Various Geometrical Configurations*. Reactor Engineering Division Bhabha Atomic Research Centre Mumbai.

[3] C. Higman, M. Van der Berg. 2003. *Gasification*. Elsevier Science.

[4] A. M Riberio, P. Neto. 2010. *Mean Porosity and Pressure Drop Measurements in Packed Beds of Monosized Spheres: Side Wall Effects*. International Review of Chemical Engineering.

[5] Harhoof, Johaness, V. Ali. 2010. *A Falling-head Procedure for the Measurement of Filter Media Sphericity*. Water Research Commision, South Africa.

[6] A. H. Ahmadi Motlagh, S. H. Hashemabadi. 2008. *Int. Commun. Heat Mass Transfer*.

[7] Kunii, Daizo, O. Levenspiel. 1977. *Fluidization Engineering*. John Willey & Sons Inc.

[8] Morrison, A. Faith. 2013. *An Introduction to Fluid Mechanics*. Cambridge University Press.

[9] T. M. Adams, A. Raghunandan. 2011 *Modified Bernoulli Equation for Use with Combined Electro-osmotic and Pressure-driven Microflows*. Proceedings of the 23rd CANCAM.