Int. J. Renew. Energy Dev. 2023, 12 (1), 1-9

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Contents list available at IJRED website

International Journal of Renewable Energy Development

Journal homepage: https://ijred.undip.ac.id

Research Article

Experimental Study of Rice Husk Fluidization Without a Sand Bed Material on a Bubbling Fluidized Bed Gasifier

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Abstract. This study aimed to determine the effect of rice husk fluidization and variation in the equivalence ratio of bubbling fluidized bed gasifiers without sand bed materials. It also aimed to improve the fluidization quality by reducing the diameter of rice husks. Therefore, the bulk density increases, whereas voidage decreases, both of which are the main parameters for improving the quality of fluidization in solid particles. Experiments were carried out at a velocity of 0.82 m/s, by varying the equivalent ratios ranging from 0.20 to 0.35, and analyzing the syngas composition, cold gas and carbon conversion efficiencies, lower heating value, and temperature distribution. An equivalence ratio of 0.30 was obtained for a bubbling fluidized gasifier with syngas compositions of 7.415%, 15.674%, 3.071%, 17.839%, and 56.031% for H_2, CO, CH_4, CO_2, and N_2, respectively. Under these conditions, we obtained cold gas and carbon conversion efficiencies and a lower heating value of 31.340%, 37.120%, and 3.881 MJ/Nm^3, respectively.

Keywords: bubbling fluidized bed gasifier, rice husk, equivalence ratio, syngas

Received: 30th April 2022; Revised: 18th July 2022 ; Accepted: 25th August 2022; Available online: 24th Sept 2022

1. Introduction

Biomass is an alternative energy source that can be used to produce clean energy (carbon neutral). As an agricultural country, Indonesia has significant potential sources of biomass energy, one of which is rice husks. In 2020, Indonesia produced 54.65 million tons of paddy rice, with a total weight of rice being 31.33 million tons (Badan Pusat Statistik, 2021) and the estimated total price of husk production was approximately 10.93–18.03 million tons based on 20–33% weight of the total rice weight (Pode, 2016). Rice husks have a calorific value of 3.954 kcal/kg (Nam *et al*., 2016) and a heating value of 13.24–16.20 MJ/kg (Mansaray *et al*., 2007; Sivabalan *et al*., 2021). In addition, rice husks have a high lignocellulosic content, consisting of cellulose (31.4–36.3%), hemicellulose (2.9–11.8%), and lignin (9.5–18.4%) (Champagne, 2004). Therefore, Indonesia has the potential for additional energy generation, which can be used as an alternative energy source to solve the energy needs problem of the country.

The conversion processes for biomass include biological, thermochemical, and physical methods. Thermochemical conversion involves pyrolysis, gasification, and combustion. During gasification, heat and electricity can be generated using low-energy-density fuels, such as biomass and waste. Gas produced through gasification can generate heat and electricity through gas engines, turbines, and boilers (Seo, 2021). In addition, gasification uses heat, steam, and oxygen to convert biomass into syngas, which is mainly carbon monoxide, carbon dioxide, hydrogen, and methane, with lighter hydrocarbons (e.g., ethane and propane) and heavier hydrocarbons (e.g., tars at temperatures higher than 700 °C; Chyuan *et al*., 2019; U. Arena, 2013; Ying *et al*., 2021). The gasification process uses gasifying agents, such as air, oxygen (O_2), carbon dioxide (CO_2), and steam (H_2O). The operational parameters of biomass gasification include the equivalence ratio (ER), gasifying agent, catalyst, and bed temperature (Seo, 2021).

The gasification process is an excellent method to treat waste, as it emits less greenhouse gases (GHGs) compared to other methods. Another advantage of the gasification process is its flexibility toward different types of feedstock (Saidi *et al*., 2020). Common feedstock for gasification comprises biomass (Firman *et al*., 2020), coal, carbonized products, plastics, and municipal solid waste (Yang *et al*., 2021). However, further research is required to obtain suitable methods and parameters for optimal gasification during the conversion of biomass into energy. Both fixed bed (downdraft) and fluidized bed gasifiers can be used for rice husk gasification. Fixed-bed gasifiers, however, suffer from hot spots owing to difficulties in heat control and a high amount of tar generation, causing blockages, plugging, corrosion, and serious operational and maintenance problems. Conversely, a stable fluidized-bed gasifier operation is possible with uniform temperature control and high heat, and mass transfer rates (Seo, 2021).

Based on the experiments conducted by Makwana *et al*., it was found that the fluidization of rice husks using a sand bed material with a bed heating process using charcoal can reduce

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https://doi.org/10.14710/ijred.2023.46068
ISSN: 2252-4940/© 2023.The Author(s). Published by CBIORE

the electrical consumption of the ceramic heater, reaching ~45%, and the significant higher heating value (HHV) of syngas is obtained at an equivalence ratio (ER) of 0.3 (Makwana *et al.*, 2015). Syngas is a synthesis gas consisting mainly of CO, H_2, CO_2, and CH_4 produced along with other gaseous products, such as H_2O, H_2S, NH_3, and tar (secondary elements) during pyrolysis at approximately 700–1000 °C (Al-rahbi and Williams, 2017; Ying *et al.*, 2021). A bubbling fluidized bed gasifier will increase gasification performance owing to the increasing heat transfer rate, good contact between solid and gas particles, and temperature distribution that tends to be evenly distributed throughout the reactor compared to fixed bed gasification. Nevertheless, the use of bed material in gasifiers (generally in the form of silica sand) for the process of fluidization presents problems. The emergence of agglomeration due to the reaction of inorganic alkali from solid fuels, such as potassium (K) and sodium (Na), with silicate from the bed material, produces low-melting silicates, characterized by lower melting points than the individual components. As a result, agglomeration occurs, which blocks the fluidization process (Bartels *et al.*, 2008). A study of fluidization of rice husk without sand bed materials by Leon and Dutta found that rice husk is under pseudo fluidization when the size of the reactor is enlarged from 0.25 m^2 to 0.5 m^2, which aims to reduce the friction between the rice husks; hence, slugging or beams does not occur (Leon & Dutta, 2010). Another study conducted by Armesto *et al.* also stated that it is difficult to fluidize rice husks without a bed material because of the low spherical value and high surface roughness of the rice husk; therefore, when agent gasification (air) is added, the slugging phenomenon occurs (Armesto *et al.*, 2002). Natarajan *et al.* and Abdullah *et al.* found that a large amount of bed materials is required to fluidize rice husks because of their low density (Abdullah *et al.*, 2003; Natarajan *et al.*, 1998). Based on previous studies, it can be concluded that it is difficult to fluidize rice husks without a bed material; nevertheless, the utilization of bed material in fluidized bed gasification is another consideration because of the formation of agglomeration and the waste from the process cannot be reused. Therefore, the authors aim to minimize the occurrence of agglomeration during fluidization and increase the utilization of waste gasification, based on the study conducted by Yahya *et al.* In their study, it was found that burning rice husks produced charcoal with high silica content that can be used as fertilizer or mixed materials in the manufacture of cement or concrete (Yahya, 2017).

In addition to the aforementioned studies, the biomass gasification and power generation (BGPG) plant located on Kundur Island, Tanjung Balai Karimun Regency, managed by Prima Gasification Indonesia Company, generate electricity using the fluidized bed gasification method without a bed material (silica sand). This power plant utilizes wood as the primary fuel in the gasification process, with a raw material requirement of approximately 40 tons of dry wood to generate 1 MWe (Asosiasi Produsen Biofuel Indonesia (APROBI), 2021).

Researchers at the Biomass and Gasification Laboratory of the University of Indonesia wanted to determine whether the fluidized bed gasification process of the rice husks could be carried out without the bed material. It is essential to understand the characteristics of the fluidization process without using the bed material by reducing the size of the rice husks through the grinding process. Because slug occurs owing to the frictional force between the particles, it can be anticipated by reducing the diameter of the rice husk to a specific size. This leads to an increase of the spherical value of the rice husk, reduction of the frictional force between the particles, and attainment of the desired fluidization process. In addition, researchers want to know the effect of equivalence ratio variation on syngas production to obtain the fluidization characterization of rice husks without the bed material in a bubbling fluidized bed gasifier reactor on syngas production.

2. Materials and Methods

2.1 Materials

The results of the moisture test, proximate and ultimate analyses, total sulfur, gross calorific value, and trace elements in rice husks were as follows: moisture in analysis, 8.60%; ash content, 20.50%; volatile matter, 57.60%; fixed carbon, 13.30%; gross calorific value, 3393.0 kcal/kg; carbon (C), 35.52%; hydrogen (H), 5.80%; nitrogen (N), 0.50%; oxygen (S), 37.60%; sulfur, 0.12%; chlorine, 0.14%; fluorine, 96.65 ppm; boron (B), 4.95 ppm; arsenic (As), 0.45%; and selenium (Se), less than 0.01 ppm. These results are related to the submitted rice husk samples collected at the Sucofindo Laboratory Jakarta in 2020.

2.2 Method

The equipment and materials used in this study comprise a reactor with a diameter of 20 cm and a height of 161.5 cm, flashlight, and fuel oil. In addition, a temperature data acquisition (DAQ) system and thermocouple type K were used. Figure 1 shows a series of the equipment used in this study.

A digital manometer, connected to a pressure tap on the reactor, was used to measure the pressure drop. The rate of air entering the reactor was measured using an orifice plate installed between the flange and digital manometer. The bed material diameter of the rice husk was reduced using a grinder. The solid density measurement of the rice husk comprised of using a hydraulic press to making pellets and then measuring the volume and weight of the pellet. For bulk density, a glass funnel, digital balance, and measuring tube were used. Syngas data retrieval was performed using a Tedlar bag and tested with a thermal conductivity detector.

2.2.1. Equivalence Ratio (ER)

The airflow rate and type of biomass are critical parameters in the autothermal gasification process, and their values can be varied independently to a certain extent (Gómez-Barea *et al.*, 2005). Both variables determined the equivalence ratio and superficial velocity (U_f). The equivalence ratio is one of the critical operational parameters in the biomass gasification process with air as the gasification agent, as expressed in Equation (1).

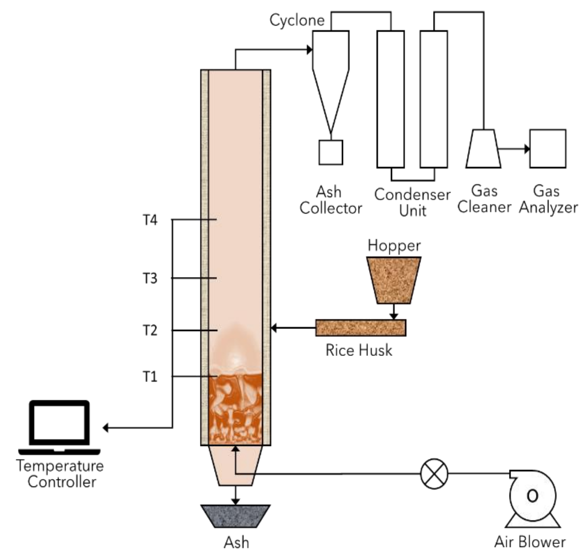

Fig. 1 Schematic of the bubbling fluidized bed gasifier apparatus.

The equivalence ratio is the ratio between the actual air to fuel ratio (AFR_a) and stoichiometric AFR_s, under complete combustion conditions (Behainne & Martinez, 2014; Motta *et al.*, 2018; Zhang *et al.*, 2015).

$$ER = \frac{AFR_a}{AFR_s} \quad (1)$$

Generally, the ER used in biomass gasification is in the range of 0.20–0.40 (Narváez *et al.*, 1996; Seo, 2021; Siedlecki *et al.*, 2011), with the lower limit indicating the amount of air required to burn a fraction of the fuel so that the heat generated is sufficient to support the endothermic reaction involved in the gasification process (Natarajan *et al.*, 1998). The upper limit is determined based on several considerations, such as the reactor temperature, fluidization quality, calorific value, and tar content in the producer (Behainne & Martinez, 2014).

2.2.2. Cold Gas Efficiency (CGE)

Gasifier performance is generally expressed as efficiency, which can be classified into hot- and cold-gas efficiencies. Cold gas efficiency results from a thermochemical process gas presented under ambient temperature conditions (Basu, 2006), and its value is the ratio of the rate of gas yield (V_g) multiplied by the calorific heating value of gas (q_g) to the rate of fuel consumption (M_b) multiplied by the calorific value of the fuel (C_b).

$$CGE = \frac{V_g q_g}{M_b C_b} \quad (2)$$

2.2.3. Bulk Density

The bulk density (ρ_b) is the overall density of the material, which is the ratio between the overall mass of the material (m_b) (including the space between particles) and the volume of space occupied (V_b), as expressed by equation (3). Bulk density can be measured by pouring samples of weighed materials through a glass funnel (Abdullah *et al.*, 2003).

$$\rho_b = \frac{m_b}{V_b} \quad (3)$$

2.2.4. Solid Density

The solid density (ρ_s) is defined as the ratio of the mass of the particles (m_s) to the total volume of the particles (V_s), as shown in Equation (4) (Behainne & Martinez, 2014), and the solid value material needs to be crushed before the process of palletization, using a press machine (Abdullah *et al.*, 2003). This study used a mold with a diameter of 6.5 mm and a compression pressure of 6 MPa.

$$\rho_s = \frac{m_s}{V_s} \quad (4)$$

2.2.5. Voidage

The mass in each particle rests on one another because of the gravitational force that forms a dense arrangement of materials, where the distance or space between them is defined as voidage, which is the ratio of particles to the total volume of particles and voids. However, voidage can also be defined as the relationship between the solid and bulk density, as shown in Equation (5).

$$\varepsilon = 1 - \frac{\rho_b}{\rho_s} \quad (5)$$

2.2.6. Pressure Drop

Fluidization is a condition in which fine solid particles behave the same as fluid when in contact with gas or liquid (Basu, 2006). To determine this condition, the pressure drop of the solid particles in the reactor should be measured. The fluidization process is indicated by a stable pressure drop change along with an increase in the airflow rate. The pressure drop that occurs in the fluidized bed zone tends to be stable owing to an increase in the (h) height dan (ϵ) void fraction in the bed. Equation (6) shows the relationship between the pressure drop (ΔP) and function of height and void fraction.

$$\Delta P = h\,(1-\epsilon)(\rho_p - \rho_g)\,g \quad (6)$$

3. Results and Discussion

3.1 Fluidization Characteristic

According to the research conducted by Abdullah *et al.*, by classifying biomass based on the Geldart classification shown in Table 1, it was found that the biomass with Group B classification provides good fluidization ability, whereas it will be challenging to fluidize the rice husk owing to the Group D classification. To improve fluidization quality, the value of bulk and solid density of materials must be increased, however the voidage parameter must be monitored (Abdullah *et al.*, 2003).

The Geldart classification provides an overview of the fluidization ability of a solid particle based on the particle size against the difference between the density of the particle and gas. Based on the Geldart classification shown in Figure 2, Group A comprises of particles that fluidize with ease, and has a good level of solid and gas mixing.

Table 1
Hydrodynamic properties of solid fuels.

Biomass	d_p (μm)	ρ_b (kg/m^3)	ρ_s (kg/m^3)	ε (-)	Geldart Classification
Sawdust [a]	786.5	241.0	570.3	0.5770	B
Rice husk [a]	1500.0	129.0	630.1	0.8000	D
Peanut shell [a]	613.4	250.0	566.8	0.5590	B
Coconut shell [a]	987.4	430.0	547.9	0.2152	B
Coal [a]	518.8	945.0	1450.0	0.3483	B
Bottom ash [a]	475.0	118.0	1400.0	0.1514	B
Rice husk [b]	840.0	373.4	1022.8	0.6342	B

[a] Study by M.Z Abdullah *et al.* (Abdullah *et al.*, 2003)
[b] This study (2021)

Therefore, Group A is frequently used as bed material in circulating fluidized beds (Basu, 2006; Cocco *et al*., 2014). In addition, the properties of the particles or materials in this group include aeratable particles or materials with a small mean particle size and/or low particle density (less than 1.4 g/cm^3). These solids fluidize easily, with smooth fluidization at low gas velocities and controlled bubbling with small bubbles at higher gas velocities (Daizo Kunii, 1991; Geldart, 1973). Group B is a group with reasonably good fluidization and mixing capabilities for solids and gases, and is often used in fluidized bed combustors and pyrolysis units (Basu, 2006; Cocco *et al*., 2014). Sand-like particles, or most particles of diameter 40–500 μm, have a density in the range of 1.4 g/cm^3 to 4 g/cm^3. These solids fluidize well with vigorous bubbling action and large bubbles that develop (Daizo Kunii, 1991; Geldart, 1973). Group C comprises of fine solid particles, that are difficult to fluidize owing to the cohesion between the particles, and considerable channeling occurs during the fluidization process. Group D, has the largest particle size, and is characterized by slug formation during the fluidization process, including at large bed sizes (spoutable).

The gasification process of rice husks without the bed material in the bubbling fluidized bed gasifier is difficult based on Geldart classification (Cocco *et al*., 2014). Moreover, the influence of the reactor size and characteristic geometry of rice husks is a problem in fluidization. Leon and Dutta conducted an experiment in which rice husk fluidization was carried out in the absence of a bed, and the cross-sectional area and height used were 0.25 × 1.0 m and 5 m, respectively. It was found difficult to fluidize due to the slugging phenomenon; hence, the bed was widened to 0.5 m (Leon & Dutta, 2010). It was then found that bubbling occurred during the fluidization process.

Through this study, it was concluded that fluidization without bed material can be carried out by expanding the bed to prevent slugging, which occurs because of the roughness and asymmetrical geometry of the rice husks, proving difficult to carry out fluidization. Based on the results of previous studies, we then suggested a novel idea to achieve fluidization by grinding the rice husks in order to reduce particle diameter, increase bulk density, reduce friction factor between particles, and increase sphericity of the rice husk. Therefore An experiment was previously conducted to visualize the fluidization of rice husks using modified acrylic cylinders.

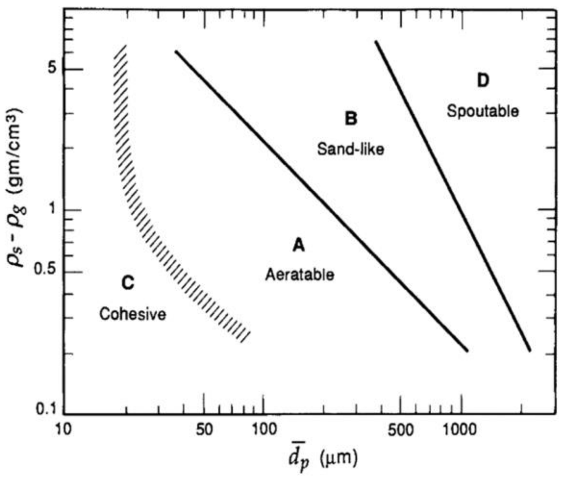

Fig. 2 Geldart classification of the particles for air at ambient conditions (Daizo Kunii, 1991).

Fig. 3 Process of fluidization of the rice husk sample: (a) without bed material and (b) after grinding without the bed material.

Figure 3a shows the appearance of the slugging phenomenon, that is indicated by the movement of solid particles in groups during the fluidization process. Then, the rice husks were ground and the bulk density was obtained using Equation (3), where the previous bulk density was from 109.84 kg/m^3 to 373.38 kg/m^3. In addition, the diameter of rice husk was reduced from 1.55 mm (Leon & Dutta, 2010), to 0.84 mm, and the voidage parameter was decreased from 0.89 to 0.63. These changes in the properties of the rice husks tended to improve the quality of the fluidization process. Based on visual observations, it was found that milled rice husks could be fluidized effectively without bed material, as shown in Figure 3b.

After fluidization without bed material, the pressure drop can be measured when the rice husks have a weight and height of 800 gram and 70 mm, respectively. This process determines the minimum velocity required for fluidization of solid particles. Based on the experimental results, the effect of increasing the flow rate on pressure drop changes is shown in Figure 4, which describes an increase in pressure drops of up to 0.08 kPa and stable flow rates from 0.82 m/s to 0.96 m/s. This indicates that, at a velocity of 0−0.82 m/s, solid particles experience an increase in bed height, which in this range is classified as a fixed bed zone. Therefore, the minimum fluidization velocity in this study was 0.82 m/s.

An increase in the airflow rate results in an increase in the drag force experienced by the particles. The drag force reaches a value equal to the weight of the solid particles; hence, the solid particles are lifted and start to fluidize. The stable change in the pressure drop along with the increase in flow rate can be explained by Equation (6), where the increase in flow rate causes the bed to rise and increases the height ($\boldsymbol{h}$) of the bed, thereby increasing the voidage ($\boldsymbol{\varepsilon}$). The increase in the bed height is anticipated with a value of $(\mathbf{1} - \boldsymbol{\varepsilon})$, so that the pressure drop changes are constant.

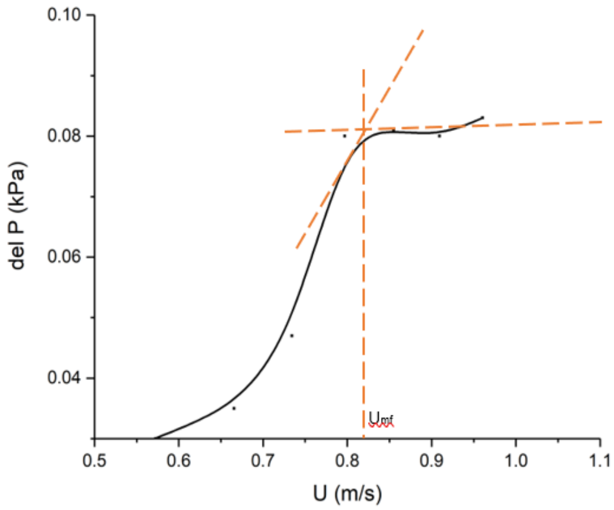

Fig. 4 Graphic of the pressure drop versus airflow rate.

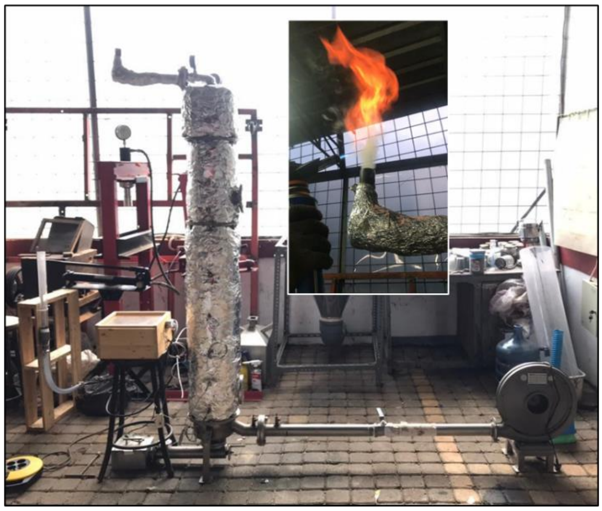

Fig. 5 Experimental configuration of rice husk fluidization without the bed material on the bubbling fluidized bed gasifier.

3.2 Effect of the Equivalence Ratio on Syngas Production

Equivalence ratio variations are carried out to determine the optimal operation of the gasifier, in general, the equivalence ratio used for gasification is in the range of 0.20–0.40 (Motta *et al.*, 2018). This study had various equivalence ratios in the range of 0.20–0.35 and the pre-heating process was performed by burning the rice husks in the reactor.

Lv *et al.*, showed that a small equivalence ratio value is not beneficial for biomass gasification because it reduces the reaction temperature (Lv *et al.*, 2004). The results by Mansaray *et al.* showed that nitrogen was present at the highest concentration (56.57±64.21 vol %), whereas CO_2 was in the range of 14.45±17.42 vol %. From the fuel gases which are of major interest, CO had the highest concentration (12.29± 19.90 vol %), followed by H_2 (3.25±4.00 vol %), and CH_4 (1.84±2.90 vol %) (Mansaray *et al.*, 2007).

Their research on the effect of equivalence ratio as one of the important parameters in gasification to determine syngas quality found that the highest concentration of H_2 and LHV occurred at an equivalence ratio of 0.20. The increase in air input results in increased CO_2 production (because of an increase in the oxidation reaction) and decreased low heating value (LHV). A study by Mansaray *et al.* also proved that variations in the equivalence ratio affect the quality of syngas production (Mansaray *et al.*, 1999). This study found that an equivalence ratio of 0.25 resulted in optimal syngas quality, as shown in Table 2, where the maximum syngas and LHV production occurred at an equivalence ratio of 0.30.

Table 2
Composition of gases and energy content in rice husks

Result	Unit	Equivalence Ratio			
		0.20	0.25	0.30	0.35
H_2	%	1.302	2.089	7.415	2.004
CO	%	4.679	5.796	15.674	11.524
CH_4	%	0.561	1.749	3.071	2.225
CO_2	%	12.444	13.727	17.830	17.368
N_2	%	81.343	76.637	56.031	68.067
CGE	%	3.465	7.803	31.340	19.144
CCE	%	8.317	13.209	37.120	30.195
LHV	MJ/Nm^3	0.933	1.585	3.881	2.470

Source: This study (2021)

3.3 Syngas Composition

The various components of syngas produced at different equivalence ratios are summarized in Table 2. Based on the analysis results of the syngas components, nitrogen gas was found as the major constituent, with values ranging from 56–81%, vol. CO_2 concentration was in the range 12–17.8%, vol. The composition of combustible gases (H_2, CO, and CH_4) had value variations between 1.3–7.4%, vol; 4.6–15.6%, vol; and 0.5–3.0%, vol, respectively. Figure 6 shows the changes in the composition to the equivalence ratio variation. Generally, the concentrations of CO_2 and N_2 increased the equivalence ratio, as well as the composition of combustible gases (H_2, CO, and CH_4), that increased at an equivalence ratio of 0.30, and then decreased at an equivalence ratio of 0.35. The maximum production of combustible gas (H_2, CO, and CH_4) was found at an equivalence ratio of 0.30 with concentrations of 7.415, 15.674, and 3.071%, vol, respectively. Hence, the highest LHV was found in this equivalence ratio.

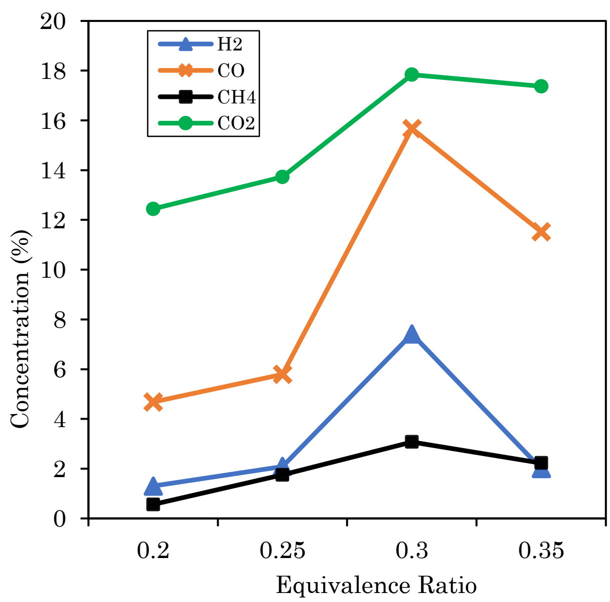

Fig. 6 Composition of syngas versus variation of the equivalence ratio.

3.4 Lower Heating Value

The calculation of the lower heating value (LHV) syngas is summarized in Table 2, where the highest LHV of 3.881 MJ/Nm^3 was obtained at an ER of 0.30, and 2.470 MJ/Nm^3 at ER 0.35, 1.585 MJ/Nm^3 at ER 0.25, and 0.933 MJ/Nm^3 at ER 0.20. The difference in LHV values indicates that the effect of the equivalence ratio on the calorific value of combustible gases, increases from 0.20 to 0.30 and decreases at 0.35. Generally, the value of LHV decreases owing to the lower concentration of hydrocarbon gas, which has a reasonably high heating value, and increases the amount of nitrogen that lowers the LHV value because of the diluting effect on syngas (Mansaray *et al.*, 1999).

3.5 Cold Gas Efficiency and Carbon Conversion Efficiency

The cold gas efficiency (CGE) is a performance parameter of the gasifier that determines how effectively the gasifier converts fuel into syngas. In a study by Seo *et al.*, CGE decreased from 70.75% to 44.23% because of an increase in ER that resulted in increased CO2 in the product gas (Seo, 2021). Panaka *et al.*, also reported that the general CGE of a biomass gasifier is typically in the range of 45%–67% (Panaka *et al.*, 1993). Natarajan *et al.*, showed that the CGE value in a bubbling fluidized bed gasifier can reach 60% under the condition that the carbon conversion efficiency reaches 90% (Natarajan *et al.*, 1998). Campoy *et al.* found that the enrichment of air from 21% to 40% v/v made it possible to increase the gasification efficiency from 54% to 68% (Campoy *et al.*, 2009). Table 2 shows the values of the cold gas efficiency (CGE) and carbon conversion efficiency (CCE) for various equivalence ratios. The highest CGE was obtained when ER 0.30 with an efficiency of 31.34%, whereas the lowest CGE of 3.465% was obtained at ER 0.20. Therefore, the smaller the CGE, the lower the CCE.

Carbon conversion is defined as the rate of change of the solid fuel (biomass) into gaseous products (syngas). It is one of the parameters expected to have a high value to ensure that desirable syngas quality is obtained. Table 2 summarizes the CCE values for the equivalence ratio variations, where the highest CCE value that can be achieved is at 37.10% and ER of 0.30, whereas the lowest ER of 0.20 with a percentage of 8.317%.

3.6 Temperature Distribution

Ceramic heaters or other external heating methods were not used in this study to maintain the reactor temperature. Therefore, the working temperature of the reactor is a result of heat generated from burning rice husks, which is difficult to maintain, particularly using the batch method employed in this study for the feeding process. Therefore, there is no additional feeding of rice husk required to stabilize the reactor temperature. The distribution of reactor temperature over time is shown in Figure 7.

The temperature distribution shown in Figure 8 is the average working temperature along the reactor with variations in the equivalence ratio, where T1 is the temperature of the reactor placed 7 cm from the grate, and the placements of T2, T3, and T4 are 20, 30, and 48 cm from the grate, respectively. When the averaging process is carried out, the temperature distribution from T2 to T4 at a variation of ER 0.20–0.35 tends to be stable with a temperature change range of 3–10 °C. Based on the average temperature data results, the anomaly occurred at ER 0.20 and 0.25 where the highest temperature was 597.80 °C and 470.88 °C, respectively, exceeding the temperature at ER 0.30 and 0.35.

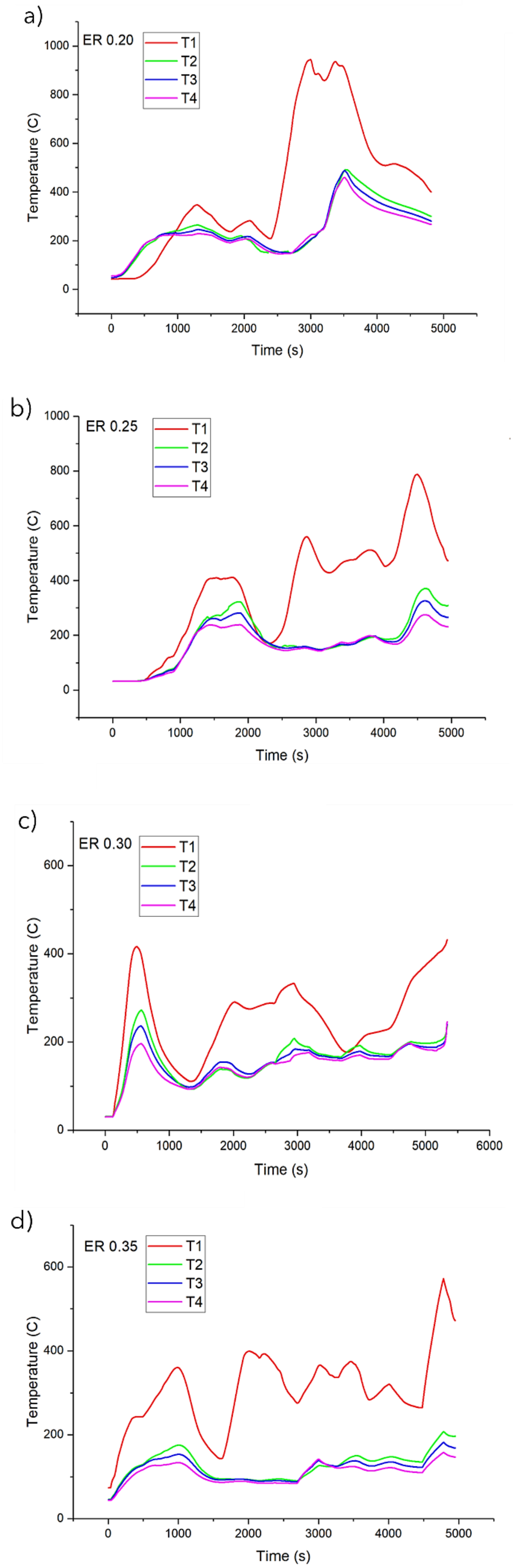

Fig. 7 Temperature distribution versus time: (a) ER 0.2, (b) ER 0.25, (c) ER 0.3, and (d) ER 0.35.

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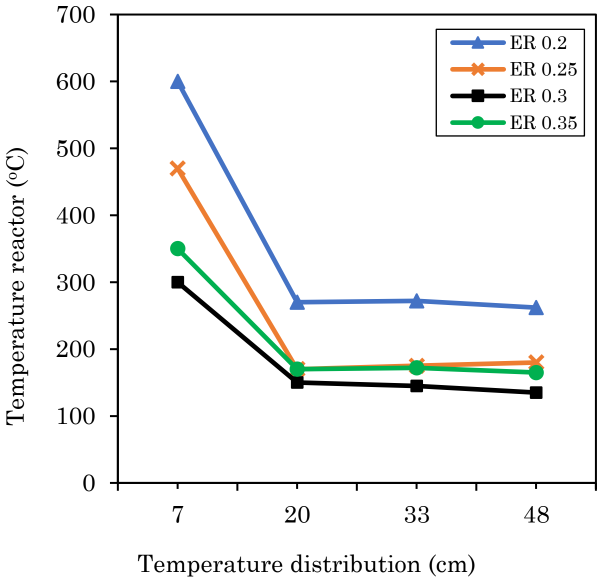

Fig. 8 Average distribution of the temperature reactor to equivalence ratio variations.

In this study, the authors predicted the occurrence of the partial combustion of syngas in the reactor. Therefore, the bed temperature significantly rises (Figure 8), at an ER of 0.20 and 0.25. This could explain the low-test results of combustible gas and energy content at ERs of 0.20 and 0.25, respectively, compared with the ERs of 0.30 and 0.35. This can be anticipated by installing a suction blower and burner on the gasification apparatus, thereby minimizing the possibility of syngas burning in the reactor.

3.7 Optimization of the Bubbling Fluidized Bed Gasifier

Based on the experimental results that have been conducted, the gasifier performance can be improved by installing an electric heater to stabilize reactor temperature, and a feeder to assist feeding the biomass into the reactor. In addition, the conditioning pressure and temperature of the reactor can be used to improve the performance. High temperatures under low-pressure conditions will produce high CO and H_2. Meanwhile, high-pressure and low-temperature conditions produce a high CH_4 gas content. Furthermore, the height of the reactor influences performance, that increases the solid and gas residence times to maximize the reactions that occur in the reactor and produce more combustible gas with lower tar content (Basu, 2006).

3.8 Simulation with OpenFOAM on Bubbling Fluidized Bed Gasification

To determine the properties of air and husk particles, the OpenFOAM simulation was performed to determine the properties of air and husk particles considering the following properties: laminar air flow in the reactor, species mole weight 28.9 kmol, density 998.2 kg/m^3, heat capacity 1007 W/m·K, dynamic viscosity 1.84×10^{-5} Pa.s, and Prandtl number 0.7. For rice husks, the following parameters were considered: Reynolds Average Stokes (RAS turbulent) flow type, mole weight 32.626 kmol (for properties of wood and similar materials), density 373.38 kg/m^3, heat capacity 1500 W/m·K, Prandtl number 1, and diameter rice husk particles 0.84 mm or 20 mesh.

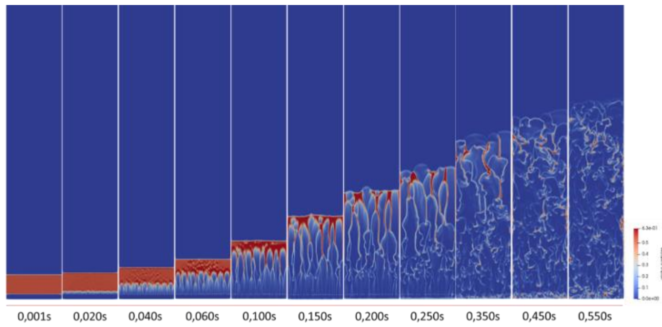

Fig. 9 Simulation results of the bubbling phenomenon on the self-bed bubbling fluidized bed gasifier.

The mesh is an important part of the simulation owing to its ability to determine discrete methods in CFD computational mathematics. There are 633724 points, 1261924 faces, 628054 internal faces, 3155009 cells (element), 5.99976 faces per cell, and 3 boundary patches for the cross-section of the 2D mesh in the fluidized bed domain. As for the element, there are 314933 hexahedra elements and 76 prisms. The orthogonal quality has a maximum of 39.7945 or an average of 1.201288.

Several parameters were used to set up the simulation, including air velocity, particle velocity, intake air temperature, particle temperature, system temperature, pressure, and viscosity. The setup of the fluidized bed simulation was as follows: air magnitude velocity or minimum fluidized velocity of 0.82 m/s on the y-axis, rice husk particle velocity of 0 m/s on the y-axis, and reactor internal velocity of 0.25 m/s on the y-axis, whereas the internal pressure was set to 101325 Pa. For the surface tension, the air fraction was 0.45, and the rice husk particle fraction was 0.55. The operating air temperature of the bubbling fluidized bed and rice husk particles was 300 K, and the reactor internal temperature was 700 K. Figure 9 shows particles floating at 0.06 s, with the bubbling phenomenon commencing after 0.06 s, and finally deteriorating in the fluid under the effect of gravity at 0.45 s.

4. Conclusion

In this study, the applicability of a rice husk in increased energy recovery was evaluated. The rice husk used in this study showed good thermal characteristics, including calorific value (3393.0 kcal/kg), volatile matter (57.60%), and ash content (20.50%) for the gasification process. The ER was obtained using a reactor with a diameter of 20 cm and height of 161.5 cm, and the minimum fluidization velocity was 0.82 m/s. From this study, it can be concluded that a reduction in the diameter of solid particles results in an increase in the bulk density, a decrease in the friction factor between particles, and an increase in the sphericity of solid particles. In addition, these factors affect the fluidization quality. The results showed that the variation if the equivalence ratio affected syngas composition, cold gas efficiency, carbon conversion efficiency, and temperature distribution. The experiment conducted at an ER of 0.3 in the bubbling fluidized gasifier reactor was found to be the optimum condition for rice husk gasification, producing syngas compositions (H_2, CO, CH_4, CO_2, and N_2) of 7.415%, 15.674%, 3.071%, 17.839%, and 56.031%, respectively. In addition, cold gas and carbon conversion efficiencies of 31.340% and 37.120%, respectively, and a lower heating value of 3.881 MJ/Nm^3 were obtained. The authors indicated that the partial combustion of syngas observed in the reactor affects the syngas and energy content test results. However, further study is recommended with additional diverse conditions and concentrations of the fluidizing bed material (sand, Al_2O_3, CaO/sand, or C_aO/Al_2O_3).

Nomenclature

AFR	Air Fuel Ratio
APROBI	Asosiasi Produsen Biofuel Indonesia
BGPG	Biomass Gasification and Power Generation
CCE	Carbon Conversion Efficiency
CGE	Cold Gas Efficiency
CFD	Computational Fluid Dynamics
DAQ	Data Acquisition
ER	Equivalence Ratio
GHG	Greenhouse Gas
HHV	Higher Heating Value
LHV	Lower Heating Value
TCD	Thermal Conductivity Detector

Acknowledgments

The authors would like to express their gratitude to the Ministry of Research and Technology/BRIN for funding this research [NKB-52/UN2.RST/HKP.05.00/2020].

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