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Research Article

Experimental Study of Rice Husk Fluidization wWithout a Sand Bed Material on a Bubbling Fluidized Bed Gasifier

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Abstract. This study was conducted aimed to determine the effect of rice husk fluidization and variation inof the equivalence ratio ofn bubbling fluidized bed gasifiers without sand bed materials. It also aimed to improve the fluidization quality by Rreducing the diameter of rice husks is the solution in this study to improve fluidization quality. ThereforeBecause of it, the value of bulk density increases, whereas and the value of voidage decreases, which both of which are the main parameters forto improving the quality of fluidization in solid particles. The eExperiments were carried out at a velocity of 0.82 m/s, by varyingchanging the equivalent ratios ranginged from 0.20 to 0.35, and analyzing the syngas composition, cold gas and efficiency, carbon conversion efficienciesy, lower heating value, and temperature distribution. The results were obtained at 0.30 An equivalence ratio of 0.30 was obtained for a in a bubbling fluidized gasifier withhaving syngas compositions of (H_2, CO, CH_4, CO_2, and N_2) respectively are 7.415%, 15.674%, 3.071%, 17.839%, and 56.031% for H_2, CO, CH_4, CO_2, and N_2, respectively. UnderAt theseis conditions, we obtained 31.340% of cold gas and carbon conversion efficienciesy, 37.120% of carbon conversion efficiency, and a 3.881 MJ/Nm^3 of lower heating value of 31.340%, 37.120%, and 3.881 MJ/Nm^3, respectivelyvalues were obtained.

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

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1. Introduction

Biomass is an alternative energy source that can be used to produce clean energy (carbon_-neutral). As an agricultural country, Indonesia has a significant potential sources of biomass energy using biomass, one of which is rice husks. In 2020, Indonesia produced 54.65 million tons of paddy rice, with athe total weight of rice being 31.33 million tons– (Badan Pusat Statistik, 2021) and the estimated total price of husk production was approximatelyaround 10.93–18.03 million tons based on 20–33% weight of the total rice weight (Pode, 2016). Rice husks haves a calorific value of 3.954 kcal/kg (Nam *et al.*, 2016) andor a heating value of 13.24–16.20 MJ/kg (Mansaray *et al.*, 2007; Sivabalan *et al.*, 2021). In addition, rice husks haves 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 generationproduction, whichthat can be used as an alternative energy source to solve the problem of energy needs problem of the country.

The cConversion processes for biomass include biological, thermochemical, and physical methods. The thermochemical conversion process involves pyrolysis, gasification, and combustion. During gasification, heat and electricity can be generated using low--energy--density fuels, such as biomass and waste. GThe gas produced through gasification can generate heat and electricity through gas engines, turbines, and boilers (Seo, 2021). In addition, Ggasification is a process of usesing heat, steam, and oxygen to convert biomass into syngas, which which isare mainly carbon monoxide, carbon dioxide, hydrogen, and methane, with lighter hydrocarbons (e.g., like ethane and propane) and heavier hydrocarbons (e.g., like 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 oOperational parameters of biomass gasification include the equivalence ratio (ER), gasifying agent, catalyst, and bed temperature (Seo, 2021).

The gasification process is known as an excellent method to treat waste, as it emitsproduces less greenhouse gases (GHGs) emissions compared to other methods. Another advantage of the gasification process is its flexibility toward different types of feedstock (Saidi *et al.*, 2020). CThe common feedstock for gasification includescomprises biomass (Firman *et al.*, 2020), coal, carbonized products, plastics, and municipal solid waste (Yang *et al.*, 2021). However, further research is requiredneeded to obtain suitable methods and parameters for optimal gasification during performance to get the best performance from biomass conversion of biomass into energy. For rice husk gasification, BBoth fixed bed (downdraft) and fluidized bed gasifiers are can be used for rice husk gasification. Fixed--bed gasifiers, however, suffer from hot spots owing to difficulties in

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heat control and a high amount of tar generation, causing blockages, plugging, corrosion, and ~~finally,~~ 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 ~~research~~ 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 the electrical consumption of the ceramic heater, reaching ~45%, and the significant~~most enormous~~ higher heating value (HHV) of syngas ~~value~~ is obtained at an equivalence ratio (ER) of 0.3 (Makwana *et al.*, 2015). Syngas is ~~arefers to~~ synthesis gas ~~mainly~~ 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 ~~b~~Bubbling fluidized bed gasifier will increase gasification performance owing~~due~~ to the increasing heat transfer rate, good contact between solid and gas particles, and ~~the~~ temperature distribution that tends to be evenly distributed throughout the reactor ~~if~~ compared to ~~the~~ fixed bed gasification. Nevertheless, the use of bed material in gasifiers (generally in the form of silica sand) for the process of fluidization ~~also~~ presents ~~its~~ problems. The~~with the~~ emergence of agglomeration due to the reaction of inorganic alkali from solid fuels, such as ~~like~~ potassium (K) and sodium (Na), with silicate from the bed material, ~~and~~ produces low-melting silicates, characterized by lower melting points than the individual components. As a result, agglomeration ~~will~~ occurs, which blocks the ~~and the process of~~ fluidization process ~~cannot be carried out~~ (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 ~~the condition of~~ pseudo fluidization~~ed~~ when the size of the reactor is enlarged from 0.25 m² to 0.5 m², which aims to reduce the friction between the rice husks~~,~~; hence~~,so~~ slugging or beams does not occur (Leon & Dutta, 2010). Another study~~research~~ conducted by Armesto *et al.*~~,~~ also ~~gives a~~ stated~~ment~~ that~~,~~ it is difficult~~hard~~ to fluidize rice husks without a bed material because of the ~~rice husk has a~~ low spherical value and high surface roughness of the rice husk; therefore, ~~, so~~ when ~~the~~ agent gasification (air) is added, the slugging phenomenon occurs~~appears~~ (Armesto *et al.*, 2002). Natarajan *et al.* and Abdullah ~~Husain~~ *et al.*~~,~~ found that a large amount of bed materials is ~~needed~~ required to fluidize rice husks because~~due~~ of~~to~~ their low density ~~of rice husk~~ (Abdullah *et al.*, 2003; Natarajan *et al.*, 1998). Based on previous studies~~the research that has been done~~, it can be concluded that it is difficult~~hard~~ to fluidiz~~s~~e rice husks without a bed material~~,~~; nevertheless, the utilization of bed material in ~~the process of~~ fluidized bed gasification is~~gives~~ another consideration because of the formation of agglomeration and the waste from the process cannot be reused. Therefore, ~~The emergence of these problems wants to be resolved by~~ the authors aim ~~and team~~ to minimize the occurrence of agglomeration during ~~the process of~~ fluidization and increase the utilization of ~~the~~ waste gasification ~~becomes another adding value~~, based on the study~~research~~ ~~done~~ conducted by Yahya *et al.* ~~i~~In their study, ~~which the result of~~ it was found that burning rice husks ~~will~~ 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~~technology~~ located on Kundur Island, Tanjung Balai Karimun Regency, managed by Prima Gasification Indonesia Company, ~~utilizses the fluidized bed gasification method without using bed material (silica sand) to~~ generate electricity using the fluidized bed gasification method without a bed material (silica sand). This power plant utilizes wood~~s~~ as the primary fuel in the gasification process, with a ~~total~~ raw material requirement~~d~~ of approximately~~around~~ 40 tons of dry wood~~s~~ to generate ~~a~~ 1 MWe ~~capacity power plant~~ (Asosiasi Produsen Biofuel Indonesia (APROBI), 2021).

~~Through previous studies, as well as the presence of commercial technology that has succeeded in utilizing biomass gasification with fluidization method without bed materials, r~~Researchers at the Biomass and Gasification Laboratory~~,~~ of the University of Indonesia~~,~~ wanted to determine~~find out~~ whether the fluidized bed gasification process of the rice husks could be carried out without the bed material~~s~~. It~~This~~ is essential to understand~~know~~ the characteristics of the fluidization process without using the bed material by reducing the size of the rice husks through the grinding process. Because~~Since~~ slug occurs ~~due~~ 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 ~~thereby~~ an increase~~sing~~ of the spherical value of the rice husk, ~~and~~ reduction~~ing~~ of the frictional force between the particles, and ~~obtaining~~attainment of the desired fluidization process. In addition, researchers ~~also~~ 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.

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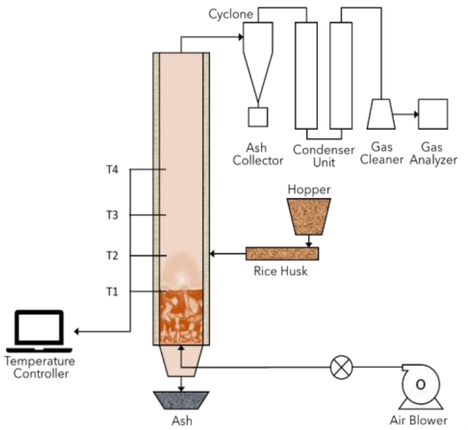

Fig. 1 Schematic of the bubbling fluidized bed gasifier apparatus.

2.2.1. Equivalence Ratio (ER)

The airflow rate and type of biomass are the most critical parameters in the autothermal gasification process, and theirwhose values can be varied independently to a certain extent (Gómez-Barea *et al.*, 2005). Both variables will determined the value of equivalence ratio and superficial velocity (U_f) (superficial velocity). The equivalence ratio is one of the most critical operational parameters in the biomass gasification process with air as the agent gasification agent, as shown expressed in Eequation (1).**Error! Reference source not found.** The equivalence ratio is the ratio between thean 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 to 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). TheWhile the upper limit is determined based on several considerations, such as the reactor temperature, fluidization quality, calorific value, andor 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 efficienciesy. Cold gas efficiency is the results from of a thermochemical process gas that has presented underin ambient temperature conditions, (Basu, 2006), and itswhose value is thea ratio ofbetween 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 bBulk 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). Measurement of Bbulk density can be measureddone by pouring some samples of weighed materials that have been weighed through a glass funnel (Abdullah *et al.*, 2003).

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

2.2.4. Solid Density

The sSolid density (ρ_s) is defined as the ratio ofbetween the mass of the particles (m_s) to the total volume of the particles (V_s), as shown inby Eequation (4) (Behainne & Martinez, 2014), and theto get the value of solid density, 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 becausedue ofto 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 ofbetween particles to the total volume of particles and voids. However, voidage can also can be defined through as the relationship between the solid and bulk density, which ais shown inby eEquation (5).

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

2.2.6. Pressure Drop

Fluidization is a condition in which fine solid particles have behaveior like the same as a fluid when in contact with gas or liquid (Basu, 2006)., Tto determine this condition, it is necessary to measure the pressure drop ofn the solid particles in the reactor should be measured. The occurrence of Tthe fluidization process is indicated by a stable pressure drop change along with anthe increase inof the airflow rate. The pressure drop that occurs in the fluidized bed zone tends to be stable owingdue to an increase in the (h) height dan (ϵ) void fraction in the bed simultaneously. Equation (6) shows the relationship between the pressure drop (ΔP) andto the 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 toBased on the research conducted by Abdullah *et al.*, by classifying biomass based on the Geldart cClassification shown in Table 1, it was found that the biomass with theGroup B classification of Group B provides good fluidization ability, whereaswhile it will be challenging to fluidize the rice husk owing todue to the Group D classificationy. to Group D, Tto improve the quality of fluidization quality, it is necessary to

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~~increase~~ the value of bulk and solid density of materials must be increased, however~~but~~ ~~still notice~~ the voidage parameter must be monitored (Abdullah *et al.*, 2003).

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

The Geldart c~~C~~lassification provides an overview of the fluidization ability of a solid particle based on the particle size ~~of the particles~~ against the difference between the density of the particle and ~~the~~ gas. Based on t~~T~~he Geldart c~~C~~lassification shown in Figure 2, Group A comprises~~is a group~~ of particles that ~~are easy to~~ fluidize with ease, and, ~~this group~~ has a good level of solid and gas mixing.~~,~~ Therefore~~thus,~~ Group A is ~~often~~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 ~~A~~aeratable particles~~,~~ or materials with~~having~~ 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~~of~~ solids and gases, and ~~this group~~ 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– ~~to~~ 500 μm, ~~with~~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~~grow~~ ~~large~~ (Daizo Kunii, 1991; Geldart, 1973). Group C comprises~~is a group~~ of fine solid particles, that~~which~~ are difficult~~this group is hard~~ to fluidize owing~~due~~ to the cohesion between the particles, and ~~much~~considerable ~~channelling~~channeling occurs during the fluidization process. Group D, has~~with~~ the largest particle size, and is ~~hads~~ characterized~~stics~~ by ~~of~~ slug formation during the fluidization process, including~~even~~ at ~~the~~ large bed sizes ~~of the bed~~ (spoutable).

The ~~process of~~ gasification process of rice husks without the ~~a~~ bed material in ~~a~~ the bubbling fluidized bed gasifier is difficult ~~to do~~ based on ~~The~~ Geldart c~~C~~lassification (Cocco *et al.*, 2014). Moreover, the influence of the reactor size and characteristic geometry of rice husks is a problem in fluidization. ~~Based on research by~~ Leon and Dutta conducted an experiment~~,~~ in which ~~an experiment on~~ rice husk fluidization was carried out in the absence~~without using~~ of a bed, and ~~where~~ the cross-sectional area and height used ~~was~~ were 0.25 × 1.0 m and ~~a height of~~ 5 m, respectively. i~~I~~t was found difficult to fluidize due to the slugging phenomenon.~~;~~ hence,~~so~~ ~~widening~~ the bed was widened~~carried out~~ to 0.5 m (Leon & Dutta, 2010). It was ~~T~~then ~~it was~~ found that bubbling occurred~~appeared~~ 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 ~~which~~ occurs because~~due~~ of~~to~~ the roughness ~~of the rice husk~~ and asymmetrical geometry of the rice husks, ~~making~~proving ~~it~~ difficult to carry out ~~the~~ fluidization. Based on the results of previous studies, we then suggested a novel~~the~~ idea ~~emerged~~ to achieve fluidization by ~~perform the~~ grinding ~~process of~~ the rice husks in order to reduce particle diameter, increase ~~the value of~~ bulk density, reduce ~~the~~ friction factor between particles, and increase ~~the~~ sphericity of the rice husk. Therefore~~So, fluidization is achieved. Previously, a~~An experiment was previously conducted to visualize the fluidization of rice husks using~~on~~ modified~~the~~ acrylic cylinders ~~that has been modified was carried out~~.

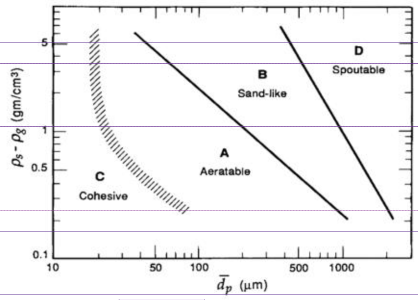

Fig. 2 ~~The~~ Geldart classification of the particles for air at ambient conditions (Daizo Kunii, 1991).

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(a) (b)

Fig. 3 Process of fluidization of the rice husk sample; (a) wwithout bed material and (a); Process of fluidization of rice husk (b) sample aafter grinding without the bed material. (b)

Figure 3a, shows the appearance of the slugging phenomenon, thatwhich is indicated by the movement of solid particles in groups duringwhen the fluidization process is carried out. Then,Then the process of grinding rice husks were ground and calculating the value of bulk density was obtained using Eequation (3) was done, where the previous bulk density was from 109.84 kg/m^3 to 373.38 kg/m^3;. In addition, as well as reducing the diameter of rice husk was reduced from 1.55 mm (Leon & Dutta, 2010), to 0.84 mm, and the voidage parameter which was previously 0.89 decreased from 0.89 to 0.63. Theise changes in the properties of the rice husks tended to improverice husks seems to influence improving the quality of the fluidization process. Based on visual observations, it was found that milled rice husks couldcan be fluidized effectivelyquite well without bed material, as shown in Figure 3b.

After getting that fluidization to occur without bed material, thethen measurement of pressure drop can be measuredcarried out, with when the rice husks have athe weight and height of 800 gramr and 70 mm rice husks, respectively. This process has determinesd the minimum velocity required for solid particles to be fluidizationed of solid particles. Based on the experimental results, the effect of increasing the flow rate on changes in pressure drop changes is shown in Figure 4, which describesing 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 athe 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 infor this study was 0.82 m/s.

AnThe increase inof theair airflow rate results ineauses an increase in the drag force experienced byon the particles. The value of drag force will reaches a value equal value to the weight of the solid particles;, hencethus, the solid particles are lifted and beginstart to fluidize. The stable change in the pressure drop along with the increases in flow rate can be explained by Eequation (6), where the increases in flow rate causes the bed to rise and increasesing the height (h) of the bed, thereby increasing the value of voidage ($\boldsymbol{\varepsilon}$). The increase in the bed height bed is anticipated with a value of $(1-\boldsymbol{\varepsilon})$, so that thechanges in pressure drop changes aretend to be constant.

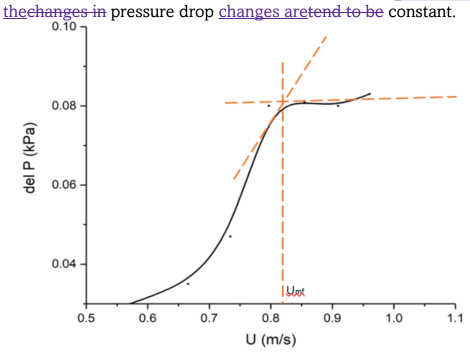

Fig. 4 Graphic of the pressure drop versusto a rate of airflow rate.

3.2 Effect of the Eequivalence rRatio on Syngas Production

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

Research by Lv *et al.*, showed that a small equivalence ratio value is not beneficial forin biomass gasification because it will reduces the reaction temperature (Lv *et al.*, 2004). Research by The results by Mansaray *et al.*, showed the results revealed that nitrogen was present atin the highest concentration (56.57±64.21 vol %), whereas. The concentration of 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 then 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 increasedcauses more CO2 production of CO_2 (because of an increase in the reaction of oxidation reaction) and a decreased of low heating value (LHV). AThe study by Mansaray *et al.*, also proved that variations inof thean equivalence ratio affects the quality of syngas production (Mansaray *et al.*, 1999). This study found that an equivalence ratio of 0.25 was the operation condition withresulted in the optimalbest syngas quality. The research results in this study found the effect of equivalence ratio on syngas production, as shown in Table 2**Error! Reference source not found.**, where the highestmaximum 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: ~~t~~This study (2021)

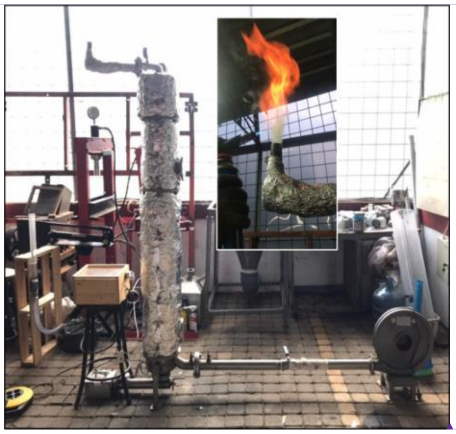

Fig. 5 Experimental configuration of rice husk fluidization without the bed material on the bubbling fluidized bed gasifier.

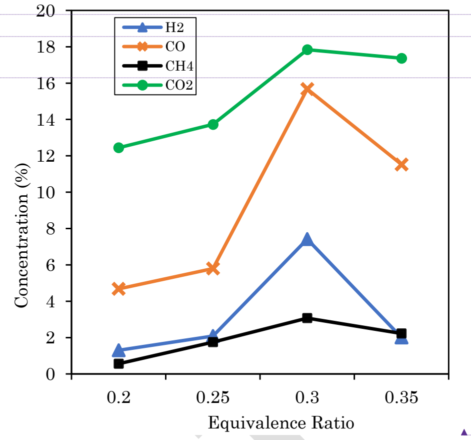

Fig. 6 Composition of syngas versus~~to~~ variation of the ~~E~~equivalence ~~R~~ratio.

3.3 Syngas Composition

The ~~v~~Various ~~in~~ components of syngas produc~~ed~~tion at different equivalence ratio ~~values~~ are summarized in Table 2. Based on the analysis results ~~of analysis~~ of the syngas components, nitrogen gas was found as the ~~largest~~major constituent ~~of the gas composition~~, with~~whose~~ values ranging~~ed~~ from 56–81 %, vol. ~~The CO~~ CO_2 concentration ~~of CO_2~~ was~~is~~ in the range ~~(~~12–17.8 %, vol~~)~~. The composition of combustible gases (H_2, CO, and CH_4) ~~respectively~~ had~~s a~~ 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 ~~d~~and N_2 increased ~~with an increase in~~ the equivalence ratio, as well as the composition of combustible gases (H_2, CO, and CH_4), that~~which~~ increased at~~o~~ an equivalence ratio of 0.30, and then decreased at~~o~~ an equivalence ratio of 0.35. The ~~highest~~maximum production of combustible gas (H_2, CO, and CH_4) was found at an equivalence ratio of 0.30 with concentrations of ~~H_2, CO, and CH_4 respectively at~~ 7.415, 15.674, and 3.071 %, vol, respectively. Hence~~thus~~, the highest LHV was found in this equivalence ratio.

3.4 Lower Heating Value

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

3.5 Cold Gas Efficiency and Carbon Conversion Efficiency

The ~~c~~Cold gas efficiency (CGE) is a performance parameter ~~of the performance~~ of the gasifier that~~o~~ determines how effectively~~well~~ the gasifier ~~can~~ converts fuel into syngas. In a~~the~~ study by~~of~~ Seo *et al.*, CGE decreased from 70.75% to 44.23% because of an increase in ER that resulted in increased~~more~~ CO_2 in the product gas (Seo, 2021). Panaka *et al.*, also reported that the general CGE ~~value~~ of a biomass gasifier is ~~usually~~typically in the range of~~between~~ 45%~~ and~~–67% (Panaka *et al.*, 1993). ~~In their research,~~ Natarajan *et al.*, showed that the CGE value in a bubbling fluidized bed gasifier can reach ~~a value of~~ 60% under ~~with~~ 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~~on equivalence ratio variations~~. The highest~~largest~~ CGE was obtained~~occurred~~ when~~at~~ ER 0.30 with an efficiency ~~value~~ of 31.34%, whereas~~and~~ the lowest~~smallest~~ CGE of ~~was~~ 3.465% was obtained at ER 0.20. Therefore, ~~T~~the smaller the~~of~~ CGE ~~value~~, the lower the~~of~~ CCE ~~value~~.

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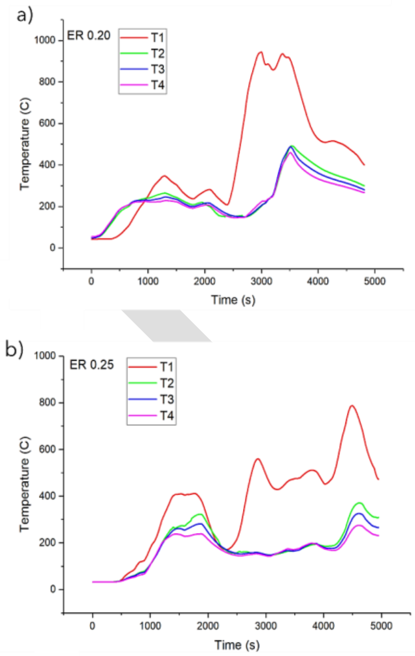
Carbon conversion is defined as the rate of change of the solid fuel (biomass) into gaseous products (syngas). It is one of the parameters expected to have a high value to ensure that desirable syngas quality is obtained. Table 2 summarizes the CCE values for the equivalence ratio variations, where the 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.



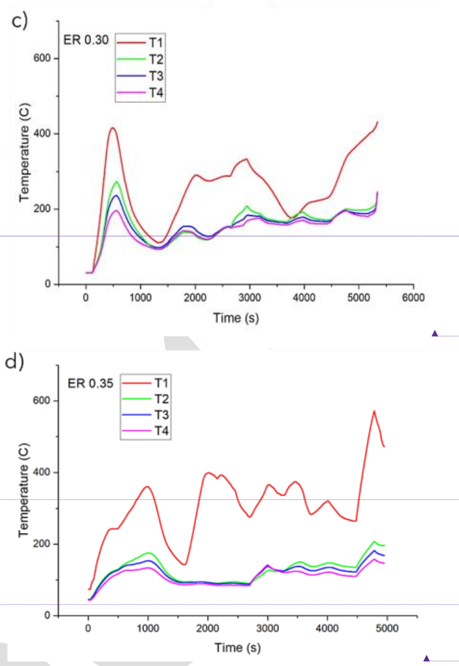


Fig. 7 Temperature distribution versus~~to~~ time: (a) ER 0.2, (b) ER 0.25, (c) ER 0.3, and (d) ER 0.35.

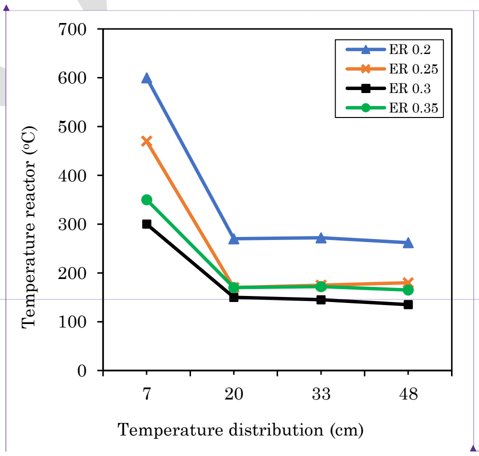


Fig. 8 Average distribution of the temperature reactor to equivalence ratio variations.

In this study, ~~T~~the authors predicted~~s~~ the occurrence of the partial combustion of syngas in the reactor. ~~So that~~Therefore, the bed temperature significantly rises ~~as seen in~~ (Figure 8) at an ER of 0.20 and 0.25. This could explain~~be an indication of why~~ the ~~test~~low-test results of combustible gas and energy content at ERs of 0.20 and 0.25, respectively, ~~are much lower~~

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when compared with to the ERs of 0.30 and 0.35. This occurrence 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 conducteddone, the gasifier performance of the gasifier can be improved by installing an electric heater to maintain the stabilizety of the reactor temperature, and installing a feeder to helpassist feeding the biomass into the reactor. In addition, the conditioning pressure and temperature of the reactor can be useddone to improve the performance., where hHigh temperatures underwith low-pressure conditions will produce high CO and H_2. Meanwhile, high- pressure and low-temperature conditions will produce a high CH_4 gas content. Furthermore, the height of the reactor also influences the performance, thatwhich will 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.

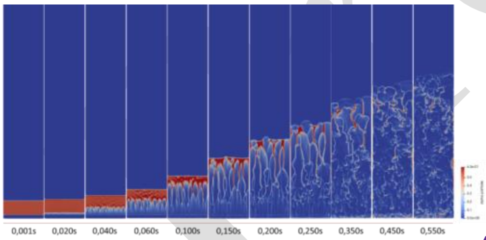

Fig. 9 Simulation results of the bubbling phenomenon on the self-bed bubbling fluidized bed gasifier.

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 weare used to set up theis simulation, including air velocity, particle velocity, intake air temperature, particle temperature, and system temperature, pressure, and property of viscosity. The setup of the fluidized bed simulation wais as follows: aAir magnitude velocity or minimum fluidized velocity ofis 0.82 m/s on the y-axis, rice husk particle velocity ofis 0 m/s on the y-axis, and the reactor internal velocity ofis 0.25 m/s on the y-axis, whereaswhile the internal pressure wais set to 101325 Pa. For the surface tension, the air fraction wais 0.45, and the rice husk particle fraction wais 0.55. The operating air temperature of the bBubbling fFluidized bBed and for air is 300 K, rice husk particles wasare 300 K, and the reactor internal temperature wais 700 K. Figure 9 shows particles still floating at 0.06 s, with thestart bubbling phenomenon commencing after 0.06 s, and the finally fallingdeteriorating 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 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

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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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