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Effect of Equivalence Ratio on the Rice Husk Gasification Performance Using Updraft Gasifier with Air Suction Mode

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Abstract

Rice husk is the waste from agriculture industries that has high potential to produce heat and electricity through the gasification process. Air suction mode is new development for updraft rice husk gasification, where blower are placed at output of gasifier. The objective of this research is to examine these new configuration at several equivalence ratio. The equivalence ratio was varied at 32% and 49% to study temperature profile on gasifier, producer gas volumetric flow rate, composition of producer gas, producer gas heating value, cold gas efficiency and carbon conversion. The time needed to consume rice husk and reach an oxidation temperature of more than 700°C for equivalence ratio of 49% is shorter than 32%. Producer gas rate production per unit weight of rice husk increase from 2.03 Nm^3/kg and 2.36 Nm^3/kg for equivalence ratio of 32% and 49%, respectively. Composition producer gas for equivalence ratio of 32% is 17.67% CO, 15.39% CO_2, 2.87% CH_4, 10.62% H_2 and 53.45% N_2 and 49% is 19.46% CO, 5.94% CO_2, 0.90% CH_4, 3.46% H_2 and 70.24% N_2. Producer gas heating value for equivalence ratio 32% and 49% is 4.73 MJ/Nm^3 and 3.27 MJ/Nm^3, respectively. Cold gas efficiency of the gasifier at equivalence ratio 32% is 69% and at 49% is 55%.

INTRODUCTION

In 2018, the total paddy productions in Indonesia were 56.54 million tons (Suharyanto, 2018). As it is known that every ton of harvested rice will produce 1.35 tons of straw, 0.1 tons of bran, 0.14 tons of broken rice and 0.2 tons of rice husks. This rice husk that has no nutrition today is an attractive source of biomass that can be used as thermal heat and electricity generation (Moraes et al., 2014). Rice husk has a higher heating value (HHV) 14,508.5 to 15,728 MJ/kg and lower heating value (LHV) 14,262.8 to 15,538.2 MJ/kg (Nakawajana et.al, 2018; Gravalos et al., 2016; Shen et al., 2012). The potential of heat energy that can be produced from the production of rice husk in 2018 is 5371 $GW_{thermal}$. The conversion of rice husk into electricity is 1.6-1.8 kg/kWh (Bhuiyan et al., 2011; Ha-Duong & Nam, 2014), the electricity potential that can be generated is equivalent to 6642 GWh. This enormous energy potential still cannot be utilized properly. Only a small portion of rice husk is used as fuel for household cooking and for burning bricks. Most of the rice husks are thrown into the environment and burned, which can create environmental hazards and air pollution for the environment. Rice husk can be converted into producer gas through gasification technology.

Gasification process is the conversion of solid into producer gas that can be burned to release energy or chemical used for production of value-added chemicals. The main components in the producer gas gas are H_2, CO and CH_4 (Basu, 2010). Many researchers have developed the conversion of rice husk into heat or electric energy

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using fixed-bed gasifier, because the design is simple and economically affordable (Nguyen et al.,2018). Downdraft gasifier has been used to convert rice husk to producer gas which is used to generate electricity (Lin et al., 1998; Pradhan et al., 2013; Htet, 2018; Nguyen, 2018).

Another type of gasifier that can be used to convert rice husk to producer gas and electricity is an updraft type (Sarkar et al., 2012; Lertsatitthanakorn et al., 2014; Sheik & Math, 2016; Njogu et al., 2015). This type is cheaper and safer than the downdraft type. In addition, this is due to the updraft type gasifier having a simple, tested, flexible construction of feed types and can handle biomass with high moisture content (max. 60%) (Ciferno & Marano, 2002). Most updraft gasifier are designed with an air blown model using a blower (Sarkar et al., 2012; Lertsatitthanakorn et al., 2014; Sheik & Math, 2016; Njogu et al., 2015). However, there are still limited papers that study the use of the model of air sucked on an updraft gasifier. The suction air model was more widely applied in the downdraft gasifier design. Previous research, we tested the type of gasifier updraft using mahogany raw material (Hendriyana et al., 2018). The performance of the gasifier updraft is very satisfying, so that in this study updraft gasifier was tested using rice husk feed on several equivalence ratio of air to fuel.

MATERIALS AND METHODS

Material of Feed Stock

Rice husk used in this experiment were obtained from rice mills around Cimahi. Rice husks were then dried in the open air using the sunlight. The ultimate and proximate analysis of rice husks is presented in Table 1.

Experimental setup

The experimental setup of gasification is presented in Figure 1. System of gasification process was composed of updraft gasifier, water seal and ash disposal pit, blower and burner. The height of the updraft gasifier used is 1.4 m with a diameter of 0.2 m. The gasifier is also equipped with a hopper to feed rice husks. To reduce heat loss, the gasifier is insulated using 3 cm thick brick powder. The gasification process

Table 1. The Characteristics of Rice Husk.

	Basu (2010)	Lin (1998)
Proximate analysis (%wt) dry basis		
Volatile matter	65.50	72.87
Fixed carbon	16.70	10.00
Ash	17.90	17.13
Ultimate analysis (%wt) dry basis		
C	45.56	46.97
H	6.75	6.70
N	0.59	0.42
O	47.10	45.78
S	-	0.025
High heating value (kJ/kg dry basis)	15,376	14,379

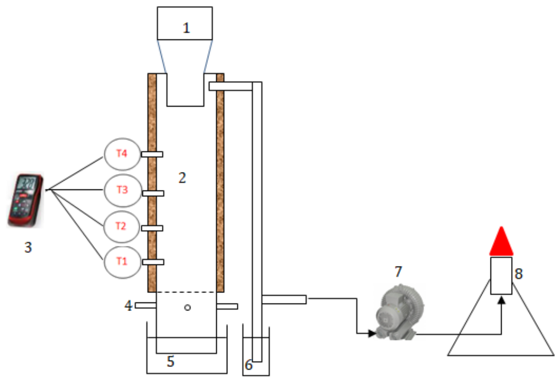

Figure 1. The experimental setup of gasification (1) Hopper (2) Gasifier (3) Thermometer (4) Air input (5) Water seal and ash pit-1 (6) Water seal and ash pit-2 (7)Blower (8) Burner.

is carried out using air from the atmosphere as a gasification agent. The air enters by suction using a blower from the side of the gasifier through four holes placed under the grate.

The experiment was started by feeding rice husk into the gasifier through the hopper. Then the blower was turned on and air was sucked through the four air pipes at the side of the gasifier. The air flow rates were measured by KRISBOW KW0600653 Hot Wire Anemometer. The biomass above the grate was ignited using a torch fire through the ignition hole. The temperatures in the updraft gasifier were monitored using the Thermocouple K-type and KRISBOW Digital Thermometer Single Input/ Dual Input Kw 06-278. Four points was measured at 15 cm (T1), 25 cm (T2), 75 cm (T3) and 100 cm (T4) above the grate.

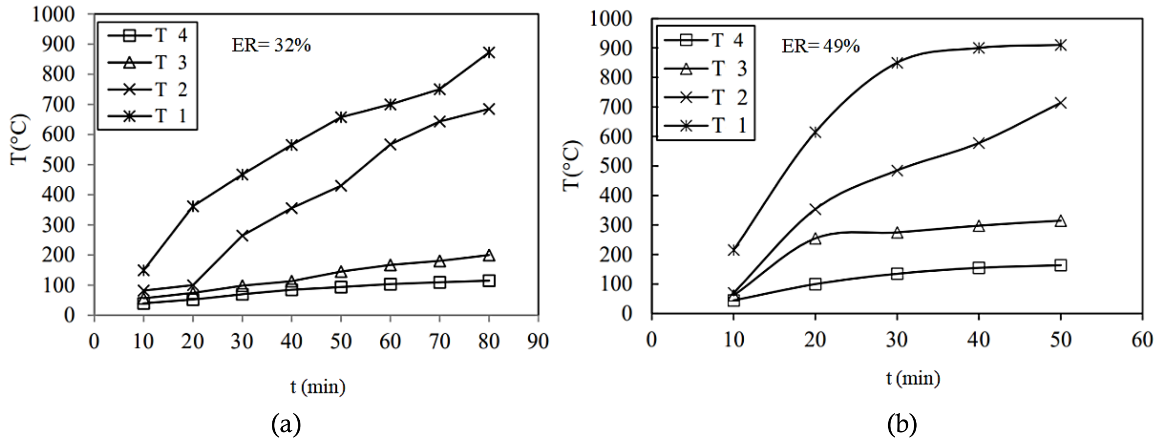

Figure 2. Temperature profile vs operation time for ER (a) 32% and (b) 49% .

The gasification process takes place continuously, where rice husks were fed continuously and ash was discharge continuously from the bottom of the gasifier. The producer gas after the blower was burned by the burner to see the quality of the fire, while the producer gas sample was analyzed using TCD gas chromatography.

Equivalence Ratio (ER)

The equivalence ratio is the ratio of the gasification air to stoichiometric air. The equivalence ratio is one important variable can be influence to the gasifier performance like temperature inside the gasifier, quality of product gas, cold gas efficiency, carbon conversion efficiency, and char production (Basu, 2010)

Cold Gas Efficiency (CGE)

The parameters that can be used to assess gasifier performance are the cold gas efficiency (CGE). The cold gas efficiency can be calculated by using Eq. (1) (Basu, 2010).

$$CGE = \frac{Q_{pg}\, LHV_{pg}}{M_{f,RH} LHV_{f,RH}} \quad (1)$$

Where, Q_{pg} is volumetric flow rate of producer gas (Nm^3/hr), LHV_{pg} is the lower heating value of producer gas (kJ/Nm^3), $M_{f,RH}$ is mass flow rate of rice husk (kg/hr) and $LHV_{f,RH}$ is lower heating value of rice husk (kJ/kg).

The lower heating value of producer gas (LHV_{pg}) is calculated by using Eq. (2).

$$LHV_{pg} = y_{H2} \,.\, LHV_{H2} + y_{CO} \,.\, LHV_{CO} + y_{CH4} \,.\, LHV_{CH4} \quad (2)$$

With, LHV_{H2} = 12,630 kJ/Nm^3, LHV_{CO} = 12,740 kJ/Nm^3 and LHV_{CH4} = 39,820 kJ/Nm^3.

Carbon Conversion Efficiency (CCE)

The carbon conversion efficiency was used to evaluate distribution of carbon in product gas compared to carbon in the biomass feed. The carbon conversion efficiency can be calculated using Eq. (3).

$$CCE = \frac{total\ mol\ of\ C\ in\ producer\ gas}{total\ mol\ of\ C\ in\ fuel} \quad (2)$$

RESULTS AND DISCUSSION

Profile of Temperature

Figure 2 shows the temperature profile inside the gasifier recorded using K-type of thermocouples at four points against time. For ER 32% the time taken to consume the feed stock was longer than ER 49%. Oxidation zone temperature for ER 32%was achieved more than 700°C after 60 min from starting time of gasification, while for ER 49% take less than 25 min. The maximum oxidation temperature which can be achieved until the end of the process for ER 32% is 872°C and 910°C for ER 49%.

The average temperature of the gasification process along the height of the gasifier can be seen at Figure 3. The combustion zone is 0-25 cm above the grate, the reduction zone is 25-50 cm above the grate, the pyrolisis zone is 50-75 cm above the grate and drying is 75-100 cm above the

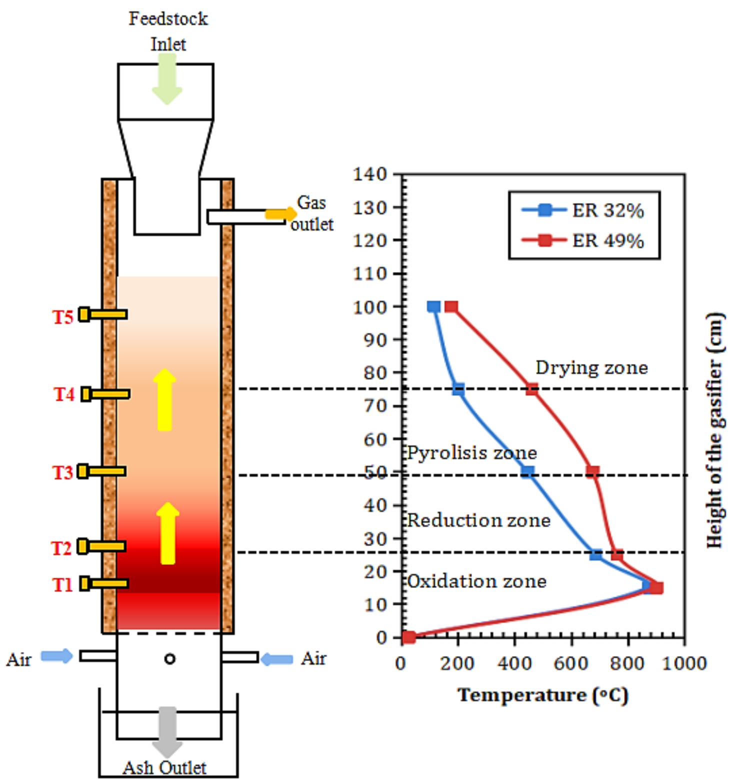

Figure 3. Temperature profile on the gasifier.

grate. The temperature of each zone increases with increasing equivalence ratio. This is due to the amount of oxygen supplied to the combustion zone increases, so the more fuel is consumed and releases heat energy is greater. The heat generated by the combustion zone is then transferred to various zones through a convection process.

Producer Gas Volumetric Flowrate

The producer gas volumetric flow rate is measured using the anemometer approach and profile against time can be seen in Figure 4. The producer gas volumetric flow rate increases from 20.3 to 21.2 Nm^3/h along with an increase in equivalence ratio from 32% to 49%. Ratio of gas production rate to weight of biomass is 2.03 Nm^3/kg and 2.36 Nm^3/kg for equivalence ratio 32% and 49%, respectively.

Composition of Producer Gas

The composition of the producer gas is presented in Figure 5. The equivalence ratio of 32% gas producer consists of 17.67% CO, 15.39% CO_2, 2.87% CH_4, 10.62% H_2 and 53.45% N_2, while the equivalence ratio 49% of producer gas contains 19.46% CO, 5.94% CO_2, 0.90% CH_4, 3.46% H_2 and 70.24% N_2.

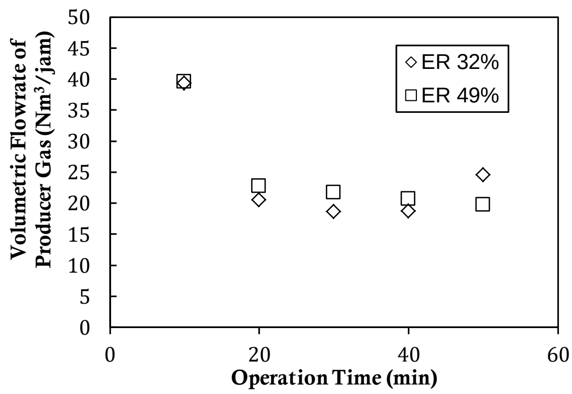

Figure 4. Producer gas volumetric flow rate against operation time.

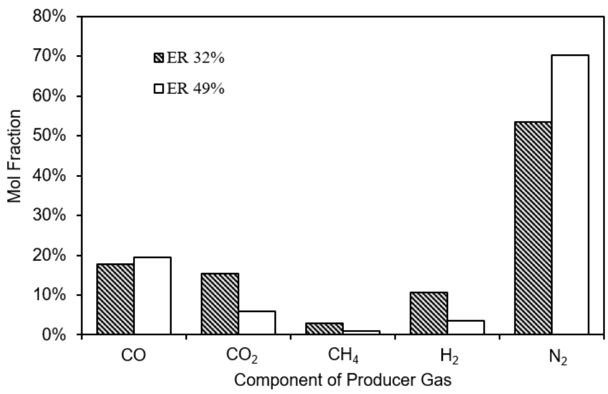

Figure 5. Composition of producer gas.

Producer Gas Heating Value, CGE and CCE

The producer gas lower heating value at the equivalent ratio of 32% and 49% is 4.73 MJ/Nm^3 and 3.27 MJ/Nm^3, respectively. The lower heating value of the producer gas decreases along with the increase in the equivalence ratio due to the higher N_2 fraction in the producer gas (see Figure 5). Figure 6 shows the CGE and CCE has decreased along with the increasing equivalence ratio.

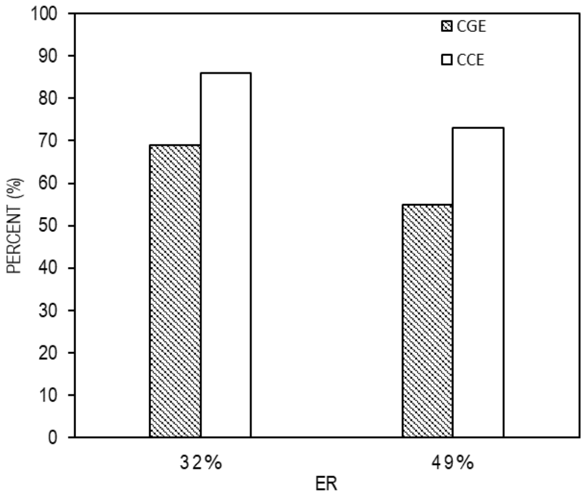

Figure 6. The cold gas efficiency (CGE) and carbon conversion efficiency CCE at different equivalence ratio (ER).

Percentage of Char Produced

The solid waste produced from the rice husk gasification process is char. The percentage of char defined as mass of char divided with mass of fuel. Where the char was produced at the equivalent ratio of 32% and 49% is 27% and 24%, respectively. The amount of char decreases with increasing equivalence ratio. This is due to the increasing number of char burned with air.

Analysis of Energy Balance

Energy balance analysis of rice husk gasification can be seen on Figure 7. Feed of rice husk with consumption rate 10 kg/h has 140.03 MJ/h. Producer gas flow rate produced at 20.03 Nm^3/h has an energy content of 96.10 MJ/h (69%) that could be used in generating electricity. Lower heating value of char rice husk (12.35 MJ/kg) was approached from Ma et al. (2015). Char rice husk still contains significant energy (24% or 33.35 MJ/h). The resulting of char rice husk from gasification process can be used as an adsorbent or catalyst.

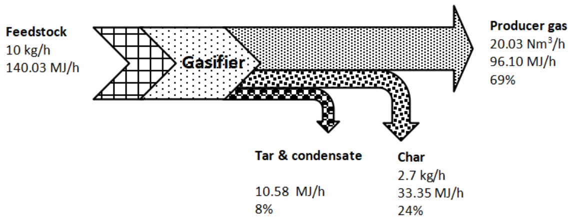

Figure 7. Pathway of energy conversion of rice husk gasification at the ER of 32%

CONCLUSION

The rate of temperature rise in the gasifier and fuel consumption increases with increasing equivalence ratio from 32% to 49%. Ratio of producer gas volumetric to mass of rice husk is 2.03 Nm^3/kg for equivalence ratio of 32% and 2.36 Nm^3/kg for equivalence ratio of 49%. The highest CGE and CCE was obtained at an equivalence ratio of 32% which is 69% and 86%, respectively. Char of rice husk produced at equivalence ratio of 32% was 27%, while in equivalence ratio of 49% it was 24%. Energy of producer gas is 69% from feed stock energy could be used to generating electricity.

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