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Modeling and Simulation of Rice Husk Gasification using Equilibrium Approach

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ABSTRACT

Gasification is a technique of changing solids into gases. So far, gasification has been widely used by utilizing coal, which contains many impurities like sulfur. Because of that, a gasification technology that utilizes biomass was developed. One of the biomass that is often found in Indonesia is rice husk. This research will use an equilibrium approach to study rice husk gasification modeling and simulation using the Aspen Plus v8.8 simulator. In addition, the influence of the number of gasification agents, such as steam and air, and gasification temperature was also studied in this research. The amount of steam used is expressed in the steam-to-biomass ratio (SBR), while the amount of air used is expressed in the equivalence ratio (ER). This study uses SBR 0.4 and 0.6, ER 0.4 and 0.6, and gasification temperatures of 750ºC and 850ºC. From this study, if the SBR is increased, the amount of H_2 will also be greater. Meanwhile, the increase in ER will reduce the amount of H_2 and CO in synthetic gas. The higher gasification temperature will increase the CO composition but decrease the H_2 gas content.

1. Introduction

An increase in population can trigger various social, energy, and economic problems. One example of problems in the energy and economic aspects is the use of non-renewable raw materials such as coal, which is commonly used in the gasification process. Therefore, natural resources are being developed to reduce the use of coal, which also contains contaminants that can harm the environment [1]. Generally, coal is processed into synthetic gas in the energy supply industry. Synthetic gas (syngas) is obtained from the gasification process, composed of H_2 and CO gases. Syngas is an intermediate product used as a raw material to make final products such as fuel, chemical compounds, fertilizers, power plant raw materials, steam, fuel gas, and other products, as presented in Fig.1. [2]. Syngas can also be used as fuel in a furnace, boiler, or gas turbine [16].

Based on data from the Worldwide Gasification Database, USA Department of Energy, in 2013, the use of syngas as raw material for the chemical industry was 45%, raw material for the fuel oil industry was 38%, raw material for power plants was 11% and raw material for the gas industry was 6 %. Based on these data, syngas is one of the important ingredients in the chemical industry, as it is produced from the coal gasification process. However, the use of coal has several drawbacks, namely that it is a non-renewable natural resource and can produce CO_2, SO_2, and NO_2 emissions. Therefore, alternative natural resources such as biomass are needed. Biomass is one of the raw materials that can produce energy that is environmentally friendly and has abundant availability. This can be a consideration for the further development of biomass to replace fossil energy, which has limited availability and high CO_2 emissions [3].

One source of biomass from agricultural waste that can be utilized in Indonesia is rice husks. According to the Badan Pusat Statistik (BPS), rice production in 2020 will reach 54.65 million tonnes. In the rice milling process, rice husks usually obtain around 20-30% by weight of rice, 8-12 bran, and 50-63.5% milled rice from the initial grain data [4]. Rice husk processing, which farmers commonly carry out, is by burning. However, this process causes air pollution. Therefore, it is necessary to treat rice husk waste, which is more effective and can increase the use value of rice husk [5].

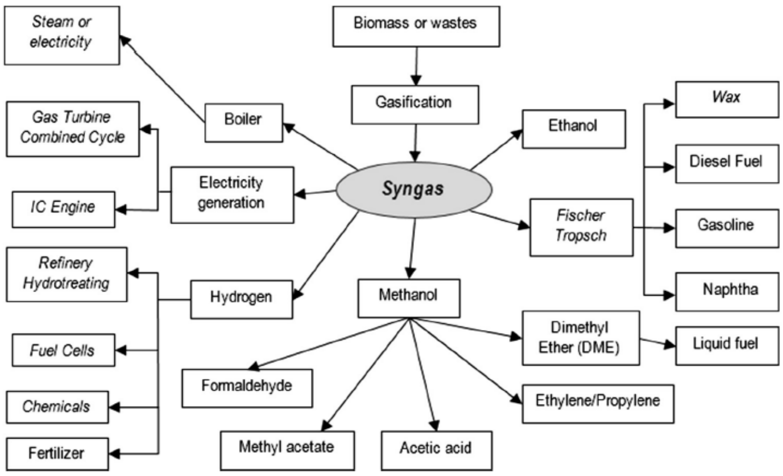

Fig. 1. The utilization of syngas in the downstream process [2]

Gasification is converting solid fuels (coal or biomass) into synthetic gas. The gasification process occurs in a gasifier where the biomass fuel is burned with limited air in the presence of steam. The gasification process will produce synthetic gas (CO and H_2) and ash [2], [6]. The composition of synthetic gas can vary in a wide range depending on biomass and operating conditions [17].

Process simulation is essential in modeling the gasification process, especially for analysis, evaluation, and design [17], [18]. Modeling gasification can be done using computational fluid dynamics (CFD) or a simulator. CFD requires comprehensive design and high computational resources [22], [23], [24], [25]. On the other hand, modeling biomass using a simulator such as Aspen Plus has gained relevance due to the database of components and thermodynamics model [26].

Previous research [7] on gasification was carried out regarding gasification of food waste. Previous research [8] examines the gasification of other biomass such as almond shells, oak wood, peanut shells, etc. Gagliano et al. [9] modeled an equilibrium approach to agricultural product biomass with a downdraft gasifier. This research will study gasification modeling in rice husks with an equilibrium approach using the Aspen Plus simulator. Several studies concluded that the Aspen Plus simulator gives a reasonable prediction for the gasification process [19], [20], [21]. In addition, variations such as steam-to-biomass ratio (SBR), equivalence ratio (ER), and gasification temperature were also carried out. SBR is defined as the ratio of the mass flow rate of steam to the mass flow rate of biomass, and ER is defined as the actual air-fuel ratio (used in the gasification) to the stoichiometric air-fuel ratio for combustion [10].

2. Research Methodology

2.1. Materials

The gasifier was modeled using Aspen Plus® simulator version 8.8 from Aspentech. The gasifier is modeled with a Yield reactor and a Gibbs reactor. Yield reactors are used to convert biomass into conventional components. In the Gibbs reactor, a gasification reaction occurs to produce synthetic gas. The thermodynamic model used in this study is Peng Robinson, which gives good results in modeling the gasification process [2].

2.2. Procedure

This research consists of 2 stages, namely validation and simulation. In validation, a rice husk gasification process will be modeled, and the results obtained in this study will be compared with research conducted by Sun [11]. The process flow diagram is presented in Fig. 2. while the data used is presented in Table 1. Rice husk will be modeled as a solid, and its composition is expressed in proximate and ultimate analysis. The synthetic gas composition of the results of this study will be compared with those obtained in the literature. The simulation was carried out by varying the SBR of 0.4 and 0.6, the ER of 0.4 and 0.6, and the gasification temperature of 750ºC and 850ºC.

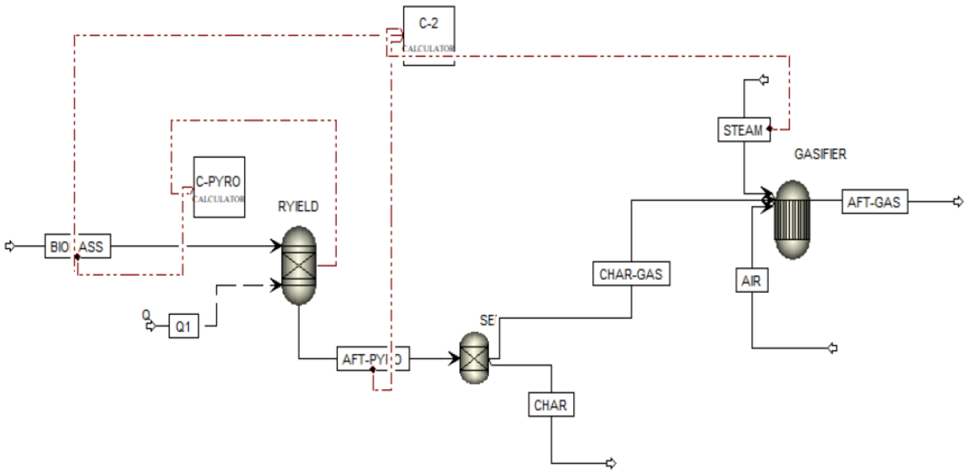

Fig. 2. Process Flow Diagram

Table 1. Ultimate and Proximate Analysis of Rice Husk [11]

Analysis	wt%
Ultimate Analysis	
Carbon	51.19
Hydrogen	6.08
Oxygen	41.3
Nitrogen	0.2
Sulfur	0.02
Chlorine	1.16
Proximate Analysis	
Volatile Matter	80 (dry basis)
Fixed Carbon	18.84 (dry basis)
Ash	1.16 (dry basis)
Moisture	20

3. Result and Discussion

3.1. Validation

The research was started by modeling and validating the gasification process. The results of this study in the form of synthetic gas composition will be compared with the results of experiments conducted by the literature [11]. If the composition of the synthetic gas in this study is close to the results obtained in the literature, then the model developed in this study can be valid.

Feed composition and process flow diagrams are presented in Table 1 and Fig 2. Gasification is carried out at a pressure of 1 atm and a temperature of 850ºC with an SBR of 0.6. A comparison of synthetic gas composition between this study and the literature is presented in Table 2.

Table 2. Comparison of synthetic gas in this study with the literature

Component	Composition (vol %)	
	Literature [11]	*This Study*
H_2	56.92	57
CO	34.28	33.97
CO_2	8.65	9
CH_4	0.06	0.06
N_2	0.09	0.08

Table 2 shows that the composition of the synthetic gas produced by this study has approached the results obtained from the literature. There are slight differences that differences in the version of the simulator used can cause. Therefore, the gasification model that has been compiled can be valid and continued for the next stage, namely simulation.

3.2. Simulation

Simulations were conducted to determine the effect of gasification process variables such as SBR, ER, and temperature. In this simulation, rice husks found in Indonesia are used. The composition of this rice husk is presented in Table 3.

In this study, an SBR of 0.4 and 0.6 was used. The ER used was 0.4 and 0.6. At the same time, the gasification temperature is 750ºC and 850ºC. The effect of SBR, ER, and gasification temperature on synthetic gas composition is presented in Fig. 3. to Fig. 5.

From Fig. 3. to Fig. 5., it can be seen that the composition of synthetic gas is affected by SBR, ER, and temperature. The greater the amount of steam used, it will increase H_2 and decrease CO in synthetic gas (Fig. 3.). With an increase in the steam used, the steam reforming and shift conversion reactions will shift to the right so that the amount of H_2 will increase and CO will decrease. In addition, CO_2 gas will also increase as a result of shifting the shift conversion reaction to the right [12].

Table 3. Ultimate and Proximate Analysis of Rice Husk in Indonesia [12]

Analysis	wt%
Ultimate Analysis	
Carbon	34.92
Hydrogen	5.59
Oxygen	39.55
Nitrogen	0.34
Sulfur	0.08
Ash	19.52
Proximate Analysis	
Volatile Matter	61.91 (dry basis)
Fixed Carbon	16.91 (dry basis)
Ash	21.18 (dry basis)
Moisture	7.84

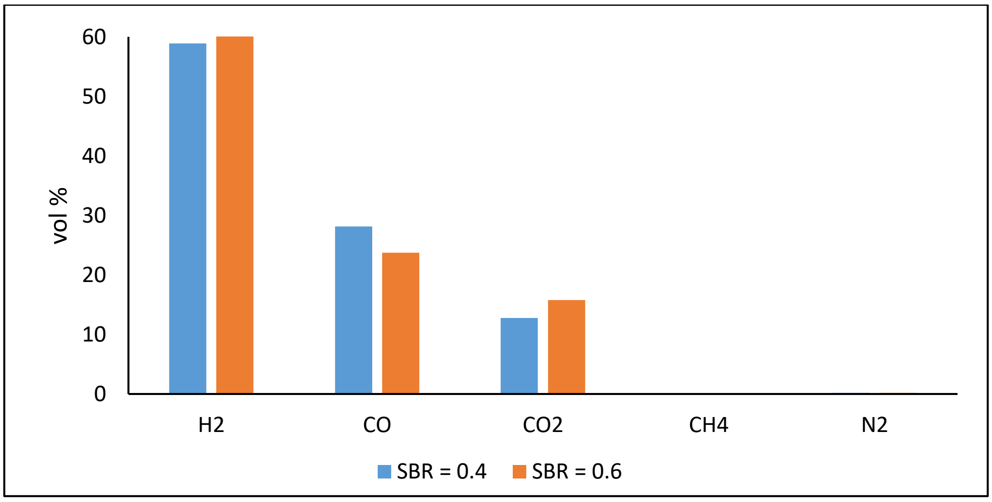

Fig. 3. Effect of SBR on Synthetic Gas Composition

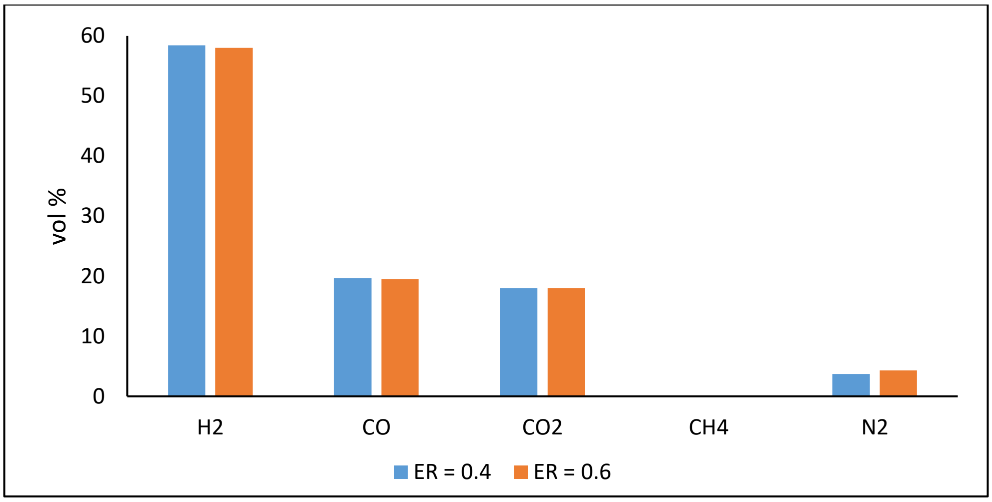

Fig. 4. Effect of ER on Synthetic Gas Composition

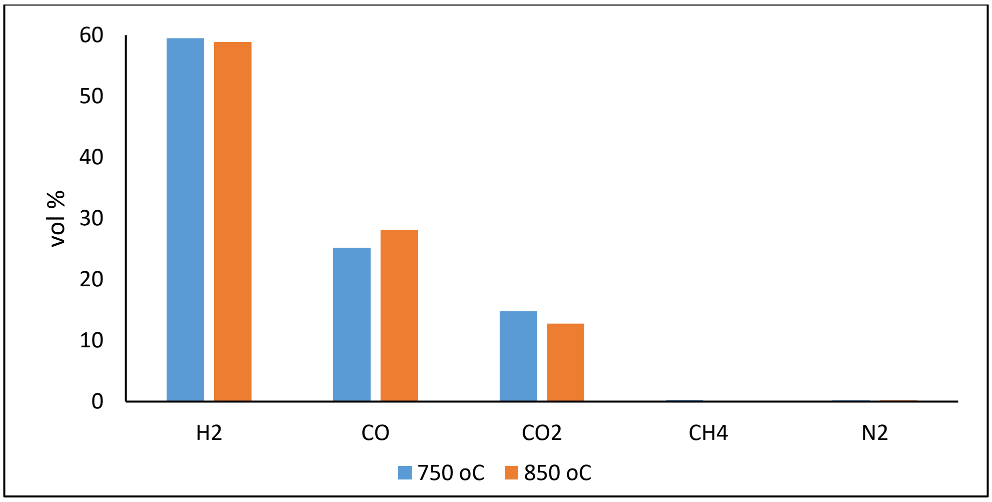

Fig. 5. Effect of Temperature on Synthetic Gas Composition

For air gasification agents (21%-vol O_2 and 79%-vol N_2), it produces lower amounts of H_2 and CO than steam. The amount of H_2 and CO will decrease while the amount of CO_2 will increase. This is because the more significant the air used, the more dominant the oxidation reaction, and the main gasification reactions, such as steam reforming and shift conversion, will decrease. In addition, the N_2 content in synthetic gas will also be more significant [12].

Gasification temperature also affects the amount of H_2 and CO_2. Gasification reactions are endothermic, such as steam reforming, and exothermic, such as shift conversion reaction. The increase in temperature will shift the steam reforming reaction to the right and the conversion shift to the left. This causes the composition of H_2 to decrease while CO will increase.

Various gasification conditions used in this study produced synthetic gas with a molar ratio of H_2 and CO above two and low N_2 and CH_4 content. These parameters indicate that the gasification of rice husks in Indonesia under the above conditions has met the specifications of synthetic gas in the chemical industry [14].

4. Conclusion

This research has successfully modeled the rice husk gasification process using the equilibrium approach in the Aspen Plus simulator. In the operating conditions of this study, namely the SBR (Steam to Biomass Ratio) of 0.4 and 0.6, the ER (Equivalence Ratio) of 0.4 and 0.6, and the gasification temperature of 750°C and 850°C have produced synthetic gas, which has the potential to be used in the chemical industry. This can be seen from the molar ratio of H_2 and CO, above 2, and the low level of CH_4 and N_2.

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