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Syngas Generation in a Crossdraft Gasifier System Using a Rice Strew Filter

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Abstract: One solution to the fossil energy crisis is to use alternative energy, such as coal conversion. Coal may be utilized as an alternative energy source via a variety of methods, one of which being gasification. Gasification is a thermochemical process that converts a solid fuel into a combustible fuel in the presence of less oxygen than is necessary for stoichiometric combustion. One of the gasification methods involves utilizing a crossdraft gasifier system using rice straw as a syngas filter. The goal of this research is to determine the ideal temperature for producing syngas with the highest efficiency through the gasification process. According to study, the most ideal temperature for producing excellent quality syngas is acquired at 750°C with syngas concentration of CH_4 1.99%, CO 7.97%, CO_2 9.03%, H_2 6.82%, O_2 12.11%, 62.08% N_2 and 16.56% efficiency reached at 650ºC.

Keywords: crossdraft gasifier, efficiency, gasification, syngas

1. Introduction

Energy demand in Indonesia is rising in line with industrial development, while oil reserves are decreasing year after year. This may result in future energy security; hence it is vital to examine energy utilization while addressing energy demand concerns. One of the causes of rising energy consumption is an increase in population, which is followed by an increase in the number of cars. To address these issues, the government provided many options through the National Energy Policy (KEN), including converting, diversifying, and intensifying energy [1],[2].

One solution to the oil energy dilemma is to employ alternate energy sources such as coal. Coal supply will rise by 637 - 664 million tons in 2022, according to the Ministry of Energy and Mineral Resources (ESDM). Coal may be utilized as an alternative energy source via a variety of methods, one of which called gasification [3],[4].

The gasification process is a thermochemical conversion of solid fuel into combustible fuel that requires less oxygen than stoichiometric combustion [5],[6]. The gasification process produces CO, H_2, CO_2, CH_4, a few long chain hydrocarbons (ethene and ethane), H_2O, N_2, and a variety of small particulates such as charcoal, ash, tar, and alkali [7],[8].

There are three types of gasifiers in the gasification process based on the flow direction; updraft gasifiers, downdraft gasifiers, and crossdraft gasifiers. These gasifiers have advantages and disadvantages in a number of areas, including gasification efficiency, pollutants in gas products, operational, economic, and environmental concerns, to mention the few [9,[10],[11]

According to studies, the higher the reactor temperature, the more syngas products with a longer flame period may be produced. According to this study, the longest flame duration was at 700ºC for 4.56 minutes and the shortest flame duration was at 600ºC for 4.10 minutes [12][13].

Based on these issues, the authors will undertake research on the sustainability and optimization of coal usage by the gasification process of the crossdraft gasifier system, including a study of the influence of reactor temperature on the rate of fuel-to-gas conversion using coal.

2. Research Methods

This study used a prototype crossdraft gasifier to convert coal into syngas, with the gasification technique employing rice straw as a filter. The Crossdraft gasifier prototype is separated into two parts: the gasification reactor and the gas cleaning system. The combustion chamber and filter are the two primary components of a gasification reactor [14].

The combustion chamber is where the gasification process takes place which is made of carbon plate material with a thickness of 2 mm. The choice of this material was based on consideration of carbon plates having a melting point of >1000°C. The combustion chamber is made in the form of a cylinder with an outer side of 60 cm and a height of 120 cm. On top of the tractor, a fuel inlet opening is made with an outside diameter of 50 cm. On the upper right of the combustion chamber, a hole with a size of 4″ is made as a place for syngas output. And at the bottom there are two holes intended for air entry by the blower and the other for disposal of tar or residual fuel.

The filter is used to separate gas from solid particles left over from the preceding phase; the particulates cling to the filter medium and settle. A straw filter is a gas cleaning device that uses straw as a binder for filthy particles still present in the gas. The straw filter is tubular with a top cover. The tube is 36 cm in height and 28.4 cm in diameter. The tube is made of stainless steel. The gas will be measured and directed to the Generator Set after passing through the straw filter in this arrangement.

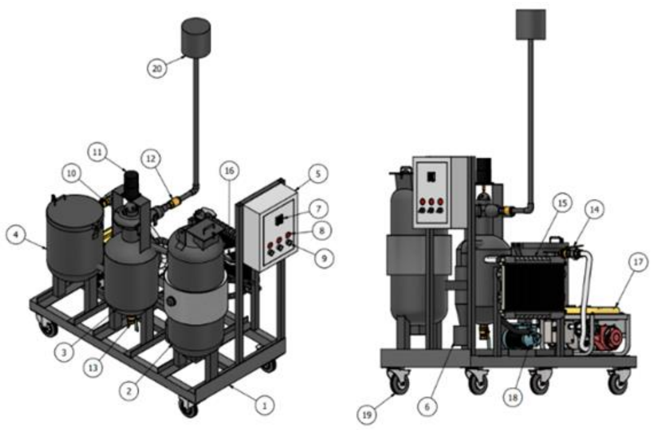

Figure 1. *Crossdraft Gasifier Design*

Description:
1. Equipment Frame
2. Reactor
3. Cooler
4. Filter
5. Control Panel
6. Cyclone
7. Set Temperature
8. Indicator Lamp
9. ON/OFF Switch
10. Blower
11. Motor
12. Flare Stack Valve
13. Cooler Valve
14. Filter Valve
15. Radiator
16. Radiator Fan
17. Generator Set
18. Pump
19. Wheels
20. Flare Stack

3. Result and Discussion

The raw material utilized is lignite coal with a gross caloric value (GCV) of 5794 cal/gr, with 2 kilograms of coal used for one procedure and 300 gr of rice straw filter used. The study used several gasification reactor temperature changes, namely 600ºC, 650ºC, 700ºC, and 750ºC, to collect data that would be examined to estimate fluctuations in gasification reactor temperature over the length of the flame. Furthermore, syngas data derived from gasification outcomes will be evaluated for composition. This syngas was studied with a Gas Analyzer at the Chemical Engineering Laboratory of Politeknik Negeri Sriwijaya. When the temperature on the control panel reaches the set-point temperature, a sample is obtained using a hose linked to the gas bag as a reservoir for the analysis syngas.

Table 1 shows the findings of observations on the generation of combustible gas fuel (syngas) with variations in reactor temperature for the duration of the flame from the study that has been conducted.

Table 1. *Variation of Reactor Temperature on Flame Duration*

Variation	Reactor Temperature(°C)	Syngas Temperature(°C)	Flame Duration (minutes)
Variation I	600	38	1.05
Variation II	650	40	3.28
Variation III	700	41	6.37
Variation IV	750	43	12.55

3.1. The Influence of Reactor Temperature Variation on Flame Duration

In the gasification process the following reactions occur:[14]

Partial oxidation process

$$C + 1/2\, O_2 \rightarrow CO \quad (1)$$

Total oxidation process

$$C + O_2 \rightarrow CO \quad (2)$$

Boudouard Reaction

$$C + CO_2 \rightarrow 2CO \quad (3)$$

Water-Gas Reaction

$$C + H_2O \rightarrow CO + H_2 \quad (4)$$

Water Gas Shift Raction

$$CO + H_2O \rightarrow CO_2 + H_2 \quad (5)$$

Methane Reaction

$$C + 2H_2 \rightarrow CH_4 \quad (6)$$

Steam Reforming

$$CH_4 + H_2O \rightarrow CO + 3H_2 \quad (7)$$

Dry Reforming

$$CH_4 + CO_2 \rightarrow 2CO + 2H_2 \quad (8)$$

One of the parameters influencing the gasification process is the temperature of the gasification reactor; the influence of this temperature change may be observed in the length of the flame created and the quality of the syngas produced. The study was conducted in four steps to determine the output mass value and flame duration for each reactor temperature variation. The output mass data for the first gasification process variation at 600°C was 0.3278 kg, and the flame duration was 2.28 minutes. The output mass data for the second gasification process variation at 650°C was 356.1 grams, and the flame duration was 3.28 minutes. The output mass data for the third variation gasification process at a temperature of 700°C was 258.6 grams, and the flame duration was 6.37 minutes. The output mass data for the variation fourth gasification operation at 750°C was 103.3 grams, and the flame duration was 12.55 minutes.

Increasing the temperature in the gasification reactor causes an increase in endothermic reactions, both heterogeneously and homogeneously, such as the Boudouard Reaction (3) and Water Gas Reaction (4), in which the carbon content in the fuel tends to react with CO_2 and water vapor at high temperatures (5). Steam Reforming (7), which is the reaction between CH_4 and H_2O, and Dry Reforming (8), which is the reaction between CH_4 and CO_2, are two other endothermic processes that occur (6). The increased rate of chemical reactions causes the coal fuel used in the gasification reactor to create combustible gas (syngas) more quickly, as seen by the longer flame duration and lower residual mass production (charcoal). Figure 2 illustrates how the length of the flame increases as the temperature of the gasification reactor increases. This is due to the fact that when temperature increases, so do the reactions that occur during the gasification and combustion processes. The higher temperature in the gasification reactor stimulates the endodermic reaction, causing the fuel to react faster and create producer gas.

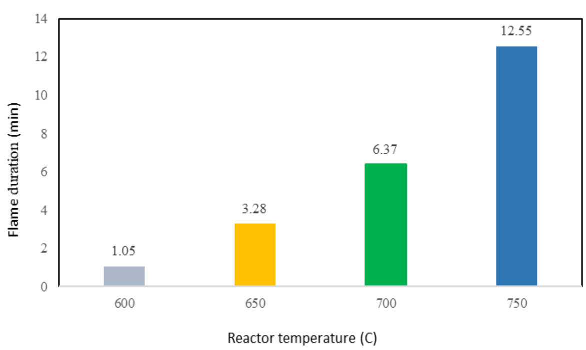

Figure 2. *The Influence of Temperature Variation on Flame Time*

3.2. The Influence of Reactor Temperature Variations on Syngas Composition

The composition of the syngas produced is also affected by reactor temperature. CO, CO_2, CH_4, H_2, N_2, and O_2 are the syngas components generated. The high calorific value of the coal utilized, in addition to the reactor temperature, can indicate the quantity of carbon content in the coal. As a result, the gasifier contains more CO than H_2. CO, H_2, and CH_4 composition values are affected by the final composition utilized [15]. Figure 3 show the influence of reactor temperature fluctuations on syngas composition.

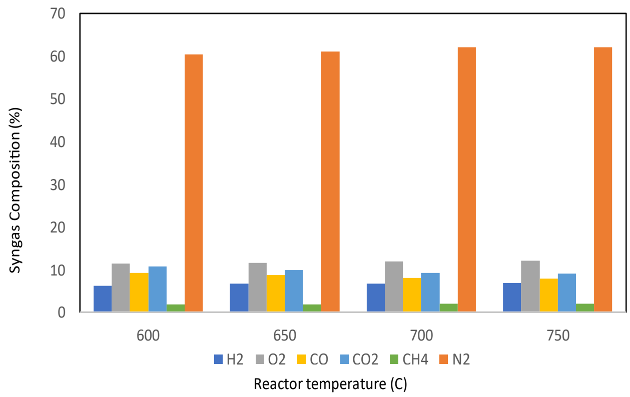

Figure 3. *The Influence of Reactor Temperature Variations on Syngas Composition*

Increasing the temperature in the gasification reactor increases carbon conversion efficiency; also, the higher the reactor temperature employed, the more volatile matter is emitted [17]. According to the images above, the composition of the syngas varies as the reactor temperature increases; CO_2 levels will be greater if the reactor temperature is low, and lower if the reactor temperature is high. Furthermore, the CH_4 level rose as the reactor temperature climbed. Rasmussen attributes the high composition of syngas at high temperatures to a reduction in hydrocarbons and the conversion of CO_2 to CO [18].

The temperature of the reactor has a significant impact on coal gasification performance due to the balance of endothermic and exothermic processes [19]. Furthermore, increasing the temperature of the reactor promotes an increase in the value of H_2. At high reactor temperatures, the Boudouard Reaction (3), Water gas reaction (4), and Water gas shift reaction (5) induce a rise in H_2 and a drop in CO_2 concentration. The concentration of CH_4 rises as the temperature of the reactor rises.

At high reactor temperatures, a dry reforming process (8) occurs, in which CO_2 is transformed to CO_2, causing the CO_2 level to drop as the reactor temperature rises. When a result, as the reactor temperature rises, so does the CO concentration. The CO concentration, however, reduces owing to the usage of filter mass since it is absorbed in the filter. The usage of filters reduces the volume percent of CO_2 and CO because they are much heavier gases than the other gases in the syngas and will be retained by the filter [20]. The surface adsorption ability of biomass as a filter material has the greatest impact [21].

3.3. The Influence of Reactor Temperature Variations on Thermal Efficiency

According to Figure 4, the reactor temperature, which influences the production of syngas content, also influences the outcomes of the thermal efficiency of the gasification process. The best thermal efficiency, 16.56%, was obtained at a reactor temperature of 650°C, while the lowest thermal efficiency, 16.14%, was obtained at a reactor temperature of

600°C. The low heating value (LHV) syngas value is calculated by multiplying the CO, H_2, and CH_4 compositions by the heating value of each component. Furthermore, the thermal efficiency value is calculated by dividing the syngas LHV by the source material (coal) LHV. The type of heat contained in coal determines efficiency, therefore whether or not efficiency relies on the quantity of calorific value transformed into combustible energy in the form of syngas.

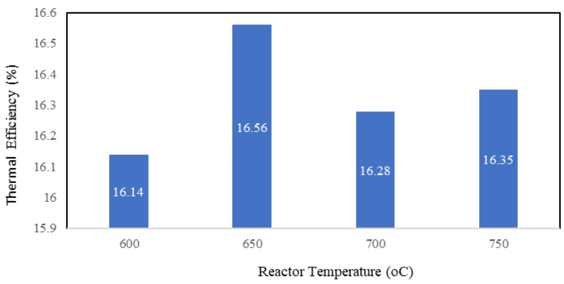

***Figure** 4. The Influence of Reactor Temperature Variations on Thermal Efficiency*

4. Conclusion

One of the elements influencing the gasification process is reactor temperature. The duration of the flame during the gasification process indicates a good gasification process, which will create good syngas. The high reactor temperature creates a longer flame because the reactions that occur during the gasification process increase with increasing temperature. The higher temperature in the gasification reactor stimulates the endodermic reaction, causing the fuel to react quicker and create syngas. According to this, the longest flame occurred at a reactor temperature of 750°C for 12.55 minutes. Changes in temperature will have an impact on the composition of the syngas produced. Increasing the reactor temperature assists in increasing the concentration of H_2, decreases the concentration of CH_4, and increases the concentration of CO_2 in the syngas. This is because at high temperatures, carbon conversion occurs while volatile matter decreases. As a result, the greatest syngas quality in terms of CH_4 composition occurs at 750°C reactor temperature with 1.99% CH_4 content.

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