Fuel substitution by wood gasification for diesel electricity generator

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Abstract. Gasification is a technology for converting biomass into energy in the form of gas. The gas produced can be used as fuel in a diesel generator with dual fuel system. The purposes of this study were to identify the gasification characteristics of sengon, pine, and calliandra woods, as well as wood pellet to produce burnable gas and to analyze the role of burnable gas produced in reducing diesel input in a dual system generator engine. In this study, a locally designed downdraft gasifier and a commercially available diesel engine generator with 12 kW maximum power output were used. The study investigated wood consumption rate, color of fire, and percentage of diesel savings from each wood type. Gasification process was running well, of which burned woods and wood pellet produced an orange-stable flame. The consumption rate of wood was 18 kg/hour for sengon, 15 kg/hour for calliandra, 8 kg/hour for Pine, while wood pellet was 6 kg/hour. Diesel savings with gas co-firing was 33%, 50% and 95% for sengon, calliandra and pine respectively. The low efficiency of diesel savings may due to heat radiation in the reactor and heat loss in the gas purification process or a decrease in efficiency of the diesel generator engine.

1. Introduction

Human needs for energy annually increases with increasing population, national development, and technological developments. Petroleum and coal are fossil-based energy sources that still serve as the main energy source in the country. According to the British Petroleum [1], in 2017 Indonesia energy consumption reached 175.2 million tons of fossil fuels. The use of petroleum continues to increase while its reserves are becoming limited, causing its management should be done judiciously. Owing to this fact, it is about right time to encourage the utilization of new renewable energy as a solution to reduce dependence on fossil energy [1].

Various renewable energy sources developed include solar, biodiesel, geothermal, wind, and biomass. Biomass energy has high potential for development in Indonesia with the amount of biomass reserves reaching as high as 261.99 million tons or an equivalent of 49.81 GW of electricity. The abundance and distribution of existing biomass throughout the country are important factors that made biomass very suitable to substitute fossil-based energy sources to produce electrical power for use in the entire territory of Indonesia. In addition to its supplementary merit with considerable amounts, also less likely to cause a negative impact on the environment, the use of biomass as a fuel has another positive influence i.e. recycling the CO₂ so that the net emissions of CO₂ into the atmosphere is zero [2].
As forest resources in Indonesia is the third largest resources in the world, it is very attractive to utilize wood biomass as renewable energy source. Sengon (Paraserianthes falcataria), pine (Pinus merkusii), and caliandra (Calliandra calothyrsus) are among recommended fast growing species that have promising potency as wood energy. Meanwhile the biomass gasification is considered as the proper technology and indispensable innovation of renewable energy for local community, especially in a remote island in the near future.

Gasification is a conversion technology from biomass to energy in the form of gases for further utilization, such as electric power generation. The gasification process starts from the imperfect combustion of wood in the reactor to produce a burnable gas, then the gas is cooled and purified, and enters into the diesel engine to be further converted into electrical energy [3]. This gas coming from gasification process streamed into a dual fuel engine system, technically designed to decrease the diesel consumption. Although the gasification gases are able to generate electric power, it is important to consider to what extent the energy coming from wood biomass can affect the amount of electrical power produced. Therefore, it is necessary to learn the burnable gas usage on the performance of diesel engines by looking at the amount of diesel consumption spent to produce certain amount of electricity.

The purpose of this study was to identify the gasification characteristics of sengon, pine, and caliandra woods, as well as wood pellet to produce burnable gas and to analyze the role of burnable gas produced in reducing diesel input in the dual system generator engine.

2. Materials and Methods

2.1 Materials
Biomass sources were 20 kg each of sengon wood chips size 4 x 2 x 1 cm; Pine wood chips size 3 x 1.5 x 1.5 cm; while Caliandra wood chips had a diameter of ± 2-5 cm and 3 cm length (Figure 1).

![Figure 1. The raw materials of wood gasification (a) sengon; (b) pine; and (c) caliandra wood](image)

Wood chips of sengon, pine, and caliandra then were dried up for five consecutive days under sunlight for 7 hours/day. This drying was done to reduce the moisture content of biomass reaching <14% [4]. According to Hardiansyah et al. [2] drying wood chips with an average wood length of 2.8-4 cm in cylindrical shape can be done using an oven with a temperature 70°C for 2 days.

2.2. Methods
2.2.1. Testing thermal gasification process
Testing thermal gasification process was done with the following stages:

a. Preparing gasifier unit with reactors measuring 30 x 30 x 60 cm, filling in water on the top water seal, preparing the blower, Ash grating is positioned at the ready to fill position and the Ash box was closed at the bottom

b. Sengon wood chips as much as 4 kg were inserted into the reactor, and then burned using a little amount of kerosene followed by turning on the blower

c. When the flame is evenly distributed at least 2/3 extents of the reactor area, the blower was turned off and the reactor top is closed. In this process the time is required for initial startup was measured.
d. Blower was returned on again, then waited until Syngas come out of the thermal nozzle, of which upon Syngas exit from thermal nozzle then the syngas was burned.

e. Observing and documenting the resulting flame color, then measuring the duration of the gasification of sengon wood to obtain the rate of biomass consumption during the gasification process

f. Once the raw material is depleted, the charcoal is ejected out through the bottom box, usually still hot and smoldering then quenched with water

g. The same procedure is done for raw materials of pine, caliandra wood, and wood pellet

2.2.2. Dual fuel engine system operation

Gasifier unit with a reactor measuring 32 x 33 x 116 cm and a 24 HP diesel engine are prepared. The steps needed to connect the gasifier unit to the diesel engine including (1) removing the nozzle and closing with the blind flange, (2) turning on water pump to flow water in a flow water scrubber with water discharge between 25-36 L/minute, (3) preparing gas clean up by filling the four compartment of gas washing tubes with water-water-diesel-diesel; The amount of diesel was 8 L for running the machines for 500 hours, (4) resulted syngas then will flow into the connecting flow tube towards diesel engine, (5) switching diesel engine on and setting the power voltage to 220 volts, (6) follow from the starting step as a test of the thermal gasification process up to closure of reactor, (7) slowly closing the syngas valve on the diesel engine until the diesel engine sucks syngas that has been cleaned through the gas clean up.

The amount of each type of wood used was 10 kg. After the combustion process then syngas was flowing into the diesel engine through the connecting tube. Measurements included how much diesel required when combined with a certain syngas from each type of wood, compared to diesel consumption on single fuel operations at the same length of operating time.

2.3. Data Analysis

2.3.1. Wood consumption rate

\[ V = \frac{\text{Amount of wood usage (kg)}}{\text{Duration of burning (hours)}} \]  \hspace{1cm} (1)

The percentage of diesel saving on diesel engine can be calculated using the following equation [2]:

\[ \% \text{ Saving} = \frac{V_1 - V_2}{V_2} \times 100\% \]  \hspace{1cm} (2)

where, \( V_1 \) = diesel consumption on single fuel engine, \( V_2 \) = diesel consumption on dual fuel engine

2.3.2. Specific gasification Ratio (SGR)

SGR is the rate of biomass gasification per reactor unit area [5]. SGR can be calculated using the following equation:

\[ SGR = \frac{m_{bb}}{A} \]  \hspace{1cm} (3)

where, \( SGR \)= Specific Gasification Ratio (kg/m² hour), \( m_{bb} \)= Biomass consumption rate (kg/hour), \( A \)= Cross-sectional area of the reactor (m²)

2.3.4. Electrical Energy Potential

Every 1 kg of dry wood has a different calorific value, and one Kcal contains 4,200 Joule of energy. The higher the heat value, the greater the energy content. Estimation of potential electrical energy can also be done using the biomass conversion approach to wood pellet (WP), as shown in Table 1.
Table 1 Conversion of biomass to electrical energy

| Energy (J) | Energy (MJ) | Electrical (kWh) |
|------------|-------------|------------------|
| 1 kg dry wood = wood calorific value x 4200 | 1 kg WP = 19.8 MJ | 3.6 MJ = 1 kWh |

In producing 1 ton of WP it takes as much as 1.5 tons of biomass [6]. According to Payne [7], every kilogram of WP contained energy amounted to 19.8 MJ. The energy in MJ units was converted into kWh units (1 kWh = 3.6 MJ) with the efficiency of the machine used at 75%.

3. Results and Discussion

3.1 Gasification

Utilization of biomass as a fuel needs pre-processing in advance to facilitate its utilization, commonly known as biomass conversion [3]. According to Susanto [8], biomass can be converted into energy through three processes, i.e. thermochemistry, biochemistry and oil-containing seed extraction. One example of thermal or thermochemical conversion techniques is gasification.

The gasification process to produce burnable gas was conducted through four phases i.e. drying, pyrolysis, oxidation, and reduction (Figure 2). Drying phase aims to remove water contained within the biomass material and turn it into moisture. Subsequently biomass materials would undergo pyrolysis process until it decomposes, which will produce tar, CH₄, and charcoal. At the combustion phase, the carbon will be burned to carbon dioxide, and hydrogen will be burned into moisture. At the reduction phase some reactions occurs that produce CO gas and H₂ as the main ingredient of burnable gas.

![Figure 2. Phases of gasification process [9]](image)

The burnable gas produced from this process still contains moisture, tar, nitrogen gas, ash particles, and at high temperatures. Efforts that can be done to remove the unwanted contents is passing the burnable gasses through gas clean up.

Figure 3 shows the biomass gasification unit used in this experiment equipped with a series of gas clean up consisting of cyclone, water condenser, water scrubber, and gas washing. The burnable gas from the reactor will flow through the cyclone to reduce its solid particles (charcoal and ash). Furthermore, gas is flowed into water condenser to be cooled down, reduce its tar content, and condensed its water content into liquid smoke. Liquid smoke is a byproduct of the gasification process that is useful for fish smoking, pesticides, as well as liquid fuels [10]. After passing the water condenser, burnable gas flowed into water scrubber to be cooled down. Burnable gas further was flown into the gas washing that is the water-water-diesel-diesel compartment to be cleaned. The water in the compartment serves to capture the particles and the remnants of tar, while the diesel serves to capture the remnants of
the particles. Eventually the cooled and cleaned burnable gas can be supplied to a diesel engine to be converted into electrical energy.

The gasification process will produce heat and flammable syngas. The gas can be used as fuel in diesel engine dual fuel system through the connection pipeline. According to Hardiansyah et al. [2] dual fuel system is a technology that aims to minimize diesel consumption although the use of a little diesel is still needed as an ignition tool. The application of dual fuel system will save diesel use up to 70% or more.

![Figure 3. Locally designed biomass gasifier](image)

### 3.2 Thermal gasification characteristics

Biomass conversion process of sengon, pine, and caliandra wood as well as wood pellet was carried out in a reactor. The amount of biomass consumption materials used is measured during a certain operating time, thus obtained the rate of biomass consumption as presented in Table 2. The initial starting time for each of the wooden biomass is 7 minutes long, while for wood pellet was 10 minutes. According to Jamilatun [11], the speed of ignition is depended on level of biomass water content, also the length of initial ignition can be affected by the shape of materials. When material was tightly compact, hard and heavy, then it would be slowly ignited and even though highly burned, it is not quickly exhausted that it could save the amount of biomass required.

| Type of biomass   | Rate of wood consumption (kg/hours) | SGR (kg/m²hours) | Energy (MJ) | Electrical (kWh) |
|-------------------|-------------------------------------|------------------|-------------|-----------------|
| Sengon            | 18                                  | 10.53            | 321.15      | 66.9            |
| Caliandra         | 15                                  | 8.77             | 289.80      | 60.4            |
| Pine              | 8                                   | 4.68             | 156.58      | 32.6            |
| Wood pellet       | 6                                   | 3.51             | 118.80      | 24.8            |

Consumption rate of sengon, caliandra, pine wood, and wood pellets, respectively were 18 kg/h; 15 kg/h; 8 kg/h; and 6 kg/h. The differences in consumption of wood can be influenced by the heat/calorific value contained in the biomass material. Judging from the calorific value, pine wood has a caloric value of 4660 kcal [12], is the largest among the three types of wood used. In addition, pine wood is also known as resin containing tree. The presence of extractive substances such as resin and tannins can increase its calorific value [13]. The higher calorific value of the material causes the combustion to be more efficient so as to save the needs of wood used.

From these data and then calculation of the SGR (Specific Gasification Ratio) value which is the rate of biomass gasification per reactor unit area [5] it was obtained a value of 10.53 kg/m² hours for sengon wood and caliandra wood amounting to 8.77 kg/m² hours while the SGR for pine wood was 4.68 kg/m² hours. The difference in the value of SGR for each biomass material used could be influenced by
the weight of biomass, the weight of charcoal formed, and the duration of the tool operation. The higher the SGR value the faster the gasification rate so that the consumption rate of biomass and the gas flow rate of burnable gas will be greater.

Meanwhile, wood biomass has the potential to increase its efficiency if the material is in uniform processed forms such as wood pellet. Based on the results in Table 2, among all the biomass materials used, wood pellet is the most efficient material. Although 6 kg of wood pellet produced only 24.8 kWh electricity but gasification using wood pellet resulted in a tool efficiency of 48.39%. Compared with other wood materials, i.e. caliandra wood required as much as 18 kg, the flow efficiency was only 17.93%. Similarly, 15 kg of caliandra wood and 8 kg of pine wood resulted in respectively tool efficiency of 19.87% and 36.81%. This was because wood pellet has uniform shape, dry, solid, and has a higher calorific value than wood, that the amount needed would be less as the combustion becoming more efficient, resulting that the energy contained in the wood pellet was not much wasted. According to Adrian et al. [14], wood pellet as a result of uniforming an existing biomass, has drier properties and smaller forms, easing combustion, storage, and distribution, and has greater heat energy when compared to woods before processing. Yokoyama [15] stated that wood pellet has a higher superiority compared to fossil fuels. Some of its advantages include: handling, ignition, and easy combustion; uniform fuel shape and properties; high energy content; and fewer toxic gas emissions.

Electricity needs per day at Gunung Walat Education Forest (GWEF) IPB University, Sukabumi, Indonesia amounted to 29.3 kWh [16]. Based on the results of this research, the needs of electricity in GWEF could be fulfilled with the installation of similar gasification tool with a capacity of 12 kWh. As shown in Table 2, as much as 18 kg of sengon wood contains an energy of 321.51 MJ or equal to 66.9 kWh when converted into units used in electricity with engine efficiency by 75%. The GWEF electricity could be provided by 15 kg caliandra wood, which would produce energy amounting to 289.80 MJ equivalent 60.4 kWh, or even with only 8 kg of pine wood, which gives 32.6 kWh of electricity in. According to Prayitno et al. [17] one factor that need to be considered in wood utilization as an energy material is the growth rate with the nature of dense branches, e.g. in the case of caliandra (C. calothyrsus). Based on caliandra biomass estimation at GWEF [16] of 116.37 tons/ha, the amount of biomass could potentially supply electricity at GWEF through wood gasification equipment for 2 years without replanting.

![Figure 4. The flame of gasification from (a) pinus wood, (b) caliandra wood, and (c) wood pellet](image)

Qualitative analysis was also done based on flame color and flame stability as a standard reference for the syngas produced before flowing into the generator set. The flame color resulting from the burning of pine and caliandra wood tends to be orange, while the combustion of wood Pellet produces a bluish orange flame color. According to British Petroleum [1] an orange flame can be caused by a hydrocarbon content that is not condensed. The results of this study were able to produce a stable flame, as shown in Figure 8. This phenomenon suggested that burnable gas produced by each biomass material have a fairly good quality and are worthy as fuel in the dual fuel engine system. In accordance with the statement by Pranolo et al. [18], biomass material that is burned and produces a stable flame, would produces gas from combustion that is suitable for use as fuel.
3.3 Operation of diesel engine dual fuel system

Prior to the experiments using syngas from woods on the dual fuel engine system, reference data was collected using the single fuel engine system using diesel as fuel. The electricity generator power provided a maximum of 12 kWh with a voltage setting at 220 volts to produce an energy of 43.2 MJ. Result of single fuel system operating machine is displayed at second column of Table 3. This data is needed for comparison with data from dual fuel system operation at the third column for calculation of diesel consumption savings.

Table 3 Diesel consumption for 1 hour usage of a diesel engine

| Wood type | Diesel fuel without gasification (L) | Diesel fuel with gasification (L) | Diesel fuel saving (%) |
|-----------|-------------------------------------|----------------------------------|------------------------|
| na        | 0.60                                | na                               | na                     |
| Sengon    | 0.40                                | 33                               |
| Pine      | 0.30                                | 50                               |
| Caliandra | 0.03                                | 95                               |

Table 3 shows a comparison of diesel consumption for single fuel systems and when dual fuel systems were operated. In general diesel consumption decreases with the addition of burnable gas. This means that burnable gas that enters the diesel engine combustion chamber can replace any amount of diesel to obtain the required power. The decrease in diesel consumption is possible due to a decrease in the flow rate of combustion air, characterized by a decrease in opening of syngas valve that causes the flow rate of burnable gas into diesel engine combustion chamber is getting bigger. According to Pranolo et al. [18] the increase in flow rate of burnable gas can increase fuel substitution and decrease diesel required.

Decreased diesel consumption can occur due to the addition of electrical loads. The higher electrical load is given, the less diesel consumption while the syngas that enters the diesel engine is increasingly larger. This is in line with results of Pranolo et al. [18] that the rate of diesel consumption is increasingly small with the increase in electrical power. Increased electric load causes increased room temperature on diesel engines, and the high temperature in combustion chamber can increase the fuel evaporation while the air condition inside become better. This phenomenon causes the combustion process to become more effective so that the rate of diesel consumption is getting smaller.

The greater the burnable gas flow rate into the engine caused the lower percentage of diesel injected into combustion chamber to keep the engine speed constant, meaning diesel replacement will be even greater. Please note that in this case, the burnable gas role is still secondary to diesel, meaning it could not replace diesel 100%. However, syngas has the advantage of achieving homogeneity of air-fuel mixture, that expected combustion delay period in combustion chamber will be getting shorter [19].

Percentage of diesel savings with burnable gas from gasification of sengon, pine, and caliandra wood were respectively 33%, 50%, and 95% (Table 3). According to Sudarmanta and Dirgantara [19], efficiency of the diesel-saving dual fuel system is generally more than 40%. These results indicate that pine and caliandra wood are suitable for use as biomass material in gasification process to be converted into electrical energy because it produces a diesel saving >40%.

The low value of diesel saving efficiency with gas gasification of sengon wood can be caused by heat radiation in the reactor and heat loss in the gas purification process, or the decrease in efficiency of the diesel engine. A diesel engine power can decrease [19] because of wasted energy from fuel. This happens because the air-fuel mixture has become very rich that combustion in combustion chamber is no longer perfect. Considering its benefit, utilization of syngas alone as fuel to generate electricity has additional benefit, because gas does not pose an environmental problem. Nevertheless, when efficiency in the utilization of syngas for power generation is increased, problems of electrification in remote areas of Indonesia could somehow be overcome.
4. Conclusions
Gasification process of sengon, pine, and calamandra woods in a locally designed gasifier unit to produce syngas has been running well. The higher calorific value of certain wood type causes the combustion to be more efficient, that lesser amount of the wood is needed. Percentage of diesel savings with syngas from gasification of calamandra wood amounted to 95%, is the highest while diesel savings with syngas of Sengon wood was only 33%. The low value of diesel savings efficiency with syngas can be caused by heat radiation in the reactor and heat loss in the gas purification process, or the decrease in efficiency of the diesel engine after certain period of operation.

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