Design and development of biomass gasifier reactor to produce syngas

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Abstract. Gasification process is strongly influenced by the gasifier reactor to produce syngas. This study aims to design and make an updraft type of gasifier reactor without blower so that it does not require electric power in its operation, but use power from engine suction. This gasifier design is suitable for small scale power plants which are not connected to the main electricity network (off-grid system) in rural and remote areas. Materials used in manufacturing the gasifier reactor are consist of type 304 3 mm stainless steel, 3 mm diameter of stainless steel pipe, 3 mm iron plate, and fire cement. The experiment and test results show that the highest efficient and the most optimal biomass in the gasification process is coconut shell charcoal, because coconut shell charcoal has a dense structure and at the time of the experiment, coconut shell charcoal was filled 15 cm below the gas outlet pipe hole. From the economic value of the gasifier reactor that has been produced, the lowest cost result is diesel with EFB charcoal, because in this experiment EFB is the biomass that is not purchased. The additional use of empty bunches of charcoal is able to save 50% diesel usage

1. Introduction

Indonesia is a large country, both land and sea, whose sea area reaches three quarters of the total area of its country and is also a country that has the longest line in the world after Canada. Given these geographical conditions, the provision of adequate, equatable, affordable electrical energy services is a special challenge faced by Indonesia [1, 2], because it will require a lot of money with relatively high technological sophistication and a long development time. The availability of electrical energy is also one of the priorities in supporting the improvement of welfare and national economic growth. Indonesia will also face constraints on fossil energy sources, such as petroleum and coal, as the main ingredients in the electricity production business in Indonesia, whose supply is decreasing and is expected to run out in the next 30 years [3].

One of the dimensions in the power system planning that must also be considered is the problem of high environmental pollution. Concern for the environment must also be a concern, because dependence on fossil energy from the power generation sector will produce greenhouse gas emissions, so there must be environmental control efforts by implementing renewable energy [3]. Energy security is a crucial problem in the context of supporting national development through the realization of sufficient, safe, quality and diverse energy availability and is evenly distributed throughout Indonesia at an affordable price [4].
In addition to the obstacles related to the use of fossil energy sources described above, there are great opportunities for Indonesia to use potential renewable energy resources, including solar energy sources, hydro and micro hydro energy sources, wind energy sources, geothermal energy sources, ocean wave energy sources, and biomass energy sources [5]. In producing electrical energy [6], especially for rural areas or remote areas that have not yet received electricity. Based on data in 2018, there were 2,288 villages that have not had electricity throughout Indonesia [7].

The difficulty of providing electrical energy in rural areas due to low population density will result in low electricity demand, so that it is not commensurate with the large investment for the development of electricity grid infrastructure [8]. Small-scale, off-grid power plants are one of the most appropriate options for dealing with this problem, either as a first step in the electrification process or as a basis for planning future rural and remote grid development. One of the local commodities that can be used as a source of renewable energy to generate electricity is oil palm [9].

Indonesia is a country that has an area of oil palm plantations reaching 8,774,226 hectares and crude palm oil (CPO) production of 33,500,691 tons in 2016. The locations of these oil palm plantations can be found in 26 provinces in Indonesia [10]. In the process of processing fresh fruit bunches into palm oil, around 45% of the material will become solid waste in the form of litter, powder, fibers, shells, and empty bunches. About 50% of the solid waste is empty bunches [11]. Until now, the use of empty bunches as fuel is still very limited. The empty bunches will have added value as a renewable energy source with the gasification process.

Gasification is one of the thermal conversion processes of biomass and coal into combustible gases. Carbonaceous solid fuels are reacted with oxygen, air, steam, or a mixture thereof to become mainly: carbon monoxide (CO), hydrogen (H2), methane (CH4), carbon dioxide (CO2), a small amount of hydrocarbons (ethane, ethene) which are known as synthetic gases or syngas [12]. The gasification process is carried out in a gasifier, which is a tool or reactor where four different thermal and chemical reactions take place, namely combustion, oxidation, pyrolysis, and drying. Gas resulting from the gasification process contains impurities such as tar, particles, nitrogen, and sulfur (H2S, COS) [12, 13]. One of the efforts to reduce tar content in the gasification process is the selection of the reactor type.

Several studies have been carried out to develop gasifier reactors and power plants made from palm oil waste. Adjar (2010) designed a gasifier furnace for updraft type empty bunches with the parameters used in the intermediate design, namely the heating value of biomass fuel, the energy required for certain purposes, and the duration of the furnace operation [7]. Rinovianto (2012) tested the updraft gasification system by modifying it into a system with two output areas, namely in the area above the gasifier such as the conventional area and in the area below the gasifier in an effort to reduce the tar content of the combustible gas [14]. Siregar (2015) made a gasifier system with the largest combustion gas capable of CO gas with the least amount of tar. The result can generate power of 40 kW with an installed gas engine capacity of 50 kW or 80% efficiency and can operate for 6 hours [15].

Wetar (2018) utilizes palm oil liquid waste to be processed as a renewable energy source in a biogas power plant [16]. Sanjaya (2018) plans a downdraft type gasification process with empty bunches as an energy source so that it can produce a gasification output power of 50.96 kWh [17]. Based on several studies that have been done, the design of a gasifier without a blower has not been carried out which utilizes the engine suction power to operate it.

Based on electricity conditions, oil palm commodity in Indonesia, and literature studies, the aim of this research is to realize a renewable energy power plant unit by utilizing local potential, namely biomass in the form of palm oil residue / solid waste. The solid waste will be processed using a gasifier to produce syngas for use as a mixture or even as a substitute for fuel oil as fuel for power plants. The gasifier reactor design uses gasification technology without a blower so it does not require electric power to operate it.
2. Methodology
The idea to design a simple biomass charcoal gasifier reactor arose based on its high efficiency during an emergency. This selection is based on the simplest updraft gasifier type, more economical, uncomplicated construction and simple mechanism, biomass charcoal will burn out, low output temperature, and have high efficiency. This reactor is designed to have a height of 110 cm and a thickness of 15 cm on each side. This design aims to achieve on grid electrification targets for residential areas that are prone to natural disasters. The prototype unit is a stainless component in the form of rectangles and squares which will later be combined into one tool, which the reactor has a function as a place to convert solid fuel into gas and at the same time keep the gas free from harmful substances.

In other words, a gasifier is a device or reactor that uses gasification techniques or the process of using heat to convert solid biomass or other carbonaceous solids into gas. With the gasification process, it can convert almost all solid organic matter into clean fuel gas. Materials that are used in the gasifier reactor manufacturing consist of type 304 3 mm stainless steel, 3 mm diameter stainless steel pipe, 3 mm iron plate, fire cement. The fixed frame unit is a component that functions as a foundation and support for the gasifier reactor. This component is made of angle iron whose job uses welding work.

In this research, the air and gas flow is made with a slight curve, with a view that the gas flow will be easier. So that this gasifier does not require electrical energy in its operation to drive the blower, but uses engine suction power. Before the process of the gasification residue begins, we process it first, with the hope that tar and other impurities in the gas will be minimum point. So that only leaves the producer gas which contains H2, CO, and CH4 which are known as syngas. Gas producer, which is rich in combustible gas, is then used as fuel for the motor that drives the generator to generate electrical energy. Air enters through the bottom of the gasifier through the air holes. This air flow is in the opposite direction to the flow of fuel entering from the top of the gasifier.

The resulting producer gas exits through the top of the gasifier, while the ash is taken at the bottom of the gasifier. The combustion reaction in this gasifier occurs near the grate followed by a reduction reaction. The reduction reaction will produce high temperature gas. The gas from the reaction (producer gas) moves to the top of the gasifier through the fuel bed, the producer gas will be in contact with the lowering fuel, causing a pyrolysis process and heat exchange between gas and fuel. The sensible heat given off by the gas is used as fuel.

In the process of determining the basic biomass fuel for gasifier design tools, three types of biomass were tested, including wood charcoal (acacia wood), and coconut shell is one type of biomass which has the potential to produce energy. One way to convert it into energy is by pyrolyzing coconut shells into charcoal. Oil palm fruit empty bunches (FEB) are waste from plantations which are very abundant in Indonesia, there have been many studies that have been carried out by utilizing the empty bunches waste to become a product of high economic value and one of them is turning it into charcoal so that it can be used as gasifier fuel.

![Figure 1. Gasifier Reactor Design; (a) Updraft Gasifier [1] (b) Reactor 3D Design](image-url)
Figure 2. Biomasses used in the gasification process; (a) acacia wood, (b) empty fruit bunch, (c) coconut shell

3. Process Principle

The gasifier reactor works by entering the filling material in the form of biomass, for example wood charcoal, coconut shell charcoal, and EFB with a maximum limit of 20 cm below the gas pipe hole connected to the cooler. Biomass first goes through a charring process until it becomes charcoal ready to enter the gasifier reactor for the gasification process. The charcoal is heated first by doing manual combustion and inserting it gradually through the upper hole, after the charcoal burning process occurs, then enough biomass is used so that the combustion takes place properly. Wait a few minutes for it to reach a temperature of 800°C-1000°C so that the gas content produced by the biomass is optimal for entering the diesel engine.

Then the gas produced from the charcoal will come out through the outlet pipe that connects the reactor and the cooler to reduce the temperature of the gas produced by the reactor. After the cooling process occurs, the gas will come out through the outlet which is connected to the filter, then the gas will enter the filter and the incoming tar filtering process occurs, with the position of the gas entering from below, the tar filtering process occurs twice, the gas that enters the steam pipe hole, The gas will circulate in the first filter, namely charcoal, after going through the process of filtering the tar in charcoal using wood charcoal as much as 3.49 kg, the next process is filtering using foam.

After removing the fire in the air filter inlet, close the filter valve then open the valve that is connected from the gas filter output pipe to the diesel engine which is connected by a hose. After entering the diesel engine, the diesel engine is connected to the generator using a belt so that it can distribute electrical energy to the load to be used. The electrical energy generated by the generator will be connected to the load used, namely 10 units of 1 kW water heater or 10 kW of load put in a bucket filled with water. Figure 4. shows different components of the biomass gasifier for the purpose of experimental setup.

Figure 3. Components of The Gasifier; (a) combustor, (b) air isolator and cooler, (c) gas filter
4. Result and Discussion

4.1. Gasifier Performance

In the pyrolysis process, to convert biomass into fuel for this gasification process, coconut shell takes about 5-6 hours, while EFB takes about 6-8 hours longer than the coconut shell pyrolysis process because the weather during the drying process of the oil palm reservoir is not optimal so that there is still water content. To ensure the performance of the gasifier reactor, testing is carried out on the diesel engine without using a load, and it is seen from the efficiency of using diesel fuel. Experiments carried out for 20 minutes showed that coconut shell charcoal is more economical. The influencing factor is the texture of coconut shell charcoal which will be denser when it enters the combustion chamber because it is thin and fast and coconut shell charcoal also has a thin texture and coconut shell charcoal has a high calorific value.

The next experiment was carried out by adding 10 units of 1 kW water heater loads which were immersed in a bucket filled with water until the water heater was immersed in the water. Experiments using weights were carried out for 20 minutes. The results of the experiment show that the highest efficiency of biomass use is the use of solar biomass plus coconut shell charcoal. The influencing factor is the calorific value of coconut shell charcoal itself, because the higher the calorific value, the higher the energy produced. Table 1 shows comparison of all fuel efficiency and table 2 informs the comparison of calorific value and temperature profile for all the fuel type that has been use in the gasification process.

4.2. Temperature Profile

To find out how the combustion performance in the reactor is, check the temperature of the combustion chamber before opening the valve that goes into the diesel engine. Each biomass has a different temperature due to the dryness of the charcoal which is not yet perfect, the charcoal structure that enters the reactor is not evenly distributed, such as empty bunches of charcoal which have a different structure. Therefore, the temperature produced by the reactor is different, as shown in the table below.

In the table below, the most optimal combustion process is coconut shell charcoal, because coconut shell charcoal has a dense structure and at the time of the experiment, coconut shell charcoal was filled 15 cm below the gas outlet pipe hole. From the table above it is also found that the density of the incoming charcoal and the amount of charcoal that goes into the combustion is most efficiently 15 cm below the outlet pipe hole. This heat measurement indicates that the Castable TNC 17 type fire cement material can withstand heat up to 1,206°C.

| Table 1. Comparison of Fuel Efficiency |
|---------------------------------------|
| **Fuel Type**                  | **Testing Without Load** | **Testing With 10 kW of Load** |
|                               | **Fuel Consumption (ml)** | **Biomass Used (kg)** | **Fuel Consumption (ml)** | **Biomass Used (kg)** |
|----------------------------------|--------------------------|----------------------|--------------------------|----------------------|
| Diesel                          | 350                      | 0                    | 800                      | 0                    |
| Diesel + acacia wood charcoal   | 220                      | 2.8                  | 380                      | 2.8                  |
| Diesel + coconut shell charcoal | 200                      | 3                    | 350                      | 3                    |
| Diesel + EFB charcoal           | 280                      | 2                    | 400                      | 2                    |

| Table 2. Comparison of Calorific Value and Temperature |
|-------------------------------------------------------|
| **Type of Fuel & Biomass**                               | **Calorific Value (kcal/kg)** | **Temperature (°C)** |
|-------------------------------------------------------|-------------------------------|----------------------|
| Diesel                                               | 8,591                         | 754.2                |
| Acacia wood charcoal                                  | 4,800                         | 1206                 |
| Coconut shell charcoal                                | 5,700                         | 1166                 |
| EFB charcoal                                          | 3,353                         | 1166                 |

4.3. Cost of Fuel Consumption

In this experiment, testing was carried out to find the economic value of the gasifier reactor that has been produced. The calculation of the value of the use of diesel fuel and the use of diesel fuel with
biomass for 20 minutes testing at no load and with a load of 10,000 watts, the calculation formula is as follows

\[
\times \quad (1) \\
\times \quad (2) \\
\times \quad + \times \quad (3)
\]

where:
- \( \times \) = Price of diesel (Rp/litre)
- \( \times \) = Price of biomass (Rp/kg)
- \( \times \) = Diesel consumption (litre)
- \( \times \) = Biomass consumption (kg)

From the calculations, it can be stated that to start a diesel engine without load and use a load for 20 minutes, the lowest cost result is diesel with EFB charcoal, because in this experiment EFB is the biomass that is not purchased. The additional use of empty bunches of charcoal is able to save 50% diesel usage. Although the cost of using diesel fuel is cheaper than some that use biomass, the design of this gasifier reactor aims to be used in isolated areas or places, and from some areas many still do not utilize biomass, for example coconut shells. if it can be processed into charcoal, there is no need to pay to buy charcoal.

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**Table 3. Comparison of Fuel Consumption Cost**

| Fuel Type          | Testing Without Load | Testing With 10 kW of Load |
|--------------------|----------------------|---------------------------|
|                    | Cost of Consumption (Rp) | Cost of Consumption (Rp) |
| Diesel             | 3,290                | 7,520                      |
| Diesel + acacia wood | 16,068               | 17,572                     |
| Diesel + coconut shell | 22,880              | 24,290                     |
| Diesel + EFB       | 2,632                | 3,760                      |

5. **Results and Discussion**

A gasifier reactor has been designed, developed, and evaluated with the aim to achieve a simple biomass gasifier in the producer gas. The results of using biomass waste combined with diesel fuel to operate a diesel power plant for 20 minutes without load, the consumption of diesel combine with coconut shell charcoal (200 ml), diesel with acacia wood charcoal (220 ml), and diesel with EFB charcoal (280 ml). The results of using biomass waste combined with diesel fuel to operate a diesel power plant for 20 minutes with a load of 10,000 watts, diesel with coconut shell charcoal (350 ml), diesel with acacia wood charcoal (380 ml), and diesel EFB charcoal (400 ml).

The results of the experiment show that the highest efficiency of biomass use is the use of solar biomass plus coconut shell charcoal. The most optimal combustion process is coconut shell charcoal, because coconut shell charcoal has a dense structure and at the time of the experiment, coconut shell...
charcoal was filled 15 cm below the gas outlet pipe hole. From the economic value of the gasifier reactor that has been produced, the lowest cost result is diesel with EFB charcoal, because in this experiment EFB is the biomass that is not purchased. The additional use of empty bunches of charcoal is able to save 50% diesel usage. In the future, testing of the performance of the gasifier is still needed in order to produce lower tar levels. Some suggestions for testing the next stage are to use a generator with a larger capacity.

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