Mini solar water heating biodiesel plant by homogeneous catalyzing

Rinjani Ratih Rakasiwi1*, Syaifurrahman2, and Usman A Gani2

1Department of Chemical Engineering, Faculty of Engineering, Universitas Tanjungpura, Jalan Prof. Dr. H. Hadari Nawawi, Pontianak, 78124, Indonesia
2Department of Electrical Engineering, Faculty of Engineering, Universitas Tanjungpura, Prof. Dr. H. Hadari Nawawi, Pontianak, 78124, Indonesia

*Corresponding Author’s E-mail: rinjani_s@yahoo.com

Abstract. Biodiesel can be generated by the catalytic vegetable oil-transesterification at 45-60°C. The heat requirement for a reaction can be obtained from solar thermal energy. West Kalimantan is crossed by the Equator where the sun shines for 10-15 hours/day. Palm Oil Production reaches 2.2 million tons making biodiesel has great potential to be produced. Implementation of the ideas is mini plant technology with solar water heaters for biodiesel production. Solar water heaters as a source of thermal energy are used as heating fluid in reactor plant. This technology is simple, without the need for electrical energy, low operating costs and environmentally friendly. The purpose of this research is to produce biodiesel by using a homogeneous catalyst of 2% KOH in a mini biodiesel plant with solar water heaters. Solar heaters are designed flat which is capable of producing hot water at 60°C, consists of a heat collector and a water storage tank made of stainless steel and polystyrene as an insulator. Transesterification is carried out for 1 hour at 65°C using homogenous catalyst of 2% KOH mass. The biodiesel yield obtained 83.42%, fulfills the requirements according to SNI in the Acid Number which is 0.42mg KOH/g and the Methyl Ester content is 99.07%.

1. Introduction
Scarcity of fossil fuel encourages people to using new renewable energy from natural resources. Indonesian government is now concerning on implementing usage of Biodiesel as renewable fuel. B20 Program is a regulation program to require the mixing of 20% biodiesel and 80% diesel which have been implemented well in the transportation sector (Public Service Obligation) starting 2018. The mandatory has carried out massively in all sectors and will be continues gradually up to B100 [1]. Biodiesel is environmentally energy which produced from vegetable oil that has a high heating value close to the diesel (37-42 MJ/Kg) [2]. Burning biodiesel is more perfect and efficient than diesel and gasoline. Biodiesel does provide a reduction in harmful emissions, such as SOx, CO, hydrocarbons, particle matter, and soot as well as NOx in optimized diesel engines, together with net CO2 emissions [3,4].

Biodiesel can be produce from crude palm oil by methanolsis reaction (transesterification with methanol). Indonesia is well-known as the fifth biggest country who producer of palm oil in the world in 2019. The amount of palm oil is able to reach 43 million metric ton. Production growth has also increased reaching 3.61% [5].

Transesterification process takes place at 32-65°C for 1-2 hours [6]. Thermal energy from sun can be absorbed directly by the solar water heater as a hot fluid for fulfill the heat of transesterification.
Indonesia is on the Equator, causes the climate to be tropical where sunlight shines around 10-15 hours/day and the energy reach 4.80 kWh/m²/day [7]. Around 60°– 80°C temperature can be attained depending on solar radiation, weather conditions and solar collector system efficiency [8]. Solar water heater replaces an electric water heater, offer long-term benefits that go beyond simple Economics and 50 tons of avoided carbon dioxide emissions alone.

Solar water heating systems include storage tanks and solar collectors. Most solar water heaters require a well-insulated storage tank and it have an additional outlet and inlet connected to and from the solar collector. Solar collectors capture the sun’s electromagnetic energy and convert it to heat energy. The efficiency of a solar collector depends not only on its materials and design but also on its size, orientation and tilt. Solar water heating system has been design can be reaches 62°C that can be used for biodiesel production [9].

Transesterification take place in jacket heating reactor with agitation. Insulated jacket to reduce heat loss. Biodiesel is currently synthesized using homogeneous alkaline catalysts because the transesterification reaction by an acid catalyst is much slower than the base-catalyzed reaction. The most common basic catalyst are potassium hydroxide (KOH), sodium hydroxide (NaOH), sodium methoxide (NaOCH₃), and sodium ethoxide (NaOCH₂CH₃). ethoxide (NaOCH) [10].

The implementation of this idea is a unit operation to produce biodiesel using solar water heater. Design and construction must be simple, easy to operate and efficient to reduce production cost. This tool can be implemented in some removed areas where there is not fuels and electric stock. The unit operation is mobile in order to get optimum thermal energy from the sun. It’s called “Mini Solar Water Heating Biodiesel Plant”. It’s expected that the people can be fulfill the fuel needs independently. This research investigated of biodiesel production in Mini Solar Water Heating Biodiesel Plant using homogenous-base catalyst. The reaction taken place at 65°C for ±1 hour, using 2% - mass of KOH as catalyst. Biodiesel analyzed to check whether it meets the standard requirements.

2. Experimental

2.1 Materials

Mini Solar Water Heating Biodiesel Plant is consists of two parts. They are mini biodiesel plant unit and solar water heater unit. Besides that, this unit is added by Solar Cell as source energy for stirrers in the transesterification reactor and washing tank.

Refined palm oil had 0.3 mg KOH/g, methanol (99.8%) pro analysis was produced from J.T. Baker, KOH-base catalyst was technical grade
Figure 1. Mini Solar Water Heating Biodiesel Plant parts: (1) Storage tank; (2) Solar collection; (3) Tubes; (4) Up-stream; (5) Down-stream; (6) Transesterification reactor; (7) jacket heating.

2.2 Produce Biodiesel from Palm Oil using homogenous-base
Solar water heater filled with water with a volume of 20 Liters. Direct the mini plant to an area that is exposed to solar radiation optimally. Temperature in transesterification reactor, atmosphere temperature and sun illumination during process measured. Refined palm oil first heated in reactor at ± 60°C for 1 hour. Catalyst was fixed at 2%-m and methanol was 30%-m at ± 65°C to ± 1 hour in agitated reactor. Biodiesel separated from glycerin and washed to remove impurities (catalyst, methanol, water and glycerin). Water and biodiesel products were stirred in the washing tank until the pH was neutral. Biodiesel distillated to increase the purity for later analyzed.

2.3 Analysis of Biodiesel Properties
Parameters tasted for biodiesel were Total Acid Number, Methyl Ester Content, Total Glycerin and Yield. Total acid number of biodiesel was calculated according to the ASTM D 664 standard. The test can be done by adding, a suitable amount of KOH to neutralized the acids in the biodiesel sample in a titration method. The acid value is the mg of KOH required to neutralize one gram of biodiesel sample.

Ester Content was obtained from the SNI 7182:2015. The fuel’s ester content indicates the amount of FAME in the fuel, and therefore, it is an indicator of the fuel’s quality. Total Glycerin was calculated using SNI 7182:2015.

Glycerin is a byproduct of the chemical reaction that produces biodiesel, may remain in the fuel if the ester is inadequately separated or washed. Glycerin also may separate out of the liquid during storage after any methanol, which acts as a solvent, has evaporated [11].

Biodiesel Yield was calculated with Eq. (1)

$$\text{Biodiesel Yield (wt.\%)} = \frac{W_b}{W_o} \times 100$$  \hspace{1cm} (1)

Where $W_b$ is the mass of biodiesel and $W_o$ is the mass of refined palm oil.
3. Result and Discussion

3.1 Specification of Mini Solar Water Heating Biodiesel Plant

The material used to make solar water heaters is lightweight, economical and easily obtained. Specifications of solar water heaters are presented in Table 1. The designed solar water heater consists of a solar collector and a water storage tank. Solar collectors consist of several parts, namely:

1. The heat transfer pipe is made of stainless steel so that it can reduce the rate of corrosion and heat can be absorbed well by the pipe.
2. The outer cover is made of acrylic glass, so it can optimize the absorbed solar energy.
3. A black coating made of polystyrene material painted black is intended to increase the absorption of heat energy by water in pipes in solar water heaters (black layer emissivity = 1)[12].

![Figure 2. Mini Solar Water Heating Biodiesel Plant.](image)

The water storage tank is made of stainless steel and an insulating layer consisting of foam and aluminum foil. The insulator layer is expected to reduce the heat of the water thereby reducing heat energy lost to the environment. The water in the pipe absorbs heat from the sun so that the temperature of the water rises. The difference in density between hot water and cold water, so hot water flows upward and cold water flows downward. Hot water is then flowed into the biodiesel reactor. This is sustainable so as to form circulation. So without the help of a pump power water can flow [13].

| Parts            | Materials                  | Dimension (length x width) cm |
|------------------|----------------------------|-------------------------------|
| Storage tank     | Shell: Stainless steel     | 70 x 7.62                     |
| Collector pipes  | Isolator: Polystyrene      |                               |
| Cover            | Stainless steel            | 70 x 2.5                      |
| Absorber         | Acrylic glass              | 70 x 100                      |
| Stream pipes     | Black Polystyrene          | 70 x 100                      |
|                  | Stainless steel            | 150 x 2.5                     |

The maximum temperature of the transesterification reactor reached 65°C and the maximum temperature of atmosphere at that time reached 37.8°C with the range of sun illumination were 1020-1280 Lux. Some things that can affect the optimum temperature of the water obtained are:
1. Sunlight shining on the earth is unstable during the experiment time
2. The heat absorbed and stored in the reactor is partially lost to the environment (Q loss).

![Figure 3. Solar water heating system.](image)

In additional solar cell installed could produced 100W of power (Dimension: 1085 x 675 x 25 mm) which could turned on two direct current mixers for reaction and for washing process.

3.2 Analysis of Biodiesel Properties

Based on the results of the parameter test, the biodiesel produced using a 2% KOH catalyst at the Mini Solar Water Heating Biodiesel Plant has met the requirements. Ester content was 99.07%. A low amount of ester may indicate that un-reacted compounds, such as triglycerides, or process related compounds such as catalyst (KOH/NaOH) or methanol remain in the fuel. Low levels also may indicate contamination with non-methyl ester compounds. These impurities may cause fuel filter plugging, engine deposits or other problems. Local low may require measuring that ester content, ester measurement also can help prevent or minimize fraud under incentive programs [11].

| Property                | Units  | Biodiesel Product | Limit     | Test Method          |
|-------------------------|--------|-------------------|-----------|----------------------|
| Ester content           | % - mass | 99.07         | 96.5 min. | SNI 7182:2015       |
| Total Acid Number       | mg KOH/g | 0.42           | 0.5 max.  | ASTM D 664          |
| Total Glycerin          | % - mass | 0.09           | 0.24 max. | SNI 7182:2015       |

Acid number is a measure of the acids in the fuel. Biodiesel result had acid number of 0.42 mg KOH/g which was suitable for standard requirement. These acids came from two sources: acid used in the production of the biodiesel that are not completely removed in the production process and acid as a byproduct from degeneration by oxidation. The acids were measured in terms of amount of KOH required to neutralize a gram of biodiesel. The acid number would change as a result of the normal oxidation process over time and recent research has shown that this change is a good indicator of B100 stability. If the fuel is not used immediately after purchase, buyers should monitor their biodiesel fuel blends for change in acid number, as an indicator of fuel degradation. The presence of acid in the fuel can harm injection system and other metallic components.
Total glycerin of 0.09 %-mass was also suitable with the biodiesel standard. Once separated, the glycerin will fall to the tank bottom and attract such polar compounds as water, monoglycerides and soap that can block filter, damage injection, cause injection coking and other engine deposits and otherwise make the fuel incompatible with vehicle material and reduce engine durability. Glycerin can be controlled through the use of good operating practices during production.

Biodiesel with a 2%-mass KOH base-catalyst had gave the yield of 83.42%. It was a low number. When the separation process accrued, it was seen that there was still an oil phase and soap phase. It was indicated that conversion reaction was not optimum yet. This could be caused by the temperature reaction which is not optimum and fluctuated. Other than that, separation process has gone quite hard. Saponification had taken placed due to the excessive use of the catalyst.

**Conclusion**

The maximum temperature of hot water in reactor from solar water heater was reached 65°C. Biodiesel has been produced in mini plants using 2%-m KOH catalyst give a yield of 83.42% , a high methyl ester content of 99.07%, a acid number of 0.42 mg KOH/g oil and a total glycerin of 0.09%-mass. And therefore it could be concluded that mini biodiesel plant-solar water heater produced biodiesel that have fulfilled the requirements according to biodiesel standard.

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