Process design of *in situ* esterification-transesterification for biodiesel production from residual oil of spent bleaching earth (SBE)

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Abstract. Indonesia is the largest producer of Crude Palm Oil (CPO) in the world. CPO refining process produces spent bleaching earth (SBE), which still contains 20-30% oil. This residual oil is very potential to be developed as a biodiesel feedstock. The purpose of this research was to develop an *in situ* biodiesel production process of residual oil of SBE, which covered stirring speed of esterification and transesterification and also transesterification time to produce biodiesel with the best characteristics. The production was conducted in a 100 L reactor. The stirring speeds applied were 650 rpm and 730 rpm, and the transesterification time varied at 60, 90 and 120 minutes. The combination of 730 rpm stirring speed for 90 minutes transesterification resulted in the best biodiesel characteristics with the yield of 85%, the specific energy of 6,738 kJ/kg and the heater efficiency of 48%. The physico-chemical properties of biodiesel was in conformity with the SNI of Biodiesel.

1. Introduction

Bleaching earth is an adsorbent that used to adsorb pigments color containing in CPO to produce bleached cooking oil. Manufacture of refining oil to produce cooking oil is the biggest consumer of bentonite. Every year, Indonesia need almost 200,000 ton bentonite for cooking oil refining industry. In refined CPO, Bentonite basically is a single use material. Bentonite is a natural resource that cannot be renewable and spent bleaching earth (used bentonite) still contains 20-30% vegetable oil [1]. The high content of vegetable oils in spent bleaching earth is potential to be utilized as biodiesel. Spent bleaching earth produced in refinery process. Chemical compounds of SBE are phosphoric acid [2], high quantities of water-insoluble substances, such as fatty acids, macroelements (sodium, potassium, calcium, magnesium, phosphorus, sulphur and chlorine) and microelements (iron, manganese, zinc, copper, iodine, cobalt and selenium), plant pigments and heavy metals (cadmium, mercury, arsenic, lead, chromium and nickel) [3,4].

Biodiesel is an alternative liquid fuels from vegetable oil which is formulated especially for diesel engines. Biodiesel is a methyl ester or ethyl ester from fatty acids which is produced by transesterification reaction between vegetable oil and methanol or biodiesel ethanol. Biodiesel production is urgently needed since the demand for diesel fuel is increased meanwhile the availability of diesel derived from petroleum are limited.
The current developed method in the process of biodiesel production is directly taken from materials containing oils and fats. This process is called in situ esterification or transesterification. Despite of being more efficient, this process will also shorten time for raw material converting process into biodiesel which is done simultaneously with oil extraction process. Biodiesel usages as a diesel substitution fuel must be followed by an efficiently and economically process technology development.

The purpose of this study was to obtain the best conditions of the biodiesel production process in the form of the stirring speed and time of in situ transesterification in the 100 L reactor. The best production process was chosen by considering performance of production process design like yield, specific energy and heater efficiency in 100 L reactor. The purpose of this research is to determine the physical and chemical properties of biodiesel production from optimization production process and in accordance with the SNI biodiesel.

2. Materials and Methods

2.1 Materials and tools
The main material used in this study was spent bleaching earth from PT. Asianagro Agung Jaya Jakarta. The chemicals materials used in the study were methanol, H₂SO₄, NaOH, HCl, 95% neutral alcohol, saturated KI solution, phenolphthalein indicator (PP), an indicator of starch 1%, HNO₃, distilled water, and several other chemicals.

The main equipment used in the production process was the reactor with 100 L capacity and vacuum filter. In addition, to the purification process, the equipment used was the deposition gourd. The equipment used for the analysis was the measuring cup, cup, porcelain cup, erlenmeyer, filter paper, spatula, funnel, pipette, the pipette volumetric, magnetic stirrer, rotary evaporator, viscometer Brookfield, burette, centrifuges and vacuum pumps, furnaces, pH meter, soxhlet apparatus, hot plate etc.

2.2 Methods

2.2.1 Raw Materials Characterization
Characterization of raw materials carried on the preliminary research stages include the determination of water content (SNI 01-3555-1998), fat (SNI 01-2891-1992) and free fatty acid (SNI 01-3555-1998).

2.2.2 Biodiesel Production Process
This stage aims to get the best treatment in the production process. Based on the previous studies of residual oil contained in the SBE tend to have a high FFA content (> 2%), so in this study biodiesel production design consists of two phases, in situ esterification and transesterification. In situ esterification was carried out by reacting 7.5 kg of spent bleaching earth with 45 L methanol and H₂SO₄ catalyst. The amount of catalyst added was 1.5% (v / w) of solids. In situ esterification process was carried out at a temperature of 65°C for 3 hours. After the reaction time was reached followed by a reaction of in situ transesterification process varied at 60, 90, and 120 minutes by adding NaOH catalyst. The amount of NaOH catalyst added was 1.5% (w / w) of the spent bleaching earth. Before it was added into the reactor, NaOH was dissolved in the methanol. The esterification and transesterification processes were carried out in situ process with variation of the stirring speed of 650 and 730 rpm. Transesterification reaction was stopped after reaching the specified time, with stopping the process of heating and stirring. After the reaction was stopped, the process of separation between the bleaching earth and methanol containing oils can be done. Separation was done by using a vacuum
filter. Solvents were also separated from the biodiesel by the evaporation. Then Biodiesel was
deposited for 24 hours and then purified after that it was heated. Furthermore, biodiesel yield was
calculated by the following equation:

\[
\text{Biodiesel yield} = \frac{m_1}{m_2} \times 100\%
\]  

(1)

Note:
m1 = mass of pure biodiesel after washing and drying (g)
m2 = mass of oil in the SBE (g)

2.2.3 Energy Analysis

Energy requirements were calculated on the heating process, \textit{in situ} esterification, \textit{in situ}
transesterification, filtration, evaporation, and biodiesel heating. The amount of energy required was
the result of multiplying the power of the motor stirrer, heater, and vacuum pumps. The energy
requirements are calculated with the following equation.

\[
E = \frac{P \times t}{m}
\]  

(2)

Where:  
E = required energy (kJ)
P = installed appliance power (kW)
t = Time use of heater (s)

The magnitude of the heating efficiency produced by the heater can be calculated by comparing the
useful heat Q with power input or power installed on the heater or may be calculated by the equation.

\[
\eta = \frac{Q}{P_{st}} \times 100\%
\]  

(3)

Where:  
\(\eta\) = Efficiency of heater (%)
Q = useful heat (kJ)
P = installed heater power (Watt)
t = Time use of heater (s)

Beneficial heat is heat that is used to raise the temperature of the material until it reaches 65 ° C. The
beneficial heat is calculated by similarities:

\[
Q = m \times cp \Delta T
\]  

(4)

Where:  
Q = beneficial heat (kJ)
cp = Specific heat of material (kJ / kg.K)
\(\Delta T\) = temperature difference (K)

2.2.4 Characterization of Biodiesel

Biodiesel which was produced from the best production processes was then analyzed to determine the
characteristics of the biodiesel. The analysis include density (AOCS Cc 10c-95), the kinematic
viscosity (ASTM D 445), a flash point (ASTM D 93), cetane number (ASTM D 613), acid value (SNI
01-3555-1998), saponification value (AOCS Cd 3-25), total glycerol content (AOCS Ca 14-56), alkyl
ester value, as well as water and sediment content (ASTM D-2709).
2.2.5 \textit{Design of Experiments and Data Analysis}

Testing method used in this study was completely randomized factorial design models. In this models, the factors involved were cross each other as well as environmental conditions encountered either homogeneous or uniform. The interaction model for completely randomized factorial design is described as follows:

\begin{equation}
Y_{ijk} = \mu + A_i + B_j + (AB)_{ij} + \epsilon_{ijk}
\end{equation}

Note:
- $Y_{ijk}$: measured response
- $\mu$: the general average
- $A_i$: the influence of stirring speed of the-i
- $B_j$: the influence of the time factor transesterification j
- $(AB)_{ij}$: the effect of the interaction between factors stirring speed level of –i with transesterification time of stage j
- $\epsilon_{ijk}$: errors

3. \textbf{Result and Discussion}

3.1 \textit{The Characteristics of Raw Material}

The raw materials used in this research is spent bleaching earth (SBE) known as used bentonite or secondhand bleaching earth. SBE is taken from P.T. Asianagro Agungjaya, Jakarta. SBE characteristics that will be analyzed include moisture content, free fatty acid value and fat content. The SBE characteristics analysis results can be seen in table 1.

| Quality characteristics | Value (%) |
|--------------------------|-----------|
| Moisture content        | 5.20      |
| Free fatty acid value   | 3.29      |
| Fat content             | 14.67     |

Moisture content of the material affects the yield of biodiesel. The presence of water in esterification and transesterification reactions can cause oil hydrolysis into free fatty acids. In addition, methyl esters which was formed will caused hydrolysis reaction with free fatty acids, thereby it reduce biodiesel yield.

The high number of free fatty acids will affect the fluency during the transesterification and may decreasing biodiesel yield. Maximum yield of biodiesel can be obtained from raw materials which have the FFA content less than 0.5% [5]. High number of free fatty acids can formed soap because free fatty acid reacts with a base catalyst in transesterification process so it will be potential to reduce biodiesel yield. The production process of biodiesel with high free fatty acid levels are conducted into two steps, it is esterification and transesterification [6].

The next analysis of SBE is the fat content. This test was conducted to determine the oil content in materials that can be extracted and converted into biodiesel. The fat number in SBE obtained is 14.67% (bb).

3.2 \textit{Stage Production of Biodiesel}

Biodiesel production process was conducted using \textit{in situ} esterification and transesterification. \textit{In situ} Esterification was carried out by reacting material contained fatty acids using alcohol solvent with the aid of acid catalysts which was done simultaneously in a reactor.
In situ transesterification method is a simple step to produce biodiesel by eliminating extraction process and oil refinement that could save production costs [7]. Triglycerides used in situ transesterification process are triglycerides derived from raw materials sources and not from oil extraction and refinement (Qian et al., 2008). It is better than conventional techniques for in situ process since it does not need to perform oil extraction and refinement separately. Extraction process, esterification and transesterification of oil residue in SBE run simultaneously within a single reactor. Thus process is more effective and save energy.

3.3 Mass Balance

Material heating process and in situ esterification get input materials such as methanol 45000 mL, SBE 7500 grams, and H$_2$SO$_4$112.5 mL for all treatments and replicates. Later during in situ transesterification process occurs catalyst addition as much as 256 grams of NaOH dissolved in 3060 mL of methanol. The results of three series processes produce a mixture of methanol, biodiesel, glycerol, impurities and residual solids SBE which is still difficult to quantify amount of mixtures. The amount of the mixture can be calculated after the separation phase of the liquid and solids in the filtration process. This filtration process outputs liquid phase as much as 41700-45000 mL and solid waste 6400-6750 grams.

The next process is evaporation to separate methanol from liquid phase because methanol has the lowest boiling point. From methanol input of 41700-45000 mL produced 40000-42800 mL and mixture of 1365-1550 mL biodiesel, glycerol, and impurities or 1325.03 to 1487.25 grams. After that, the mixture was precipitated to separate biodiesel and glycerol. This process can be separated from crude biodiesel amount 833.63 to 983.25 grams and glycerol 491.40 to 567 grams. Crude biodiesel was washed using water to remove impurities, which dissolves in the water soluble such as catalysts and residual methanol. From washing process, it produced pure biodiesel as much as 786.60 to 940.50 grams and waste in the form of impurities as much as 21.38 to 68.40 grams. Losses that occur in biodiesel production process was the methanol amount to 5060 - 8060 mL. The losing of methanol occurs in esterification, transesterification, and evaporation process. Methanol is evaporated into the environment through a gap of the tool.

3.4 Biodiesel Yield

This process produced 72.65 to 84.5% yield. Variance analysis indicates that the treatment of transesterification time significantly influence (P <0.05) to biodiesel yield. Meanwhile, the mixing speed is not significant (P> 0.05) to biodiesel yield production. The interaction between the stirring speed and transesterification time also did not significantly affect the generated yield. Furthermore, the Duncan test which was conducted to know the effects of time indicated that the yield of the transesterification time of 60 minutes and 120 minutes were not significantly different. Meanwhile, the transesterification time of 90 minutes was significantly different from the transesterification time of 60 minutes and 120 minutes.

Figure 1. Biodiesel Yield in Various Treatment
The mixing speed affects yield production, but after the equilibrium, the mixing speed will not be significant. The stirring speed of biodiesel production process is closely related to the homogeneity of mixture reaction to reach the complete reaction. The higher stirring speed, the higher collisions between particles of the reactants so that the reaction will proceed more perfect. It can be seen from the results of the study (figure 1) that increasing stirring speed will increase the biodiesel yield. However, according to the research of Noureddini and Zhu [9], it shows that there are significant differences to produced yield on the stirring speed of 150-300 rpm but on the stirring speed between 300 rpm and 600 rpm shows the slight or inconsiderable difference. Time is one factor that determines the amount of yield production. The longer the reaction time will influence the chance methyl esters formed that automatically increase significant result of high biodiesel yield. However, if it reaches a point of equilibrium reaction, the reaction time have no effect on the yield of methyl ester. The conversion of triglycerides into methyl esters increased rapidly during the first 180 minutes to reach 98% yield and more than 180 minutes of time did not affect biodiesel yield [10]. The results showed that the longer time of \textit{in situ} transesterification reaction, the higher result of yield. Optimum yield was reached at reaction time of 90 minutes and dropped back to the reaction time of 120 minutes (figure 1). These result is consistent with the study of Qowim’s [11] which states that the optimal time of \textit{in situ} transesterification biodiesel process of SBE is at 104.73 minutes after \textit{in situ} esterification for 3 hours and yield will fall back after that time.

The highest yield obtained from the production process using 100 L reactor was at 84.5%. The Yield was obtained from transesterification treatment time for 90 minutes with a stirring speed of 730 rpm.

### 3.5 Analysis of Energy Needs

Energy measurement was the direct energy in the form of fuel energy or electrical energy. Observation and measurement energy needs were in material heating process, \textit{in situ} esterification, \textit{in situ} transesterification, filtration, methanol evaporation, and biodiesel heating. The energy measurement on biodiesel production process was the specific energy that required to process for each kilogram of material.

The specific energy required in the biodiesel production process was in the range of 6596.55 to 6832.99 kJ per kilogram of material. The variance analysis results showed the significant transesterification time (P <0.05) to the total specific energy needs. Meanwhile the stirring speed was not significant (P> 0.05) to the total specific energy needs. The further Duncan test on the treatment period showed that the specific energy needs of transesterification total treatment time of 60 minutes and 90 minutes were significantly different from the transesterification time of 120 minutes.

| Process                        | Average needs of The specific energy (kJ / kg of material) |
|--------------------------------|----------------------------------------------------------|
| Material Heating               | 391.25 ± 15.85                                           |
| \textit{In situ} esterification| 933.81 ± 0.00                                            |
| \textit{In situ} Transesterification | 439.72 ±131.10                                         |
| Filtration                     | 196.34 ± 4.46                                            |
| Evaporation                    | 3521.42 ± 91.16                                          |
| Biodiesel Heating              | 1268.03 ± 78.63                                           |

The production process with 650 rpm stirring speed and transesterification time of 60 minutes took the smallest specific needs energy. Otherwise, the production process with the stirring speed of 650 rpm
and transesterification time of 120 minutes took the highest total specific energy needs. Time is one of determinant factor in the energy use. Total energy needs equals to transesterification time. The longer the time of transesterification process, the more electrical energy was required to drive the agitator and heating materials. The energy required by each kilogram of material in the production process of all treatments was still too small compared to the energy that can be produced by biodiesel as much as 40–100 kJ/kg biodiesel [12].

The highest specific energy needs was in the evaporation process because this process need heat and mechanical energy in a long time. Meanwhile, the smallest specific energy was required by the filtration process because this process just applied a vacuum pump with the power 373 W. The energy needs of each process can be seen in table 2.

3.6 The specific energy needs in heating raw materials process, in situ esterification and transesterification

The process of raw material heating was used to raise material temperature like methanol, SBE, and a catalyst until reached temperature of 65 °C. In this process, used energy was the heat energy that coming from heater and mechanical energy from motor to move the agitator. The stirring was done in order to get heat more evenly so that the heat transfer from the heating medium to the material became faster and the material reached the optimal temperature too. After the temperature reached 65 °C, the esterification process were ready to carry out by maintaining the temperature and stirring for three hours. After the esterification process was completed, it was followed by the transesterification process at temperature of 65 °C with stirring. The total specific energy in the three processes of all the treatments were in the range of 1595.29 to 1922.16 kJ/kg of material. The results of variance analysis showed the transesterification time and stirring speed significantly (P <0.05) against the specific energy needs of these three processes. Meanwhile the interaction between the transesterification time and stirring speed did not significantly affect the specific energy needs of these three processes. Furthermore, the Duncan test on the treatment period showed that the specific energy needs of the three treatments were significantly different for all transesterification.

![Figure 2. The specific energy needs on the various treatments](image)

The time of transesterification gave significant effect on specific energy in the heating process, esterification and in situ transesterification because time was a power multiplier factor to get the value of the energy needs. The greater time, the greater energy needs would be. Meanwhile the stirring speed significantly affected the specific energy needs to these three processes, especially in the heating process materials for the higher rate of stirring, the better heat transfer occurs, and the heat was more evenly spread to the material so that the time required to reach a temperature of 65 °C was faster and energy took getting smaller. It can be seen in figure 2.
3.7 Energy Balance
The energy balance was used to determine the total energy input used in a process. In calculating the total energy, the energy needs was not divided by the mass of fuel. In the process of heating materials, esterification, transesterification, and filtration of the total energy produced by the heater, the motor, and a vacuum filter was \(77732-93466\) kJ. Based on the energy input, of \(68587-83113\) kJ, the energy was lost to the environment only in the form of heat. The next process was the process of evaporation. In this process was amounted to \(121\) 370 kJ of energy required in the form of heat energy from the heater and the mechanical energy of the motor stirrer. The energy was used in the form of heat to vaporize methanol in the amount of \(38213-41453\) kJ. The rest was wasted as heat into the environment. The final process was drying which required heat energy of \(1,080\) kJ used separately to evaporate the residual water in biodiesel.

3.8 Heater Efficiency
The heater functions as heat providers to accelerate the reaction between methanol with triglycerides in SBE. The heater efficiency showed how well this equipment to withstand the heat produced by the heater. The heater efficiency was calculated by comparing the power used to heat the material from room temperature until it reached a temperature of 65 °C with power that was attached to the heater.

![Figure 3. Heater Efficiency on Various Treatment](image)

The heater efficiency of the equipment used in this study ranged from 42.99% - 48.05%. This condition showed that there were about 51.95% - 57.01% of heat was not used to heat the material. The results of the variance analysis showed the stirring speed and interaction between treatment time with the stirring speed affected significantly (P <0.05) on the efficiency of the heater. While in situ transesterifikai time is not significant (P> 0.05) on the efficiency of the heater. Duncan test showed the combination treatment transesterification time of 90 minutes and the stirring speed 730 rpm and transesterification time of 120 minutes and the stirring speed 730 rpm were significantly different from other treatment combinations.

The production process with a stirring speed of 730 rpm had a thermal efficiency that was greater than the process speed of stirring 650 rpm (figure 3) because the higher speed, the heat transfer was better and spread evenly on the material so that the time required to heat the material could be minimized. On the other side, the efficiency of the best heater use was on the treatment of stirring speed of 730 rpm with a time of 90 minutes transesterification. Meanwhile, the efficiency of the smallest heater use was on the treatment with stirring speed 650 rpm with a time of 90 minutes transesterification.

3.9 Biodiesel Characterization
Characterization of biodiesel was conducted to the best treatment derived from the yield parameters, energy needs, and the heater efficiency. The best treatment of the biodiesel production process was the production process with a stirring speed of 730 rpm with time of transesterification 90 minutes.
3.9.1 **Density**
Density showed the ratio of sample weight with the weight and volume of water at the same temperature. The density was one of the most important characteristics in biodiesel. It was associated with power and calorific value produced by the diesel engines per unit volume of biodiesel. The density of best treatment result biodiesel was 0.855 g / ml.

3.9.2 **Viscosity**
Viscosity was the resistance possessed fluid which was flowed within the capillary against the force of gravity. It was usually expressed in the time to flow at a certain distance. This characteristic was very important because it affected the performance of injectors in the diesel engines. The viscosity value obtained from biodiesel on best treatment was 5,863 cSt.

3.9.3 **Cetane Number**
Cetane number indicated how fast the diesel engine fuel injected into the combustion chamber could ignite spontaneously after mixed with air. The cetane number of biodiesel on best treatment was amounted to 54.5. This number met the requirements of ISO Biodiesel which was at least 48.

3.9.4 **Flash Point**
Flash point was the lowest temperature point during the formation of the flame ignition test (flame test). These characteristics were related to security in the storage and handling of fuel. The flash point of biodiesel on best treatment was 172 °C.

3.9.5 **Water Level and Sediment**
Water level and sediment showed how well the purification process was carried out after biodiesel produced. The water level and sediment of biodiesel on best treatment was less than 0.005 ml that was considered undetectable or very small. This condition indicated that the circuit of biodiesel purification process succeeded in reducing the presence of impurities in the form of water and sediment.

3.9.6 **Saponification**
Saponification showed the molecular weight of triglycerides tested to estimate the largest component in the material. The saponification obtained was amounted to 205.5 mgKOH / g.

3.9.7 **Acid Number**
Acid numbers indicated the biodiesel acid content of free fatty acids derived from the degradation of ester or free fatty acids that were not contaminated with methyl ester in the esterification process. The resulted acid number reduced from the prior acid number before the SBE oil was converted into biodiesel. The esterification and transesterification process successfully reduced the level of free fatty acids. The acid number of the biodiesel reached 0.711 mg NaOH / g.

3.9.8 **Total Glycerol Content**
The content of total glycerol was calculated from the sum total of bound glycerol and free glycerol contained in the fuel. The existence of residual glycerol and glycerides which were not converted might harm engine especially for the -OH group that was chemically aggressive toward non-ferrous metals and the mixture of chromium led deposits in the combustion chamber [13]. Total glycerol content was 0.16% (w / w).

3.9.9 **Alkyl esters value**
Level of alkyl esters represented the number of organic acids which were fused as esters and had a relationship with the acid number, and saponification glycerol levels [14]. The biodiesel alkyl esters level indicated the level of purity. The level of alkyl esters of biodiesel on best treatment was amounted to 99.296% (w / w).
The results of biodiesel physical and chemical characterization of the nature on the best treatment was in the transesterification time for 90 minutes with a stirring speed of 730 rpm in accordance with SNI. The results showed that biodiesel produced was suitable for the use as fuel for diesel engines. The physical and chemical characterization and the comparison with SNI can be seen in table 3.

The best treatment for biodiesel production was transesterification time of 90 minutes and stirring speed of 730 rpm.

Table 3. Comparison of characteristics of biodiesel results on best treatment combination with Indonesian Standard of Biodiesel

| No. | Parameter                      | Biodiesel A2B2a | Standar SNI | Unit  |
|-----|--------------------------------|-----------------|-------------|-------|
| 1   | Kinematic viscosity            | 5.863 ± 0.028   | 2.3 - 6.0   | cSt   |
| 2   | Density                        | 0.855 ± 0.001   | 0.850 - 0, 890 | g / ml |
| 3   | Cetane Number                  | 54,500 ± 0.283  | min 48      |       |
| 4   | Flash Point (closed cup)       | 172,000 ±11,314 | min 100     | C     |
| 5   | Water dan Sediment             | Trace           | max 0,05    | % vol |
| 6   | Acid Value                     | 0,711 ± 0,038   | max 0,8     | mg NaOH/gr |
| 7   | Total Glycerol                 | 0,160 ± 0,014   | max 0,24    | % mass |
| 8   | Saponification                 | 205,500 ± 4,950 |             | mg KOH/gr |
| 9   | Alkyl Esters Value             | 99,296 ± 0,007  | min 96,5    | % mass |

4. Conclusion
The raw materials of SBE had an acid value more than 2% so that the biodiesel production process was performed through in situ esterification process and was followed by in situ transesterification. The best treatment biodiesel production process in 100 L reactor with the yield parameters, specific energy needs, and the efficiency of the production process with the heater was 730 rpm stirring speed and transesterfication time 90 minutes with the yield of Biodiesel 84.5%, specific energy needs 6,738.35 kJ/kg and heater efficiency 48.05%. The biodiesel produced from the process had the value of the density of 0.855 g/ml, 5.863 cSt viscosity, flash point 172°C, cetane number 54.5, acid value 0.711 mgNaOH/g, saponification value 205.5 mgKOH/g, total glycerol 0, 16% mass, alkyl ester value of 99.296% mass, and trace content and sediment. The physico-chemical properties of biodiesel was in conformity with the SNI of Biodiesel. This research need to have future research about reusing evaporated methanol because of big proportion of used methanol and economic analyses: feasibility of biodiesel production process from residual oil of SBE.

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