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The Potency of Biodiesel Production from The Local Used Frying Oil Through The Electrocatalysis Method

Haris Numan Aulia[1]*

[1]Polytechnic of Energy and Mineral (PEM) Akamigas, Cepu, Indonesia.

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ABSTRACT

The objective of this study was to optimize the operating conditions for an electrocatalytic method of producing biodiesel from local used frying oil (UFO). The effects of electrical voltages (5-30 V), methanol-to-oil molar ratios (4:1-8:1), KOH catalyst concentrations (0.5-1.25% w/w), and electrolysis time (30-120 min) on biodiesel yield were investigated. The highest biodiesel yield of 95.3% was obtained at a voltage of 30 V, methanol-to-oil molar ratio of 6:1, catalyst concentration of 1% w/w, and electrolysis time of 120 min. A regression model was developed to predict the optimum operating conditions, resulting in a maximum biodiesel yield of 95.54%. The predicted optimum operating conditions were a voltage of 24.4 V, methanol-to-oil molar ratio of 5.8:1, catalyst concentration of 1% w/w, and electrolysis time of 120 min. The net profit of the biodiesel business using local UFO as a feedstock was estimated to be IDR 738,000 per month based on a simple economic calculation. These findings demonstrate the potential for using electrocatalytic methods to produce biodiesel from local UFO, and the economic feasibility of producing biodiesel in small-scale industries.

1. INTRODUCTION

The high demand and consumption of fossil fuels around the world have attracted the attention of researchers to look for alternative energy sources because the availability of fossil fuels is decreasing and emissions resulting from the burning of fossil fuels are one of the causes of environmental pollution. Therefore, it is necessary to find alternative energy sources that are renewable, economically competitive, technically feasible, and environmentally friendly. Biodiesel, a renewable alternative liquid fuel derived from triglycerides, is one of the most promising fuels to meet the diesel oil need.

The year 2005 is a crucial year and the beginning of a massive biodiesel research development in Indonesia. At that time, the price of fossil fuels raises more than 100%, which was from 60 to 148 USD per barrel. Furthermore, the Indonesian government is looking for alternative fuels. The government issued the Presidential Regulation Number 5 Year 2006 concerning the national energy policy and Presidential Instruction Number 1 Year 2006 concerning the provision and utilization of biofuels as alternative fuels, thereby further spurring the development of biodiesel research in Indonesia. The government has gradually set the mandatory use of biodiesel in blends with diesel, which are B10 in 2015, B20 in 2018, and B30 in 2020. Furthermore, the government will increase the mandatory use of biodiesel in the coming year with a target of B80 in 2030 which is in line with Indonesia's commitment to reduce greenhouse gas (GHG) emissions by 41% in 2030.

*Correspondence author.
E-mail : harisnumanaulia@yahoo.com (Haris Numan Aulia)

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Biodiesel, containing mono-alkyl esters of long chain fatty acids, is an alternative fuel resulting from vegetable oils or animal fats. It can be used as a fuel for diesel engines. The high price of crude vegetable oil as a raw material for biodiesel can increase production costs. Overall, around 75-90% of the price of biodiesel fuel comes from the purchase of crude vegetable oil. In addition, the use of crude vegetable oil as biodiesel feedstock can increase the cost of the food chain. Therefore, the use of wastes as raw materials for biodiesel can reduce production costs so that it is more effective in the industrialization and commercialization of biodiesel fuel. An increase in biodiesel fuel demand significantly encourages efforts to produce biodiesel from wastes. One of the potential wastes, that can be utilized as a raw material for biodiesel, is used frying oil (UFO). This waste is often dumped directly into the environment by restaurants and other similar facilities.

The selection of biodiesel production technology plays a major role in determining the overall economic feasibility. Therefore, the use of UFO as a biodiesel feedstock can be considered a more economical and sustainable solution. Production of biodiesel from the UFO has been carried out by several researchers through the process of transesterification and acid-catalyzed esterification, heterogeneous base-catalyzed transesterification, transesterification by enzymatic process, transesterification via non-catalyzed subcritical methanol, microwave-assisted transesterification, ultrasonic wave-assisted transesterification, and electrolysis method. The alkaline-catalyzed process has low catalyst and energy efficiencies. The acid-catalyzed process has a low reaction rate and can form by-products. The enzymatic process is expensive. The process via non-catalyzed subcritical methanol is expensive and complicated and requires high pressure and temperature. The microwave-assisted process results in low yields. The ultrasonic wave-assisted process is expensive and cannot be run at room temperature. Compared to the other methods, the electrolysis method has many advantages in which it has lower energy consumption because it can be operated at room temperature, it needs a short reaction time when using co-solvents, it eliminates the waste oil refining and dewatering steps, it reduces water consumption in biodiesel washing, and it produces less waste.

This study employed local used frying oil (UFO) obtained from the Student Dormitory of Vyatra PEM Akamigas (Cepu, Blora, Central Java, Indonesia) as a biodiesel feedstock. As the UFO has not undergone any treatment, it was used as it is in this study. The electrolysis method for producing biodiesel is affected by various factors such as electrical voltage, molar ratio of methanol-to-oil, catalyst concentration, and electrolysis time. Therefore, optimization of the operating conditions is required to enhance the production of biodiesel using local UFO as a feedstock. This study presents a novel approach, as it is the first to optimize the operating conditions in the electrolysis process for producing biodiesel from local UFO. The study aimed to investigate the effect of electrical voltage, molar ratio of methanol-to-oil, catalyst concentration, and electrolysis time on the production of biodiesel using the electrolysis method. Additionally, optimization was carried out to predict the optimal conditions that would result in maximum biodiesel yield using a regression model. A simple economic analysis was performed to estimate the net profit of producing biodiesel from local UFO.

2. METHODS

2.1. Materials

The local UFO was collected from the Student Dormitory of Vyatra PEM Akamigas, in Cepu, Blora Regency, Central Java, Indonesia. Chemicals such as KOH, acetone (99.9%), TetraHydroFuran (99.9%), and methanol (99.9%) were purchased from Merck (Germany).

2.2. Experimental set-up

The equipment used included graphite anode-cathode, magnetic stirrer, hotplate, power direct current (DC) supply, oven, glass beaker, separating funnel, analytical balance, measuring cylinder glass, stative, and clamps. The experimental set-up of the biodiesel production reactor can be seen in the Figure 1.

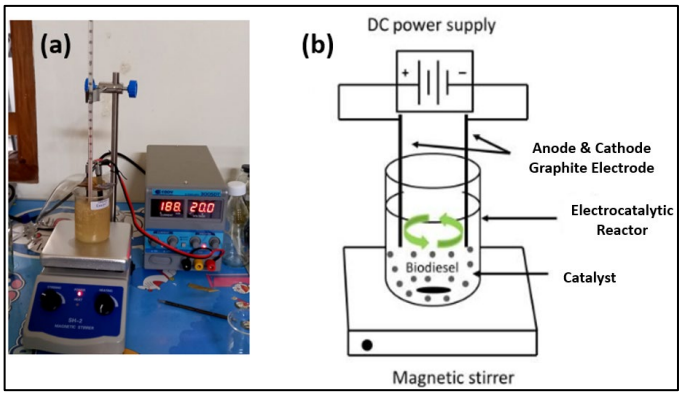

Figure 1. The design of the biodiesel production reactor. (a) a series of tools (b) components that make up the tool.

2.3. Research procedures

This research was conducted at the Laboratory of Fundamentals and the Laboratory of Downstream Oil and Gas at PEM Akamigas (Cepu, Blora, Central Java, Indonesia). The local UFO was utilized as the feedstock for biodiesel production via the electrolysis method, which involved variations in electrical voltage, molar ratios of methanol-to-oil, catalyst concentrations, and electrolysis times. Graphite electrodes were employed in the electrolysis process as they are inert. The inter-electrode distance was maintained at 1 cm. The catalyst employed in the process was KOH, which was mixed with CH_3OH until completely dissolved. The research flow chart is presented in Figure 2, which is described in detail in sections 2.3.1 to 2.3.3.

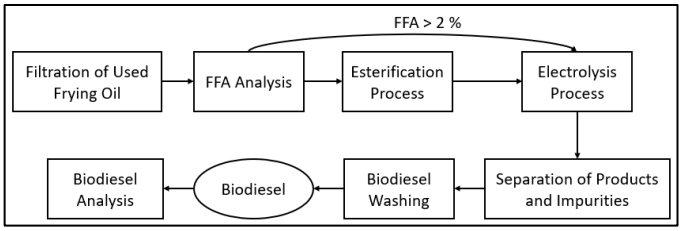

Figure 2. Research Flowchart.

2.3.1. Preparation of biodiesel feedstock

Initially, a vacuum filter was assembled, and a filter paper with a diameter of 125 mm was positioned on a buchner funnel. Subsequently, the local UFO was poured into the buchner funnel, and the vacuum pump was switched on until the local UFO screening process was finished. The filtered local UFO was then collected and stored in a bottle.

2.3.2. Analyzing the feedstock

5 grams of local UFO and 50 ml of KOH solution were put into the erlenmeyer flask and then stirred. The mixture was heated to 40 oC. Then, 2-3 drops of PP indicator were added. Furthermore, the mixture was titrated with 0.1 N KOH solution until the colour of the mixture turned pink and did not disappear for 30 seconds. Finally, the free fatty acid content (%FFA) of local UFO was calculated using equation (1).

$$\%FFA = \frac{25.6 \times Titrant\ Volume \times Titrant\ Normality}{Weight\ of\ the\ UFO} \quad (1)$$

2.3.3. Electrolysis process

First, a solution of KOH (1% w/w oil) was prepared by mixing it with methanol. A solution of acetone (10% w/w oil) was also prepared by mixing it with distilled water (2% w/w oil). Next, 50 grams of local UFO were mixed with the KOH-methanol solution and the acetone-water solution in a beaker glass. The molar ratio of methanol to oil was varied from 4:1 to 8:1. The electrolysis process was carried out at different voltages (5, 10, 20, and 30 V) with an agitation speed of 300 rpm, using graphite electrodes as both cathode and anode. The anode-cathode distance was maintained at 1 cm. The electrolysis process was carried out for 30, 60, 90, and 120 minutes. The resulting biodiesel was separated using a separatory funnel and left to stand for 24 hours. The biodiesel was then washed with hot distilled water at a temperature of 50 °C until the last wash was clean. The water content of the biodiesel was reduced by heating it in an oven at 110 °C for approximately 2 hours. Finally, the yield of biodiesel was calculated.

2.4. Analysis

2.4.1. Free Fatty Acid (FFA)

Ten grams of the local UFO were placed into a 250 ml Erlenmeyer flask containing 50 ml of 95% ethanol. The mixture was heated to boiling on a hot plate and allowed to cool to room temperature. Next, phenolphthalein was added to the cooled solution for titration with 0.1 N KOH to the equivalence point.

2.4.2. Kinematic Viscosity

The kinematic viscosity was carried out by measuring the time required to drain the local UFO in a capillary tube from "a" to "b". The sample was placed in a viscometer and placed on a thermostat. The liquid was then drawn into the viscometer above the "a" mark using a pump, and allowed to flow down to point "b". The time taken for the liquid to flow from point "a" to point "b" was recorded using a stopwatch. The viscosity test was conducted at a temperature of 40 °C using an Ostwald viscometer. The principle of the test was to compare the viscosity of the sample with that of a reference fluid, in this case, distilled water (aquadest).

2.4.3. Density

Density testing was performed using the measuring cylinder glass method. A clean and empty 10 mL measuring cylinder glass was first weighed, and then 5 mL of the local UFO was added to the cylinder using a digital balance measuring instrument. The density of the local UFO was then calculated.

3. RESULT AND DISCUSSION

The FFA level in the local UFO was 1% (Table 1). If the FFA value < 2%, the esterification process does not required. The esterification process is only needed to reduce the free fatty acid content contained in the raw material because it affects the yield of biodiesel. The results of the local UFO characteristics can be seen in Table 1.

Table 1. Characteristics of the local UFO

Parameters	Values
FFA (%)	1.0
Kinematic Viscosity (cST)	80.55
Density (g/cm^3)	0.912

3.1. The effect of the electrical voltage

The increase in electrical voltage in the electrolysis process increased the energy content in the reaction, so the reaction rate increased. The hydroxyl ions (OH-), which were produced during electrolysis, also increased along with the increase in electrical voltage. Methoxide ions can be formed when methanol reacted with the hydroxyl ions, so the higher the electrical voltage, the more the methoxide ions were formed and the more the biodiesel yield was produced. Based on the Figure 3, the highest biodiesel yield was obtained at a voltage of 20 V, which was 95%. When the voltage was increased to 30 V, the biodiesel yield remained at 95% because there was no increase in the OH- ion concentration, so the reaction rate remained constant. Figure 3 shows the biodiesel yield at various electrical voltages, while Figure 4 shows the biodiesel yield obtained at various electrical voltages.

In this study, an increase in electrical voltage can increase the electrical current flowing in the cell. According to previous research, hydroxide ions were continuously formed at the cathode during the electrolysis process. The interaction between hydroxide ions and methanol facilitated the transesterification of the oil, indicating that the oil transesterification reaction occurred near the cathode. Reyero et al reported that biodiesel yield increased with an increase in the OH- ion concentration, but decreased with a decrease in voltage. Results from other studies also showed that increasing the electrolysis voltage led to a significant increase in biodiesel production. Consistent with the result of this study, a previous study reported that the biodiesel yield increased from 88% to 93% with increasing electrolysis voltage from 20 to 40 V. The result of this study was better than the previous study, which might be caused by differences in the free fatty acid contents of the raw materials used.

3.2. The effect of the molar ratio of methanol-to-oil

Based on Figure 5, the optimal methanol-to-oil molar ratio is 6:1. Increasing the methanol-to-oil molar ratio from 4:1 to 6:1 resulted in an increase in the biodiesel yield from 93% to 95.1%. However, when the molar ratio was increased to 7:1 and 8:1, the biodiesel yield decreased to 95% and 91%, respectively. Excess methanol acted as an emulsifier, causing some of the biodiesel to enter the water phase during washing, which reduced the biodiesel yield.

The methanol-to-oil molar ratio is one of the most significant factors in biodiesel production. An increase in the ratio has a positive impact on yield during the biodiesel production process. The excess methanol resulted in an increase in the methanol content in the final product. During the settling step, a layer of excess methanol formed on top of the oil. The optimum point of the molar ratio of triglyceride to methanol was found to be 1:6 as not all the methanol added reacted with the triglycerides in the oil. Figure 5 shows the biodiesel yield obtained at different molar ratios of methanol-to-oil, while Figure 6 displays the biodiesel obtained for the variation of the methanol-to-oil molar ratio. Previous research reported that the optimum methanol-to-oil molar ratio was 7:1. When the ratio exceeded 7:1, the electrical conductivity decreased, as the catalyst concentration was determined by the weight of the oil. Furthermore, an increase in the methanol-to-oil molar ratio resulted in a decrease in biodiesel yield, which may be due to the dilution of the oil reactant by methanol. However, other studies reported that a maximum biodiesel yield of 98% was obtained at a molar ratio of methanol-to-oil of 4:1, using a NaOH catalyst concentration of 1% v/v. Similarly, a maximum biodiesel yield of 97% was obtained at a molar ratio of methanol-to-oil of 21:1. The difference in the optimum molar ratio of methanol-to-oil between the previous studies and this study might be due to the different free fatty acid contents in the raw materials used.

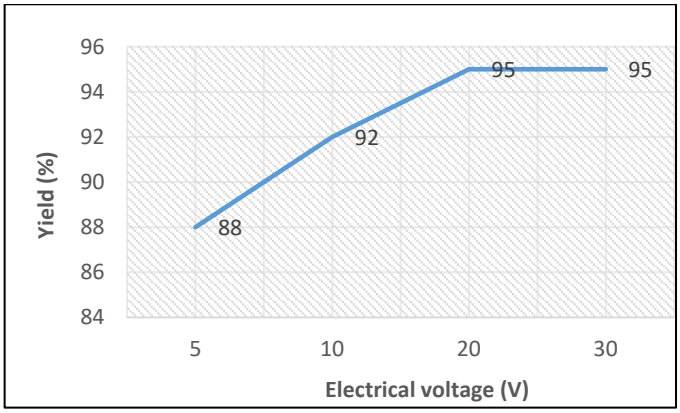

Figure 3. Effect of electrolysis voltages on biodiesel yield. Molar ratio of methanol-to-oil = 6:1, catalyst = 1 %w/w, time = 120 minutes.

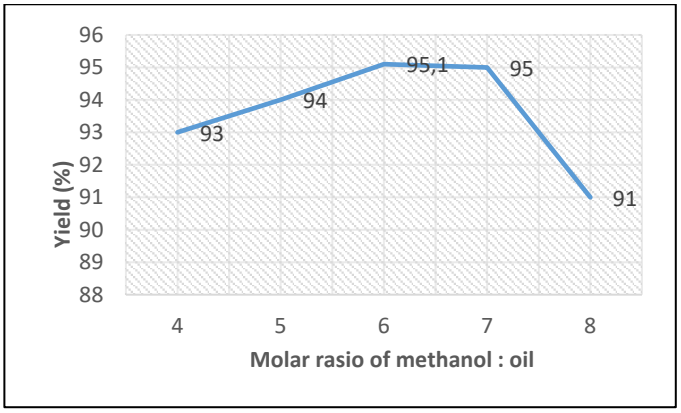

Figure 5. Effect of methanol-to-oil molar ratio on biodiesel yield. Voltage = 20 V, catalyst = 1 %w/w, time = 120 minutes.

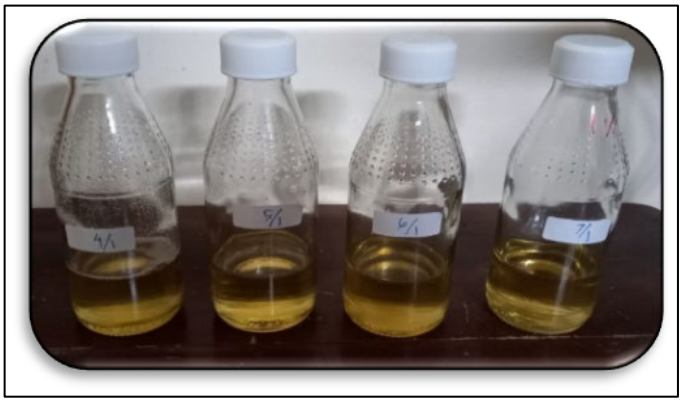

Figure 4. Biodiesel yield at various electrolysis voltages.

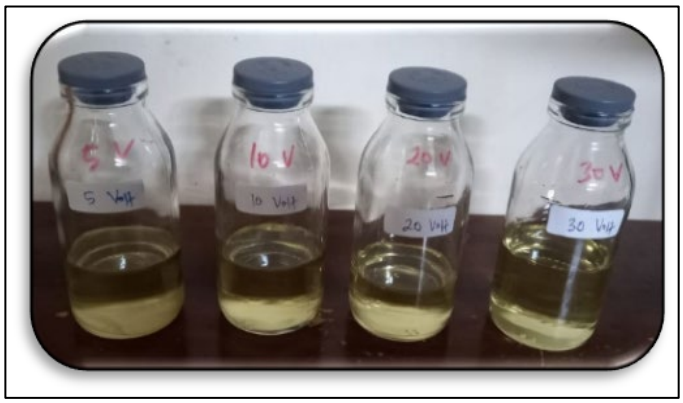

Figure 6. Biodiesel yield at various methanol-to-oil ratios.

3.3. The effect of the catalyst concentration

The transesterification reaction is difficult to occur without the help of a catalyst. The biodiesel yield reaches the optimal value when the KOH concentration is at the right level. The mechanism of transesterification of the local UFO oil with an alkaline catalyst can be seen in Figure 7. The entire process is a series of three reaction sequences and a reversible reaction, in which di- and mono-glycerides are produced as intermediates. The first step (Equation 2) is the reaction between the base and the alcohol, which produces an alkoxide and a protonated catalyst. Nucleophilic attack of the alkoxide on the carbonyl group of the triglyceride produces an intermediate (Equation 3), which results in the formation of an alkyl ester and a triglyceride anion (Equation 4). In the final step, deprotonation of the catalyst occurs, which produces a new active catalyst (Equation 5). The catalyst reacts again with other alcohol molecules until monoglycerides are formed, and undergo the same reaction to produce alkyl esters and glycerol (Schuchardt et al., 1998).

The presence of the KOH catalyst facilitated the reaction to move more quickly towards equilibrium and increased the oil conversion. The catalyst enhanced the solubility of methanol, thereby increasing the reaction rate, leading to an increase in biodiesel production with an increase in the KOH concentration. However, the amount of catalyst had to be optimized to avoid soap formation, as it could cause two problems: reduction of biodiesel yield and difficulty in separating biodiesel from glycerol. According to Figure 8, increasing the catalyst concentration from 0.5 to 1%w/w resulted in an increase in biodiesel yield from 93 to 95%. But, exceeding a catalyst concentration of 1%w/w led to a reduction in biodiesel yield. This was due to an increase in the saponification reaction caused by the catalyst concentrations above 1%w/w. The formation of soap increases the solubility of the produced methyl ester, resulting in the formation of an emulsion between the two phases and increased viscosity of the reactants, leading to difficulties in separating the two phases and reducing the biodiesel yield. Figure 8 shows the biodiesel yield at various concentrations of the KOH catalyst, while Figure 9 shows the biodiesel produced at varying catalyst concentrations. Previous studies reported similar results as this study, where the maximum biodiesel yield was obtained at a catalyst concentration of 1%w/w. Adding more catalysts to the system will cause the unwanted saponification reaction to develop further, reducing the yield. Other previous studies reported the maximum biodiesel yield at a catalyst concentration of 1%w/w using an ultrasonic-assisted reactor with a value of 97.12% and using a microvace-assisted reactor with a value of 90%. Based on the findings of these studies, the presence of ultrasound during the process can increase biodiesel yield. Hence, an ultrasonic-assisted reactor for the local UFO can be employed in the future to enhance biodiesel yield.

In the saponification reaction, triglycerides react with alkali (potassium hydroxide), causing the bonds between the oxygen atoms in the carboxylate group and the carbon atoms in the glycerol to break apart. The oxygen atom then binds to potassium from the potassium hydroxide, causing the end of the carboxylic acid chain to dissolve in water. This potassium salt of the fatty acid is what is then referred to as soap. Meanwhile, the OH group in the hydroxide will bond with the glycerol molecule, and if the three fatty acid groups are released, the saponification reaction is considered complete. Figure 10 illustrates the saponification reaction.

3.4. The effect of electrolysis time

The longer the reaction time, the longer the contact between the catalyst, methanol, and oil, which increases the conversion of oil into biodiesel. The reaction involved in biodiesel production is reversible. Therefore, when the equilibrium is reached, the synthesis process should be stopped to ensure efficient energy use. This is supported by the fact that when the reaction was continued for up to 120 minutes, the biodiesel yield conversion tended to be constant compared to the reaction time of 90 minutes (Figure 11). The yield value was constant because the reversible transesterification reaction had reached an equilibrium state. Figure 11 shows the biodiesel yield at various electrolysis times, while Figure 12 shows the

biodiesel produced at various electrolysis times. A previous study [21] also reported that the optimal time to complete the reaction was 120 minutes, so the results of this study corroborate the previous study. Furthermore, another study [15] stated that the maximum biodiesel yield (34.2%) from used frying oil was obtained at a chitosan catalyst concentration of 10%w/w and an electrolysis time of 4 hours, but the yield decreased by 5.1% as the electrolysis time increased to 6 hours. The result of this study was much better than the previous study, which might be due to the different free fatty acid contents in the raw materials used.

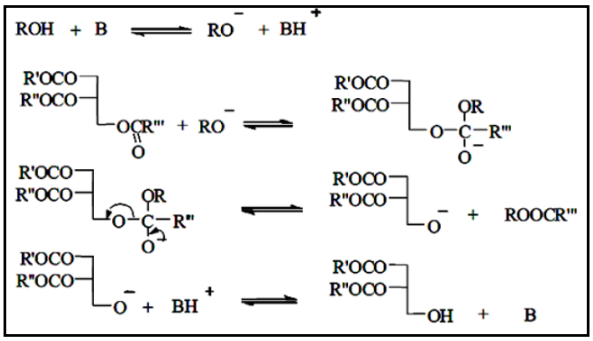

Figure 7. Reaction Mechanism for the Stage of Biodiesel Formation.

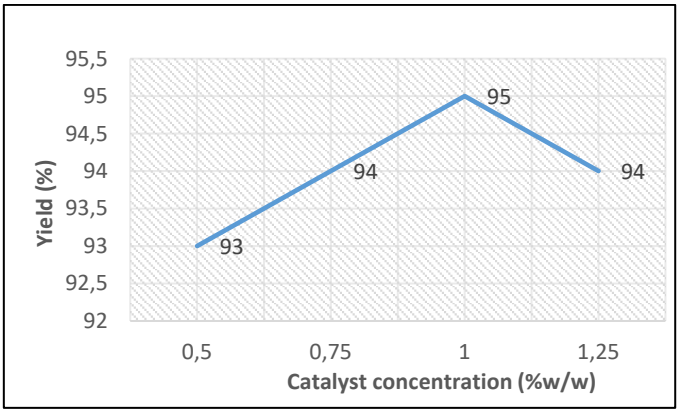

Figure 8. Effect of catalyst concentration on biodiesel yield. Voltage=20 V, Methanol-to-oil = 6:1, time = 120 minutes.

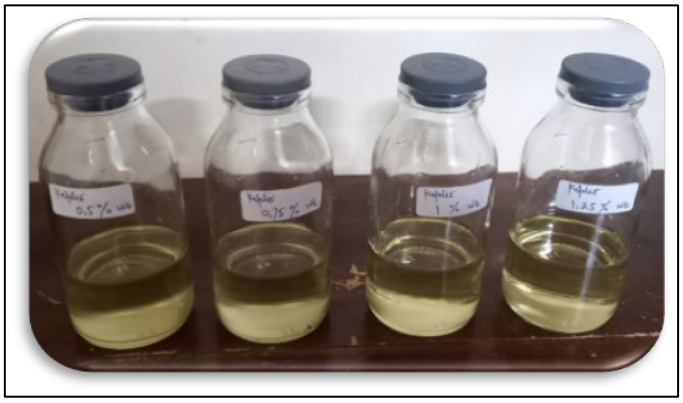

Figure 9. Biodiesel Yield on Variable % wt KOH Catalyst.

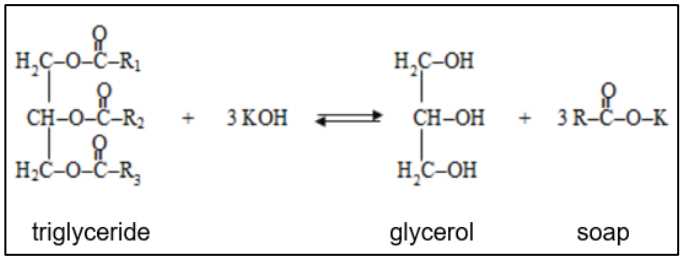

Figure 10. Saponification Reaction.

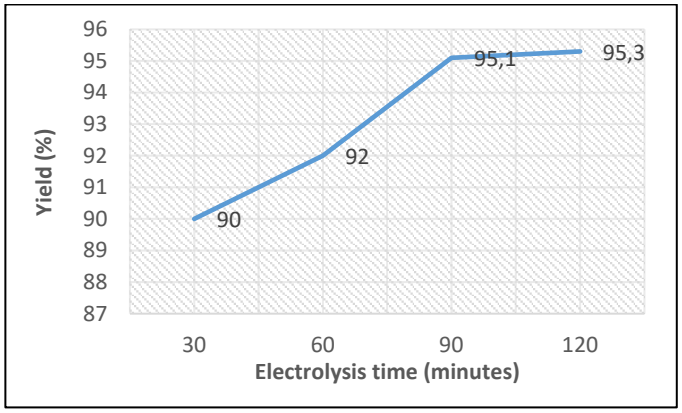

Figure 11. Effect of electrolysis time on biodiesel yield. Voltage = 20 V, Methanol-to-oil = 6:1, catalyst = 1 %w/w.

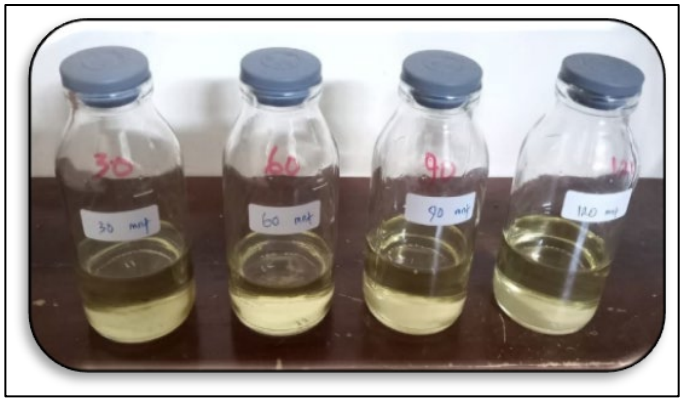

Figure 12. Biodiesel Yield on Variable Electrolysis Time.

3.5. Mathematical model

In this study, four affecting factors in biodiesel production (electrical voltage, methanol:oilmethanol-to-oil molar ratio, catalyst concentration, and electrolysis time) were examined. The summary of the experimental results in this study is shown in the Table 2. The correlation between the affecting factors and the biodiesel yield can be expressed using a regression model. By using the Microsoft Excel software, the regression model was found and written in equation (6).

Table 2. Experimental results

	Electrical voltage (V)	Methanol : oil	Catalyst concentration (%w/w)	Time (minutes)	Biodiesel yield (%)
Run	X1	X2	X3	X4	Y
1	5	6	1	120	88
2	10	6	1	120	92
3	20	6	1	120	95
4	30	6	1	120	95
5	20	4	1	120	93
6	20	5	1	120	94
7	20	6	1	120	95.1
8	20	7	1	120	95
9	20	8	1	120	91
10	20	6	0.5	120	93
11	20	6	0.75	120	94
12	20	6	1	120	95
13	20	6	1.25	120	94
14	20	6	1	30	90
15	20	6	1	60	92
16	20	6	1	90	95.1
17	20	6	1	120	95.3

$$Y = 38.454 + 0.938X_1 + 8.975X_2 + 21.361X_3 + 0.150X_4 - 0.019X_1^2 - 0.772X_2^2 - 11.113X_3^2 - 0.0006X_4^2 \quad (6)$$

Where :

Y = Biodiesel Yield (%)

X_1 = Voltage (V)

X_2 = Methanol-to-oil molar ratio

X_3 = Catalyst concentration (%w/w)

X_4 = Electrolysis Time (minutes)

The model can predict the biodiesel yield with a high R2 value which was 0.9515. The correlation between the experimental data dan modeled data is shown in the Figure 13. Therefore, the model was very potential to be used to predict the optimum condition in the biodiesel production of the local UFO in this study.

The regression statistics are shown in Table 3. Furthermore, the significance of the model to the biodiesel yield can be determined by the value of "significance F" in Table 4. If the "significance F" value is less than 0.05, then the biodiesel yield is significantly affected by the model presented in equation (6).

Moreover, the test of significance of each factor on the response (biodiesel yield) is shown in Table 5. The factors, having a p-value < 0.05, had a significant effect on the predicted biodiesel yield obtained using the model. Based on Table 5, all factors (X_1, X_2, X_3, X_4) had a p-value < 0.05. It means that all factors were significant in the model in predicting the response (biodiesel yield). The less the p-value, the more significant the factors are. Therefore, the

factors of X_1 (electrical voltage) and X_2 (molar ratio of methanol-to-oil) gave more significant effects in the model in predicting the biodiesel yield than the factors of X_3 (catalyst concentration) and X_4 (electrolysis time).

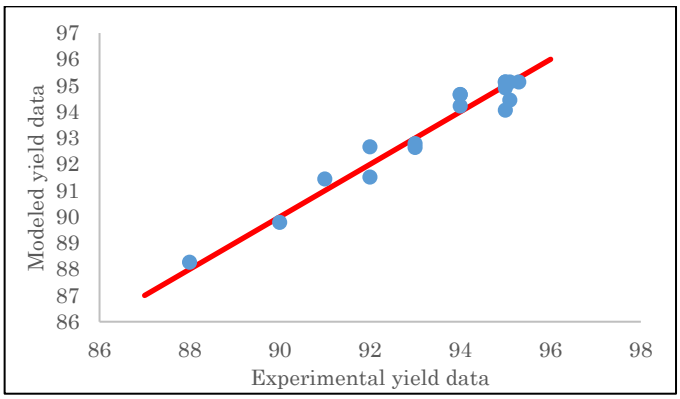

Figure 23. Correlation between the experimental yield data dan modeled yield data

Table 3. Regression Statistic

Multiple R	0.975463
R Square	0.951527
Adjusted R Square	0.903055
Standard Error	0.657417
Observations	17

Table 4. Test of significance of the model on the response (biodiesel yield)

	df	*SS*	*MS*	*F*	*Significance F*
Regression	8	67.87301	8.484126	19.630 20303	0.000172
Residual	8	3.457581	0.432198		
Total	16	71.33059			

3.6. Prediction of the optimum conditions

The model shown in the equation (6) was able to make resulted in goodmore accurate predictions compared to the experimental biodiesel data, as shown in the Figure 13. Based on the Table 3, the model resulted in a high R2 value of 0.9515. FurthermoreIn addition, based on the Table 4 demonstrate that the 4, the model can significantly predict the biodiesel yield significantly because it had awith a "significance F" value < 0.05. Therefore, the model can be confidently utilized to forecast the optimal conditions for maximum biodiesel yield within the constraints presented in Table 6. These constraints were obtained from the minimum and maximum values of each factor examined in this study, as shown in Table 2.

By using the model with the constraints shown in the Table 6, the maximum biodiesel yield was successfully predicted with a help of MS. Excel. The predicted maximum yield was 95.54% which was obtained at optimum conditions of a voltage of 24.4 V, molar ratio of methanol:oilmethanol-to-oil of 5.8:1, a catalyst concentration of 1 %w/w, and an electrolysis time of 120 minutes.

3.7. Economic analysis

Financial analysis or feasibility of biodiesel production from the local UFO was analyzed in this study for small-scale business production. The analysis was based on several assumptions regarding production scale and other factors, and included a summary of the feasibility indicators of small industrial-scale biodiesel production businesses designed by the author. The indicators used were as follows: biodiesel production was calculated based on the local UFO volume per month, with an average price of IDR 3000/L from the collector. The study found that 0.5 L of local UFO can be converted to 0.477 L of biodiesel. 100 L of local UFO was needed per day, or 3000 L per month, to produce 2.862 L of biodiesel per month. The selling price of biodiesel was IDR 9,000/L, with additional income potential from selling glycerol at a price of IDR 20,000/L.

Investment Cost

Investment cost calculation is as follows: Drum (oil storage area) = IDR 200,000. One set of 10 L capacity biodiesel reactor = IDR 8,000,000. Total cost = IDR 8,200,000.

Fixed cost

Fixed costs are costs that must be incurred and the amount is not affected by the number of products produced. Fixed

costs for producing biodiesel from used cooking oil are as follows: Electricity = IDR 1.000,000. Manpower (1 man) = IDR 2,500,000. Total cost = IDR 3,500,000.

Variable cost

Variable costs are those whose amount is influenced by the number of products produced. The variable costs are as follows: Cooking oil 100 L @ IDR 3,500 × 30 days = IDR 10,500,000. Potassium hydroxide (KOH) 1 kg @35.000 x 30 days = IDR 2.400,000. Methanol 10 L x @35.000 x 30 days = IDR 10,500,000. Total cost = IDR 23,400,000.

Total production costs

Total production costs = fixed costs + variable costs = IDR 3,500,000 + IDR 23,400,000 = IDR 26,900,000.

Income and Profits

The by-product in the form of glycerol can be another source of income. Biodiesel 2.862 L @ IDR 9,000 = IDR 25,758,000. Glycerol 98 L @ IDR 20,000 = IDR 1,960,000. Total income = IDR 27,718,000.

Profit = Total income – Total production cost = IDR 27,718,000/month – IDR 26,900,000/month = IDR 818,000/month

Business Feasibility Analysis

The business feasibility analysis used the break even point (BEP), and the pay back period (PBP). BEP is utilized to determine the sales volume required for a company to cover all costs and break even without incurring losses or profits. It is achieved when the total production cost is equal to the selling value of biodiesel from used cooking oil. The BEP is formulated as follows: BEP = total production costs per month / selling price per liter = IDR 26,900,000 per month / IDR 9,000 per liter = 2,989 liters per month. The calculated BEP indicates that producers will break even if they sell 2,989 liters of biodiesel per month at a selling price of IDR 9,000 per liter. The estimated PBP value can be calculated to show the payback period for an industrial investment. PBP is the expected time required by the industry to recover the invested capital. An industry is deemed feasible if its PBP value is lower than the project's economic life. PBP can be calculated using the formula: PBP = investment value ÷ profit per month = IDR 8,200,000 ÷ IDR 818,000 per month = 10.02 months.

Table 6. Constraints in optimization

Factors	Minimum	Maximum
Electrical voltage	5	30
Methanol-to-oil molar ratio	4	8
Catalyst concentration	0.5	1.25
Electrolysis time	30	120

Table 5. Test of significance of each factor in the model on the response (biodiesel yield)

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	38.45409	7.296649	5.27010	0.000755	21.62799	55.2802
X_1	0.938234	0.125629	7.46828	7.1393E-05	0.648533	1.227935
X_2	8.975848	1.653184	5.42943	0.000623761	5.163599	12.7881
X_3	21.36066	7.453212	2.86596	0.020958374	4.17352	38.54779
X_4	0.150728	0.052133	2.89121	0.020161411	0.030509	0.270947
X_1^2	-0.01922	0.003636	-5.2846	0.000742059	-0.0276	-0.01083
X_2^2	-0.77299	0.136672	-5.655	0.000478199	-1.08815	-0.45782
X_3^2	-11.1139	4.328551	-2.5675	0.033252885	-21.0955	-1.13221
X_4^2	-0.00061	0.000323	-1.8858	0.096034088	-0.00135	0.000136

4. CONCLUSION

The local UFO contains triglycerides and FFA content <2%, allowing it to be directly electrolyzed with methanol to produce biodiesel. This study evaluated the effects of various factors on biodiesel yield, including electrical voltage, molar ratio of methanol-to-oil, catalyst concentration, and electrolysis time. Results showed that increasing the voltage from 5 to 20V increased the biodiesel yield from 88% to 95%, but higher voltages did not improve yield. Similarly, an increase in the methanol-to-oil molar ratio from 4:1 to 6:1 increased the yield from 93% to 95.1%, but ratios above 6:1 decreased the yield to 91%. The highest biodiesel yield (95%) was obtained with a 1%w/w KOH catalyst concentration, and using lower or higher concentrations decreased yield. Yield increased with longer electrolysis times, with the highest yield (95.54%) obtained at 120 minutes. The model developed had an R2 of 0.9515, and predicted optimum conditions were a voltage of 24.4 V, a methanol-to-oil molar ratio of 5.8:1, a catalyst concentration of 1%w/w, and an electrolysis time of 120 minutes, resulting in a maximum biodiesel yield of 95.54%. Small-scale production utilizing 300 liters of local UFO per month generated a monthly profit of IDR 818,000.

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