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Article

Biodiesel production from used cooking oil and cost appraisal for the purpose of reduction in dependence on petroleum oil in Laos

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ABSTRACT

To mitigate dependence on fossil fuels, the government of Lao PDR has promoted the development of alternative fuel production in the country. Biodiesel is one of the most feasible and attractive fuels. This paper presents a lab-scale biodiesel production from used cooking oil (UCO) and its cost appraisal. This biodiesel production is based on the base-catalyzed transesterification reaction. The optimum parameter value in terms of catalyst concentration and amount of methanol is examined to achieve the best biodiesel yield. The results of this study revealed that the optimized condition for producing biodiesel from 1 liter of UCO is obtained using 12 g of KOH and 20 % of MeOH under the operating temperature of 60 °C and mixing time of 30 min. With this condition, the maximum yield of biodiesel is obtained at 91.3%. The total cost of production for 1 liter of biodiesel produced is approximately 17782 LAK. Production quantity at break-even point is about 41989 liters, achieving a payback period of 2.67 years.

1. Introduction

1.1 Overview

Laos is one of the 13 least developed countries in the Asia Pacific Region; however, annual economic growth increased rapidly from 2010 to 2015. This resulted in an increase in the national energy demand continuously [1]. As a landlocked country lacking underground petroleum sources, fossil fuel is 100% imported from abroad (mainly through Vietnam and Thailand). This fossil fuel is mostly utilized in the transportation and agricultural sectors. Due to the abundant availability of hydropower sources, a small proportion of fossil fuel is used for electricity generation in rural areas without the national grid. For instance, fossil fuel is used for lighting-based diesel generators and stationary stable-load motors (e.g., rice mills and water pumps) [2]. Fossil fuel demand is increasing with the increase in population and industrialization. The national policy related to energy-saving and improving fuel efficiency has been released, along with a plan to promote biofuel production in the country to achieve the goal of mitigating dependence on fossil fuels. Biodiesel has been interested and studied by several institutions in the country to develop the production processes and its potential to meet national demands. However, it is still a low-level technique, and it does not result in comprehensive findings. UCO can be a resource. However, in Lao PDR, it is mostly poured down the sink or thrown as waste oil into the trash. This is far from the ideal solution and can be caused major environmental issues. Moreover, fat in UCO will later harden, causing a blockage in the drainage system. Improper disposal of UCO can often go against regulatory guidelines. According to the Environmental Protection Agency (EPA), pouring animal fats and vegetable oils into water has similar destructive impacts on the aquatic environment as petroleum oils [3]. Hence, proper recycling of UCO will reduce the risk of harming natural resources and the environment caused by free fatty acids and grease in the UCO. Opting into UCO recycling as a resource for renewable and green fuel generation supports sustainable development growth.

1.2 Biodiesel production from UCO

Biodiesel can be produced from more than various types of feedstocks, including both edible and non-edible vegetable oils. A high concentration of triglycerides in these feedstocks is most significant to the high productivity of biodiesel. Edible oil is mainly used for human consumption. Economically, it is not introduced as biodiesel production feedstocks due to the limited supply with high demand for fuel and food production. The most common edible oil feedstocks are included palm, soybean, sunflower, rapeseed, and peanut oils. Due to it is not suitable for consumption, non-edible oil is mainly used in industrial applications for producing biofuel, soap, detergent, and paints. Various chemical processes are required for extracting non-edible oil. The most common non-edible oil feedstocks used for biodiesel production are included tallow castor, jatropha, and used cooking oils. However, a high amount of free fatty acid in these feedstocks results in a reduction in biodiesel yield [4]. Biodiesel is made up of methyl or ethyl esters of fatty acids through a transesterification process, which is a well-established chemical reaction where alcohol reacts with triglycerides in the presence of a catalyst. The main products produced are biodiesel and glycerin [5]. Conventionally, the transesterification is often catalyzed by a base catalyst (sodium hydroxide, NaOH, or potassium hydroxide, KOH). However, the biodiesel production process can also be catalyzed by various types of catalysts such as acid catalysts, enzymatic catalysts, solid catalysts, and industrial/biological sourced catalysts [6]. The selection of a catalyst should be considered in terms of cost-effectiveness and environmental possibilities. Besides catalysts, feedstocks constitute a factor that affects the efficiency of the reaction process and the quality of produced biodiesel. Feedstock for producing biodiesel can be vegetable oils (both edible and non-edible oils), animal fats, and even municipal waste oils [7]. This makes biodiesel a sustainable and eco-friendly biofuel. However, the production cost of biodiesel is relatively high, resulting from the low energy efficiency of its conversion process and high raw material cost. These are considered the major obstacles and economic challenges for the poorest developing countries. Feedstock price is considered the major contributor to the total cost of biodiesel production.

To avoid direct consumption of food crops, non-edible oils are a good option for biodiesel production feedstock. However, it does not resolve the problem that requires a large plantation land area. UCO could be used as a feedstock for biodiesel production, producing biodiesel of similar quality to that produced from fresh oils [8]. As waste from cooking activities is to be disposed of, biodiesel production from UCO is considered the most promising potential and effective way of reducing the total costs [9] with an economically and environmentally viable solution, providing an alternative method for the final disposal of the waste oil [10]. The price of biodiesel produced from UCO will be significantly reduced as low-cost feedstock. The biodiesel production cost can be reduced by 60 - 70% by using UCO as feedstock [11,12]. However, using UCO for biodiesel production requires pre-treatment steps before processing the transesterification. Unlike fresh oil, UCO contains high water and solid impurities obtained during cooking activities. In most cases, heating and filtration are sufficient for removing water and solid particles contained in UCO [9]. In addition, obtaining heat and other spices during cooking activities results in variably physical and chemical properties of UCO, especially free fatty acid (FFA) contain. The base catalyst transesterification is only suitable for feedstocks with a low FFA. With a high FFA, two steps of biodiesel production are often conducted. The first step is the esterification process to reduce the acid value, commonly using an acid catalyst (e.g., H_2SO_4 or HCl). Then, the second step of the transesterification process can be conducted to convert triglycerides along with alcohol into biodiesel and glycerol [13]. Moreover, to accelerate the reaction and increase the production yield, heating to maintain the operating temperature in a range of 50-60°C is favorable [9]. Production of biodiesel from waste oils has been comprehensively investigated by using various reactors [11,14] and catalyst types [15]. Many studies have been performed in terms of techno-economic feasibility [16]. However, low technical risks, simplicity, acceptable production yield, and low materials, as well as equipment costs, are most suited for the implementation of biodiesel production in the poorest developing countries [7], and Lao PDR is included. To the author's best knowledge, the well-established process for biodiesel production in the last two decades has been the transesterification process. In the context of Lao PDR, studies of biodiesel production are much less common. There is not a techno-economic analysis that can be found in the literature yet. Therefore, this study presents biodiesel production and its cost appraisal using UCO as feedstock based on the current economic situation in Lao PDR. The first objective is determining the optimum production conditions based on a lab-scale finding. Fundamental properties of biodiesel fuel products are examined. The second objective is the economic feasibility of biodiesel production from UCO.

2. Materials and Methods

2.1 Feedstock Collection and Preparation

UCO used in this experimental study is collected from a fried chicken restaurant in Vientiane's capital, Lao PDR. According to random interviews with the owner of several restaurants in the Vientiane capital, the generation of waste cooking oil is in the range of 10-30 liters per day. This revealed that there is a huge potential for biodiesel production in Laos. Chemical materials are also obtained from local chemical stores. UCO obtained is filtered to remove impurities and boiled for water separation before entering the production process.

2.2 Biodiesel Production in a Lab-scale Methodology

The alkaline transesterification reaction with KOH or NaOH is the most used for biodiesel production from UCO. Using an acidic catalyst (often used H_2SO_4) is not preferable due to the corrosive effects, and it is only considered for a case with high FFA content in oil, as shown in Figure 1. Therefore, the alkaline transesterification reaction was selected for this study. This is because of lower technical risks, more simplicity, and lower materials and equipment costs with acceptable biodiesel yield. At first, it is imperative to determine the value of the FFA of UCO. This step is well-known as titration. Phenolphthalein, methanol, and KOH are used for this process. The percentage of FFA is calculated as in Eq (1):

$$\%FFA = \frac{amount\ of\ KOH\ used \times 56.1 \times 0.1}{amount\ of\ waste\ oil \times 1.99} \tag{1}$$

After five times repeating titrations to know the average KOH used, %FFA is calculated, and it is about 3.6%, which is lower than 5%. It means that this waste oil could be acceptable for direct biodiesel production using a base catalyst transesterification reaction [5] with methanol as alcohol and KOH as the catalyst. This method has relatively low technical risks, simplicity, and acceptable production yield, including the low price of materials and equipment. A lab-scale procedure is performed for 500 ml of UCO. After filtrating and heating, UCO is left to cool down to 60±2°C before mixing with a mixture of KOH catalyst and methanol. All mixtures are strongly stirred for 30 minutes to achieve a good result of mixing and then, left for 8-10 hours to separate glycol from biodiesel. Since the lab-scale procedure aimed to achieve maximum production, the percentage of biodiesel yield is the main interesting variable. The percentage of biodiesel yield can be calculated, as in Eq (2):

$$\%yield = \frac{amount\ of\ biodiesel\ produced}{amount\ of\ waste\ oil\ used} \times 100 \quad (2)$$

Thereafter, the produced biodiesel is cleaned with distilled water and heated up to remove water again to be ready for the determination of physicochemical properties. Figure 1 illustrates the flow chart of biodiesel production from UCO.

2.3 Cost estimation analysis

One of the major obstacles in utilizing biodiesel is a price that is higher than petrol diesel. Hence, the use of UCO as feedstock can be reduced the cost of biodiesel against petrol diesel. Moreover, UCO is a renewable resource. Economic analysis is an important tool for evaluating the feasibility and optimization of biodiesel production. Many research works have been carried out in techno-economic studies of biodiesel production from waste oils [17–21]. In the present study, economic analysis is based on the estimation of economic criteria such as fixed cost, variable cost, and capital cost for 1 liter of biodiesel produced.

3. Results and Discussion

3.1 Optimization of Biodiesel Production based on Lab-scale Experiment

The experiment is implemented by 1) varying amounts of alcohol and 2) catalyst while the rest variables are fixed. The results are presented in Table 1 and Table 2, respectively. For the case of variation of alcohol (Methanol), it is carried out by changing methanol from 15 – 25% (with 5% intervals) of UCO while catalyst (KOH), stirring time, and the temperature are fixed at 7 g, 30 min, and 60±2°C, respectively. It is found that the maximum yield of biodiesel production from the UCO is 89.0% at an amount of methanol of 20%. Although alcohol is capable of increasing the efficiency of the reaction, increasing further alcohol beyond the optimum dosage will be resulted in an expensive biodiesel refining process [22]. For the case of variation of catalyst (KOH), it is carried out by changing KOH from 6g, 7g, and 8g while methanol, stirring time, and temperature are fixed at 20%, 30 min, and 60±2°C, respectively. It was found that the maximum yield of biodiesel production from the UCO is 91.3% at an amount of KOH of 6g. This could be explained by the use of catalysts for accelerating the transesterification process time. When adding more of the catalyst beyond the optimum dosage will be resulted in saponification that converts triglyceride to soap, leading to viscousness and poor diffusion of the reactants, and thus decreasing biodiesel production yield [23].

From the lab-scale experimental findings, it could be concluded that the optimized condition for producing biodiesel from the UCO of 1 liter is using methanol of 20% of the feeding waste oil, KOH of 12g, maintaining the operating temperature of 60°C, and mixing time of 30 min. Hence, this condition will be information for economic analysis in the following section. The basic properties of the produced biodiesel are presented in Table 3.

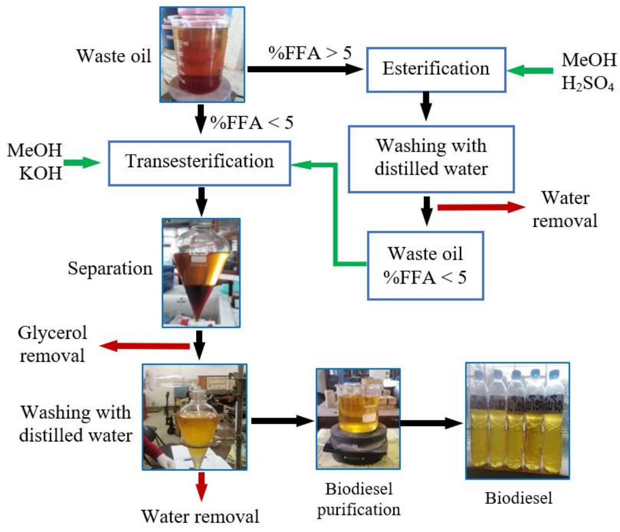

Figure 1. Flow chart diagram of biodiesel production

3.2 Economic evaluation

From the optimum condition obtained by experimental attempts, it shows that the maximum biodiesel yield is 91.3 %. Thus, producing biodiesel from the UCO of 1 liter requires methanol of 0.2 liters (20%) and potassium of 12 g. For simplicity, it is considered that the total cost of biodiesel production includes fixed cost, variable cost, and overhead cost. The fixed cost is the cost related to utilities and operating labor, while the variable cost is included the cost of feedstock, raw materials, and other consumables. Although UCO is free, it might have some costs for collecting and transporting. This cost is estimated at 1667 LAK/liter of UCO. The cost of methanol is 8000 LAK/liter of UCO, and the cost of KOH is 960 LAK/liter of UCO. The cost of utilities and operations is mostly considered for utility consumption, including water, electricity, and other consumables. However, it does not include the capital cost for equipment and machines. The detail of cost appraisal followed the method of [12], and its results are listed in Table 4. It is noticed that the production cost of biodiesel from UCO in the present study is 17782 LAK per liter of UCO used (around 1.02 USD based on the exchange rate on 30 November 2022). It is lower than the present price of petroleum diesel in Lao PDR. This production cost is a significant variable for evaluating economic feasibility. When the production cost is smaller than that of the unit selling price, it would be considered that the production facility is economically feasible. The production cost of biodiesel varies considerably with the type and cost of raw materials, conversion technology, and production scale [7]. In this study, a biodiesel production machine with a capacity of 150 liters per batch is considered. This machine can be imported from Thailand with an estimated total cost of about 200,000 THB (approximately 98,110,000 LAK). The machine has a lifespan of about ten years. Maintenance cost is considered 5 % of the total machine cost, and scrap value is 20 % of the total machine cost.

Table 1. Effect of variation of methanol (MeOH) on biodiesel production

Waste oil (ml)	MeOH (%)	KOH (g)	Operating temperature (°C)	Mixing time (min)	Biodiesel yield (%)	Glycerin (g)
500	15	7	60±2	30	87.6	65.0
	20				89.0	86.0
	25				87.0	87.2

Table 2. Effect of variation of potassium hydroxide (KOH) on biodiesel production

Waste oil (ml)	MeOH (%)	KOH (g)	Operating temperature (°C)	Mixing time (min)	Biodiesel yield (%)	Glycerin (g)
500	20	6	60±2	30	91.3	78.5
		7			89.0	86
		8			85.9	86

Table 3. Basic properties of the produced biodiesel

Properties	Test method	Produced biodiesel
Specific gravity@15°C	ASTM D1298	0.881
Flash point (°C)	ASTM D97	150
Viscosity kinematic @40°C (cSt)	ASTM D 445	4.84
API gravity @60°C	ASTM D1298	29.1
Calorific value (MJ/kg)	ASTM D240	38

Considering the 10 % of interest rate, the capital recovery factor (CRF) and sinking fund factor (SFF) can be calculated as follows:

$$CFR = \frac{i(1+i)^n}{(1+i)^n-1} \quad (3)$$

$$SFF = \frac{i}{(1+i)^n-1} \quad (4)$$

where *i* is the interest rate, and *n* is the project period (year). In this study, biodiesel production can be performed 1 batch per week using a UCO of 150 liters per batch. This is assumed that it requires time to collect UCO from restaurants and villagers. After considering holidays, the production process can be performed the production within 48 weeks throughout the year. Using the maximum biodiesel yield of 91.3 %, it requires UCO for feedstocks of about 7200 liters per year and can be produced biodiesel of about 6574 liters per year. Since in Laos, there is no agreement on the unit selling price of biodiesel yet, a price lower than that of a present unit selling diesel here is considered. Assuming to use the unit biodiesel selling price of about 18000 LAK per liter, it requires production quantity at a break-even point of about 41989 liters and a payback period of 2.67 years or approximately 2 years with 8 months. Hence, it can be concluded that biodiesel production from UCO, under assuming conditions in this study is economically feasible.

Table 4. Cost estimation of biodiesel production from UCO

Description	Amount	Unit
(A) Material cost (MC)		
(1) UCO collection	1667	LAK/L
(2) MeOH	8000	LAK/L
(3) KOH	960	LAK/L
Total (A): (1+2+3)	10627	LAK/L
(B) Utilities		
Electricity		
Assuming UCO 1 liter = 0.9 kg		
1 kWh = 799 LAK for industry use		
Cp, water = 4.18 kJ/kgK		
Cp, waste oil = 1.67kJ/kgK		
Heat loss = 20%		
(4) Mixing MeOH/KOH	0.00042	kWh/L
(5) Mixing UCO/(MeOH/KOH)	0.0025	kWh/L
(6) Heating water, 25-60°C	0.051	kWh/L
(7) Removing water from UCO, 25 - 100°C	0.039	kWh/L
(8) Removing water from biodiesel, 25 - 100°C	0.039	kWh/L
Water		
Assuming to use water 150 liter for a batch		
1379 LAK for 1 m³ for industry use		
(9) Cost of water for washing biodiesel	1.38	LAK/L
Total (B): (4+5+6+7+8+9)	1.51	LAK/L
Variable cost (VC): (A+B)	10628	LAK/L
(C) Fixed cost (FC)		
Assuming needed 2 workers for a batch, 2×80000 LAK/batch		
(10) Labor cost (LC)	1067	LAK/L
(11) Insurance & tax 15% of LC	160	LAK/L
Total (C): (10+11)	1227	LAK/L
(D) Direct cost (DC) = (A+B+C)	11855	LAK/L
General overhead 50% of DC	5927	LAK/L
Total production cost (A+B+C+D)	17782	LAK/L

4. Conclusion

This paper presents biodiesel production from UCO through a base catalyst transesterification reaction. The optimum parameter value for catalyst concentration and methanol is examined. In addition, the cost estimation of 1 liter of biodiesel produced is evaluated. The result showed that the optimized catalyst and methanol are 12g and 20% of KOH and MeOH for 1 liter of UCO used under the operating condition of a temperature of 60°C and mixing time of 30 min, producing a biodiesel yield of 91.3%. The total cost of production for 1 liter of biodiesel from UCO is 17782 LAK. It is reduced by about 56 % when compared with using fresh oil as feedstock, and this cost is comparatively low by about 11 % of the cost of petrol-diesel in the present time in Laos. With the assumed conditions in this study, a production quantity at the break-even point is about 41989 liters, and it will achieve a payback period of 2.67 years. With this result, it can be concluded that it is possible to integrate the waste oil from cooking activities into productive processes to produce biodiesel with low production costs and negative impacts on the environment.

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Ethical issue
The author is aware of and complies with best practices in publication ethics, specifically concerning authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The author adheres to publication requirements that the submitted work is original and has not been published elsewhere in any language.

Data availability statement
Datasets analyzed during the current study are available and can be given following a reasonable request from the corresponding author.

Conflict of interest
The author declares no potential conflict of interest.

References
[1] Han Phoumin, Lao PDR Energy Outlook 2020, Chapter 1 Introduction, 2020. eria.org/uploads/media/Research-Project-Report/Lao-Energy-Outlook-2020/Lao-PDR-Energy-Outlook-2020.pdf.
[2] S. Kham, M. Bouathep, P. Phouvong, K. Southone, I. Keophayvan, Status and potential for the development of biofuels and rural renewable energy The Lao People's Democratic Republic, 2009.
[3] USEPA, Oil Spills Prevention and Preparedness Regulations, (n.d.). https://www.epa.gov/emergency-response/vegetable-oils-and-animal-fats (accessed October 24, 2022).
[4] A.S. Elgharbawy, W.A. Sadik, O.M. Sadek, M.A. Kasaby, A review on biodiesel feedstocks and production technologies, J. Chil. Chem. Soc. 65 (2021) 5098–5109. https://doi.org/10.4067/S0717-97072021000105098.
[5] B.R. Moser, Biodiesel production, properties, and feedstocks, Vitr. Cell. Dev. Biol. - Plant. 45 (2009) 229–266. https://doi.org/10.1007/s11627-009-9204-z.
[6] M.K. Lam, K.T. Lee, A.R. Mohamed, Homogeneous, heterogeneous and enzymatic catalysis for transesterification of high free fatty acid oil (waste cooking oil) to biodiesel: A review, Biotechnol. Adv. 28 (2010) 500–518. https://doi.org/10.1016/j.biotechadv.2010.03.002.
[7] K. Al-attab, A. Wahas, N. Almoqry, S. Alqubati, Biodiesel production from waste cooking oil in Yemen: a techno-economic investigation, Biofuels. 8 (2017) 17–27. https://doi.org/10.1080/17597269.2016.1196326.
[8] V. Innocenzi, M. Prisciandaro, Technical feasibility of biodiesel production from virgin oil and waste cooking oil: Comparison between traditional and innovative process based on hydrodynamic cavitation, Waste Manag. 122 (2021) 15–25. https://doi.org/10.1016/j.wasman.2020.12.034.
[9] C.D. Mandolesi De Araújo, C.C. De Andrade, E. De Souza E Silva, F.A. Dupas, Biodiesel production from used cooking oil: A review, Renew. Sustain. Energy Rev. 27 (2013) 445–452. https://doi.org/10.1016/j.rser.2013.06.014.
[10] A. Mohammadshirazi, A. Akram, S. Rafiee, E. Bagheri Kalhor, Energy and cost analyses of biodiesel production from waste cooking oil, Renew. Sustain. Energy Rev. 33 (2014) 44–49. https://doi.org/10.1016/j.rser.2014.01.067.
[11] Z. Yaakob, M. Mohammad, M. Alherbawi, Z. Alam, K. Sopian, Overview of the production of biodiesel from Waste cooking oil, Renew. Sustain. Energy Rev. 18 (2013) 184–193. https://doi.org/10.1016/j.rser.2012.10.016.
[12] S. Joshi, P. Hadiya, M. Shah, A. Sircar, Techno-economical and Experimental Analysis of Biodiesel Production from Used Cooking Oil, 7 (2019) 2–7. https://doi.org/10.1007/s41247-018-0050-7.
[13] B.H.H. Goh, C.T. Chong, Y. Ge, H.C. Ong, J.H. Ng, B. Tian, V. Ashokkumar, S. Lim, T. Seljak, V. Józsa, Progress in utilisation of waste cooking oil for sustainable biodiesel and biojet fuel production, Energy Convers. Manag. 223 (2020). https://doi.org/10.1016/j.enconman.2020.113296.
[14] M.K. Pasha, L. Dai, D. Liu, M. Guo, W. Du, An overview to process design, simulation and sustainability evaluation of biodiesel production, Biotechnol. Biofuels. 14 (2021) 1–23. https://doi.org/10.1186/s13068-021-01977-z.
[15] M.R. Khodadadi, I. Malpartida, C.W. Tsang, C.S.K. Lin, C. Len, Recent advances on the catalytic conversion of waste cooking oil, Mol. Catal. 494 (2020) 111128. https://doi.org/10.1016/j.mcat.2020.111128.
[16] Y. Liu, X. Yang, A. Adamu, Z. Zhu, Economic evaluation and production process simulation of biodiesel production from waste cooking oil, Curr. Res. Green Sustain. Chem. 4 (2021) 100091. https://doi.org/10.1016/j.crgsc.2021.100091.
[17] P.T.A. Samad, M.S. Perdani, D.N. Putri, H. Hermansyah, Techno-economic analysis of portable plant from waste cooking oil, Energy Procedia. 153 (2018) 263–268. https://doi.org/10.1016/j.egypro.2018.10.062.
[18] A.A.S.A. El-gharabawy, Cost Analysis for Biodiesel Production from Waste Cooking Oil Plant in Egypt, Int. J. Smart Grid. 1 (2017). https://doi.org/10.20508/ijsmartgrid.v1i1.2.g2.
[19] S.K. Karmee, R.D. Patria, C.S.K. Lin, Techno-economic evaluation of biodiesel production from waste cooking oil—a case study of Hong Kong, Int. J. Mol. Sci. 16 (2015) 4362–4371. https://doi.org/10.3390/ijms16034362.

[20] J.B. Hirkude, J. Randhir, V.W. Belokar, Techno-economic conversion of Waste Fried Oil into Biodiesel through Transesterification, IOP Conf. Ser. Mater. Sci. Eng. 377 (2018). https://doi.org/10.1088/1757-899X/377/1/012160.
[21] Y. Zhang, M.A. Dubé, D.D. McLean, M. Kates, Biodiesel production from waste cooking oil: 2. Economic assessment and sensitivity analysis, Bioresour. Technol. 90 (2003) 229–240. https://doi.org/10.1016/S0960-8524(03)00150-0.
[22] I.A. Musa, The effects of alcohol to oil molar ratios and the type of alcohol on biodiesel production using transesterification process, Egypt. J. Pet. 25 (2016) 21–31. https://doi.org/10.1016/j.ejpe.2015.06.007.
[23] O.A. Aworanti, A.. Ajani, S.E. Agary, K.A. Babatunde, O.D. Akinwumi, Evaluation of Process Parameters for Biodiesel Production from Vegetable and Palm Waste Frying Oils Using a Homogeneous Catalyst, Int. J. Energy Eng. 2019 (2019) 25–35. https://doi.org/10.5923/j.ijee.20190902.01.