Prospect of Biodiesel from Sludge Palm Oil in Malaysia

Abu Saleh Ahmed[1,*], Md. Rezaur Rahman[2], Sinin Hamdan[2], Muhammad Khusairy Bin Bakri[2,3], and Khairul Anwar Mohamad Said[2]

[1]*Centre for Research of Innovation and Sustainable Development (CRISD), School of Engineering and Technology, University of Technology Sarawak (UTS), No 1, Jalan Universiti, 96000 Sibu, Sarawak, Malaysia*

[2]*Faculty of Engineering, Universiti Malaysia Sarawak, Jalan Datuk Muhammad Musa, 94300, Kuching, Sarawak, Malaysia.*

[3]*Composite Materials and Engineering Center, 2001 Grimes Way, Pullman, 99164, Washington State, U.S.A.*

Abstract

High feedstock costs make biodiesel production impractical and economically unfeasible, particularly as most feedstocks are unknown for performance. Waste oil, such as sludge palm oil (SPO), may be used to produce biodiesel. This study examined the efficiency and prospect of Sludge Palm Oil Biodiesel (SPOB) production from SPO through transesterification. One-step and two-step transesterification methods were performed for SPOB conversion. However, only a two-step method was effective in converting SPO into SPOB. SPO's high free fatty acid (FFA) content necessitated a two-step process to reduce FFAs to less than 4% before SPOB conversion. Step 1 yielded 78% SPOB at 2 hours, 0.03:1 acid catalyst–to–oil, and 8:1 alcohol–to–oil. The optimal SPOB yield for step 2 at 4 hours, 0.01:1 alkaline catalyst–to–oil, and 9:1 alcohol–to–oil was 78%. SPOB components were analyzed using FTIR with SPOB having a 1435.04 cm-1 methyl peak. The diesel engine performance test mixed SPOB with mineral diesel at different concentrations with 30% SPOB blends in mineral diesel offers the lowest fuel consumption (0.1089 ml/s), maximum braking horsepower (24.9266 rpm), and best mechanical efficiency. Density, flash point, and heating value were also tested to identify SPOB's physical characteristics and discussed in detail.

Keywords: *Sludge Palm Oil, Free Fatty Acids, Transesterification, Fourier Transform Infrared Spectrometer, Diesel Engines*

1. Introduction

Growth in oil consumption, rapid diminishing of oil reserves, and the high price of oil are mainly due to rapid population and massive global industrial growth [1]. Furthermore, massive global industrial growth and political problems between countries resulted in soaring oil prices with low resources [2]. On the other hand, biodiesel is biodegradable and non-hazardous, with low sulfur content that is environmentally feasible [3]. Thus, biodiesel is identified as a potentially clean and

* Corresponding author.
E-mail address: abuasaleh@uts.edu.my

Manuscript History:
Received 27 December, 2023, Revised 19 February, 2024, Accepted 8 March, 2024, Published 30 April, 2024

https://doi.org/10.33736/jaspe.6411.2024

renewable energy resource. Not only that, using biodiesel increases energy security, improves air quality and the environment, and provides safety benefits [4].

Biodiesel is a monoalkyl ester of fatty acids derived from renewable feedstocks, such as vegetable oils, animal fats, waste oils, or other greases [5]. It is a clean and biodegradable alternative fuel. Biodiesel is a renewable energy resource produced through the transesterification process with mono-hydric alcohol, which converts fats and oils into biodiesel. It is an environmentally friendly, non-hazardous, non-toxic fuel with low sulfur content [6].

A tropical crop called oil palm is farmed primarily for palm oil extraction. It is the world's highest-yielding and least cheap vegetable oil, making it a source of biodiesel and the preferred cooking oil for millions worldwide [7]. In addition, numerous packaged and fast meals, personal care and cosmetic items, and home cleansers frequently include palm oil and its derivatives [8]. Palm oil output increased twofold between 2003 and 2013 due to the demand for these goods, which is expected to continue [9-11]. When considering both production and trade, palm oil ranks as the world's most significant tropical vegetable oil, making up one-third of vegetable oil output in 2009 [12, 13]. The dominance of palm oil may be attributed to several factors, including its low cost and adaptability as a component in many processed goods [14], as well as its yield, nearly four times that of other oil crops [15].

The utilization of waste oils, such as sludge palm oil (SPO), presents a promising avenue for sustainable biodiesel production. However, challenges such as high feedstock costs and performance uncertainties have hindered its economic feasibility. This research explores the novel approach of producing Sludge Palm Oil Biodiesel (SPOB) through transesterification, focusing on efficiency, performance, and prospects. Two distinct transesterification methods, namely one-step and two-step processes, were evaluated to convert SPO into biodiesel. The study found that the two-step method was essential due to SPO's high free fatty acid (FFA) content, necessitating FFA reduction before conversion. The objectives of this research are to assess the efficiency of SPOB production through transesterification, analyze its chemical composition, evaluate its performance in diesel engines, and characterize its physical properties.

Therefore, an investigation was conducted into the efficiency and feasibility of Sludge Palm Oil Biodiesel (SPOB) production from sludge palm oil (SPO) through transesterification. Comparison and evaluation of one-step and two-step transesterification methods for SPOB conversion were undertaken, focusing on yield and purity. The chemical composition of SPOB was analyzed using Fourier Transform Infrared Spectroscopy (FTIR), with emphasis on characteristic peaks indicative of biodiesel. Diesel engine performance tests were conducted to assess the combustion characteristics and efficiency of SPOB blends with mineral diesel at various concentrations. The physical properties of SPOB, including density, flash point, and heating value, were determined to understand its suitability as a viable alternative fuel. By addressing these aims and objectives, this research contributed to the advancement of sustainable biodiesel production by offering insights into the efficient utilization of waste oils and enhancing the understanding of Sludge Palm Oil Biodiesel (SPOB) as a viable alternative to conventional diesel fuels.

2. Sludge Palm Oil (SPO) as biodiesel and its prospect

SPO is a by-product of the palm oil milling process or, in simpler words, a waste product of the palm oil mill [16]. This by-product contains high amounts of oil, dirt, and impurities, as shown in Figure 1. Sludge palm oil, also known as palm oil mill effluent (POME), is a brown slurry of roughly 95 % water, 0.5 to 1 % residual oil, and 4 to 5 % particles, mostly organic [17]. Additionally, there are significant levels of organic nitrogen in the effluent. However, many low-grade oils from the palm oil industry can be converted into biodiesel [18]. The considerable amount of fatty acids by weight percentage is commonly palmitic acid, oleic acid, and stearic acid [16]. The highest percentage of composition is palmitic acid at 42.84 wt%, while the lowest percentage of composition is caproic acid at 0.02 wt%. Due to its high percentage of saturated fatty acids and free fatty acids, SPO exists in the semi-solid or solid phase at room temperature [16]. Therefore, SPO has higher pour and cloud points than regular palm oil [16].

Figure 1. Sludge palm oil in a beaker.

As one of the world's biggest palm oil producers and exporters, Malaysia produces many low-grade oils, such as SPO, from palm oil industries. The annual production of SPO reaches 41 million tons. Therefore, SPO can be a feasible material for producing biodiesel in Malaysia [16], even though edible oils such as soybean, rapeseed, and palm oil have been used to make biodiesel as a mineral diesel substitute [19]. Table 1 shows the composition of biodiesel and mineral diesel. However, the sustainability of these feedstocks is a major potential drawback for biodiesel production [16]. In addition, large-scale biodiesel production from edible oils could result in a global imbalance in the food supply and demand market [20]. Moreover, many countries and governments do not encourage research on biodiesel production using edible oils. Thus, non-edible oils such as waste oils could be alternative feedstocks for biodiesel production [21].

Table 1. Classification of compositions for biodiesel and mineral diesel.

Property	Diesel	Biodiesel
Calorific value (MJ/kg)	44.34	42.80
Viscosity at 40 °C	2.86	4.82
Viscosity index	98	154
Pour point °C	-6	-2
Flashpoint °C	65	128
Cloud point °C	5	8
Specific gravity (29 °C)	0.792	0.84
Refractive index at 40 °C	1.32	1.46

In addition, analysis shows that the alkali-catalyzed process using virgin vegetable oil or crude oil to produce biodiesel results in higher raw material costs [21]. However, used or waste oils are available at lower costs than good-grade oils. Furthermore, a lower feedstock price is significant to the

e-ISSN: 2289-7771

industry as 70 to 85 % of production costs originate from the feedstock. The lower raw material cost results in lower production costs using waste or inedible oils as feedstock to produce biodiesel [22]. Therefore, sludge palm oil provides a common feedstock for making biodiesel at a lower production cost for the industry.

Biodiesel produced from waste oils has the advantage of having similar performance characteristics as biodiesel produced from crude oils. Like biodiesel made from crude oil, waste oil biodiesel exhibits performance characteristics similar to petroleum diesel while emitting less carbon monoxide, particulate matter, and volatile organic chemicals that cause smog and health problems. Also, a recent study shows that biodiesel produced from waste oils resulted in an 86 % reduction in lifecycle greenhouse gas emissions compared to conventional petroleum diesel. In contrast, soybean-based biodiesel had 54 % fewer lifecycle greenhouse gases [22]. Hence, this shows an additional positive perspective of using sludge palm oil (waste oils from palm oil mills) as the raw material for producing biodiesel.

2.2 Transesterification process

Transesterification is the most efficient and reliable method to produce high-quality, clean biodiesel [23]. This is mainly due to the ability of the transesterification process to yield a high volume of biodiesel at room temperature with low pressure and a short reaction time required [24]. It is a chemical reaction process where triglyceride molecules in oils or fats react with alcohol to form esters or biodiesel and glycerol with the presence of a catalyst [25]. It is where triglyceride molecules displace the alcohol from an ester to form biodiesel in the presence of an acid or alkali catalyst. Figure 2 shows the chemical reaction of methanol transesterification.

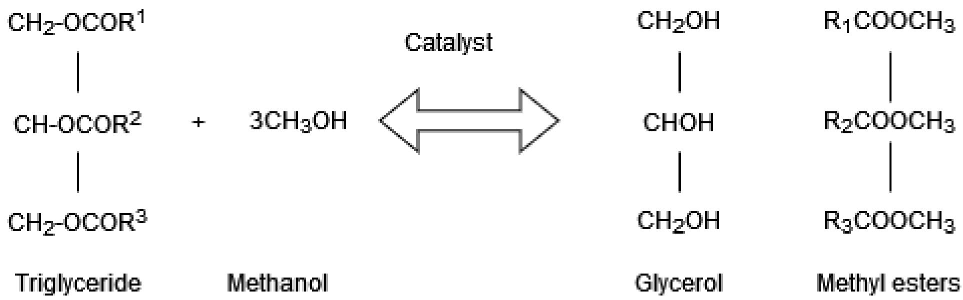

Figure 2. The overall chemical reaction of transesterification with methanol.

3. Methodology

3.1 Materials

The Sludge Palm Oil (SPO) was collected from FELCRA Palm Oil Mill, Kota Samarahan, Sarawak, Malaysia, courtesy of Felcra Jaya Samarahan Sdn. Bhd. It was then stored in the Energy Laboratory, Department of Mechanical and Manufacturing Engineering, Universiti Malaysia Sarawak, for subsequent laboratory works. Materials and equipment used for biodiesel production were methanol (MeOH) (99 % absolute), potassium hydroxide (KOH) (92 % pure), sulfuric acid (H_2SO_4), ethanol (EtOH), diethyl ether (Et_2O), phenolphthalein (php), sludge palm oil (SPO), orbital shaker, magnetic stirrer cum heater, and electronic weighing scale.

3.2 Cleaning and pre-treatment of sludge palm oil

SPO first proceeded with sedimentation to sediment the larger particles and dirt from the oil. The layer of oil formed on top of the dirt was then poured into a new beaker for storage and subsequent filtration process. Filtration of cleaned oil then proceeds with 3 to 4 repetitions to entirely remove any smaller particles and dirt that might exist in SPO. Finally, filtered SPO was then heated slowly to 100 °C to remove water content and other dirt. Finally, the clearer fluid of SPO was poured and stored for the subsequent biodiesel production.

3.3 Free fatty acids measurement

Titrimetry determined the FFAs value in SPO. The acid value is the number of KOH (in mg) required to neutralize the fatty acids contained in 1 gm of the fat. Reagents required include of solvent mixture (95 % ethanol + diethyl ether, 1:1 v/v) and 0.1M KOH in ethanol with 1 % phenolphthalein in 95 % ethanol. Firstly, 5.0g of SPO was weighed into a 100 ml conical flask, adding 50 ml of solvent mixture. Next, gentle heating of the mixture with a hot stirrer plate was conducted. Then, it was titrated with KOH solution (with 25 ml burette graduated in 0.1 ml) with continuous stirring till the end point of phenolphthalein indicator (persisting pink color for at least 10 s). The formula calculated this acid value (56.1 x M x V)/ W, where V is the amount of KOH solution used in ml, M is the molarity of the KOH mixture, and W is the weight of the SPO sample in gm. Suppose the FFAs value is greater than 4 %. In that case, the FFAs must be removed through a pre-treatment process using sulfuric acid as a catalyst or proceed with a one-step transesterification process if otherwise.

3.4 One-step catalyzed transesterification

Firstly, pre-treated SPO was heated until a temperature higher than 100 °C to remove water content. Methoxide solution was prepared by mixing the different methanol–to–oil ratios of 5:1, 6:1, 7:1, 8:1, 9:1, and 10:1 with KOH (by volume). The amount (in gm per liter of oil used) required was derived by the amount of KOH (ml) used during titration with an additional 5.0. The methoxide mixture was heated to 50 °C and then mixed with heated SPO. A magnetic stirrer cum heater was used to heat and stir the mixture at 400 rpm for two reaction hours while maintaining a temperature of 65 °C. Also, the orbital shaker was used to shake the mixture for 2 hours at room temperature at a speed of 250 rpm. Then, the mixture was allowed to settle for 2 hours or overnight to separate into two distinctive layers. The lower layer of glycerol was removed, while the upper layer of methyl ester was washed with desterilized water. The produced biodiesel was filtered with filter paper to produce pure biodiesel. Finally, filtered biodiesel was heated to above 100 °C to remove water content.

3.5 Two-step catalyzed transesterification

3.5.1 Acid-catalyzed esterification reaction

The first step was a pre-treatment step to remove high FFAs content in SPO. Pre-treated SPO was heated to a temperature greater than 100 °C to remove the water content in SPO. H_2SO_4 and MeOH were mixed in a beaker. Different methanol–to–oil ratios of 5:1, 6:1, 7:1, 8:1, 9:1, and 10:1 as well as different sulphuric acid–to–oil ratios of 0.01:1, 0.02:1, 0.03:1, 0.04:1, 0.05:1, and 0.06:1 by volume were analyzed to obtain the optimum esterification process parameter ratio. This mixture was heated to 50 °C. The heated acid alcohol mixture was then poured into heated SPO. This newly formed mixture was allowed to react for 2 hours at a temperature of 60 °C and stirring speed of 200 rpm with a magnetic stirrer cum heater or an orbital shaker shaking at 250 rpm for 2 hours. Then, the mixture was allowed to settle for an hour, and the upper layer of the methanol-water portion was removed. The lower layer was washed with desterilized water to remove impurities and excess sulphuric acid. The oily product was heated to above 100 °C to remove water content and proceed with the subsequent procedure for biodiesel production.

3.5.2 Base catalysed transesterification reaction

The second step was a biodiesel production step from the previous step oily product. The oily product from Step 1 was heated at 50 °C until it became clearer fluid. A mixture of potassium hydroxide and methanol was heated to 50 °C. Different methanol-to-oil ratios of 5:1, 6:1, 7:1, 8:1, 9:1, and 10:1 by volume and potassium hydroxide-to-oil ratios of 0.01:1, 0.02:1, 0.03:1, 0.04:1, 0.05:1, and 0.06:1 by weight were studied to obtain the optimum biodiesel production parameters ratio. The methanol and potassium hydroxide mixture was poured into a heated oily product. It was allowed to react for 4 hours at a temperature of 60 °C with a stirrer speed of 200 rpm with a magnetic stirrer cum heater or an orbital shaker shaking at 250 rpm for 4 hours. The mixture was then settled overnight and removed from the lower layer of glycerol. The upper layer of methyl ester was washed with desterilized water to remove excess alcohol. The produced biodiesel was then filtered to remove impurities. Finally, the filtered biodiesel was heated to slightly above 100 °C to remove the water content for pure biodiesel.

3.6 Characterization of SPO biodiesel

3.6.1 Fourier Transform Infrared (FTIR) spectroscopy

The Shimadzu Fourier Transform Infrared Spectrometer model IRAffinity^{-1} was used to examine the chemical bonds and functional groups of the pieces prepared from 400cm^{-1} to 4000cm^{-1}.

3.6.2 Titrimetric analysis

Titrimetric is a category of quantitative analytical techniques where an analyte's concentration is measured based on its stoichiometric interaction with a reagent that is gradually added to a sample until a predetermined amount of the analyte is consumed. Titration was conducted three times and had its average taken to improve titration result accuracy. The FFAs value was calculated based on the formula of $\frac{(5.61 \times M \times V)}{W}$.

3.6.3 Heating value, density, flashpoint

The heating value of these oil products was conducted with Bomb Calorimeter Parr 6400. The density of SPO, SPOB, and mineral diesel was determined with Anton Paar Density Meter DMA-35, and the Flashpoint of SPOB was determined with Seta Multiflash Automatic Flash Point Tester Model 34000-0.

4. Results and Discussion

4.1 Sludge palm oil titrimetry

Figure 3 shows the product of titrimetric analysis, while Table 2 shows the SPO titrimetric results. It shows that the second titration shows the highest acid value, while the third titration shows the lowest acid value. An average result shows that the average acid obtained was 44.87 % from all three titrations. According to Fernandez-Maestre [25], It is important to get an average titration value by running at least a few repetitions to ensure it falls in the range of wanted values to measure.

Table 2. SPO FFAs titrimetric results.

	First	Second	Third	Average acid value (%)
W/g	8.22	7.33	7.88	
V/ml	66.90	60.00	60.4	
Acid Value	45.64	45.95	43.03	44.87

Figure 3. End-product of the titrimetric method.

4.2 One-step and two-step transesterification

A one-step transesterification method was conducted with an orbital shaker or magnetic stirrer cum heater to convert SPO into biodiesel. Even though this method could produce SPO biodiesel, the yield was meagre due to SPO's high free fatty acids (FFAs) content. Thus, only a tiny portion of SPO was converted into biodiesel, while most of it was turned into soap through a reaction between free fatty acid and an alkali catalyst. Furthermore, it caused severe emulsification [26]. The emulsions are not welcome if it is not handled properly. They are likely to produce an unstable composition, which causes several issues, particularly in many refining process operations [26]. Therefore, the biodiesel conversion procedure has proceeded with a two-step transesterification method. The two-step transesterification method was applied due to the high FFAs content in SPO, which is 44.87 % (more than 4%). The variables are defined and studied through experimental procedures, namely type of equipment, optimum methanol–to–oil ratio, and catalyst–to–oil ratio required to be investigated.

4.2.1 Effect of type of equipment used

From Figure 4, biodiesel conversion efficiency for magnetic stirrer falls between a range of 51 to 55 %, with an average percentage of 52.33 % of yield. However, the biodiesel conversion efficiency with orbital shaker falls between 72 to 78 % at an average percentage of 75 %. Thus, biodiesel conversion is more efficient using an orbital shaker than a magnetic stirrer cum heater [27-29]. It is mainly due to the orbital shaker's continuous and high mixing rate than the magnetic stirrer cum heater [27-29]. Also, biodiesel could be produced efficiently and effectively at room temperature, thus proving mixing rate is an essential parameter than the temperature during biodiesel production. Therefore, the orbital shaker was chosen as the best-optimized equipment for biodiesel conversion [30].

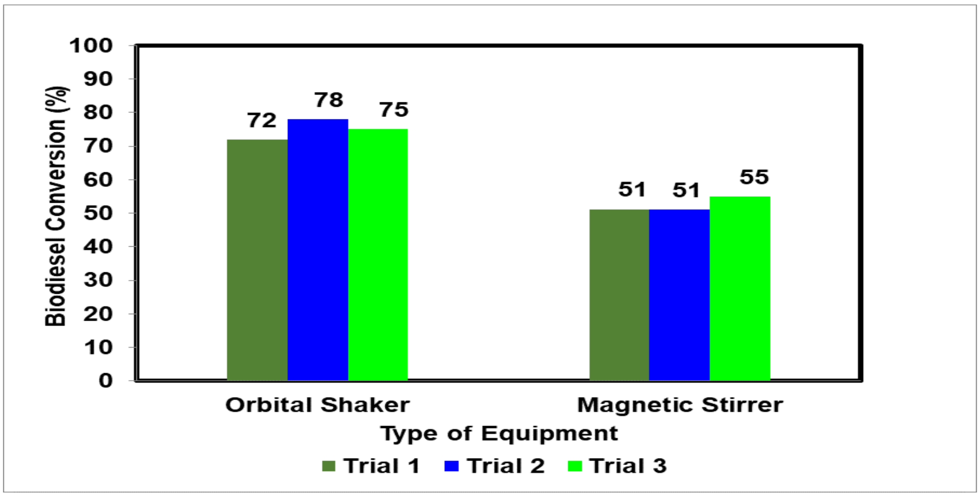

Figure 4. Comparison of biodiesel conversion between different types of equipment used.

4.2.2 Effect of catalyst-to-oil ratio

H_2SO_4 was used as a catalyst in the esterification process. The amount of catalyst used affects the reaction rate and oil acid value [31]. The esterification process aims to lower the SPO-FFAs to less than 4%. Thus, this procedure was conducted to determine the optimum catalyst-to-oil ratio, resulting in an oily product of the lowest acid value. Figure 5 shows the acid value of ester after the esterification process, and the titration method was used to determine its acid value. From Figure 5, the optimum catalyst-to-oil ratio was 0.03:1 or 3% H_2SO_4. KOH was used to produce biodiesel as a catalyst in the transesterification process. Figure 6 shows the effect of alkaline catalysts on biodiesel yield. From Figure 6, the optimum base catalyst-to-oil ratio is 0.01:1, with a maximum biodiesel yield of 78 %. Therefore, the additional base catalyst does not improve the efficiency of biodiesel conversion while lowering its biodiesel yield.

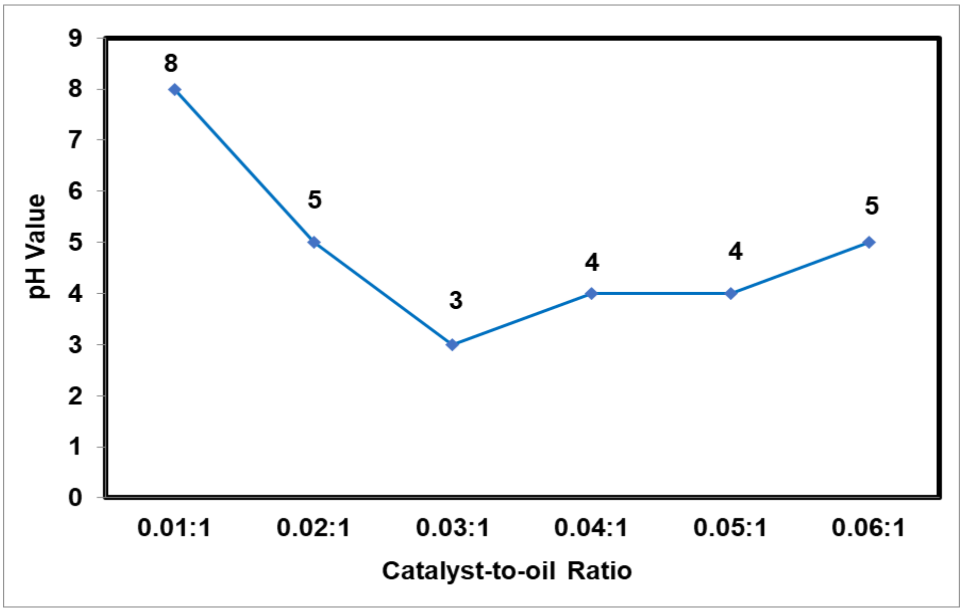

Figure 5. Effect of ratio of H_2SO_4 on lowering acid value.

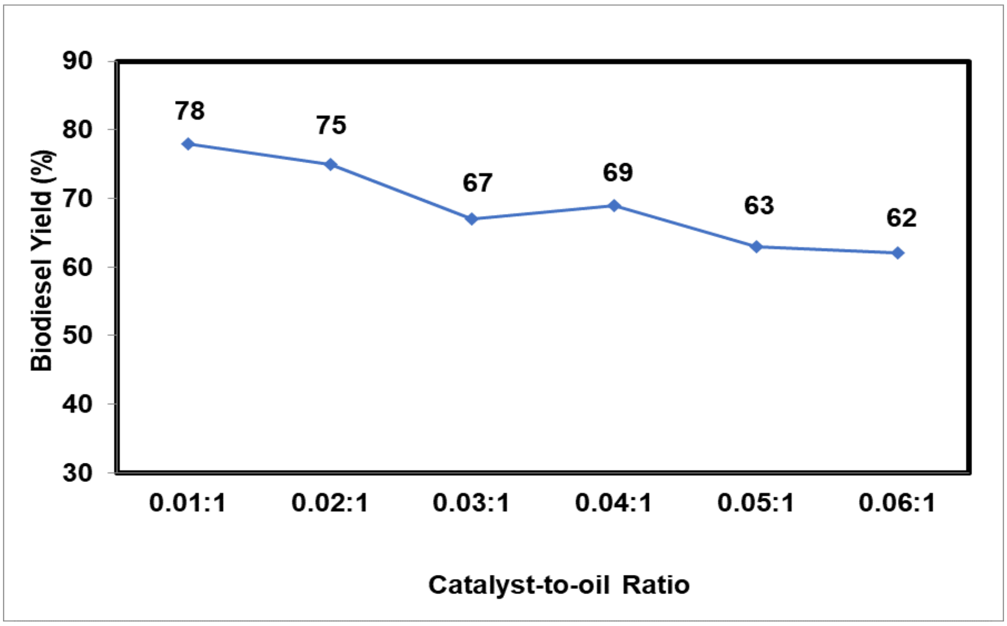

Figure 6. Effect of ratio of KOH on biodiesel yield.

4.2.3 Effect of alcohol-to-oil ratio

MeOH was used as the alcohol for SPO biodiesel conversion. MeOH in the esterification process was used to remove water content and FFAs in oil, while MeOH was used in transesterification to convert SPO into biodiesel [32]. Figures 7 and 8 show the alcohol-to-oil ratio effect on ester and biodiesel yield, respectively. The optimum alcohol-to-oil ratio with the highest ester yield is 8:1 by volume for the esterification process. The optimum alcohol-to-oil ratio with maximum biodiesel yield for transesterification is 9:1 by volume. Excess addition of methanol does not increase the yield amount of efficiency of biodiesel conversion, but it creates waste, and it is not economically feasible as the biodiesel yield decreases [33]. Thus, the optimum alcohol-to-oil ratio is vital for maximum biodiesel yield at low cost and minimal waste. Figure 9 shows the obtained SPO and SPOB.

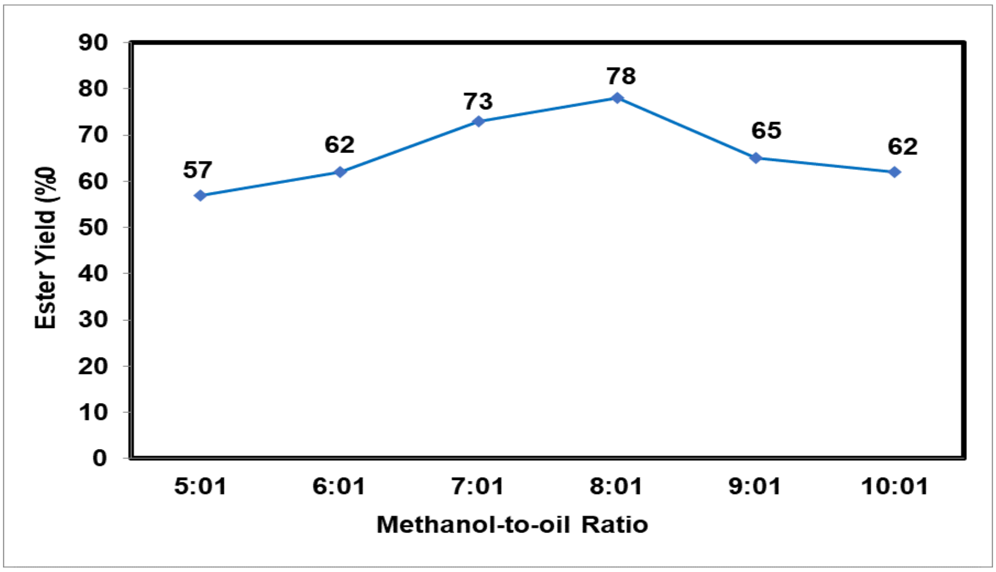

Figure 7. Effect of methanol-to-oil ratio on ester yield for esterification.

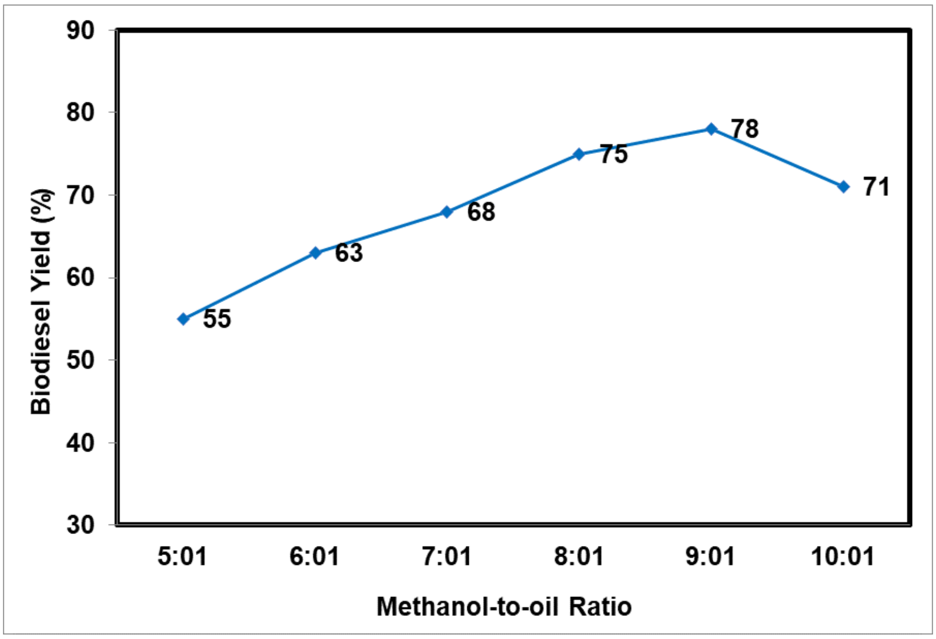

Figure 8. Effect of methanol-to-oil ratio on biodiesel yield for transesterification.

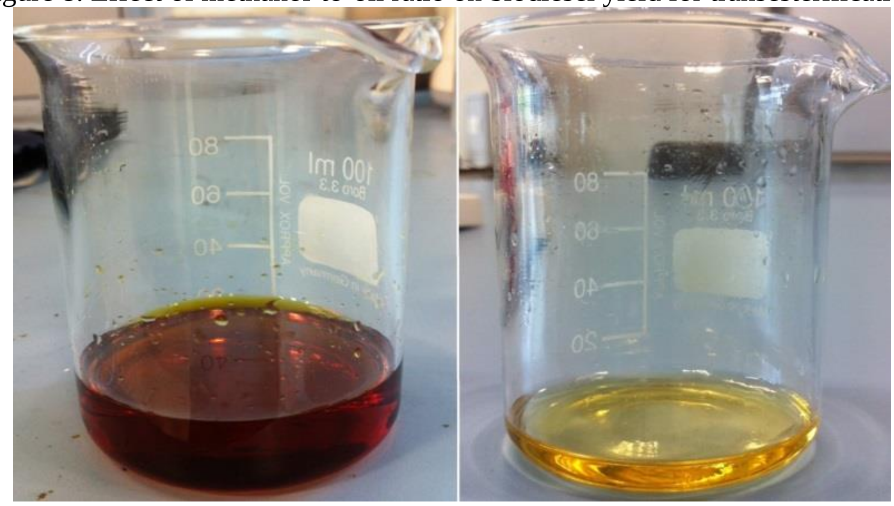

Figure 9. Samples of SPO (left image) and SPOB (right image).

4.3 Sludge palm oil biodiesel (SPOB), sludge palm oil (SPO), and mineral diesel spectrum analysis

FTIR graphs of SPOB, SPO, and diesel are shown in Figures 10, 11, and 12, respectively. The spectrum ranges from 750 cm^{-1} to 4000 cm^{-1}. The main difference between these spectrums is SPOB spectrum has a peak at 1741.72 cm^{-1}, which shows the presence of a methyl ester carbonyl bond (C=O). The fact of this bond shows that SPOB is a fatty acid methyl ester (FAME) or biodiesel [34]. The stretching vibration of the C-O ester is notified at 1238 cm^{-1}, 1163 cm^{-1}, and 1095 cm^{-1}. The stretch vibration of sp^2 C-H is also found at 3005 cm^{-1}, sp^3 C-H at 2922 cm^{-1}, and 2852 cm^{-1} [34].

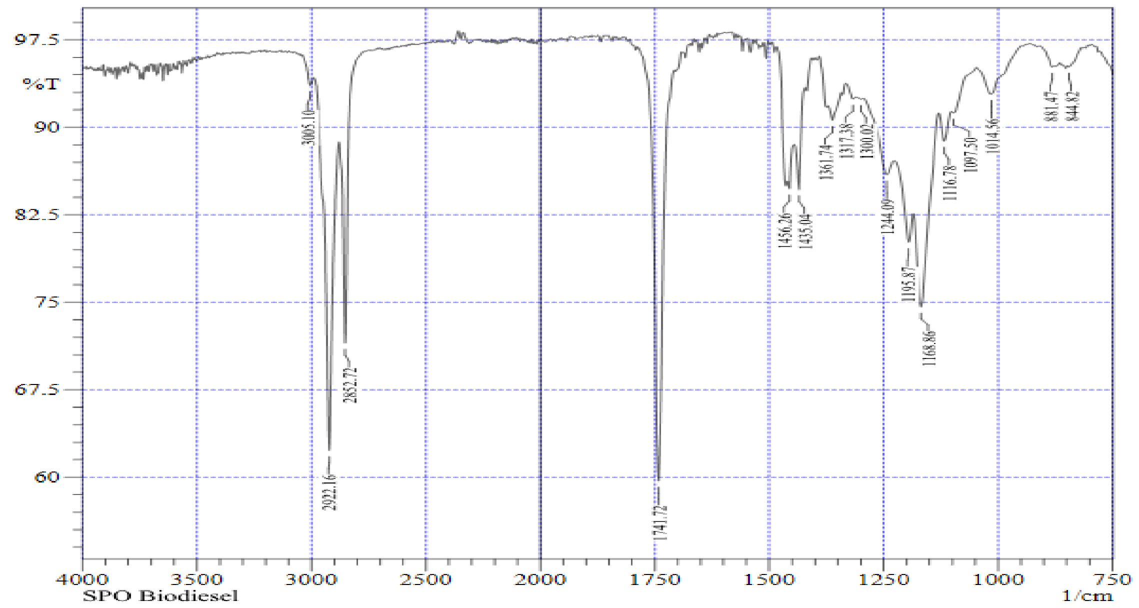

Figure 10. FTIR spectrum for SPO biodiesel.

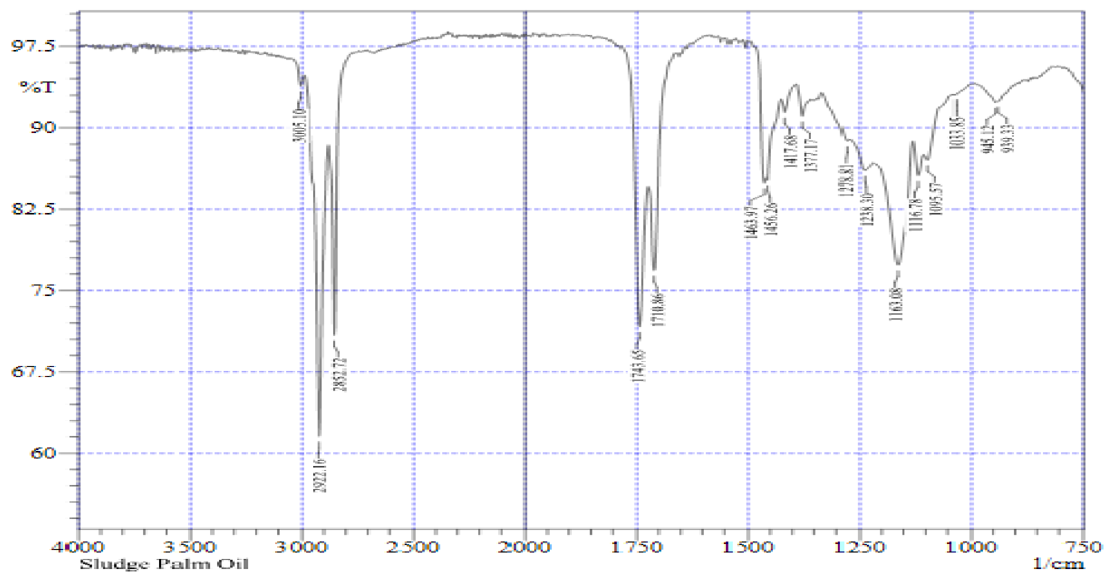

Figure 11. FT IR Spectrum for SPO.

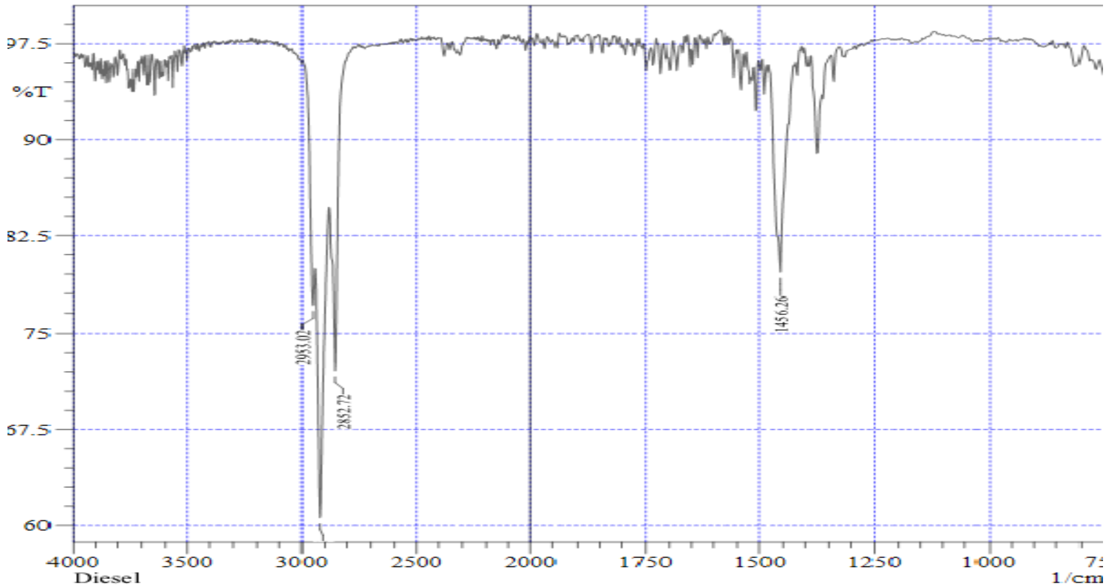

Figure 12. FTIR spectrum for mineral diesel.

4.4 Diesel engine performance analysis

A diesel engine performance test was conducted with 20 ml blends and 120 N loads. The study performance parameters were tabulated in Table 3, and graphs were plotted from Figures 13 to 17. From Figure 13, the fuel consumption rate generally decreases with increasing SPOB blends. However, the decreasing trend stopped at 40% SPOB blends and increased at 50 % SPOB blends. Figure 14 shows a general increment of specific fuel consumption with the percentage of SPOB blends. It is mainly due to decreasing energy content with an increment of biodiesel. Figure 15 shows a general decrease in brake horsepower of a diesel engine with an increased percentage of SPOB blends. This graph shows that B30 offers the highest brake horsepower and is more competent than mineral diesel. Figures 16 and 17 show that B30 delivered the highest mechanical efficiency of a diesel engine with its usage and generated the highest speed. Thus, from Figures 13 to 17, B30 or 30 % SPOB blend in diesel is the best-performing fuel with the lowest fuel consumption rate, generates the highest brake horsepower, and displays the highest mechanical efficiency while producing the highest speed [34].

Table 3. Comparison of performance parameters between SPOB blends.

SPO Biodiesel Blend	**Fuel Consumption Rate, FCR (ml/s)**	**Specific Fuel Consumption, SFC (ml/kW)**	**Brake Horsepower, Bhp (kW)**	**Engine Power Output, P (kW)**	**Mechanical Efficiency, η (%)**
B0	0.1111	40.6256	24.9110	0.4923	43.10
B10	0.1103	41.9287	24.8240	0.4770	42.95
B20	0.1093	42.3280	24.8951	0.4725	43.07
B30	0.1089	42.7350	24.9266	0.4680	43.13
B40	0.1089	43.4594	24.8792	0.4602	43.04
B50	0.1091	44.4840	24.8399	0.4496	42.98

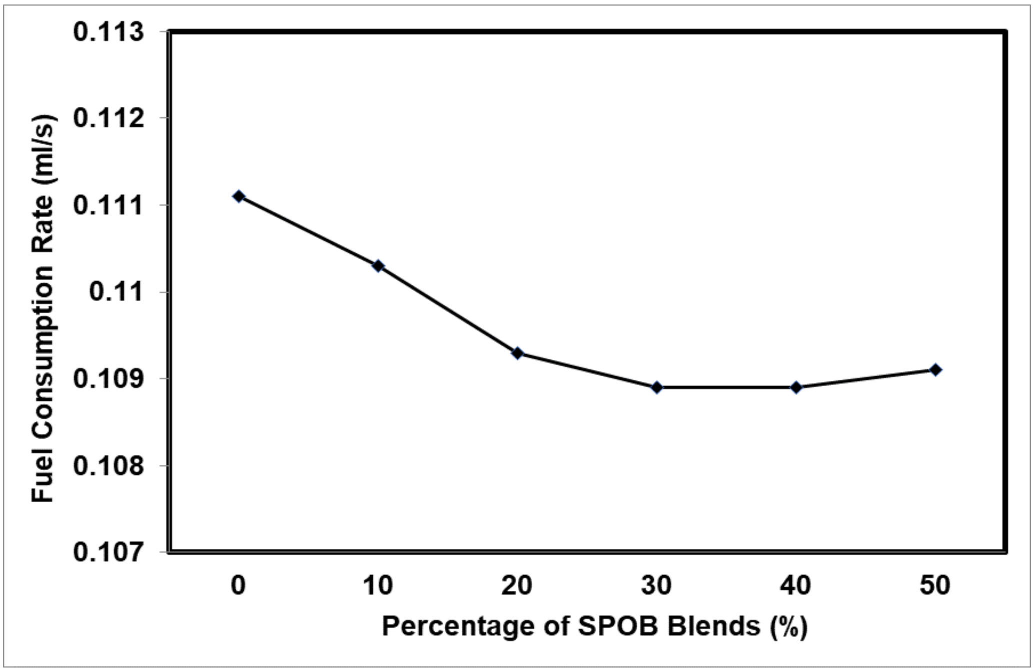

Figure 13. Comparison of fuel consumption rate with different percentages of SPOB blends.

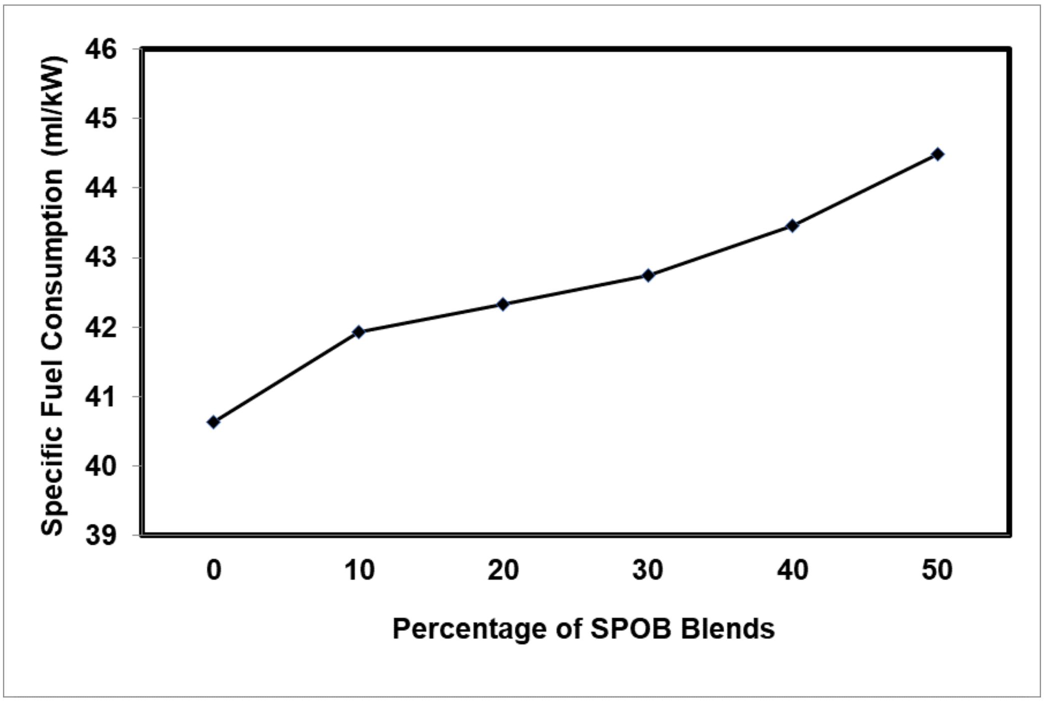

Figure 14. Comparison of specific fuel consumption with different percentages of SPOB blends.

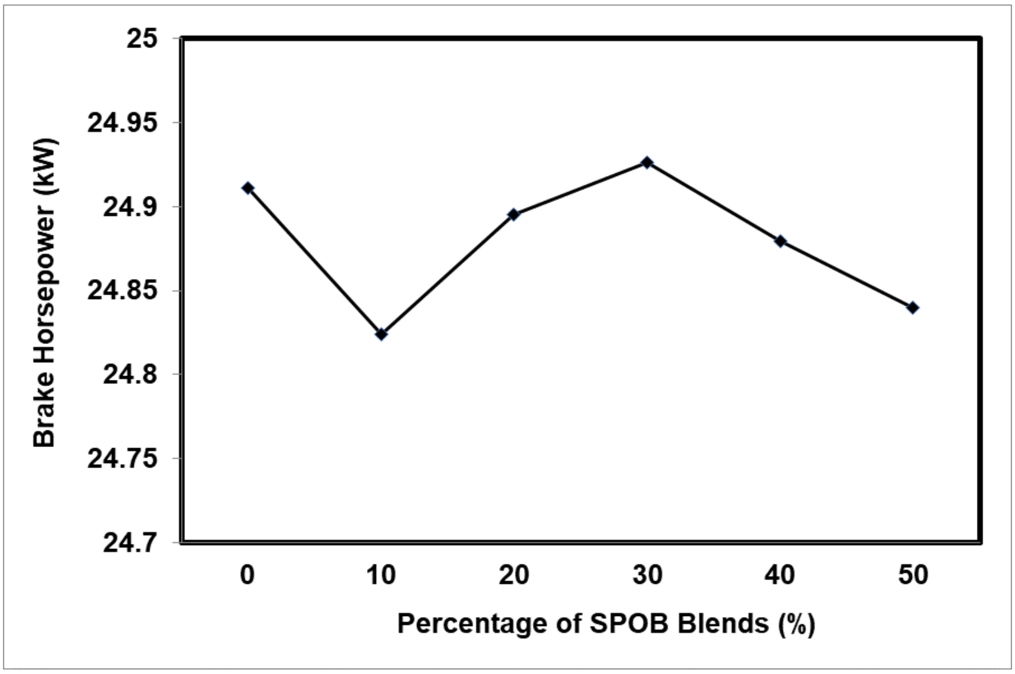

Figure 15. Comparison of brake horsepower with different percentages of SPOB blends.

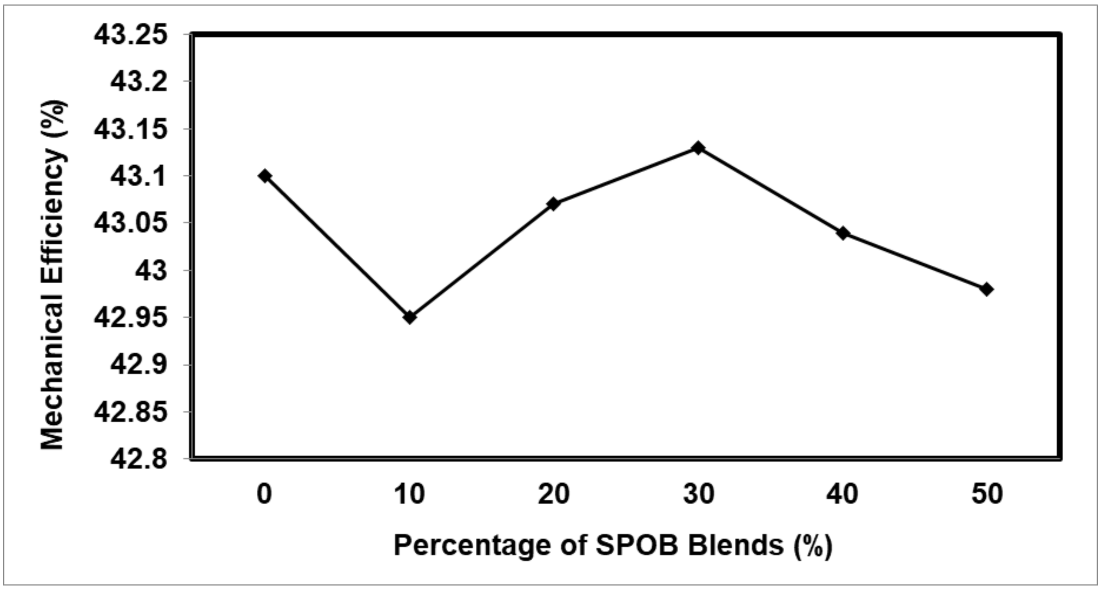

Figure 16. Comparison of mechanical efficiency with different percentages of SPOB blends.

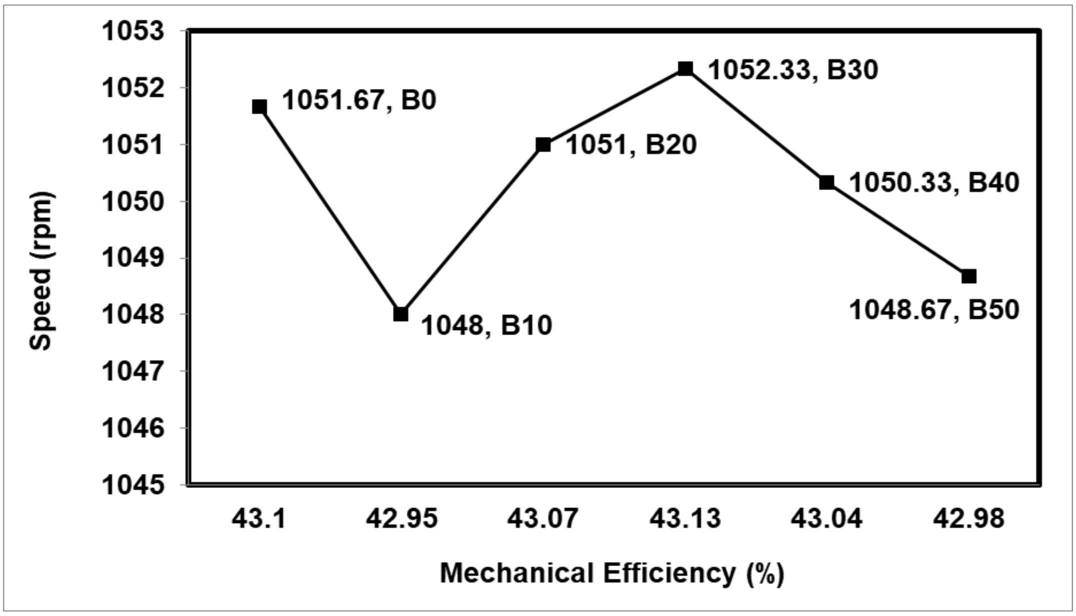

Figure 17. Graph of speed versus mechanical efficiency for different SPOB blends.

4.5 Heating value, density, flash point of SPO, SPOB, and mineral diesel

The heat value of a fuel is the amount of heat released during its combustion. From Figure 18, mineral diesel exhibited the highest heating value, while SPO exhibited the lowest heating value. It was due to the high amount of oxygen content [35, 36]. Therefore, SPOB generates a heating value between SPO and mineral diesel. From Figure 19, SPO exhibits the highest density value for its oil, while mineral diesel exhibits the lowest density value. Therefore, SPOB has a density value between the density value of SPO and mineral diesel. Density is a crucial biodiesel property that affects the quality of the fuel. Therefore, density prediction is of utmost importance for properly formulating an optimal mix of raw materials that optimizes the cost of producing biodiesel while allowing the generated fuel to fulfil the necessary quality criteria [18].

On the other hand, the experimental data shows that the flash point obtained for SPOB is 146°C. The flash point is the lowest temperature at which fuel may generate enough vapor to ignite, creating flames. Therefore, biodiesel's flash point is greater than regular diesel's [37,38].

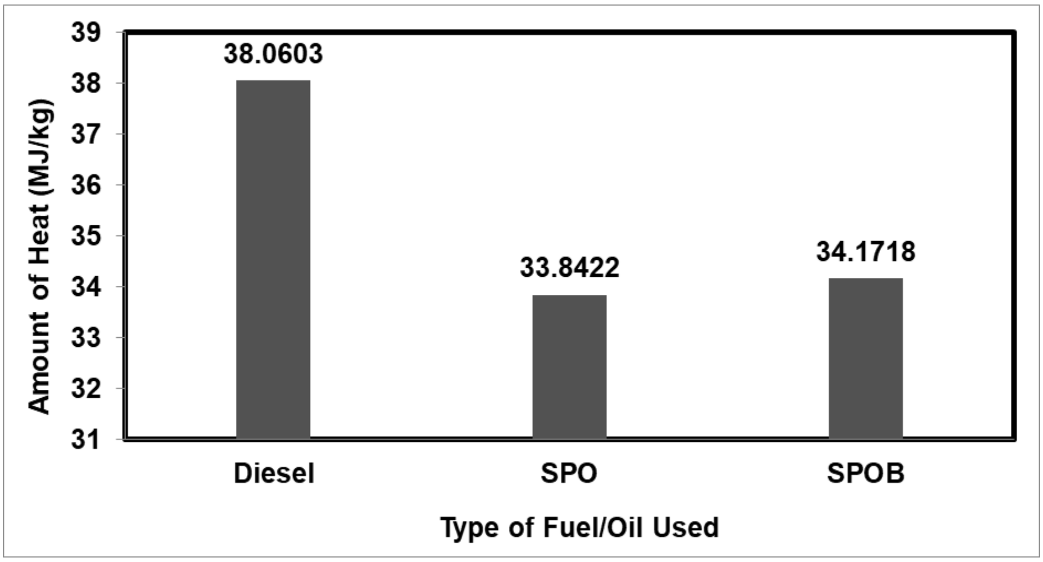

Figure 18. Comparison of different fuels and the corresponding amount of heat generation.

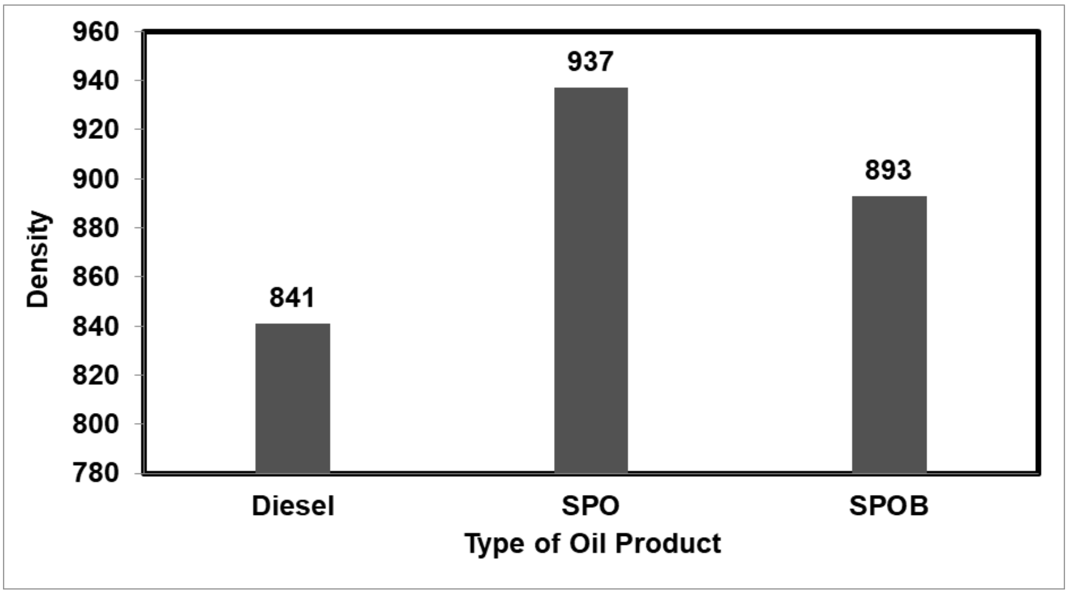

Figure 19. Comparison of density between different types of fuel.

5. Conclusions

The two-step transesterification method was proven more effective than one-step transesterification in producing SPOB due to the high FFAs content in SPO. Through this research, the tested FFAs content in SPO was higher than 4%. Thus, the two-step transesterification method is more suitable for avoiding emulsification and separation problems for biodiesel yield. Therefore, the orbital shaker is the most appropriate equipment for SPOB production, including the esterification and transesterification processes. For the esterification process, the optimum catalyst-to-oil ratio is 0.03:1 with the optimum methanol-to-oil ratio of 8:1. Whereas, for the transesterification process, the optimum catalyst-to-oil ratio is 0.01:1 with the optimum methanol-to-oil ratio of 9:1 for maximum SPOB yield. During the diesel engine performance test, an increasing percentage of SPOB blends with mineral diesel results in decreasing fuel consumption rate, a general decrease in brake horsepower, and a general decrease in mechanical efficiency for each tested blend. However, the increment of SPOB blends increases the specific fuel consumption, as biodiesel has lower energy than mineral diesel. Thus, increased biodiesel content in each blend would increase the specific fuel consumption. Through this test, B30 is identified as the best-performing blend of fuel with the lowest fuel consumption rate of 0.1089ml/s, producing the highest brake horsepower of 24.9266 kW with 43.13 % mechanical efficiency.

Acknowledgements

The authors would like to thank FELCRA, Kota Samarahan, Sarawak, Malaysia, for supplying SPO throughout this research. Also, most profound gratitude to the Department of Mechanical and Manufacturing Engineering and Department of Chemical Engineering, Universiti Malaysia Sarawak, for providing facilities to undertake this research.

Conflict of Interest

We declare no conflict regarding the publication of the study.

References

[1] Arezki, R., Jakab, Z., Laxton, D., Matsumoto, A., Nurbekyan, A., Wang, H., Yao, J. (2017). Oil Prices and the Global Economy. IMF Working Paper, International Monetary Fund, 1-30. https://www.imf.org/~/media/Files/Publications/WP/wp1715.ashx

[2] Lam, M.K., Lee, K.T., Mohamed, A.R. (2010). Homogeneous, heterogeneous and enzymatic catalysis for transesterification of high free fatty acid oil (waste cooking oil) to biodiesel: A review. Biotechnology Advances 28(4), 500-518. https://doi.org/10.1016/j.biotechadv.2010.03.002

[3] Yaakob, Z., Mohammad, M., Alherbawi, M., Alam, Z., Sopian, K. (2012). Overview of the Production of Biodiesel from Waste Cooking Oil. Renewable and Sustainable Energy Reviews. 18(1), 184-193. https://doi.org/10.1016/j.rser.2012.10.016

[4] Huang, D., Zhou, H., Lin, L. (2012) Biodiesel: An alternative to Conventional Fuel. Energy Procedia 16 (C), 1874-1885. https://doi.org/10.1016/j.egypro.2012.01.287

[5] Dermirbas, A. Karslioglu, S. (2007) Biodiesel Production Facilities from Vegetable Oils and Animal Fats. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects 29(2), 133-141. https://doi.org/10.1080/009083190951320

[6] Muanruksa, P., Winterburn, J., Kawekannetra, P. (2019) A novel process for biodiesel production from sludge palm oil. MethodsX 6(1), 2838-2844. https://doi.org/10.1016/j.mex.2019.09.039

[7] Vijay, V., Pimm, S.L., Jenkins, C.N., Smith, S.J. (2016) The impact of oil palm on recent deforestation and biodiversity loss. PLoS One 11(7), e0159668, https://doi.org/10.1371/journal.pone.0159668

[8] Dias, M.F.R. (2015). Hair cosmetic: An overview. International Journal of Trichology 7(10), 2-15. https://doi.org/10.4103/0974-7753.153450

[9] FAO. (2015). Food and Agriculture Organization of the United Nations http://faostat3.fao.org/home/E

[10] Corley, R.H.V. (2009). How much palm oil do we need? Environmental Science & Policy 12(2), 134-139. https://doi.org/10.1016/j.envsci.2008.10.011

[11] World Agricultural Outlook (2012) Food and Agricultural Policy Research Institute. http://www.fapri.iastate.edu/outlook/2012/

[12] International Finance Corporation (2011). The World Bank Group Framework and IFC Strategy for Engagement in the Palm Oil Sector. Washington D.C. World Bank.

[13] Potts, J., Lynch, M., Wilkings, A., Huppé, G., Cunningham, M., Voora, V. (2014) The state of sustainability initiatives review 2014: Standards and the green economy. International Institute for Sustainable Development (IISD) and the International Institute for Environment and Development (IIED) 29(1), 332.

[14] Malaysian Palm Oil Industry (2011). Malaysian Palm Oil Board. http://www.palmoilworld.org/about_malaysian-industry.html

[15] Schmidt, J.H., Weidema, B.P. (2007) Shift in the marginal supply of vegetable oil. The International Journal of Life Cycle Assessment, 13(3), 235–239. https://doi.org/10.1065/lca2007.07.351

[16] Hayyan, A., Alam, M. Z., Mirghani, M. E., Kabbashi, N. A., Hakimi, N. I., Siran, Y. M., Tahiruddin, S. (2010). Sludge Palm Oil as a Renewable Raw Material for Biodiesel Production by Two-Step Process. Bioresource Technology 101(20), 7804-7811. https://doi.org/10.1016/j.biortech.2010.05.045

[17] Onyia, C.O., Uyu, A.M., Akunna, J.C., Norulaini, N.A., Omar, A.K. (2001) Increasing the fertilizer value of palm oil mill sludge: bioaugmentation in nitrification. Water Science & Technology 44(10), 157-162. https://doi.org/10.2166/wst.2001.0608

[18] Brahma, S., Nath, B., Basumatary, B., Das, B., Saijia, P., Patir, K., Basumatary, S. (2022) Biodiesel production from mixed oils: A sustainable approach towards industrial biofuel production. Chemical Engineering Journal Advances 10(1), 100384. https://doi.org/10.1016/j.ceja.2022.100284

[19] Hassan, M.H., Kalam, M.A. (2013). An overview of biofuel as a renewable energy source: development and challenges. Procedia Engineering 56(1), 59-53. https://doi.org/10.1016/j.proeng.2013.03.087

[20] Gui, M., Lee, K., Bhatia, S. (2008). Feasibility of Edible Oil vs. Non-Edible Oil vs. Waste Edible Oil vs. Biodiesel Feedstock. Energy 33(11), 1646-1653. https://doi.org/10.1016/j.energy.2008.06.002
[21] Guana, G., Kusakabe, K. (2012). Biodiesel Production from Waste Oily Sludge by Acid-Catalyzed Esterification. International Journal of Biomass & Rewwable 1(1), 1-5.
[22] Greer, D. (2010). Recycling Local Waste Oil and Grease into Biodiesel. Biocycle Energy 51(7), 56.
[23] Gebremariam, S.N., Marchetti, J.M. (2017) Biodiesel production technologies: a review. AIM Energy. 5(3), 425-457. https://doi.org/10.3934/energy.2017.3.425
[24] Taher, H. Al-Zuhair, S., Al-Marzouqi, A.H., Haik, Y., Farid, M.M. (2011) A review of enzymatic transesterification of microalga oil-based biodiesel using supercritical technology. Enzyme Research 2011(1), 1-25. https://doi.org/10.4061/2011/468292
[25] Fernandez-Maestre, R. (2020) The importance of teaching titration curve in analytical chemistry. Periodico Tche Quimica 17(34), 213-219.
[26] Raya, S.A., Saaid, I.M., Ahmed, A.A., Umar, A.A. (2020) A critical review of development and demulsification mechanisms of crude oil emulsion in the petroleum industry. Journal of Petroleum Exploration and ProductionTechnologyy 10(1), 1711-1728. https://doi.org/10.1007/s13202-020-00830-7
[27] Edin, T., Ahmed, A.S., Rahman, R., Hamdan, S. (2013) Biodiesel Production from Jatropha Oil as an Alternative Fuel for Diesel Engine. Journal of Energy & Environment. 18-24.
[28] Harreh, D., Saleh, A.A., Reddy, A.N.R., Hamdan, S. (2018) And experimental investigation of Karanja biodiesel production in Sarawak, Malaysia. 2018(1), 1-8. https://doi.org/10.1155/2018/4174205
[29] Reddy, A.N.R., Saleh, A.A., Islam, M.S., Hamdan, S., Maleque, M.A. (2016) Biodiesel production from crude Jatropha oil using a highly active heterogeneous nanocatalyst by optimizing transesterification reaction parameters. Energy & Fuels 30(3), 334-343. https://doi.org/10.1021/acs.energyfuels.5b01899
[30] Baharathiraja, B., Selvakumari, A.E., Jayamuthunagai, J., Saravanaraj, A., Arumugam, A. (2022) Chapter 5 – Biodiesel production: Key factors affecting th efficiency of the process. In: Arumugam, A (ed). Production of Biodiesel from Non-Edible Sources, 153-178. https://doi.org/10.1016/B978-0-12-824295-7.00006-1
[31] Saha, R., Goud, V.V. (2014) Ultrasound assisted transesterification of high free fatty acids Karanja oil using heterogeneous base catalysts. Biomass Conversion and Biorefinery 5(1), 195-207. https://doi.org/10.1007/s13399-014-0133-7
[32] Musa, I.A. (2016) The effects of alcohol to oil molar ratios and the type of alcohol on biodiesel production using transesterification process. Egyptian Journal of Petroleum 25(1), 21-31. https://doi.org/10.1016/j.ejpe.2015.06.007
[33] Chozhavendhan, S., Singh, M.V.P., Fransila, B., Kumar, R.P., Devi, G.K. (2020). Current Research in Green and Sustainable Chemistry 1-2(1), 1-6. https://doi.org/10.1016/j.crgsc.2020.04.002
[34] Kumar, S., Jain, S., Kumar, H. (2020) Experimental Study on Biodiesel Production Parameter Optimization of Jatropha–Algae Oil Mixtures and Performance and Emission Analysis of a Diesel Engine Coupled with a Generator Fueled with Diesel/Biodiesel Blends. ACS Omega 5(28), 17033-17041. https://doi.org/10.1021/acsomega.9b04372
[35] Shukla, P.C., Gupta, T., Agarwal, A.K. (2014) A Comparative Morphological Study of Primary and Aged Particles Emitted from Biodiesel (B20) vis-a;-vis Diesel Fuelled CRDI Engine. Aerosol and Air Quality Research 14(3), 934-942. https://doi.org/10.4209/aaqr.2013.05.0162
[36] Ahmed, A.S., Rahman, M.R., Bakri, M.K.B. (2022) New bio-energy source for biofuel from indigenous kepayang fruit in Malaysia. Biofuels 1(1), 1-13. https://doi.org/10.1080/17597269.2022.2107652
[37] Guoveia, L., Olivera, A.C., Congestri, R., Bruno, L., Soares, A.T., Menezes, R.S., Filho, N.R.A., Tzovenis, I. (2017). Biodiesel from microalgae. In: Gonzalez-Fernandez, C., Munoz, R. (eds) Microalgae-Based Biofuels and Bioproducts, 235-258. https://doi.org/10.1016/B978-0-08-101023-5.00010-8
[38] Khan, A., Ahmed, A.S., Bakri, M.K.B., Reddy, A.N.R., Rahman, M.R. (2021) Performance of Coconut Biodiesel Fueled Diesel Engine with Exhaust Gas Emission Analysis. Materials Science Forum 1030(1), 149-158. https://doi.org/10.4028/www.scientific.net/MSF.1030.149