**Schleichera oleosa** L oil as feedstock for biodiesel production

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**Highlights**

- *Schleichera oleosa* L oil as the potential resource for biodiesel production.
- The optimization using four different catalysts for transesterification process.
- The optimum ester yield obtained was 96 by KOH.
- The properties of *Schleichera oleosa* L biodiesel satisfied with ASTM D6751 specifications.

**Abstract**

The non-edible oil from *Schleichera oleosa* possesses the potential as a feedstock for biodiesel production. In this study, the biodiesel production was performed using two-step transesterification process on a laboratory scale. The parameters studied were reaction temperature, molar ratio of methanol to oil, catalyst concentration, reaction time and catalysts type. An analysis of variance (ANOVA) was used to determine the methyl ester yield. The optimum conditions were obtained as follows: reaction temperature at 55 °C, methanol to oil molar ratio of 8:1, 1 wt.% of hydroxide catalyst (KOH and NaOH) and 1 wt.% methoxide catalyst (CH\textsubscript{3}OK and CH\textsubscript{3}ONa) for reaction time 90 min. Based from these optimum conditions, the observed ester yields from different catalysts were average 96%, 93%, 91% and 88% for KOH, NaOH, CH\textsubscript{3}OK and CH\textsubscript{3}ONa respectively as the catalyst. *S. oleosa* methyl ester (SOME) exhibited a satisfying oxidative stability of 7.23 h and high cetane number (50.6) compared to petrol diesel (49.7). Besides, SOME has good pour and cloud point of −3.0 °C and −1.0 °C respectively due to high unsaturated fatty chain. As a conclusion, this study reveals that biodiesel production from SOME, as one of non-edible feedstock, is able to be an alternative for petrol diesel. Moreover, the produced biodiesel from SOME could be used in diesel engine without major modification due to its properties and can be used in cold regions.

**1. Introduction**

Recently, the rise of petroleum consumption in industrial, transportation and technology developments has been leading to depletion of the limited fossil fuel resources in the world.
Because of this, researchers have been putting more attention to find alternative energy such as biodiesel which is believed can lower the dependency of fossil fuel and to support the environmental sustainability [1,2]. Biodiesel can be produced from various vegetable oils and animal fats. However, the feedstock types, availability and material cost are the obstacles to the commercialization of biodiesel production.

There are oil and fat feedstock distribution for top ten developed countries such as animal feedstock (52%), rapeseed (11%), soybean oil (20%), sunflower oil (5%), palm oil (6%), and others vegetable oils (5%) that are identified as potential resources for biodiesel production [3]. This is because edible oils have high yield of biodiesel and they are easily processed (transesterified) due to their lower free fatty acids [4]. In contrary, the use of edible oils has given problems such as serious destruction of vital soil resources. Moreover, the prices of edible oil plants have increased dramatically in the last ten years which have affected the economic viability of biodiesel industry [3,10]. Therefore, many studies have been performed in exploration of non-edible oil which also is able to reduce the production cost and solving the food vs. fuel issue [5,6]. Many researchers, in the last decades, have focused and promoted commercialization of biodiesel as well as low cost from non-edible oils that are grown in forest and unused land such as Jatropha curcas, Calophyllum inophyllum, Moringa oleifera, Croton megalocarpus, Cerbera odollam, Terminalia, Madhuca indica, Pongamia pinnata, Guizotia abyssinica and Neem. These feedstocks are considered as potential alternative to biodiesel production [7,8].

This study is aimed to investigate the biodiesel production from Schleicheria oleosa oil, as the promising non-edible feedstock, using four types of homogeneous alkaline catalysts: KOH, NaOH, CH3OK and CH3ONa. Then, the fuel properties of the obtained biodiesel were analyzed according to ASTM and EN method.

2. Description of S. oleosa

S. oleosa is belonging to Sapindaceae family and also known as Kusum fruit. S. oleosa is widely found in the sub-Himalayan region, throughout central and Southern India, Burma, Ceylon and Timor. The oil obtained from its seeds is called Kusum oil or Macassar oil, which categorized non crops food and used for the cure of itch, acne and burns [9,10]. The flowers are yellowish green, fascicled in spike like axillary racemes 7.5–12.5 cm long. The fruits are berry, globose or ovoid, and hard skinned [10]. The seeds are brown, irregularly elliptical, slightly compressed, oily, enclosed in a succulent aril [11]. The oil content of the seed is around 59–72% with yellowish green color.

3. Materials and methods

3.1. Extraction of S. oleosa oil

The extraction of crude S. oleosa oil (CSOO) was done by using a screw extruder machine. Additional process by hydraulic manual pressing machine was performed to increase the oil yield from CSOO which repeated for several times. The S. oleosa seeds were afterward sun dried for one week then cleaned. Seed samples were cooked in an oven for 2 h then were pressed with four replications in the screw press oil expeller at an optimum screw-speed of 120 rpm. At each of test conditions, crude oil and cake were collected and weighed. The remained cake was wrapped with a filter and placed inside the press machine. The extraction with press machine was done several times and after the predetermined time, the extraction process stopped. The oil yield of CSOO was calculated by the following equation:

\[
\text{Oil yield} = \left( \frac{O_{\text{io}}}{W_{\text{io}}} \right) \times 100\% \quad (1)
\]

where, \(O_{\text{io}}\) = the extracted weight of S. oleosa oil (g); \(W_{\text{io}}\) = the weight of S. oleosa seed (g).

3.2. Reagents and chemicals

Methanol (reagent grade), phosphoric acid, sulphuric acid, potassium hydroxide, sodium hydroxide, potassium methoxide, sodium methoxide, sodium sulfate, calcium chloride were purchased from Metta Karuna Enterprises, Kuala Lumpur, Malaysia. These chemicals were analytical grade (99.98%) chemicals and were used as received without any further purification.

3.3. Experiment set up

In this study, a small scale laboratory reactor consisting of 1 L double-jacketed condenser (functioned to recover methanol), thermometer and motor stirrer was used to produce biodiesel from CSOO.

3.4. Properties of CSOO and methyl ester

Fuel properties of biodiesel are dependent on the fatty acid composition (FAC) of the oil. In this study, physical and chemical characteristics of crude oil and methyl ester produced are analyzed. Besides, the fatty acid oil profile was determined by GC model number Agilent 7890 with flame ionization detector. The column was packed with ZB-wax 30 m capillary column (inner diameter 0.25 mm, film thickness 0.25 µm, split 1:20). The carrier gas was high-purity hydrogen where injector and detector temperatures were 250 °C. Oven temperature was maintained at 100 °C for 10 min, then was increased by 15 °C/min and held at a final temperature of 240 °C for 15 min. The physical, chemical properties and fatty acid compositions of fuel were analyzed as per the standard methods. The FAME content was calculated using the following equation:

\[
\text{FAME} = \frac{\sum A - A_{\text{io}}}{A_{\text{io}}} \times C_{\text{io}} \times V_{\text{io}} \times 100\% \quad (2)
\]

where FAME = fatty acid methyl ester content (%); \(\sum A\) = total peaks area of fatty acid methyl ester; \(A_{\text{io}}\) = area of the peak corresponding to internal standard, methyl heptadecanoate; \(C_{\text{io}}\) = concentration of methyl heptadecanoate solution in heptane (mg/ml); \(V_{\text{io}}\) = volume of methyl heptadecanoate solution (ml); \(m\) = mass of biodiesel sample (mg). Ester yield is defined as follows:

\[
\text{Ester yield} = \frac{\text{FAME} \times B_{\text{io}}}{O_{\text{io}}} \times 100\% \quad (3)
\]

where FAME = fatty acid methyl ester content (%); \(B_{\text{io}}\) = weight of S. oleosa biodiesel (g); \(O_{\text{io}}\) = weight of crude S. oleosa (g).

3.5. Optimization analysis

The statistical analysis was carried out with Expert 8.0.7.1 (StatEase, Inc) software and the experimental optimization was obtained by analysis of variance (ANOVA). Optimization of the transesterification process was conducted by four experiment factors to examine the effects of reaction methanol to oil molar ratio, temperature, reaction time and catalyst concentration on the yield of biodiesel. Range and levels of the investigated variables are listed in Table 1.

The factors were temperature (\(X_1\)), KOH catalyst concentration (\(X_2\)), methanol to oil molar ratio (\(X_3\)) and reaction of time (\(X_4\)). The upper temperature level, 65 °C, was chosen as the boiling point.
of methanol and the lower level was 45 °C. Catalyst concentration levels were 0.50–1.50% by weight of oil, methanol/oil molar ratio levels were 4:1–12:1 and the reaction time started at 30 min to 150 min. Once the experiment performed, the response variable (biodiesel yield) was fitted in a second-order model in order to correlate the response variable to the independent variable. The response was expressed as the function independent variables, according to the following equation:

\[ Y = b_0 + \sum_{i=1}^{k} b_i X_i + \sum_{i=1}^{k} \sum_{j=1}^{k} b_{ij} X_i X_j + e \]  

(4)

where \( Y \) is the response factor; \( X_i \) and \( X_j \) is the independent variable; \( b_i \) is the intercept; \( b_i \) is the first order coefficient of the model; \( b_{ij} \) is the quadratic coefficient of \( i \) factor; \( b_{ij} \) is the linear coefficients of the model for the interaction between \( i \) and \( j \) factors; \( k \) is the number of factors studied and optimized in the experiment; and \( e \) is the experimental error attributed to \( Y \).

3.6. Biodiesel production procedures

3.6.1. Degumming process

Degumming process is to remove the contained gums, for instance, phosphate, protein, carbohydrate, water residue and resin. This process is also beneficial as it would improve the oxidation stability of biodiesel from CSOO oil. The CSOO oil was treated with 1 vol.% of phosphoric acid (H\textsubscript{3}PO\textsubscript{4}, 20% concentration) with heating at 60 °C. Approximately after 20 min of reaction time at 1000 rpm, the mixture was separated by density separation process using separating funnel where the phosphate compounds resided at the bottom. The gums were separated from the oil and washed several times with distilled water at 50 °C. After washing, the water content was evaporated by vacuum pump at 65 °C for 30 min to avoid oxidation of oil. The oil was then hydrated and removed by centrifugation for 30 min to obtain oil with low content of phospholipids, Ca and Mg. Finally, the oil was strained by paper filter.

3.6.2. Acid-catalyzed pretreatment (esterification) process

This process was started by preparing a laboratory reactor of 1 L double-jacketed flask with a mechanical stirrer connected to a reflux system. 500 ml of degummed \textit{S. oleosa} oil (DSSO) was poured into the reactor and mixed with sulphuric acid (1 vol.% and methanol (8:1) at adjusted temperature 65 °C. During the reaction, the mixture was stirred constantly using a magnetic stirrer at a speed of 1000 rpm for 3 h. The oil was then cooled down for 15 min with stirring without heating. The esterified \textit{S. oleosa} oil (ESOO) was then taken from the reactor and washed with distilled water to stop the reaction and to separate the catalyst and the alcohol from the oil phase. The ESOO was centrifuged for 30 min to achieve good separation of the phases and was run in a rotary evaporator for 20 min at 65 °C to remove methanol from the esterified oil.

3.6.3. Alkaline-catalyzed (transesterification) process

The process was begun by mixing ESOO with methanol and each of alkaline catalysts (KOH, NaOH, CH\textsubscript{3}OK and CH\textsubscript{3}ONa) separately. The methanol and catalyst was stirred vigorously by motor stirrer for 15 min. The mixture was then mixed with ESOO in double-jacketed flask and stirred continuously using motor stirrer which equipped at the flask. After the reaction had completed, the methyl ester was transferred into a separating funnel into two layers where the top layer was consisted of methyl ester while the lower layer was consisted of thick red high viscous glycerol with excess methanol. The transesterified product (methyl ester) was then washed 2–3 times with distilled water to remove the dissolved glycerol in the methyl ester phase. Afterward, the SOME was dried using 50 g CaC\textsubscript{2} in beaker glass for a day and then filtered by a paper filter. SOME was further dried with 50 g Na\textsubscript{2}SO\textsubscript{4} for 2–3 h and filtered by a paper filter. The methyl ester was then recovered (up to 97%) by distillation under rotary evaporator with vacuum conditions (temperature 65 °C and 500 mmHg). Lastly, the methyl ester was left in vacuum chamber (25 °C) for 30 min to maintain the biodiesel’s freshness for further fuel properties analysis.

Optimization was performed in order to achieve the maximum ester yield and the studied variables were methanol to oil ratio (4:1; 6:1; 8:1; 10:1; 12:1), amount of catalyst (0.50, 0.75, 1.00, 1.25 and 1.50 wt.%), reaction time (30, 60, 90, 120 and 150 min) and reaction temperature (45, 50, 55, 60 and 65 °C). From these variations, the observed optimum condition was used to conduct biodiesel production of CSCO. The physiochemical properties and fatty acid compositions were analyzed as per the standard methods.

The purity level of the biodiesel affects its fuel properties. The methyl ester, hence, was purified by washing gently three times with warm distilled water to remove residual catalyst, glycerol, methanol and soap by using a centrifuge and rotary evaporator. Also, solid traces from the methyl ester were removed with a filtration process. The schematic of the complete oil extraction and oil transesterification process flow diagram is shown in Fig. 1.

4. Results and discussions

4.1. Characterization properties and fatty acid composition of CSCO

In this study, the important physical and chemical properties of CSCO, for instance, viscosity, density, water content, acid value, calorific value, flash point, etc. were measured and tabulated in Table 2. The CSCO seed contained 68% oil with green yellow color. The observed kinematic viscosity of CSCO was slightly lower (39.68 mm²/s) compared to Gandhi et al. [10] which is 40.36 mm²/s. The acid value measured in the CSCO was 20.6 mg KOH/g and the water content of the CSCO was very low 0.0005 vol.% The iodine value of CSCO 92.6 I\textsubscript{2} was indicated as high unsaturated acid which would improve the low temperature properties of biodiesel as shown in Table 3. The major constituent of CSCO obtained was unsaturated acid, which are 58%. As for the fatty acid profile, oleic acid (C18:1) was found as the dominant fatty acid. It was found that oleic acid (C18:1) was the highest than other acid with value of 49.91%, where this value is in accordance with other works; by Gandhi et al. [10] and Sudrajat et al. [9] found oleic acid to be 49.29% and 49.01% respectively. The saturated acids, arachidic acid (C20:1) and palmitic acid (C16:0), were found as 27.21% and 0.09% respectively.

4.2. Statistical analysis

From the study, it is found that the KOH is the best catalyst which achieved the highest methyl ester compared than other catalysts (NaOH, CH\textsubscript{3}OK and CH\textsubscript{3}ONa). Therefore, the regression analysis was employed to generate the full quadratic model of best

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Range and level coded of ANOVA.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
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<td></td>
</tr>
<tr>
<td>Temperature (X\textsubscript{i})</td>
<td>°C</td>
</tr>
<tr>
<td>KOH catalyst concentration (X\textsubscript{j})</td>
<td>wt.%</td>
</tr>
<tr>
<td>Methanol to oil ratio (X\textsubscript{k})</td>
<td>mol/mol</td>
</tr>
<tr>
<td>Time (X\textsubscript{l})</td>
<td>min</td>
</tr>
</tbody>
</table>
catalyst (KOH) to predict the yield of SOME in terms of coded values is shown in following equation:

\[ Y = 96.31 - 6.87(\text{Reaction of temperature}) \\
- 4.05(\text{KOH Catalyst concentration}) \\
+ 5.44(\text{Methanol to oil ratio}) + 1.24(\text{Reaction of time}) \\
+ 14.09(\text{Reaction of temperature : Methanol to oil ratio}) \\
+ 1.02(\text{Reaction of temperature : Reaction of time}) \\
+ 12.09(\text{KOH Catalyst concentration : Methanol to oil ratio}) \\
- 18.91(\text{Methanol to oil ratio})^2 \]  

(5)

The analysis of variance (ANOVA) test was carried out to evaluate the statistical significance of the model equation and the statistical result is represented in Table 4. The result showed that the F-test model (10.28) with a low p-value (0.0006) less than 0.05 indicates that the model significance. The quality of the model fitness was verified by the coefficient of determination \( R^2 \). The coefficient of determination was 0.8004 which indicated the fitted model with could explain 80.04% of the variability. The obtained \( R^2 \) showed that the model was reliable in predicting the response as more than 80% of the variability in the experiment was covered and it is recommended to have \( R^2 \) not be less than 80\% [14]. Table 4 showed the methanol to oil ratio has the lowest p-value (0.0006) and the highest f value (16.74), these results indicate that the methanol to oil ratio is the most important variable in CSOO biodiesel production. Fig. 2 shows that the predicted value is quite close to the actual values.

4.3. Effect of methanol

The addition amount of methanol to a crude oil causes the large branched molecules of vegetable oils break down into smaller linear methyl ester oils [15–17]. In order to optimize the reaction conditions, this process requires excess of methanol to drive the reaction to completion as well as base catalysts such as potassium hydroxide, sodium hydroxide, potassium methoxide and sodium methoxide. In the literature review, it is mentioned that molar ratio of 6:1 is normally used for low free fatty acid to obtain methyl ester yields as high as 98% (w/w) [18]. However, most of researchers have been using sodium hydroxide as the alkaline catalyst since it is economical and can be produced quickly [1,19,20]. The methanol to oil molar ratio within range of 4:1 to 12:1 was adopted from many literatures [21–23]. However, the more use of excess alcohol can cause operation problems relevant to the downstream process and difficulty in product recovery.

The relationship of different catalysts reacted with varied methanol to oil molar ratio against the ester yield is shown in Fig. 3. The displayed results, also, indicate the key effect on the transesterification process. It was observed that the maximum yield for SOME was obtained at the methanol to oil molar ratio of 8:1 with KOH catalyst (96%). Meanwhile, the ester yield from...
the same molar ratio but with other catalyst was obtained lower: 92%, 91% and 88% for catalyst type NaOH, CH₃OK and CH₃ONa respectively.

The transesterification reaction with caustic catalyst achieved higher ester yield than with methoxide catalyst. This is noticeable since the high free fatty acid of CSOO is suitable with KOH catalyst in high rate esters formation and could ensure a complete reaction when excessive methanol causes longer time for the subsequent separation stage to separate methanol from emulsified products. The excess methanol with caustic or methoxide catalyst could act as an emulsifier and increase the solubility of glycerol in the ester phase, making the separation more difficult [24–26].

4.4. Effect of reaction temperature

The reaction temperature can influence the process and yield of biodiesel. A higher reaction temperature can reduce the viscosities of oils and results faster reaction rate in lesser reaction time. However, Leung and Guo [20] and Eevera et al. [27] found that when the reaction temperature increases beyond the optimal level, the yield of the biodiesel product decreases because the higher reaction temperature accelerates the saponification reaction of triglycerides. The reaction temperature must be less than the boiling point of alcohol in order to ensure that the alcohol will not be leaked out through vaporization. The optimal temperature ranges from 50 to 60 °C depending on the oil used [15,20,28]. Ma and Hanna [15] stated that higher temperature and longer period will burn the alcohol and will reduce the methyl ester yield. The effect of reaction temperature and type catalyst on ester yield is shown in Fig. 4. The maximum ester yield (96%) was obtained at 55 °C with KOH catalyst, which the highest compared with other catalysts: NaOH (92%), CH₃OK (90%) and CH₃ONa (88%). Lower temperature would reduce ester yield on transesterification reaction. Additionally, a reaction temperature that is greater than 60 °C in

![Fig. 2. Predicted versus actual (%) of yield values.](image)

![Table 4 ANOVA result for Schleichera oleosa methyl ester.](image)

<table>
<thead>
<tr>
<th>Source</th>
<th>Sum of squares</th>
<th>d/f</th>
<th>Mean square</th>
<th>F value</th>
<th>p-value</th>
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</thead>
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<tr>
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<tr>
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</tbody>
</table>

![Fig. 3. Effects of methanol to oil ratio and type catalyst on ester yield at catalyst concentration of 1 wt.%, 55 °C, 90 min and 1000 rpm.](image)

![Fig. 4. Effects of temperature and catalyst type on ester yield at molar ratio 8:1, catalyst concentration of 1 wt.%, 90 min and 1000 rpm.](image)
alkali catalyst would produce soap formation and glycerides before the completion of alcoholysis.

4.5. Effect of reaction time

In order to study the effect on reaction temperature, methanolysis of vegetable oil was performed near to the boiling point of the alcohol around 60–65 °C [29,30]. Freedman et al. [28] investigated that the conversion rate of fatty acid esters increases with reaction time. At the beginning, the reaction is slow due to the mixing and dispersion of alcohol into the oil. After a while, the reaction proceeds faster. Normally, the yield reaches the maximum at a reaction time less than 90 min and remains relatively constant with a further increase in the reaction time [20,31]. Moreover, excess reaction time will lead to a reduction in the ester yield due to the backward reaction of transesterification resulting loss of esters as well as causing more fatty acids to form soaps [19,32].

In this study, the alkaline catalyzed transesterification was run using four types of catalyst (KOH, NaOH, CH₃OK and CH₃ONa) which acid value of less than 2 mg KOH/g. After that, transesterification process for CSOO was carried out at various periods from 30 to 120 min. The ester yield product from reaction time and type catalyst is illustrated in Fig. 5. The reaction time reached the steady state methyl ester yield at 90 min. The best catalyst obtained from this experiment was with KOH resulting a yield of 96% of ester yield from CSO, followed by with catalyst NaOH (94%), CH₃OK (91%) and CH₃ONa (88%).

4.6. Effect of the amount and type catalyst

This study also observed the effect of the amount and the type catalyst during transesterification process for molar ratio 8:1, at 55 °C and 90 min at constant 1000 rpm. The ester yield greater than 90% was achieved by 1.00 wt.% of all catalysts (KOH, NaOH, CH₃OK and CH₃ONa). Fig. 6 displays the relationship between the different amount and type catalyst with the catalyst concentration on the ester yield. It is shown that KOH and NaOH catalysts gave higher ester yield than CH₃OK and CH₃ONa catalysts for higher free fatty acid oil and unsaturated chain. The pretreatment and esterification processes were performed to reduce sodium soaps formation and to increase ester yield, since there was a little emulsifier formation during washing the upper methyl ester phase when using CH₃ONa and CH₃OK catalysts. The highest ester biodiesel yielded was produced by using KOH catalyst (95%), followed by using NaOH (93%), CH₃OK (90%) and CH₃ONa (88%). The results determined the contribution relationship of the catalysts in ester yield production such that KOH > NaOH > CH₃OK > CH₃ONa to produce a better ester yield. This explains the lack of linear increase in the yield with the increase in catalyst concentration.

4.7. Characterization properties of SOME

The obtained characterization properties of SOME produced under ANOVA analysis were compared with other researchers’ results [9,10,33] and with ASTM 6751 and EN 14214 biodiesel standards. The comparison of the properties is presented in Table 5. From this table, compared to crude oil, the kinematic viscosity was successfully reduced from 39.68 to 4.27 mm²/s where this value satisfied ASTM 6751 and EN 14214 standards. SME viscosity of 14.20 mm²/s which reported by Gandhi et al. [10] and KME kinematic viscosity of 16.40 mm²/s which reported by Sudrajat et al. [9] are obviously less desirable than SOME due to its much lower viscosity as the result of the effectiveness of the production approach using ANOVA to produce FAME as well as following ASTM 6751 and EN 14214 standards. Moreover, density was found to be 856.5 kg/m³ at 15 °C which is also an acceptable result. The obtained results were also compared to the existing results reported by Gandhi et al. [10] (850.0 kg/m³), Sudrajat et al. [9] (906.0 kg/m³) and Mohd et al. [33] (856.0 kg/m³). SOME possesses the lowest acid value of 0.26 mg KOH/g obtained from this study, compared to other studies as 0.73 mg KOH/g [9] and 0.523 mg KOH/g [33]. The obtained flash point (FP) was 136.5 °C and satisfies both ASTM and EN standards of 130 and 120 °C respectively, which indicates a safe use for transportation, handling and storage. The calorific value was found to be 41.821 MJ/kg which satisfies with EN standards of minimum 35 MJ/kg. The obtained calorific value of SME and KME are fit with the literatures values, which are 41.650 MJ/kg [10] and 40.228 MJ/kg [9] respectively. The SOME oxidation stability was considerably compiled the ASTM 6751 and EN 14214 biodiesel standards which was 7.23 h. Also, the observed PP, CP and CFPP values are acceptable according to the ASTM and EN standards as the observed values were −3.0 °C, −1.0 °C and −4.0 °C respectively. The water content was found to be 0.025 vol.% which is lower than the maximum standard specified by ASTM D6751 (0.05 vol.%). Copper strip corrosion was found to be 1a which meets both ASTM and EN standards. Iodine value was found to be 102.8 gI₂/100 g which satisfy the EN standard of Max. 120 gI₂/100 g and cetane number was found to be 50.6 which satisfy the ASTM standard of Min. 47 but slightly lower than EN standard of Min. 51. This might be due to the high
percentage of unsaturated fatty acid in S. oleosa which resulted in higher iodine value and lower cetane number compared to CIME percentage of unsaturated fatty acid in S. oleosa. As shown in Table 5, the literature reviews do not provide the existing value to be compared to this study. In conclusion, the obtained results in this study show that all these properties are acceptable and mostly meet both ASTM D6751 and EN 14214 standards.

5. Conclusion

In this study, ANOVA study was practiced in the experimental work to produce biodiesel and a quadratic model was suggested to predict the ester yield. The $R^2$ value obtained was 0.8004 which indicates an acceptable fit of the model with the experimental data. The main finding in this study is to determine the effects of methanol to oil ratio, types of catalyst, catalyst concentration, reaction time and temperature reaction on the methyl ester conversion (% FAME). Resulting from this study, the optimal set for biodiesel production is defined with best percentage of methyl esters yield average 96% and was produced at methanol/oil molar ratio 8:1, catalyst concentration KOH of 1.00 wt.% and the reaction temperature of 55 ℃ with period of 90 min. The properties of the produced biodiesel from this study, which are viscosity, density, water content, calorific value, iodine value, acid value, saponification number and cetane number, were in accordance with ASTM D6751 and EN 14214 standards. According to the experimental results, it can be concluded that SOME has good pour and cloud temperature of −3.0 ℃ and −1.0 ℃ respectively. It could be used a potential alternative, sustainable and environment friendly fuel. Additionally, it can be used in the diesel engine without major modification. A further study of blending of biodiesel with petrol diesel is suggested since it would be able to improve the SOME properties in diesel engine.

Acknowledgments

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.fuel.2015.04.046.

References


Table 5

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<tr>
<td>Kinematic viscosity at 40 ℃</td>
<td>mm²/s</td>
<td>D 445</td>
<td>1.9–6.0</td>
<td>2.91</td>
<td>4.27</td>
<td>14.2</td>
<td>16.40</td>
<td>3.58</td>
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<tr>
<td>Density at 15 ℃</td>
<td>kg/m³</td>
<td>D 1298</td>
<td>860–900</td>
<td>809.1</td>
<td>856.5</td>
<td>850.0</td>
<td>906.0</td>
<td>856.0</td>
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<tr>
<td>Flash point</td>
<td>℃</td>
<td>D 93</td>
<td>Min.130</td>
<td>71.5</td>
<td>136.5</td>
<td>150.0</td>
<td>–</td>
<td>188.0</td>
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<tr>
<td>Pour point</td>
<td>℃</td>
<td>D 97</td>
<td>–15 to 16</td>
<td>–2.0</td>
<td>–3.0</td>
<td>–</td>
<td>–</td>
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<tr>
<td>Cloud point</td>
<td>℃</td>
<td>D 2500</td>
<td>–3 to 12</td>
<td>–5.0</td>
<td>–1.0</td>
<td>–</td>
<td>–</td>
<td>–</td>
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<tr>
<td>CFP</td>
<td>℃</td>
<td>D 6371</td>
<td>Max.19</td>
<td>–8.0</td>
<td>–4.0</td>
<td>–</td>
<td>–</td>
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<tr>
<td>Calorific value</td>
<td>MJ/kg</td>
<td>–</td>
<td>–</td>
<td>45.825</td>
<td>41.821</td>
<td>41.650</td>
<td>–</td>
<td>39.210</td>
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<tr>
<td>Sulfur content (5 15 grade)</td>
<td>ppm</td>
<td>D 20846</td>
<td>Max. 10</td>
<td>38.73</td>
<td>7.89</td>
<td>–</td>
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<tr>
<td>FAME content</td>
<td>% m/m</td>
<td>EN 14103</td>
<td>Min. 96.5</td>
<td>–</td>
<td>96.81</td>
<td>–</td>
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<tr>
<td>Methanol content</td>
<td>% m/m</td>
<td>EN 14110</td>
<td>Max. 0.20</td>
<td>–</td>
<td>0.04</td>
<td>–</td>
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<tr>
<td>Condensable carbon residue 100%</td>
<td>% m/m</td>
<td>EN ISO 10370</td>
<td>Max. 0.02</td>
<td>0.87</td>
<td>0.01</td>
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<td>Cetane number</td>
<td>–</td>
<td>D 613</td>
<td>Max. 47</td>
<td>49.7</td>
<td>50.6</td>
<td>–</td>
<td>57</td>
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<td>Water content</td>
<td>% v/v</td>
<td>D 12937</td>
<td>Max. 0.05</td>
<td>0.00038</td>
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<td>0.820</td>
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<td>Copper Strip corrosion (3 h at 50 ℃)</td>
<td>–</td>
<td>D 130</td>
<td>Max. 3</td>
<td>1a</td>
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<td>Oxidation stability at 110 ℃</td>
<td>h</td>
<td>EN 14112</td>
<td>Min. 3</td>
<td>25.8</td>
<td>7.23</td>
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<td>Acid number</td>
<td>mg KOH/g</td>
<td>D 664</td>
<td>Max. 0.5</td>
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<td>0.73</td>
<td>0.523</td>
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<td>Iodine value</td>
<td>I₂/100 g</td>
<td>EN 14111</td>
<td>Max. 120</td>
<td>–</td>
<td>102.8</td>
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a Result.