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EFFECT OF REACTION TIME ON VARIOUS PROPERTIES OF PALM OIL BIODIESEL IN CONTINUOUS BIODIESEL REACTOR

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ABSTRACT

Biodiesel consists of the fatty acid esters of simple alcohols, which pave the way to replace fossil diesel fuel with biodiesel in transportation. Using a continuous flow transesterification process is the viable option to produce biodiesel with reduced time and cost. In this study, different concentrations of catalyst potassium hydroxide at 1.0%, 1.5% and 2.0% were experimented to determine the higher recovery of biodiesel from palm oil. By increasing the methanol concentration 2-3 times higher than the stoichiometric requirement with respect to the catalyst concentration, the methyl ester yield increase gradually at a ratio of 0.5%. The maximum methyl ester yield was 96.0% for a 7.5:1.0 molar ratio. The samples taken at 10 min intervals were analysed for kinematic viscosity and specific gravity. In comparison with methyl ester yield, the maximum yield (96.0%) was obtained at 7.5:1.0 molar ratio and 2.0% catalyst concentration, which has minimum kinematic viscosity. For continuous transesterification of palm oil using static mixer, the optimum condition for maximum methyl ester yield (96.0%) was 7.5:1.0 molar ratio and 2.0% catalyst concentration.

Keywords: biodiesel, continuous reactor, palm oil, transesterification.

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INTRODUCTION

In developed and developing nations, the energy demand of the growing world population pressurises researchers to adopt and improve technical means and ways to fulfil the thirst for energy and improve the standard of living. Several studies showed that biodiesel is a better alternative fuel than fossil-based diesel in terms of engine performance, emission reduction and environmental benefits (Canakci and Van Gerpen, 2000; Kusumo *et al.*, 2017; Peterson *et al.*, 1997; Yun *et al.*, 2016). Biodiesel is a fuel that can be produced straight from vegetable oils (edible and non-edible), recycled waste cooking oil, and animal fats for use in compression ignition (diesel) engines (Krawczyk, 1996); it can be produced locally, thus helping to reduce the country's dependence on imported crude oil. The cost of cooking oils used as raw material for biodiesel production, the viability of a continuous transesterification process and the recovery of high-quality glycerol as a biodiesel by-product are primary options to be considered to lower the cost of biodiesel (Ma and Hanna, 1999). Direct use of vegetable oils and their blended oil fuels has several problems. In the early transesterification stage, the reaction is limited by the mass transfer of alcohol to the vegetable oil phase (Van Gerpen *et al.*, 2004). Considering the characteristics of the transesterification reaction, a laboratory-scale continuous-flow reactor system using a static mixer method was developed and investigated (Thompson and He, 2007). Several alternative energy resources have been explored worldwide to meet the growing energy requirements. The search for alternate fuels for the use of transport and other sectors

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globally need more research on biofuels (Khairil *et al.*, 2018; Silitonga *et al.*, 2018,). Most biodiesel production systems available in the market are batch-type only. Hence, the biodiesel production as a continuous system needs more attention and requires high-quality result-oriented research on the continuous production of biodiesel system. The biodiesel as a partial/complete replacement of diesel in compression-ignition type engines significantly decreased the CO and HC emission, which is likely since this blend promotes complete combustion, whereas there is a slight increase in NOx emissions due to higher oxygen contents (Damanik *et al.*, 2019). Among the vegetable and tree born oils, palm oil has excellent resistance to oxidation and high heat exposure for an extended period of time (Kurnia *et al.*, 2016; Mahlia *et al.*, 2019). In this study, the effect of different properties at various molar ratios of the higher recovery of biodiesel from palm oil using continuous reactor with static mixer was experimented and optimised.

MATERIALS AND METHODS

The biodiesel feedstock used for this study was palm oil and it was procured from local oil mill, Chinthamani Pudhur, Coimbatore district, Tamil Nadu. Various properties of palm oil biodiesel were studied using ASTM standards.

Kinematic Viscosity

The kinematic viscosity of the sample was determined by Redwood Viscometer using ASTM: 445-72 procedure. The water bath in the viscometer was heated to the testing temperature of 40ºC. The sample was filtered in a B_{200} mesh and poured into the oil cup of the viscometer. The sample was stirred to make it homogenous and adjusted to achieve the testing temperature. A 50 mL measuring cylinder was placed below the jet of the viscometer. The time taken for filling 50 mL of sample was noted with a stopwatch. The sample's kinematic viscosity was calculated by using Equations (1) and (2). The experiment was replicated three times and average values were reported.

Kinematic viscosity of test sample,

$$V\,(\mathrm{mm^2/s}) = 0.26 \times t - 179/t \text{ for } 34 <t> 100\mathrm{s} \quad (1)$$

$$V\,(\mathrm{mm^2/s}) = 0.24 \times t - 179/t \text{ for } 34 <t> 100\mathrm{s} \quad (2)$$

where, t is the time taken for filling 50 mL of oil sample, s.

Specific Gravity

The specific gravity was determined using a specific gravity bottle (IS: 1448-1972). The specific gravity bottle was washed in acetone and dried in an autoclave. The empty weight of the specific gravity bottle with a lid was weighed using a weighing balance. The water weight and the specific gravity of the bottle with lid were weighed and taken. The specific gravity of the bottle was again washed with acetone and dried in autoclave. The weight of the sample and specific gravity bottle with lid was weighed. The experiments were conducted at 40°C. The sample's specific gravity was calculated, the experiment was replicated three times, and average values were reported.

Flash Point

Pensky Martens, a semi-automatic flash point tester was used to determine the flash point of biodiesel (IS: 1448-1992 method) in the range of 25°C to 400°C. The test was performed by filling biodiesel up to a definite mark, fixing the cover and heating the biodiesel at a rate of 5°C/min to 6°C/min. A stirrer was used to ensure uniform temperature distribution in the test sample. The flash point was recorded at the time of distinct flash in the interior of the biodiesel cup by reading the temperature.

Cloud Point

The cloud point and pour point apparatus were used to measure the cloud point of test samples. The ASTM D-97/57 method was adopted for this experiment. The test jar with oil was heated to 46.0°C and then cooled to 15.5°C in a water bath maintained at 7°C. After this pretreatment, the ring jacket was placed at 25 mm from the bottom of the test jar and was kept in the jacket. The capillary thermometer was immersed 3 mm above the bottom of the test jar, and the jacket was cooled between -1°C and 2°C. The sample was frequently inspected at 3°C intervals by removing the test jar from the jacket and observing crystal formation in the sample due to the cooled bath in the apparatus, and that temperature was recorded as the cloud point of the test sample. Each inspection was completed within 5 s.

Pour Point

The pour point of the test sample was determined by the same procedure followed for the cloud point except for the position of the thermometer. The thermometer was immersed to 3 mm below the surface of the test sample. The inspection continued until there was no sample movement at the horizontal position of the test jar for 5 s. The temperature recorded under these conditions was taken as the pour point of the test sample.

Free Fatty Acid

Association of Official Chemists Society (AOCS) Method, Ca 5a-40 was used to determine the Free Fatty Acid (FFA) of oil. An oil sample of 7.05 ± 0.5 g was weighed in a conical flask. 75 mL of ethanol and 2 mL of phenolphthalein were added to the sample. The oil sample was titrated against 0.25 N sodium hydroxide, shaking the flask vigorously until the appearance of the first permanent pink colour persisted for 30 s. The FFA content was calculated as oleic acid as given below in Equation (3).

$$\text{FFA as oleic acid (\%)} = \frac{\text{Volume of alkali consumed (mL)} \times \text{Normality} \times 28.2}{\text{Weight of sample (g)}} \qquad (3)$$

Performance Evaluation of Continuous Transesterification System

For optimising the parameters used in the continuous transesterification system, the catalyst amount and molar ratio were considered. Up to 5% FFAs, the transesterification reaction can be done with an alkaline catalyst. The FFA of raw oil used for this study was less than 5%, and hence potassium hydroxide was selected as a catalyst.

Catalyst Amount

The FFA of palm oil was found as 3.3%, which is lesser than 5.0% and so as the first stage of experiments, three different levels of concentration of potassium hydroxide were used (1.0%, 1.5% and 2.0%) in this work to determine the higher recovery of biodiesel if the yield is less, higher concentration of catalyst will be used to carry out the study.

Molar Ratio

The molar ratios for this study were taken by different methanol to oil ratios of 4.5:1.0, 6.0:1.0 and 7.5:1.0 to study their effects on biodiesel yield. The molecular weight of the oil was calculated based on the fatty acid composition of the oil.

Reaction Temperature

At the beginning of the experiment, the water bath temperature was fixed at 50ºC. Then the heat discharged from the pump raises the temperature to the required temperature of 60ºC. The primary advantage of the higher temperatures influences shorter reaction time. Sometimes the higher reaction temperature also causes the methanol to vaporise, resulting in decreased yield (boiling point 65°C). When the temperature decreases, the reaction rate also decreases. The sample was collected for every 10 min interval, which was subsequently evaluated for certain properties such as specific gravity and kinematic viscosity.

Biodiesel Yield

The quantity of biodiesel was measured after each experimental trial based on molar ratio, reaction temperature and time. The measured quantity was weighed and the following Equation (4) was used to calculate the biodiesel yield.

$$\text{Biodiesel yield (\%)} = \frac{\text{Wight of the biodiesel}}{\text{Weight of the oil}} \times 100 \qquad (4)$$

Fatty Acid Methyl Ester Composition

For confirmation of fatty acid methyl ester (FAME) of palm oil biodiesel, MS spectra of the unknown sample were compared with MS spectra from the NIST mass spectral library provided with the GC/MS system. The samples were prepared by diluting ester in hexane and used in a gas chromatography-mass spectrometer (GC-MS, Agilent 7890B-5977A model). The condition maintained for analysing the biodiesel quality is given below.

GC column	:	DB-5 ms
Carrier gas	:	Helium gas
Carrier gas flow rate	:	1.0 mL/min
Injection mode	:	splitless
Purge flow to split vent	:	20 mL/min
Mass spectrometer conditions		
Injection port temperature	:	250°C
Source temperature	:	200°C
Inference temperature	:	230°C
Data collection mode	:	scan

The column was heated at 50°C for 5 min and then the temperature was increased to 200°C at 15°C/min and held at 200°C for 45 min.

RESULTS AND DISCUSSION

The continuous transesterification system was developed to produce biodiesel from palm oil. The reaction mixture (potassium hydroxide, methanol and raw oil) was circulated with the help of the pump at higher pressure to make the turbulent flow inside the reactor. The samples were drawn from the system at different intervals to analyse the biodiesel yield and the selected properties. The value of the FFA present in the selected oil was 3.3%. For optimising the operational parameters for higher biodiesel yield from selected palm oil, three different levels of molar ratio (4.5:1.0, 6.0:1.0 and 7.5:1.0), catalyst concentration (1.0%, 1.5% and 2.0%) and reaction time (20-60 min) were selected. The catalyst and alcohol used in this study were potassium hydroxide and methanol. The experiment was continued until it reached the constant value of specific gravity and kinematic viscosity of the produced biodiesel.

TABLE 1. METHYL ESTER YIELD IN CONTINUOUS TRANSESTERIFICATION SYSTEM

Trials	Reaction temperature maintained at 50°C		
	Molar ratio	Catalyst concentration (%)	Methyl ester yield (%)
T1	4.5:1.0	1.0	93.00
		1.5	93.50
		2 .0	94.00
T2	6.0:1.0	1.0	94.50
		1.5	94.75
		2.0	95.00
T3	7.5:1.0	1.0	95.50
		1.5	95.75
		2 .0	96.00

Effect of Properties of Palm Oil Biodiesel at Different Molar Ratio

Fuel properties such as specific gravity and kinematic viscosity as detailed in the methodology were studied for raw oil and biodiesel produced in a continuous transesterification process using a static mixer. In continuous production, for analysing the above properties after 30 min run on batch mode, the samples were taken at 10 min intervals.

Effect of Kinematic Viscosity at 4.5:1.0 Molar Ratio

The kinematic viscosity of the palm oil was 30.3 mm^2/s. The combination of the molar ratio at 4.5:1.0 and 1.0% concentration of catalyst, the kinematic viscosity of palm oil biodiesel produced were reduced to 10.07, 9.75, 8.01, 7.37, 6.21 and 5.76 mm^2/s for the reaction time of 10, 20, 30, 40, 50 and 60 min respectively. From the graph, it was noted that the kinematic viscosity of palm biodiesel was 5.76 mm^2/s at 60 min reaction time and the viscosity of biodiesel produced was stabilised. The reduction in the kinematic viscosity of the oil was 81.0% at 60 min, as compared to palm oil. The combination of the molar ratio of 4.5:1 and 1.5% concentration of catalyst, the kinematic viscosity of palm oil biodiesel produced was reduced to 9.42, 8.41, 7.72, 7.37, 6.29 and 5.55 mm^2/s for the reaction time of 10, 20, 30, 40, 50 and 60 min, respectively. The kinematic viscosity of palm biodiesel was 5.55 mm^2/s at 60 min reaction time and the viscosity of biodiesel produced was stabilised after this reaction time. The reduction in kinematic viscosity of the oil was 81.5% at 60 min reaction time, as compared to that of palm oil. At the molar ratio 4.5:1.0 and 2.0% concentration of

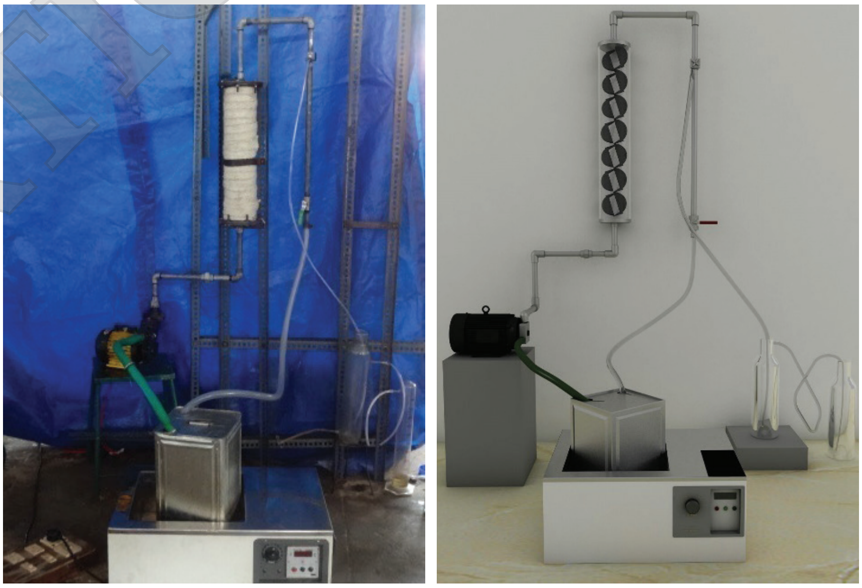

Figure 1. Continuous transesterification rector.

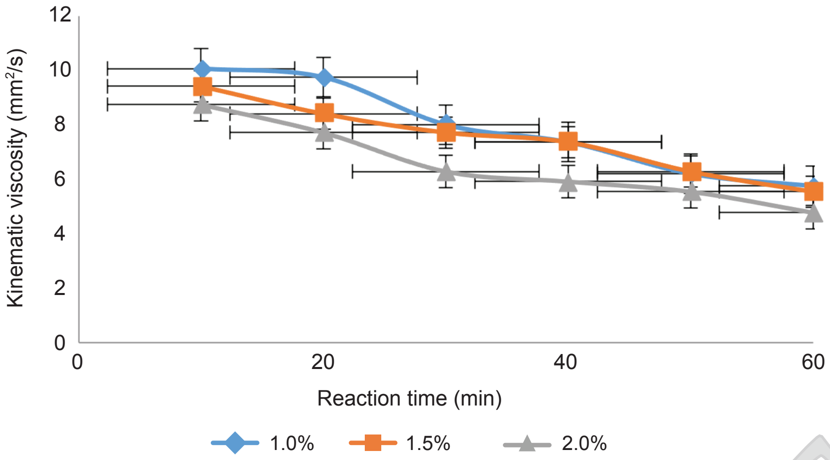

Figure 2. Effect of reaction time on kinematic viscosity of biodiesel produced at 4.5:1.0 molar ratio.

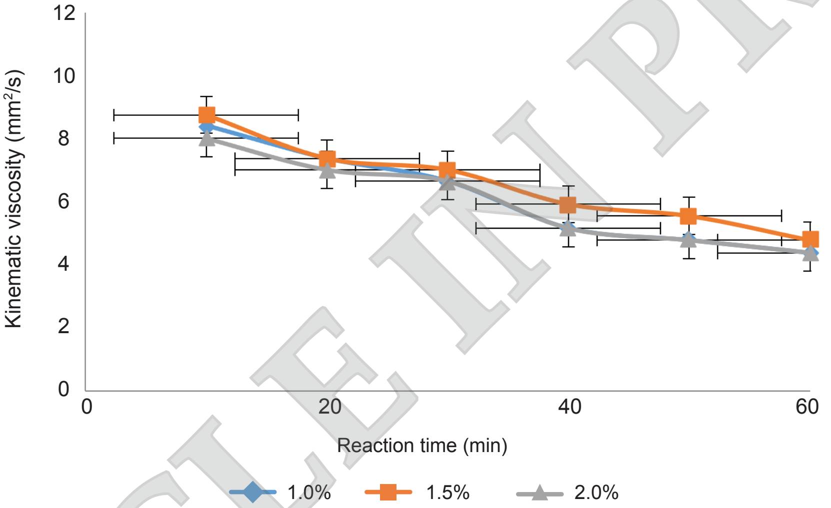

Figure 3. Effect of reaction time on kinematic viscosity of biodiesel produced at 6.0:1.0 molar ratio.

catalyst, the kinematic viscosity of palm oil biodiesel produced was reduced from 8.75 to 4.78 mm^2/s for the reaction time of 10 to 60 min respectively. The kinematic viscosity of palm biodiesel was reduced with respect to an increase in reaction time. At 60 min time intervals the reduction in kinematic viscosity of the oil was 84.0% as compared to palm oil (*Figure* 2).

Effect of Kinematic Viscosity at Molar Ratio of 6.0:1.0

The kinematic viscosity of palm oil biodiesel was reduced from 8.41 to 4.38 mm^2/s for the reaction time of 10 to 60 min, respectively. The kinematic viscosity of palm biodiesel was reduced with respect to the increase in reaction time. The kinematic viscosity of the biodiesel produced was stabilised. The kinematic viscosity of palm biodiesel was 4.38 mm^2/s at 60 min reaction time. The reduction in kinematic viscosity of the oil was reduced to 85.4% at 60 min reaction time, as compared to that of palm oil. The combination of molar ratio 6.0:1.0 at 1.5% concentration of catalyst, the kinematic viscosity of palm oil biodiesel was reduced to 8.75, 7.37, 7.01, 5.92, 5.55 and 4.78 mm^2/s for the reaction time of 10, 20, 30, 40, 50 and 60 min respectively. The reduction in kinematic viscosity of the oil was 84.1% at 60 min, as compared to that of palm oil. With the 2.0% catalyst concentration, the kinematic viscosity of palm oil biodiesel produced was reduced from 8.01 to 4.38 mm^2/s for the reaction time of 10, 20, 30, 40, 50 and 60 min respectively. The reduction percentage in kinematic viscosity of the oil was 85.4 mm^2/s at 60 min reaction time, compared to palm oil (*Figure* 3).

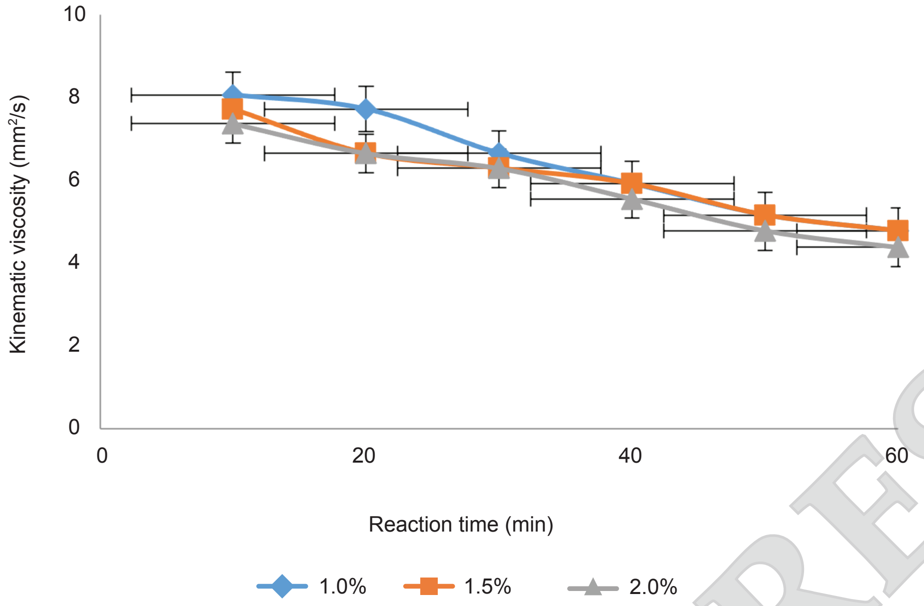

Figure 4. Effect of reaction time on kinematic viscosity of biodiesel produced at 7.5:1.0 molar ratio.

Effect of Kinematic Viscosity at Molar Ratio 7.5:1.0

The kinematic viscosity of palm oil biodiesel was reduced to 8.06, 7.72, 6.65, 5.92, 5.16 and 4.78 mm^2/s for the reaction time of 10, 20, 30, 40, 50 and 60 min, respectively. It was noted that the kinematic viscosity of palm biodiesel of 4.78 mm^2/s at 60 min reaction time the viscosity was stabilised. The reduction in kinematic viscosity of the oil was 84.07% at 60 min of the process as compared to palm oil. At a 1.5% catalyst concentration of 7.5:1.0 molar ratio, the kinematic viscosity of palm oil biodiesel produced was reduced from 7.72 to 4.78 mm^2/s for the reaction time of 10, 20, 30, 40, 50 and 60 min respectively. The reduction in kinematic viscosity of the oil was 84.1%. The molar ratio of 7.5:1.0 at a 2.0% concentration of catalyst, the kinematic viscosity of palm oil biodiesel produced was reduced from 7.37 to 4.38 mm^2/s for the reaction time from 10 to 60 min. The kinematic viscosity of palm biodiesel was reduced due to increase in reaction time. The reduction in kinematic viscosity of the oil was 85.4% at 60 min, as compared to palm oil (*Figure 4*).

From the results, it is concluded that the kinematic viscosity decreases with an increase in reaction time. The kinematic viscosity obtained at these concentrations met with the fuel standard of IS:9466-1980 (3.5-5.0 mm^2/s). The minimum kinematic viscosity 4.38 mm^2/s was obtained at 6.0:1.0 and 7.5:1.0 molar ratio at 2.0% catalyst concentration. Compared with methyl ester yield, the maximum methyl ester yield of 96% was obtained at a 7.5:1.0 molar ratio and 2.0% catalyst concentration, which has a minimum kinematic viscosity of 4.38 mm^2/s. Similar results were observed by Dhanasekaran and Dharmendirakumar (2014) that minimum kinematic viscosity of 4.1 mm^2/s was achieved at 6:1 molar ratio at 2.0% catalyst. It indicated the completion of the reaction process and the removal of heavy glycerin.

Effect of Specific Gravity at 4.5:1.0 Molar Ratio

The specific gravity of palm oil was observed as 0.901. Similar to kinematic viscosity, the specific gravity of the oil also decreased with an increase in reaction time. *Figure 5* shows the effect of the catalyst on the specific gravity of biodiesel at 4.5:1.0 molar ratios. At 1% catalyst concentration, the specific gravity was 0.883 at the initial stage; as the reaction time increases, the specific gravity decreases gradually to 0.877. Initially, at 1.5% of the catalyst concentration, the specific gravity was 0.882 and decreased to 0.877. Similarly, at 2.0% catalyst concentration, the initial specific gravity was 0.880; as the reaction time increased, the specific gravity gradually decreased to 0.874. The minimum specific gravity of 0.874 was obtained at 2.0% catalyst for a 4.5:1.0 molar ratio. The percentage reduction of specific gravity for the 4.5:1.0 molar ratio at 1.0%, 1.5% and 2.0% catalyst concentration was from 2.6% to 3.0%.

Effect of Specific Gravity at 6.0:1.0 Molar Ratio.

The effect of the catalyst on the specific gravity of biodiesel for 6.0:1.0 molar ratio at different catalyst

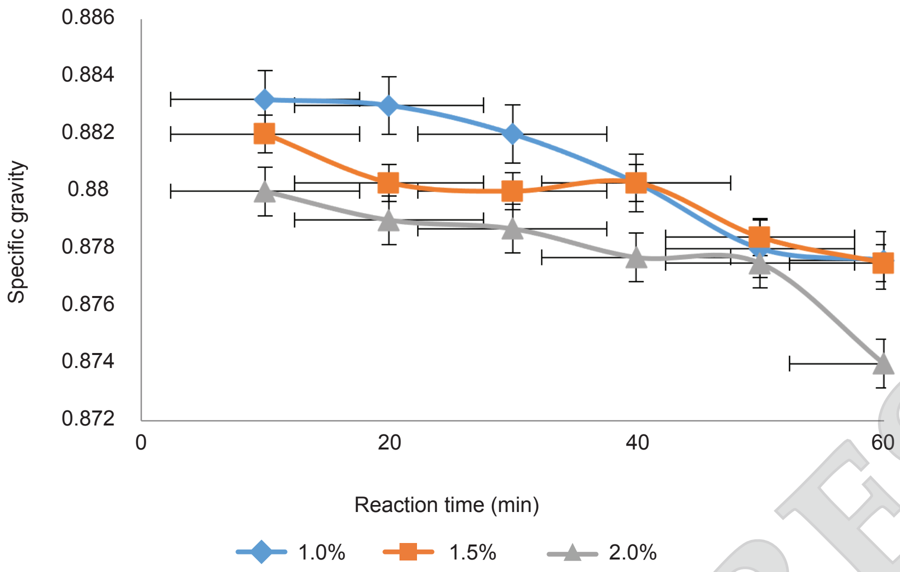

Figure 5. Effect of reaction time on specific gravity of biodiesel produced at 4.5:1.0 molar ratio.

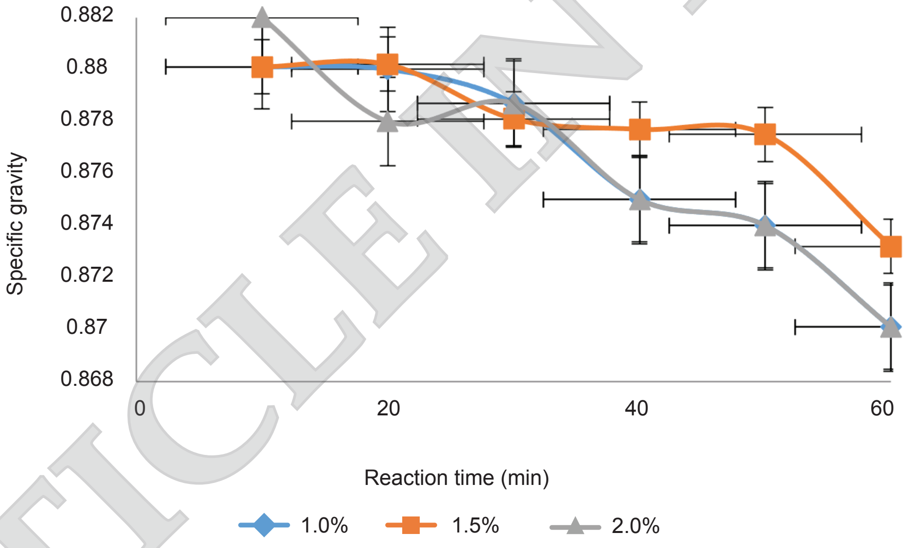

Figure 6. Effect of reaction time on specific gravity of biodiesel produced at 6.0:1.0 molar ratio.

concentrations, as shown in *Figure 6* indicates that, at 1.0% catalyst concentration, the specific gravity of 0.880 was decreased to 0.870. Initially, at 1.5% catalyst concentration, the specific gravity was 0.880 and decreased to 0.873. The specific gravity for 2.0% catalyst concentration was 0.882, as the reaction time increases, the specific gravity decreased gradually to 0.873. For 6.0:1.0 molar ratio, the minimum specific gravity of 0.870 was obtained at 1.5% catalyst. The percentage reduction in specific gravity for the above molar ratio was around 3.4%.

Effect of Specific Gravity at 7.5:1.0 Molar Ratio

The specific gravity of biodiesel for 7.5:1.0 molar ratio at different reaction times and catalyst concentration effect is shown in *Figure 7*. It indicated that the specific gravity was 0.880 and decreased to 0.874. At 1.5% catalyst concentration, the specific gravity was 0.880 and decreased gradually to 0.874. Similarly, at 2.0% catalyst concentration, the specific gravity was 0.880 and decreased to 0.870. For all the catalyst concentrations at the initial stage, the

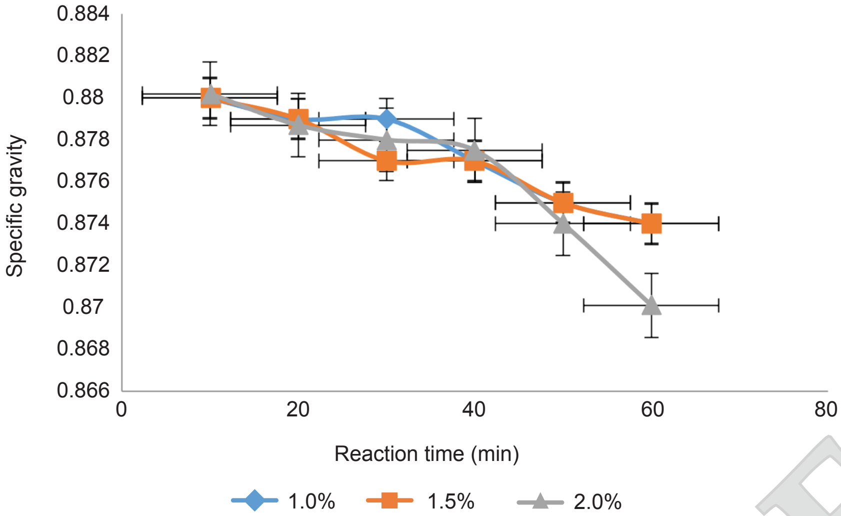

Figure 7. Effect of reaction time on specific gravity of biodiesel produced at 7.5:1.0 molar ratio.

specific gravity also decreased when the reaction time increased. The minimum specific gravity of 0.870 was obtained at 2.0% catalyst. The reduction of specific gravity in this molar ratio at three different catalyst levels was from 3.0% to 3.4%.

From the above results, it is concluded that at the 7.5:1.0 molar ratio, the specific gravity decreased gradually with increase reaction time. The specific gravity obtained at this concentration met with the fuel standard of IS:1448-1972 as specified by the Indian standards (0.87-0.90). The minimum specific gravity (0.870) was obtained at 6.0:1.0 and 7.5:1.0 molar ratio for 2.0% catalyst concentration. Compared with methyl ester yield, the maximum yield of 96.0% was obtained at a 7.5:1.0 molar ratio and 2.0% catalyst with minimum specific gravity.

Similar results were observed by Padmarag and Kavita (2012) and results indicated that a lower value of specific gravity of (0.866) is an indication of the completion of the reaction process and the removal of heavy glycerin.

The experimental trials concluded that the combination of a 6.0:1.0 molar ratio and 1.0% catalyst concentration performed better for higher recovery of biodiesel yield and fuel properties. The kinematic viscosity of biodiesel produced at a molar ratio of 4.5:1.0 and 2.0% catalyst concentration was equivalent to the viscosity of biodiesel produced at other higher molar ratios. The catalyst used under these conditions was higher than that, leading to more catalysts present in the biodiesel. During the water washing of biodiesel, the biodiesel yield will be reduced due to repeated washing to neutralise the biodiesel. In the case of a 7.5:1.0 molar ratio with three levels of catalyst concentration (1.0%, 1.5% and 2.0%), the biodiesel yield was greater than 95.0%. The higher biodiesel yield recorded under this condition is due to 150 times higher than the stoichiometric requirement (*i.e.*, 3:1), and also, the excess amount of methanol used in the transesterification process must be recovered before washing the product (*i.e.*, raw biodiesel).

The biodiesel yield for the combination of 6.0:1.0 at three different catalyst levels was 94.5% to 95.0%. Among the three combinations, 6.0:1.0 with 1.0% catalyst concentration was selected for biodiesel production. Therefore, for the other two higher concentrations of catalyst amount, the biodiesel yield was closer to that of 1.0% catalyst concentration. Furthermore, the reduction in kinematic viscosity was 85.0%, which was higher than the other two catalyst combinations.

From the study, the optimised condition for the continuous transesterification system for the tested palm oil was a 6.0:1.0 molar ratio with 1.0% catalyst concentration operated for 30 min in batch mode and then converted into a continuous mode for 60 min. The properties of biodiesel derived from palm oil at optimised conditions are presented in *Table 2*.

TABLE 2. PROPERTIES OF PALM OIL BIODIESEL

No.	Particulars	Palm oil biodiesel
1	Kinematic viscosity @ 40°C, mm^2/s	5.92
2	Specific gravity @ 40°C	0.877
3	Flash point, °C	165.00
4	Cloud point, °C	10.00
5	Pour point, °C	7.00
6	Energy content, MJ	330.87

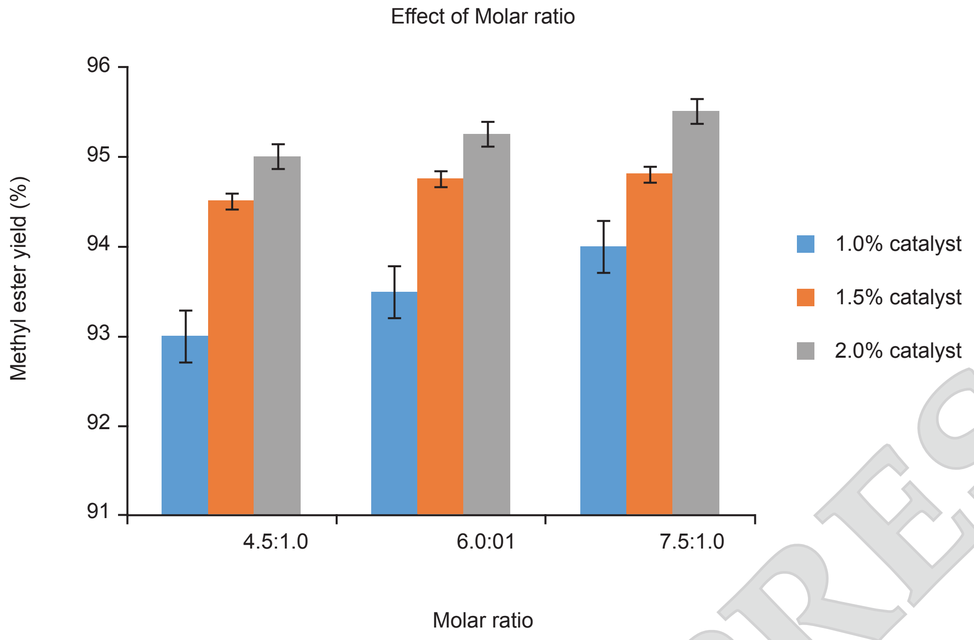

Figure 8. Methyl ester yield of palm oil in continuous transesterification system.

The kinematic viscosity of the biodiesel produced was 5.92 mm^2/s which was the same as that of the values obtained from waste cooking palm oil biodiesel (4.77 mm^2/s) (Hussanai Sukkathanyawat and Kittisak Wichianwat, 2023).

Flash Point

The flash point of biodiesel is higher than diesel fuel (Mofijur *et al.*, 2017). Furthermore, the flash point of palm oil biodiesel (165°C) was three times higher than diesel fuel (55°C). The higher flash point indicates the in-volatile nature of oils. The flash point obtained for maximum methyl ester yield met with the fuel standard of (IS:1448-1992 method). The flash point of the Waste cooking palm oil biodiesel is 166°C (Hussanai Sukkathanyawat and Kittisak Wichianwat, 2023).

Cloud Point

The cloud point of the palm oil biodiesel for maximum methyl ester (96%) was 10°C. The cloud point obtained for maximum methyl ester yield met the fuel standard of ASTM D-97/57 (-3°C to 12°C). Most of the fuel properties of biodiesel compare well with fossil diesel except cloud point. One major disadvantage of biodiesel is its relatively poor cold flow properties, affecting an engine's performance in cold weather, *i.e.*, moderate temperature climates (Robert, 2018). The cloud point of the Waste cooking palm oil biodiesel is 7°C (Hussanai Sukkathanyawat and Kittisak Wichianwat, 2023).

Pour Point

Pour point of the palm oil biodiesel for maximum methyl ester was found as 7°C. The cloud point obtained for maximum methyl ester yield met with the fuel standard of ASTM D-97/57 (-15°C to 10°C). The higher pour point of edible oils than diesel fuel indicates the poor flow characteristics of oil at lower temperatures. Generally, the pour point of vegetable oils was higher than diesel fuel, which indirectly correlates to the poor flow characteristics of oil at lower temperatures (Bazooyar *et al.*, 2015). From the waste cooking palm oil biodiesel, the pour point is 6°C as equivalent as that of palm oil biodiesel produced in this experimental analysis (Hussanai Sukkathanyawat and Kittisak Wichianwat, 2023).

Fatty Acid Methyl Ester Composition

Gas chromatography-mass spectrometry (GC-MS) was used to determine the fatty acid composition of palm oil biodiesel. For confirmation of fatty acid methyl ester (FAME) of palm oil biodiesel, MS spectra of the unknown sample were compared with MS spectra from the NIST mass spectral library provided by GC/MS system. The palm oil fatty acid methyl ester (POFAME) consist of palmitic acid methyl ester ($C_{16:0}$), caprylic acid methyl ester ($C_{8:0}$), capric acid methyl ester ($C_{10:0}$), undecylenic acid ($C_{11:0}$), pelargonic acid ($C_{9:0}$), arachidic acid methyl ester ($C_{20:0}$), palmitoleic acid ($C_{16:1}$), and their quantity are represented in *Table 3*.

TABLE 3. FATTY ACID METHYL ESTER OF PALM OIL BIODIESEL

Compositions	Values (%)
Caprylic acid ($C_8H_{16}O_2$)	0.10
Capric acid ($C_{10}H_{20}O_2$)	5.96
Undecylenic acid ($C_{11}H_{20}O_2$)	0.12
Palmitic acid ($C_{16}H_{32}O_2$)	41.5
Pelargonic acid (3(CH_2) 7CO 2H)	1.57
Arachidic acid ($C_{20}H_{32}O_2$)	1.13
Mystric acid ($CH_3(CH_2)_{12}COOH$)	1.40
Stearic acid ($C_{18}H_{36}O_2$)	38.6
Methyl 8-methyl-nonanoate ($C_{11}H_{22}O_2$)	5.96
18-Nonadecen-1-ol ($C_{19}H_{38}O$)	2.43
Cyclododecanemethanol ($C_{13}H_{26}O$)	1.23
Total	**100**

Comparing the GC-MS analysis of fish oil biodiesel, the major esters were identified as methyl esters of palmitic acid, linoleic acid, oleic acid, linolenic acid, and stearic acid for biodiesel produced in the present study (Whetstine, 2020).

CONCLUSION

The effect of reaction time on various properties of palm oil biodiesel in a continuous biodiesel reactor was studied, and the optimised condition for continuous transesterification system for the tested palm oil was found as a 6.0:1.0 molar ratio with 1.0% catalyst concentration operated for 30 min as batch mode and then converted into a continuous mode for 60 min. The biodiesel yield for the molar ratio combination of 6.0:1.0 at three different catalyst levels was 94.5% to 95.0%. Other two higher concentrations of catalyst amount, the biodiesel yield was closer to that of 1.0% catalyst concentration. Moreover, the reduction in kinematic viscosity was 85.0%, which was higher than the other two catalyst combinations with a biodiesel yield of 94.75%.

The optimised condition identified for the continuous biodiesel production by this research was using a 6.0:1.0 molar ratio with a minimum of 1.0% catalyst concentration. This is to recommend that future work on the process optimised by this study will be tested in the large high-capacity continuous reactor of more than 100 L/hr will give good results in producing biodiesel from palm oil. The continuous biodiesel production is a novel idea to produce raw palm oil into biodiesel using a transesterification reactor under the optimised condition. The present article will give more hope and knowledge about biofuels from palm oil using different conditions to the readers in the oil palm industry.

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