

Production of Methyl Ester (Biodiesel) from Used Cooking Oils via Trans-esterification process

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ABSTRACT

Used cooking oil was undergoing trans-esterification reaction to produce biodiesel fuel. Method of production consisted of pretreatment steps, trans-esterification, separation, washing and drying. Trans-esterification of treated oils was studied at different operation conditions, the methanol to oil mole ratio were 6:1, 8:1, 10:1, and 12:1, at different temperature 30, 40, 50, and 60 °C, reaction time 40, 60, 80, and 120 minutes, amount of catalyst 0.5, 1, 1.5, and 2 wt.% based on oil and mixing speed 400 rpm. The maximum yield of biodiesel was 91.68 wt.% for treated oils obtained by trans-esterification reaction with 10:1 methanol to oil mole ratio, 60 °C reaction temperature, 80 minute reaction time and 0.5 wt.% of NaOH catalyst. The physical properties such as specific gravity, kinematic viscosity, acid number, flash point, pour point, and water content, were measured and compared them with American Standard Test Methods (ASTM D6751). The results of these properties for biodiesel product at (6:1, 8:1, 10:1, and 12:1 of methanol to oil mole ratio) were within the range of American Standard Test Methods (ASTM D6751).

Keywords:Biodiesel, trans-esterification, used cooking oils

انتاج الميثيل استر (الديزل الحيوي) من زيوت الطهي المستخدمة بواسطة عملية الاسترة التبادلية

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الخلاصة

خضع زيت الطهي المستخدم لتفاعل الاسترة التبادلية لانتاج وقود الديزل الحيوي. طريقة الانتاج تضمنت المعالجة، الاسترة التبادلية، الفصل، الغسل والتجفيف. درست الاسترة التبادلية للزيوت المعالجة في ظروف تشغيل مختلفة، النسبة المولية للميثانول الي الزيت كانت 6:1، 8:1، 10:1، و 12:1 عند درجات حرارة مختلفة 30، 40، 50 و 60م°، زمن التفاعل 40، 60، 80 و 120دقيقة، كمية العامل المساعد 0,5، 1، 1,5 و 2% نسبة وزنية وسرعة الخلط 400 دورة بالدقيقة. اعلى انتاج من وقود الديزل الحيوي كان 91,68 نسبة وزنية من الزيوت المعالجة التي تم الحصول عليها عن طريق تفاعل الاسترة التبادلية مع 10:1 نسبة مولية للميثانول الي الزيت، 60م° درجة حرارة التفاعل، 80 دقيقة زمن التفاعل، 0,5 % نسبة وزنية من هيدروكسيد الصوديوم العامل المساعد. الخواص الفيزيائية مثل الكثافة النوعية، اللزوجة، عدد الحمضية، نقطة الوميض، نقطة الانسكاب و المحتوى المائي، قيست ثم قورنت مع طريقة الاختبار الامريكية القياسية ASTM D6751. نتاج هذه الخصائص لمنتج وقود الديزل الحيوي عند (6:1، 8:1، 10:1 و 12:1 من الميثانول الي الزيت كنسبة مولية) كانت ضمن مدى معايير ASTM D6751 .

الكلمات الرئيسية: وقود الديزل الحيوي، الاسترة التبادلية، زيوت الطهي المستخدمة

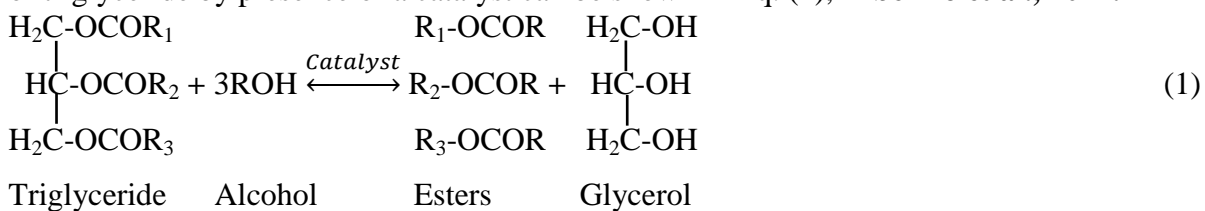
1. INTRODUCTION

Biodiesel is a mono alkyl ester of long chain fatty acids biodegradable, nontoxic fuel oil that is essentially free from sulfur and aromatics, producing lower exhaust emissions than conventional diesel fuels derived from renewable lipid such as vegetable oils and animal fats, **Hassan et al., 2013**. In view of the crises of petroleum fuel depletion and the rise in price of petroleum fuel. Therefore, there are a strong need to reduce the world's dependence on fossil fuels and replace it with other more sustainable energy sources such as geothermal energy, solar energy, tidal energy, wind energy, and biofuel, **Nakpong and Wootthikanokkhan, 2010 and Ayodeji et al., 2014**. Biodiesel is renewable and contributes less to global warming than petroleum fuel due to its closed carbon cycle. The primary feedstock can grow season after season and most of carbon in the fuel was originally removed from the air by the plant. **Fig. 1**, shows the biodiesel carbon cycle, **Prah, 2010**. Biodiesel also contains little or no sulphur and it has a higher flash point. The higher flash point of biodiesel allows safe handling and storage, **Kumar et al., 2010**. Biodiesel is safe can be used in diesel engines with few or no modifications needed, faster biodegradation. Biodiesel has greater lubricity than conventional diesel, which results in longer engine component life. All these advantages will make biodiesel as a friendly fuel for environment, **Jaichandar and Annamalai, 2011**.

This work, intend to produce methyl ester (biodiesel) from used cooking oils. Used cooking oils are a promising alternative to vegetable oil for biodiesel production because it is cheaper than pure vegetable oil. Selecting used cooking oil can lead to reduce the water pollution from pouring the used cooking oils into river, also the restaurants can no longer reused of used cooking oils which may causes the cancer from dioxin, because during frying many harmful compounds are formed, **Fan et al., 2009**. The concentration of free fatty acid in used cooking oil, indicating whether esterification must be performed or not, in this work the concentration of free fatty acid less than 3%, therefore the acid-catalyzed esterification was not necessary, **Ribeiro et al., 2011**. This research focused on biodiesel production from used cooking oils via alkali-catalyst trans-esterification. Various parameters were used to produce biodiesel such as alcohol (methanol) to oil mole ratio, reaction temperature, reaction time, and amount of catalyst (sodium hydroxide).

2. TRANS-ESTERIFICATION REACTION

Trans-esterification is the method in which the vegetable oils or animal fats are reacted with alcohol in the presence of a suitable catalyst to form esters and glycerol, trans-esterification reaction of triglyceride by presence of a catalyst can be shown in Eq. (1), **Riberiro et al., 2011**.



Trans-esterification has the sole aim of lowering the viscosity of the oil, **Jaichandar and Annamalai, 2011**.

3. EXPERIMENTAL WORK

3.1 Material

The materials used in this study are summarized in **Table 1**.

3.2 Equipment

The equipment used in this study to produce biodiesel from used cooking oil is summarized in **Table 2**.

3.3 Estimation of Free Fatty Acid (FFA)

The free fatty acid in the used cooking oil was analyzed using titration method. 10 g of filtered oil mixed with 40 ml of iso-propyl alcohol and 2-3 drops of phenolphthalein, **Gadwal and naik., 2014**. The mixture put on conical flask and then titrated with 0.1N of sodium hydroxide solution (4 gram of sodium hydroxide in 1 liter of water) with constant shaking until a pink color persists for 30 second. The percentage of free fatty acid was calculated using Eq. (2), **Gadwal and naik., 2014**.

$$FFA\% = \frac{28.2 * 0.1 * \text{titer value}}{\text{weight of used cooking oil (g)}} \quad (2)$$

3.4 Apparatus

A three neck flask was placed on a hotplate stirrer, an overhead stirrer was fixed on center neck of three neck flask, a reflux condenser and thermometer in other two neck as shown in **Fig. 2**. A condenser was used to condense any escaped vapors, and a thermometer is used to monitor the temperature of the reaction.

3.5 Biodiesel Production

1. The first step of biodiesel production is pretreatment of used cooking oil, used cooking oils contain considerable amount of solid particles, and water. To get rid of water, the used cooking oils heated on hotplate stirred at 120 ° C for 2 hours. Solid particles are can very easily be removed using Buchner funnel and filtering flask. Used cooking oils poured through a filter paper (Ø 125 mm) in a Buchner funnel. The solid particles are trapped by filter paper and oil is drowning through the funnel into filtering flask below by a vacuum pump.
2. Mixing of alcohol and catalyst, the volume of alcohol (methanol) was measured and poured into conical flask. The catalyst (sodium hydroxide) in pellet form was weight and mixed with alcohol to produce alkoxide solution (sodium alcoxide). The mixture was then heated to desirable temperature and shaking until all the catalyst dissolved. The flask was covered with watch glass during shaking to reduce the loss of alcohol by evaporate easily.
3. The trans-esterification reaction is carried out at constant agitation at 400 rpm. The operation parameters were the mole ratio of methanol to oil 6:1, 8:1, 10:1, and 12:1, reaction temperature were 30, 40, 50, and 60 ° C, the amount of sodium hydroxide were 0.5, 1, 1.5, and 2 wt.% based on oil, and at different reaction time 40, 60, 80, and 120 minutes. The pretreated oil of 100 ml was measured and poured into the three-neck flask and heated until reached to the reaction temperature. The alcohol and catalyst mixture is transferred into three-neck flask containing heated oil and the agitation started. The reaction considered starting at this moment.
4. After trans-esterification reaction is completed, the mixture was placed in a separating funnel. Then allowed to settle down overnight to ensure complete separation the reaction mixture into two layers, the upper layer is biodiesel (yellow) and lower layer is glycerol (red to orange) and may contains unreacted oil, methanol and catalyst. The lower layer was drained off from the mixture. The upper layer was drained for next steps.
5. After trans-esterification the upper ester layer (biodiesel) was separated from the bottom glycerol phase. The biodiesel layer may contain sodium hydroxide (NaOH), methanol and traces of

glycerol. The biodiesel was washed with warm distilled water (40-60) ° C and the volume of distilled water added was approximately 20% of biodiesel volume, **Ahmed et al., 2009**. Washing is carried out by spraying warm water into the top of the separating funnel, stirred gently for few minutes to prevent the soap formation. After that the washed biodiesel allowed to settle in the separating funnel. The washing process was repeated for several times (3-6) times, until pH of washed water became equal to the 7 by using Universal indicator paper.

6. After washing step was completed, the biodiesel may contain some traces of water and methanol. Biodiesel was placed in oven at 110 ° C for 1 hour to remove the remaining methanol and traces of water, **Gadwal and Naik, 2014**. And then the final product of biodiesel stored for further use.

3.6 Properties Measurement of the Biodiesel

Specific gravity, kinematic viscosity, acid number, flash point, pour point, and water content properties of used cooking oil and biodiesel were determined by using various methods according to American Standard Test Methods (ASTM D6751).

3.6.1 Specific gravity (Sp.gr) (15 ° C)

Density is the weight of a unit volume of fluid while the specific gravity is the ratio of the weight of the same volume of the oil to the weight of the same volume of water, **Balat and Balat, 2008**. This property is usually measured at 15 ° C , **Mata et al., 2010**.

Specific gravity measurements were carried out using a pycnometer in accordance with ASTM D-941 standards. The specific gravity was calculated using Eq. (3).

$$Sp. gr = \frac{W3-W1}{W2-W1} \quad (3)$$

Where

W1= weight of empty pycnometer

W2= weight of pycnometer with water

W3= weight of pycnometer filled oil.

3.6.2 Kinematic viscosity

Kinematic viscosity is a measure of the resistive flow of a fluid under gravity, **Samuel et al., 2013**. Kinematic viscosity was measured for used cooking oil and biodiesel at 40 ° C, by measuring the time for a volume liquid to flow under gravity through U-Tube Viscometer in accordance with ASTM D-445.

3.6.3 Acid number

Acid Number is defined as the quantity of base, expressed in milligram of potassium hydroxide, that is required to neutralize all acidic (free fatty acid) constituents present in one gram of oil, **Fan et al., 2009**. It is determined for used cooking oil and biodiesel according to the ASTM D-664.

3.6.4 Flash point

The flash point of a fuel is the minimum temperature at which the fuel will ignite (flash) on application of an ignition source. Minimum flash point temperature is required for proper safety and handling of diesel fuel, **Samuel et al., 2013**. Flash point was determined by Pensky-Martens Closed Cup test until accordance with ASTM D-93.

3.6.5 Pour point

Pour point refers to the temperature at which the oil in solid form starts to pour, **Yap et al., 2011**. Pour point is useful in estimating the relative amount of wax in oil, **Balat and Balat, 2008**. It is determined in accordance with ASTM D- 97.

3.6.6 Water content

Water content for used cooking oil and biodiesel product was determined in accordance with ASTM D-2709.

4. RESULT AND DISSCUSIONS

4.1 Determination of Fatty Acid Composition

The fatty acid composition of used cooking oil was determined using gas chromatography (UNITED TECHNOLOGIES PACKARD) using a column SE-30, and flame ionization detector (FID). The initial column temperature 100°C , and then increased to 300°C at $10^{\circ}\text{C}/\text{minute}$. Injector temperature was 300°C and detector temperature was 325°C . The flow rates of gases helium He (carrier gas), the flow rate of carrier gas was 30 ml/minute this process was carried out in Ibn Sina Center. The fatty acid composition of used cooking oil determined using gas chromatography with flame ionization detector is shown in **table 3**, shows that the major fatty acid is stearic acid with mass concentration of 49.3065%.

4.2 Effect of Reaction Temperature on the Biodiesel Yield

Reaction temperatures were that used in this work from 30 to 60°C , the highest reaction temperature 60°C was selected because it is near the boiling point of methanol (64°C) with reaction time 40, 60, 80, 120 minutes. All experiences carried out at 40 minute of reaction time for different temperature to choose the best reaction temperature for different mole ratio.

Fig. 3, shows the biodiesel yield with reaction temperature and mole ratio of the transesterification reaction at 40 minute. The lower yield of biodiesel was 70.81 wt.% at the reaction temperature 30°C with 12:1 methanol to oil mole ratio. The best yield percentage was 90.185 wt% obtained using 60°C reaction temperature with 10:1 methanol to oil mole ratio. As shown in **Fig. 3**, the biodiesel yield increased with reaction temperature.

Higher reaction temperature increases the reaction rate and shortened the reaction time due to the reduction in viscosity of oils, increasing the temperature causes an increase in molecule activity. This means that more molecule have more energy; thus, the possibility of molecule to collision increased. Then consequently, higher conversion values that lead to increase in yield of product material are obtained. However, the increase reaction temperature beyond the optimal level (60°C) leads to decrease of biodiesel yield, because higher reaction temperature accelerates the saponification of triglycerides and causes methanol to vaporize resulting in decreased yield. And the transesterification reaction temperature should be below the boiling point of alcohol (methanol) to prevent the alcohol evaporation, if the temperature of reaction is high, methanol lend to evaporate faster and finally the reaction loses one of the important ingredients.

4.3 Effect of Reaction Time on the Biodiesel Yield

Fig.4 shows the biodiesel yield with reaction time and mole ratio. After choosing the best temperature for each mole ratio, the experiments were carried out at different times with the best temperature. The lower yield of biodiesel was 70.95 wt% at reaction time 120 minutes with 12:1 methanol to oil mole ratio. The best yield percentage was 91.68 wt.% obtained after 80 minutes reaction time with 10:1 methanol to oil mole ratio.

Biodiesel yield increased clearly from 40 to 80 minute. However, the reaction time was increased beyond 80 minute, the biodiesel yield was decreased. This behavior was clear at minute 120. Effect longer reaction time gives higher yield than using shorter time. So, 80 minute of reaction time gave a good result than other reaction times used here, in other words, the biodiesel yield increases with increasing the reaction time. However, based on the results, it shows that the biodiesel yields were lower when reaction time of 120 minute was used. This undesirable result may be due to the higher soap formation when longer reaction time was used. Thus, the rate of soap formation was also increased.

4.4 Effect of Catalyst Concentration on the Biodiesel Yield

The yield of biodiesel is also affected by the concentration of catalyst. The type and amount of catalyst required in the trans-esterification process usually depend on the level of free fatty acid and water content on oil, which is used to produce biodiesel, **Kumar et al., 2010**. Used cooking oil, which has been used in the present work, has low level of free fatty acid and water, alkali catalyst trans-esterification is suitable to be used, **Kumar et al., 2010**. Sodium hydroxide was used as alkali catalyst, because it is cheaper and is widely used, **Ma and Hanna, 1999**.

Fig. 5 shows the biodiesel yield with concentration of NaOH catalyst at different methanol to oil mole ratio. Four different catalyst percentages, 0.5, 1, 1.5, and 2 wt.% of sodium hydroxide, were selected for trans-esterification reaction. These percentages were weight fraction based on oil. The results show that the biodiesel yield decreases with increasing amount of catalyst from 0.5 to 2 wt.%. The best yield of biodiesel was achieved at 0.5 wt.% of NaOH catalyst at different methanol to oil mole ratio. The lower yield of biodiesel was 32.21% with 2 wt.% of NaOH catalyst, at 6:1 methanol to oil mole ratio and 60 °C. The best conditions of reaction temperature 60 °C, reaction time 80 minute, and methanol to oil mole ratio 10:1, the experimental carried out for 0.3 and 0.7 wt.%, when the catalyst was 0.3 wt.%, the yield of biodiesel was 89.09%, while at 0.7 wt.%, the yield of biodiesel was 86.7%. Increasing the catalyst concentration from 0.3 to 0.5 wt.% the biodiesel yield increased. Increasing the catalyst concentration from 0.7 to 2 wt.% the biodiesel yield decreased. Restricted according to the reaction level of NaOH in methanol if it above or not. The results showed that the best suited catalyst concentration giving the best yields and viscosities of the ester is 0.5 wt.% for higher values the yields were lower. Catalyst concentration is closely related to the free acidity of the oil. When there is free fatty acid content, the addition of more sodium hydroxide, compensates this acidity and avoids catalyst deactivation. The addition of an excessive amount of catalyst, however, giving rise to the formation of an emulsion, which increase the viscosity and leads to the formation of gels that because NaOH became above saturation in sodium methoxide solution. These hinder the glycerol separation and, hence, reduce the apparent ester yield. Increases in catalyst concentration will not increase the conversion and will lead to extra costs because it is necessary to remove it from the reaction medium at the end.

4.5 Effect of Methanol to Oil Mole Ratio on Biodiesel Yield

The mole ratio of alcohol to oil is most important factors that influence the conversion of oils to its ester. Theoretically, three moles of alcohol are required for each mole of triglyceride to produce three moles of biodiesel and one mole of glycerol. But since trans-esterification is a reversible reaction, excess amount of alcohol are used to ensure that oils will be completely converted to ester, **Anitha and Dawn, 2010**. In reality the mole ratio should be higher than the theoretical ratio to drive the reaction to completion.

Methanol was used as alcohol in this work, because of its low cost. Adding the methanol has an ability to react with triglycerides quickly and sodium hydroxide is easily dissolved in it, **Ahmed et al., 2009**.

Alcohol to oil mole ratio always has positive effect on biodiesel yield. Experiments were conducted with methanol to oil mole ratio of 6:1, 8:1, 10:1, and 12:1 using a constant mixing speed of 400 rpm. **Fig. 6** shows the increasing of biodiesel yield with temperature. The biodiesel yield increased as the mole ratio increased, with best results 90.182 wt.% being for a mole ratio 10:1 at 60 °C. nevertheless, a later increase of mole ratio to 12:1 did not result in an increase in the yield, at higher reactant ratio a large amount of alcohol is present in the trans esterified products, requires large amount of energy to distill the products, since a lower value is obtained 88.36 wt.%

Fig. 7 shows the evolution of biodiesel with catalyst concentration. The biodiesel yield increased as the methanol to oil mole ratio increased. As can be observed, with 6:1 methanol to oil mole ratio, the biodiesel yield was 85.58 wt.% at 0.5 wt.% of NaOH. While, the best results 91.684 wt.% being for a mole ratio 10:1. As shown in **Fig. 7**, increasing catalyst concentration from 0.5 to 2 wt.%, cause decreasing in biodiesel yield, but at a high methanol to oil mole ratio the decreases is lower. As can be observed the yield of biodiesel when the catalyst concentration increased from 0.5 to 2 wt.% with 6:1, the result decreased from 85.58 to 32.21 wt.%, while the biodiesel yield with 12:1 mole ratio decreased from 88.36 to 64.62 wt.% when NaOH concentration increased from 0.5 to 2 wt.%.

The higher alcohol to oil mole ratio interferes with the separation of glycerol because there is an increase of solubility of alcohol in glycerol. In addition, an excess of alcohol was able increase the conversion of di-monoglycerides, but there is possibility of recombination of esters and glycerol to form monoglycerides because of their high ratio and increasing during the course of the reaction, in other words the reactions conducted with low mole ratio. At the beginning ester yield increases with increase in mole ratio of methanol to oil but the incremental gain in ester yield decreases with increase in the mole ratio.

4.6 Selection of Best Operation Conditions and Effect of Mole Ratio on Physical Properties

The best operation conditions of the trans-esterification process to produce biodiesel from used cooking oil, which gives the higher yield of biodiesel were, 10:1 methanol to oil mole ratio, 60 °C reaction temperature, 80 minute reaction time and 0.5 wt.% of NaOH catalyst at constant stirring speed 400 rpm. The higher yield was achieved at these condition was 91.68 wt.%.

The used cooking oil and biodiesel were tested to determine the physical properties according to ASTM. **Table 4** shows the test result for used cooking oil and biodiesel product at 6:1, 8:1, 10:1, and 12:1 methanol to oil mole ratio. These physical properties depend on the practical parameters which used to produce biodiesel.

As shown in **Table 4** the kinematic viscosity of used cooking oil was 50.099 cSt. Kinematic viscosity is a very important property of a diesel fuel because it affects the engine fuel injection system predominantly at low temperature, **Balat and Balat, 2008**. The high viscosity may lead to poor atomization of the fuel, incomplete combustion, choking of the injectors, ring carbonization and accumulation of the fuel in the lubricating oils, one of the best way to avoid those problems and reduce the viscosity is trans-esterification process. After trans-esterification process the kinematic viscosity of biodiesel from 6:1, 8:1, 10:1, and 12:1 methanol to oil mole ratio were, 6.098, 6.098, 5.6, and 5.28 respectively. Hence, an increase in the methanol to oil mole ratio reduced the kinematic viscosity as shown in **Fig.8**. These results show that the value of kinematic viscosity of biodiesel were at the same range of ASTM standard (1.9 to 6) cSt, but these value are higher than value of diesel (2.6 cSt). So it is preferable to get biodiesel of low viscosity that can not cause any problems in fuel injection.

Specific gravity is another important property of the fuels that affects the fuel injection system. The specific gravity is measured at 15 °C for used cooking oil and biodiesel product at different methanol to oil mole ratio. The specific gravity of used cooking oil was 0.9276, and for biodiesel were, 0.887, 0.8776, 0.873, and 0.861 at 6:1, 8:1, 10:1, and 12:1 respectively of methanol to oil mole

ratio. It is note the value of specific gravity decreased after trans-esterification reaction, and it is decreased with increasing methanol to oil mole ratio as shown in **Fig.9**. The values of specific gravity were within the range of ASTM standard (0.86 to 0.9), which is higher than that of the petroleum diesel (0.85). So that the biodiesel produced has a good specific gravity.

The flash point for used cooking oil was 180 °C, while the flash point of biodiesel which produced at 6:1, 8:1, 10:1, and 12:1 methanol to oil mole ratio were 150, 166, 100, and 80 °C respectively, shown in **Fig.10**. Biodiesel have higher flash point than the petroleum diesel meaning that they are less flammable hence they are safer to handle and storage, though the flash point of biodiesel is high, still some storage precautions are needed to be taken. The flash point for each 6:1, 8:1, and 10:1 mole ratio are higher than diesel flash point, while the flash point of biodiesel at 12:1 mole ratio it's within the value of flash point of diesel as (50 to 80) °C, **Ahmed et al., 2009**.

Pour point refers to the temperature at which the oil in the solid form starts to pour or melt. In cases where the temperatures fall below the pour point, the entire fuel system including all fuel lines and fuel tank will need to be heated. Pour point for used cooking oil was -8 °C, while the pour point for biodiesel which produce at different methanol to oil mole ratio were, -6, -5, -8, and -10 at 6:1, 8:1, 10:1, and 12:1 respectively. The pour point of biodiesel is higher than pour point of petroleum diesel fuel.**Fig.11** shows the value of pour point at different methanol to oil mole ratio. These results of pour point of biodiesel were found to be agreement with ASTM biodiesel standard (-15 to 10) °C.

The water content in used cooking oil was 0.095% by volume. The presence of water in biodiesel can cause corrosion of metallic engine parts or produce soaps when it reacts with triglycerides. Water may also induce the formation of microorganisms, due to these negative effects. The ASTM standard limit for water content was 0.05% by volume of biodiesel, **Fan et al., 2009**. In this experimental, it was found that there was no water content in biodiesel produced from used cooking oil at different methanol to oil mole ratio.

Acid number is used as a guide in the quality control as well as monitoring oil degradation during storage. Acid number for used cooking oil was measured and it was found 1.04 mg KOH/g of oil. The ASTM standard for acid number for biodiesel is 0.8 mg KOH/g of oil. The acid number of biodiesel in this work as shown in **Fig.12** at 6:1, 8:1, 10:1, and 12:1 methanol to oil mole ratio were, 0.53, 0.5, 0.43, and 0.39 respectively, these results are positive character of biodiesel.

5. CONCLUSION

The biodiesel production from used cooking oil was affected by, methanol to oil mole ratio, temperature of reaction, reaction time and catalyst concentration, the following conclusions were obtained

1. At the gas chromatography analysis found the major fatty acid composition is Stearic acid with mass concentration of 49.3065%.
2. Biodiesel yield was increasing with temperature of reaction within the range of (30-60 °C).
3. Biodiesel yield was slightly affected by reaction time, it was increased when the reaction time increases from 40 to 80 minutes then the yield decreases beyond 80 minute of reaction time.
4. Increasing the methanol to oil mole ratio causes the yield to increase up to methanol to oil ratio of 10:1, then it will decrease beyond 10:1.
5. There was a negative effect of increasing sodium hydroxide concentration on the biodiesel yield.
6. The maximum yield of biodiesel produced by trans-esterification was 91.68 wt.% at the conditions methanol to oil mole ratio 10:1, reaction temperature 60 °C, 80 minute of reaction time and 0.5 wt.% based on oil of sodium hydroxide concentration.
7. The characterization results of biodiesel produced such as specific gravity, kinematic viscosity, acid number, flash point, pour point and water content at 10:1 methanol to oil mole ratio were 0.873, 5.6, 0.43mg KOH/g of oil, 100 °C, -8 °C and 0 respectively, they were within the range of ASTM D6751.

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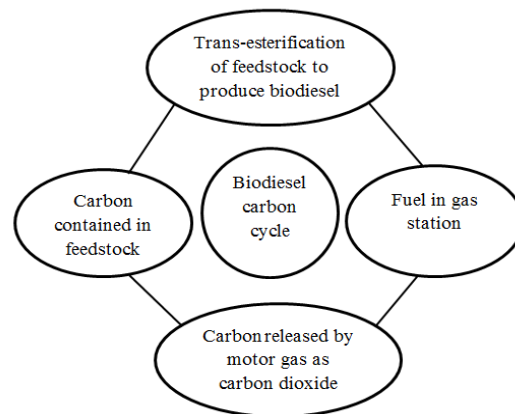


Figure 1. Biodiesel carbon cycle.



Figure 2. Equipment of trans-esterification Reaction.

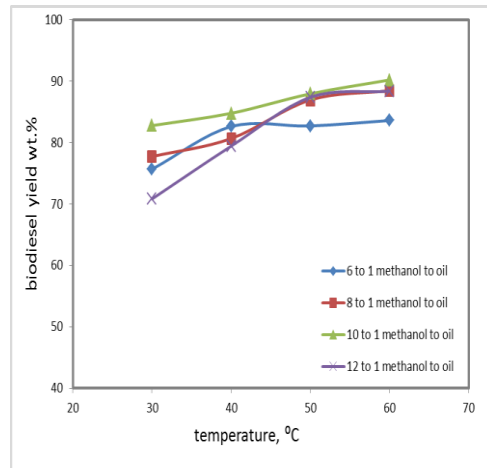


Figure 3. Effect of temperature on the biodiesel yield.

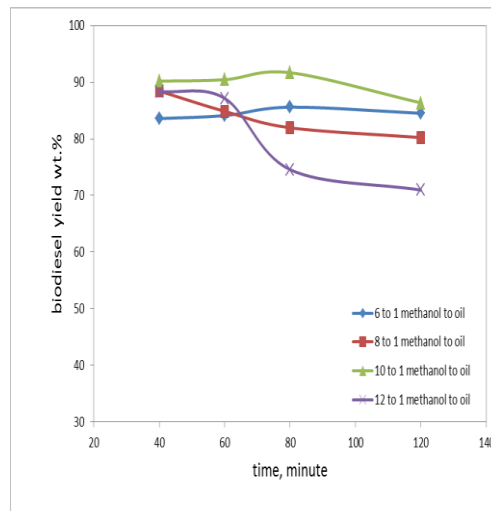


Figure 4. Effect of time on the biodiesel yield.

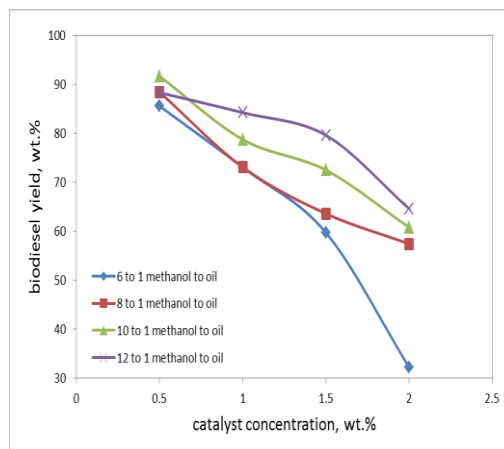


Figure 5. Effect of catalyst concentration on biodiesel yield.

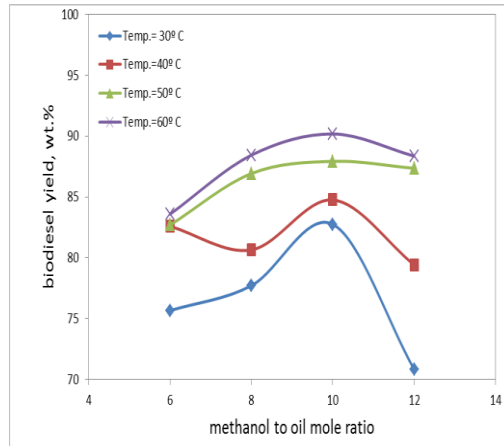


Figure 6. Effect of methanol to oil mole on biodiesel yield at different temperature.

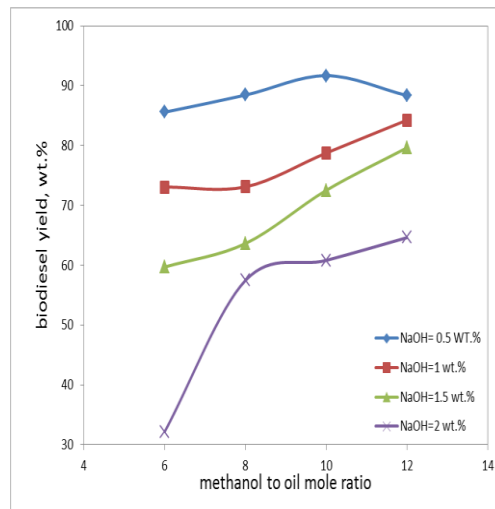


Figure 7. Effect of methanol to oil mole ratio biodiesel yield at different catalyst concentration.

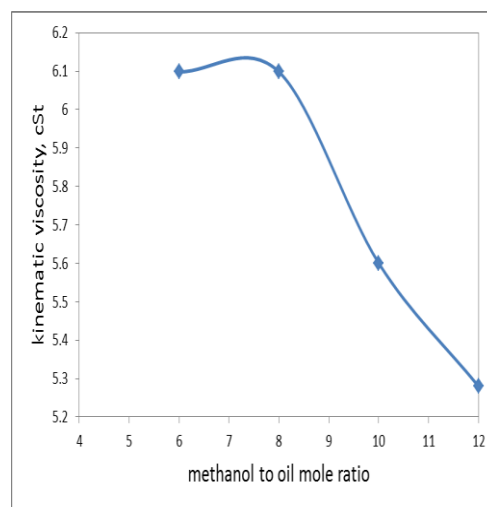


Figure 8. Kinematic viscosity of biodiesel at different methanol to oil mole ratio.

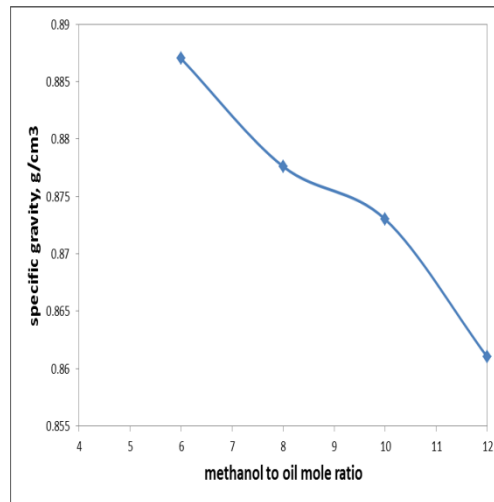


Figure 9. Specific gravity of biodiesel at different methanol to oil mole ratio.

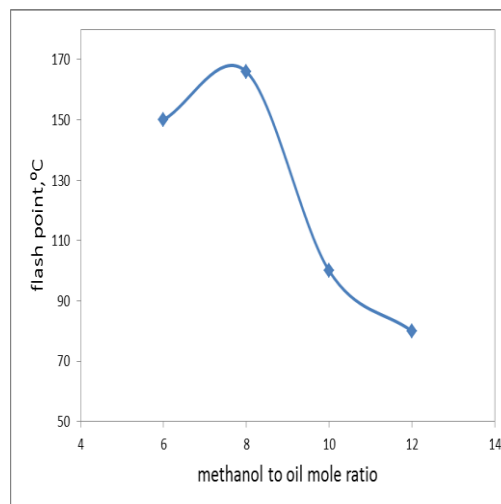


Figure 10. Flash point of biodiesel at different methanol to oil mole ratio.

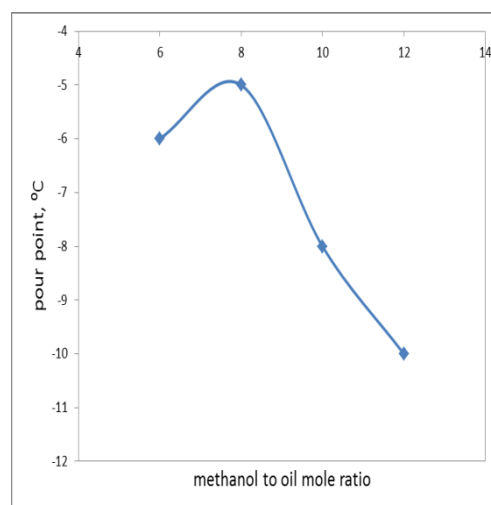


Figure 11. Pour point of biodiesel at different methanol to oil mole ratio.

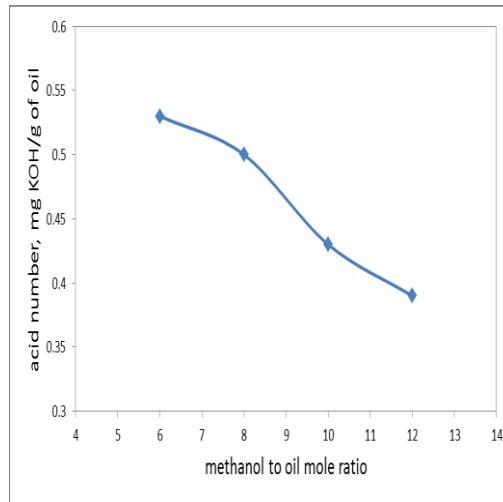


Figure 12. Acid value of biodiesel at different methanol to oil mole ratio.

Table 1. The materials used and their sources.

No	Materials	Sources
1	Used cooking oil	kitchen
2	Methanol (CH ₃ OH)	LOBAL Chemie (local market)
3	Sodium hydroxide pellets (NaOH)	LOBAL Chemie (local market)
4	Iso-propyl alcohol ((CH ₃) ₂ CHOH)	THOMAS BAKER
5	Phenolphthalein C ₂₀ H ₁₄ O ₄	THOMAS BAKER

Table 2. The Apparatus used and their sources or origin.

No	Name of equipment	Sources/ origin
1	Hotplate stirrer	DAIHAN LABTECH CO., LTD/ Lab Tech
2	Buchner funnel and filter flask	Germany
3	Reflux condenser	Germany
4	Mercury thermometer	Germany
5	Three-neck flask	Germany
6	Digital overhead stirrer	PHOENIX instrument RSO 20D
7	Electronic balance	KEREN (max 320g)
8	Separation funnel	ISOLAB/ Germany

Table 3. Fatty acid composition of used cooking oil.

Common Name	C: D	Retention Time, minute	Mass concentration %
Palmitic acid	C _{16:0}	13.103	6.1262
Stearic acid	C _{18:0}	15.287	49.3065
Oleic acid	C _{18:1}	16.655	1.1993
Linoleic acid	C _{18:2}	14.24	0.0228

M.Wav

881.454g/mol

C= Carbon atoms, D= Double bond

M.Wav= Average Molecule Weight.

Table 4. Shows the physical property of the used cooking oil and biodiesel.

Physical property	Used				
	cooking oil	6:1	8:1	10:1	12:1
Specific gravity (g/cm ³)	0.9276	0.887	0.877	0.873	0.861
Kinematic viscosity ,cSt	50.099	6.098	6.098	5.6	5.28
Flash point , °C	180	150	166	100	80
Pour point, °C	-8	-6	-5	-8	-10
Water content, Vol%	0.095%	0	0	0	0
Acid number, mg KOH/g of oil	1.04	0.53	0.5	0.43	0.39