

Experimental Investigation of Basic Properties Biodiesel Fuels (B100, B20, B5) Produced from Waste Cooking Oil (WCO) Using Trans-Esterification Process

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Abstract: Rising fuel price, depletion of traditional energy reserves and environmental issues are the main drivers for production of biodiesel from alternative resources such as (WCO), it has become more attractive to researchers in recent time. This study aims to convert Waste Cooking Oil (WCO) to biodiesel by esterification and trans-esterification processes using potassium hydroxide as a catalyst and to determine its essential properties. The study found out that the physical properties of biodiesel (B100) derived from WCO meet the required American Society for Testing and Materials (ASTM) standard specifically for biodiesel (ASTM D6751). In addition, both blended fuels B5, and B20 met the ASTM D7467 standard. The results showed that the density range from 884.3 -850.5 Kg/m³, and viscosity values at 40°C range from 5.92-3.67 mm²/s, the cloud point range from 0-5°C, while the flashpoints take the range from 192-68°C for the three fuels (B100, B20, B5), also the gross specific energy values are from 39.803-45.412 KJ/Kg, the cetane number range from 51.2-57.8 for the three fuels. The GC-MS analysis of biodiesel shows that the main fatty acid methyl esters are Palmitic, Stearic, Linoleic, and Oleic with other fatty acids. The produced biodiesel is sustainable, less toxic, has higher lubricity and a higher oxygen content than petroleum diesel. It can be used mainly as a fuel in many applications as in CI engines, boilers for generation of electricity and producing heat.

Keywords: - Bioenergy, Biodiesel, B100, B20, B5, WCO, Esterification, Trans-esterification, Fatty Acid.

1. Introduction

Several economic and environmental factors act for converting Waste Cooking Oil (WCO) into an alternative fuel such as increasing demand of traditional fuel sources leads to depletion of fossil fuel recourse during the coming decades, high prices, and negative effects on the environment resulting from fossil fuel emissions like air pollution and Greenhouse Gas (GHG) [1]. In addition, recycling WCO is harmful to health, and disposal of waste is not environmentally friendly. Hence, it is essential to search for a sustainable alternative fuel source like biodiesel derived from used vegetable oils or animal fats that are environmentally friendly, especially in the transportation sector, representing more than 61% of fossil fuel consumption [2-4].

The use of virgin vegetable oils has a high cost of raw materials; nearly 70-95% of the total production cost of biodiesel is related to the cost of raw materials. In contrast, using non-edible oil like WCO as a raw material can effectively reduce the feedstock cost to 60-70%. Therefore, the use of WCO as a feedstock with bases like Potassium Hydroxide(KOH) and Sodium Hydroxide (NaOH) as a catalyst added to alcohol in trans-esterification process, it has been widely spread because of its availability, low price and high rate reaction [5, 6]. In addition, extensive use of edible oils to produce biodiesel may raise ethical concerns that cause starvation in developing countries [7]. Also, the use of edible oils are unlikely to be sustainable in the longer term due to the impacts of land use, and its price. Now the researchers turn to use WCO as a secondary raw material, which gives additional advantages by reducing disposal concerns or pollution problems like water and soil pollution [8].

For example, 1 liter of WCO can contaminate 1000 liters of water; it decreases in drainage performance and increases energy consumption (estimated at 25%) in wastewater treatment [9], especially when there is a lot amount of WCO, for example, in Jordan the amount of WCO about 320 million liters/year [10].

The general properties of biodiesel are in some cases close to petroleum diesel fuel, but the process of mixing them has a positive impact on the properties of the fuel, such as flash point, pour point, cetane number, viscosity, and exhaust emissions.[33] Therefore, it can be used in operating engines without further modification [7, 11]. Biodiesel can be blended easily with petroleum

diesel in any proportions for running a diesel engine [12].

In Jordan, the transportation sector alone is responsible for 49 % of final energy consumption in 2018. This sector will remain the main energy consumer. It is predicted to increase to 53.4% by 2030 [13], so it is important to find alternative and renewable transportation fuels in biodiesel, bioethanol, biogas, etc. Recent studies reported that renewable sources would cover 50 % of the total energy demands by 2050, while in 2100, the contribution of renewable energy sources in different sectors will reach 80% [13].

In the biodiesel production field, the most common method used is the trans-esterification process (alcoholysis) which can be defined as the reaction of vegetable oil or animal fats with alcohol (from C₁ to C₄). These alcohols react quickly with triglycerides in the presence of strong alkaline catalysts like sodium hydroxide or potassium hydroxide in less reaction time and at atmospheric pressure with reasonable reaction temperature with a high level of conversion to form esters at low cost and good quality product [5]. Generally, 3:1 molar ratio of oils and alcohol are used in the trans-esterification process, as shown in Figure 1[14].

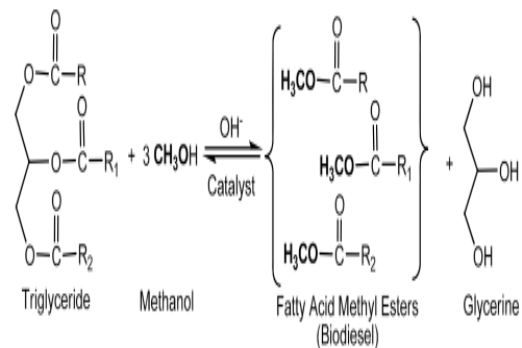


Figure 1: Trans-esterification of triglycerides with MeOH to Fatty Acids Methyl Esters in the presence of catalysts

Many researchers studied most effective parameters and methods to get biodiesel from WCO like [6, 9, 15-19]. Recently, Degfe et al. [20], Devaraj et al [21]. While other researchers studied the emissions of biodiesel and blend fuels like Qi et al. [22], Abu-Jrai et al. [23], Adaileh et al.[24], Sinha et al. [25].

2. Chemical Materials

The following chemical materials have been used in the experiments: Methanol (CH_3OH) (99.5% purity), Ethanol ($\text{CH}_3\text{CH}_2\text{OH}$) (99.9% purity) from, Potassium Hydroxide (KOH) (90% purity), Sulphuric Acid (H_2SO_4) (95-97% purity), Distilled Water, Phenolphthalein (PhPh), Acetic Acid (CH_3COOH) (99.85% acidity) Petroleum Diesel, WCO feedstock (sunflower and corn) from Wadi Mousa city restaurants in Jordan.

3. Equipment and Apparatus

The main equipment and apparatus required for the laboratory scale production of biodiesel are Hot plate magnetic stirrer, Condenser, Separating funnel, Round bottom flask, Thermometer, Stand for separating funnel and condenser, ring for separating funnel, Weighing balance, Beakers, Volumetric flask, Burette, Erlenmeyer flask.

4. Method

The mixing vegetable oil (sunflower, corn) WCO was collected from different restaurants in Wadi Mousa city, and the conversion process conclude with different steps as seen in the following Figure 2.

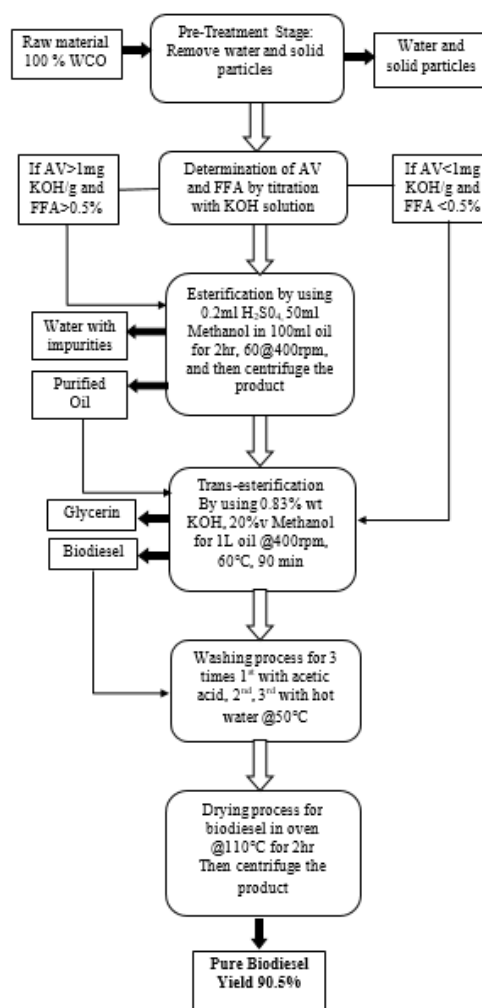


Figure 2: Conversion process of WCO

4.1 Pre-Treatment Stage

The first step in the pre-treatment stage is started by leaving the sample for 24-hour gravity separation, also called (settling). This separation step allows solid particles and water to settle to the bottom, since their density more than the oil, after that the water and solids can be drained off, leaving only the oil feedstock behind. While there were little amounts of water and some small insoluble impurities in the oil that must be removed by filtering process through passing it to a cotton cloth to remove all them and heated the oil at 110°C to remove moisture content [19].

4.2 Determination of AV and FFA contents by titration

WCO is used many times in the frying process. Therefore, the amount of Free Fatty Acid(FFA) must be measured for the oil sample because during the frying, the amount of heat and the moisture

content of oil increase the oxidation and hydrolysis of triglycerides lead to increase FFA content then change chemical and physical properties of the oil [26]. Since the FFA in high percent value in the waste oil will be considered a severe bottleneck for the process of trans-esterification, it must be less than 0.5% to avoid the side reaction (soap form), which causes a reduction in the percentage yield.

The titration process takes place for the determination of Acid Value (AV) and FFA content, 1 ml of WCO, 10 mL ethanol, and two drops of phenolphthalein indicator are used, then the titration with KOH solution was done until the color change to the pink. the next two equations Eq.(1) and Eq.(2) used to calculate these values [27].

$$AV = \frac{MW(KOH) \cdot V(\text{from titration}) \cdot N(KOH)}{m_{\text{oil}}} \quad (1)$$

Where V is the volume of KOH (ml), N is the normality of KOH (mol/L), m is the mass of sample (g), and MW is the molecular weight of KOH =56.1g/mol.

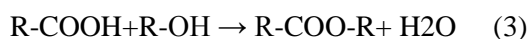
The FFA can be calculated by using Eq. (2)

$$FFA (\%) = 0.503 \cdot AV \quad (2)$$

Thus, AV=6.49 mg KOH /g oil, and FFA=3.27%

4.3 Esterification

The mechanism of esterification reaction occurs as seen in Eq. (3) [28]



The esterification reaction occurs in a 500 ml reaction flask with a magnetic stirrer, a condenser, and thermometer; 0.2 ml Sulphuric Acid was dissolved in 50 ml Methanol. Then 100 ml of the oil was introduced into the reaction flask, which was put at the stirring hot plate, until the temperature reached 60°C, the sulphuric acid that dissolved in Methanol was added, and the mixture was continuously stirred at 400 rpm for 2 h with a temperature not more than 60°C. The mixture was transferred to a separating funnel and it was allowed to stand for 24 hours. The oil settled in the lower layer, containing dissolved methanol in the oil phase and moisture. The mixture was centrifuged

and dried at a temperature of 110°C to remove the dissolved methanol, and water by evaporation. At the same time, the upper layer contained water that produced from esterification reaction, excess Methanol, and Sulphuric Acid [29]. After the process is completed, the AV, FFA were calculated again by titration process. The results of the second round of titration are presented as seen in Table 1.

Table 1: The value of AV and FFA before and after esterification

Treatment	AV(mg KOH /g oil)	FFA%
Before Esterification	6.49	3.27
After Esterification	1.34	0.67

The previous value of FFA (0.67%) is slightly higher than 0.50% but can be accepted so that the trans-esterification process can be done.

4.4 Trans-esterification

The optimal condition in this process must be determined to increase the percentage yield of produced biodiesel so the amount of catalyst used in the trans-esterification process can be done by the titration process. The titration solution was prepared by adding 1 gram of Potassium Hydroxide (KOH) to 1 liter of distilled water in a small beaker and stirring the solution well until all of the catalysts are dissolved. 1 ml of WCO has added to 10 ml of Ethanol, and it was stirred well by using stirring magnetic plate to get a homogeneous mixture. Two drops of Phenolphthalein were added as an indicator to the mixture. KOH solution was poured drop by drop by a burette to the mixture until it turns the color into a pink solution and the color stay for 20 sec at least this process was repeated for three times, then the average volume was recorded. The amount of catalyst used can be determined from the volume of titration, which is added to the amount of catalyst that gives 0% FFA contents KOH required per 1-liter oil is 7g. From the purity of KOH, which is 90% pure, the extra amount will be required is $7/0.90=7.8g$ [18]. In addition, the oil was titrated with KOH solution and need 1.5ml. So additional amount of KOH needed to complete the process is $=1.5+7.8=9.3g$. This is equal to 0.83 wt%, and 200

ml Methanol is required for 1-liter waste cooking oil (The volume of Methanol used 20% of the volume of waste cooking oil). For proceeding transesterification reaction, Methoxide was prepared by adding 9.3g of KOH to 200 ml of Methanol and mixing well for 30min by using stirring plate until all of the catalyst completely dissolved in the Methanol.

Then the Methoxide solution was added to 1 liter of hot WCO (60°C) in an Erlenmeyer flask and was put on the stirring hot plate at the rate of 400 rpm for 1 hour and a half as many researchers found that is the best stirring speed and reaction time at a temperature range between 60-65°C (temperature must not be more than the methanol boiling point). After mixing, the mixture was left in a warm place for 24 hours for phase separation. In phase separation, the biodiesel was separated from the glycerol phase. Glycerol is heavier than biodiesel, so it was settled down at the bottom due to gravity. While, the biodiesel is at the top of the Separation funnel that is used to drain the glycerol from biodiesel.

4.5 Purification process (washing process and drying process)

The produced biodiesel contains suspended particles and impurities like the unreacted catalyst and unreacted alcohol that are usually not significant and affect the biodiesel quality (physical-chemical properties). The washing of biodiesel was carried out in two ways: washing with acetic acid and then washing with hot distilled water. Adding acetic acid at the first washing time is the best solution, and it will work well to keep the soap from forming between oil and water. For this purpose, 0.5 liters of acetic acid was added to the biodiesel to ensure the impurities settle down with it. The other two times, with distilled water at temperature 50°C, followed by drying it in the oven at temperature 110°C for 2 hours, and then centrifuge the product at 6000 rpm for 20 min. After that, the percentage yield was calculated by using the following [30].

$$Yield\% \left[\frac{\text{Amount of biodiesel produced}}{\text{Amount of oil used}} \times 100 \right] \quad (4)$$

The approximated value of the yield was about =90.5%.

4.6 The 3-27 Test for Biodiesel

The 3-27 conversion test is a qualitative test, which will be done to make sure that the reaction with alcohol is completed. By adding 3 ml of biodiesel to 27 ml of Methanol at 25°C (room temperature) mix and shake them well, then left the solution for 15 min if any things settles in the bottom or if any spots of oil appear at the top of beaker the test is failed. This means that the amount of catalyst used is not enough. The test will pass when biodiesel completely dissolves in the Methanol, or little cloudy color appears with no precipitation in the bottom [21]. Then the AV and FFA will be measured again by titration process to explore if it is around the acceptable range or not. The results showed that their values are AV=0.57 mg KOH /g oil, FFA=0.29%.

After that, the three samples were prepared B100 (pure biodiesel), B5 (5% biodiesel, 95% petroleum diesel), B20 (20% biodiesel, 80% petroleum diesel) by volume (The blending of biodiesel with petroleum diesel by volume is completely miscible). Then several tests were conducted for the three biodiesel samples to investigate its physical properties and determine if their properties met both ASTM D6751 and EN14214 standards to check the quality.

5. Results

The physical properties of the three fuel samples, and commercial petroleum diesel in terms of density, viscosity, flash point, cloud point, heating value, and Cetane Number, are summarized in Table 2.

Table 2: Physical properties of the three fuel samples and commercial petroleum diesel

Physical Properties	Biodiesel Type			
	B100	B20	B5	Petroleum Diesel
Density at 15 °C (Kg/m ³)	884.3	856.2	850.5	835.1
Kinematic Viscosity at 40°C (mm ² /s)	5.92	4.14	3.67	3.31
Kinematic Viscosity at 100°C (mm ² /s)	2.12	1.5	1.41	1.14
Viscosity index (VI)	193.5	100.8	131.9	12.51
Flash Point (°C)±0.1°C	7	9	8	68
Cloud Point(°C)±0.1°C	192	70	68	68
Heating Value (gross specific energy) (MJ/Kg)	5	1	0	-3
Cetane Number	39.80	44.93	45.41	45.62-46.48
	3	6	2	
	51.2	53.6	57.8	Min 51

It is essential to mention biodiesel fuel standards EN14214 (European Union), which determine some of the physical properties ranges for biodiesel (B100) in Table 3.

Table 3: European Committee for Standardization EN 14214 biodiesel fuel standard [31].

Property	Test method	Limits	Units
Acid Value	EN 14104	0.5 max	mg KOH/g
Density, 15°C	EN 3675, ISO 12185	860-900	Kg/m ³
Kinematic viscosity, 40°C	EN 3104, ISO 3105	3.5-5	mm ² /s
Flashpoint	EN 3679	120 min	°C
Cloud point	EN23015	Max 16	°C

Cetane number	EN 5165	ISO 51 min	-
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The following Table 4 determines the ASTM D7467 biodiesel – petroleum diesel blend (B6-B20) fuel standard.

Table 4: ASTM D7467 biodiesel – petroleum diesel blend (B6-B20) fuel standard [31].

Property	Test method	Limits	Units
Biodiesel content	ASTM D7371	6-20	% volume
Acid Value(AV)	ASTM D664	0.3 max	mg KOH/g
Kinematic viscosity, 40°C	ASTM D445	1.9-4.1	mm ² /s
Flashpoint	ASTM D93	52 min	°C
Cetane number (CN)	ASTM D613	40 min	-

The physical properties of biodiesel (B100) based on ASTM D6751 are summarized in Table 5.

Table 5: ASTM D6751 physical properties of biodiesel (B100) fuel standard [19].

Property	Test method	Limits	Units
Density, 15°C	ASTM D1298,	860-900	Kg/m ³
Kinematic viscosity, 40°C	ASTM D445	1.9-6.0	mm ² /s
Cloud point	ASTM D 2500	-3to 12	°C
Flash point	ASTM D93	>130	°C
Cetane number	ASTM D613	≥47	-
Heating Value	ASTM D240	> 35	MJ/Kg

5.1 Chemical Analysis:

GC-MS was used to determine the chemical composition of produced biodiesel, indicate the type of fatty acid methyl ester in it, and determine

saturation and unsaturation composition. The results are summarized in Table 6.

Table 6: Fatty Acid methyl ester composition in the biodiesel

Name of fatty acid	Carbon chain (structure)	Formula	Fatty acid methyl ester	Formula	Molecular Weight (Kg/mole)
Myristic	C14:0	C ₁₄ H ₂₈ O ₂	Methyl Myristate	C ₁₅ H ₃₀ O ₂	242.4
Palmitic	C16:0	C ₁₆ H ₃₂ O ₂	Methyl Palmitate	C ₁₇ H ₃₄ O ₂	270.46
Palmitoleic	C16:1	C ₁₆ H ₃₀ O ₂	Methyl Palmitoleic	C ₁₇ H ₃₂ O ₂	268.44
Stearic	C18:0	C ₁₈ H ₃₆ O ₂	Methyl Stearate	C ₁₉ H ₃₈ O ₂	298.51
Oleic	C18:1	C ₁₈ H ₃₄ O ₂	Methyl Oleate	C ₁₉ H ₃₆ O ₂	296.50
Linoleic	C18:2	C ₁₈ H ₃₂ O ₂	Methyl Linoleate	C ₁₉ H ₃₄ O ₂	294.48
Arachidic	C20:0	C ₂₀ H ₄₀ O ₂	Methyl Arachidate	C ₂₁ H ₄₂ O ₂	326.57

From the previous results it is clearly seen that the conversion of WCO to biodiesel was successfully performed in the lab using a homogeneous basic catalyst trans-esterification process with (20% V) Methanol to oil ratio and (0.83% wt) of KOH as a catalyst at 60°C, at a stirring speed of 400 rpm for 90 min reaction time. As a result, a percentage yield is (90.5%), which is an acceptable percentage for the WCO conversion. The produced biodiesel can be blended with petroleum diesel in any proportion because it is completely miscible. However, ASTM D975 and D7467 only allow up to 5vol% and 20vol% of biodiesel to be blended with petroleum diesel [31]. Biodiesel and petroleum diesel are not chemically similar. Biodiesel is long-chain of at least 96.5% fatty acid alkyl ester (FAAE) from carbon range from C12 to C24 with saturation and unsaturation components [32]. While in the current study, the fatty acid methyl ester ranges derived from a fatty acid that has carbon range (C₁₄-C₂₀) with saturation composition of Myristic (C14:0), Palmitic (C16:0), Stearic (C18:0), Arachidic (C20:0), and unsaturation composition with one double bond Palmitoleic (C16:1) and Oleic (C18:1) and linoleic (C18:2) which is another unsaturation component that have two double bond. The oleic fatty acid is the main fatty acid in the produced biodiesel that has more than 53%, so FFA in the produced biodiesel can be represented as in grams of oleic acid.

It is important to say that the fatty acid compositions depend on feedstock. They are affected by factors such as soil type, plant health, climatic conditions, and plant maturity upon harvest. In addition, this

chemical composition will affect the physical properties of biodiesel, such as CN, which depends on the fatty acid composition of biodiesel. The longer the fatty acid carbon chains and the more saturated molecules, the higher the cetane number [7].

As shown in the previous results in Table 2, the kinematic viscosity of biodiesel is (5.92 mm²/s) at 40°C, which is in the range of ASTM D445, indicating the range from 1.9 to 6 mm²/s. However, this value is more than the value determined by EN ISO 3104, EN ISO 3105, which indicates the range must be from 3.5 to 5 mm²/s. Then, the kinematic viscosity value for the fuel petroleum diesel is 3.31 mm²/s at the same temperature. The values at 40°C for B5, and B20 are (3.67 mm²/s) and (4.14 mm²/s) respectively, which are in the range that determined from ASTM D445 for blend ratio from B6-B20 that indicate the value of kinematic viscosity will be from 1.9 to 4.1 mm²/s at 40 °C. It was seen that the kinematic viscosity values for B5 and B20 are less than the value of the B100 and more than the value of petroleum diesel. When the kinematic viscosity was measured at temperature 100°C for B100, the value is (2.12 mm²/s), and it is still slightly higher than the value of petroleum diesel (1.14 mm²/s) at the same temperature. Based on the previous results, the difference between the two values for B100 and petroleum diesel at 100°C is less than the difference at 40°C. When blend with petroleum diesel increased, it was clear that the kinematic viscosity decreased for B5 and B20 (1.41 mm²/s, 1.5 mm²/s) at 100°C.

On the other hand, the viscosity index values of B100, B20, and B5 are 193.57, 100.89, and 131.98, respectively. While it is 12.51 for petroleum diesel which is low value. This difference is due to the chemical composition difference between the fuels (complex molecules have a high viscosity index than the straight chain). The values can be classified as B20 is high, the others are very high, and the value for B100 is the highest one. This means that B100 is more stable viscosity under fluctuation temperature. So the lower VI, the more the viscosity is affected by the changes in temperature. Therefore, B20 is highly affected in viscosity by changes in temperature than other fuels, after petroleum diesel.

The density of B100 at 15°C is more than the density for both B5 and B20, which is equal (884.3 kg/m³) and this value is in the range of both ASTM D1298 and EN ISO3675, EN ISO 12185 standard that determined the density between (860-900 kg/m³). This is because the chemical composition of B100 is different from blends fuel (B5, B20) and petroleum diesel, which has low density than B100. The density of B5 is equal to 850.5 kg/m³, which is closer to the petroleum diesel density that equal 835.1 kg/m³, and that value is acceptable because the amount of petroleum diesel in this fuel is 95%. While biodiesel is, 5% and this will give density close to the petroleum diesel. However, an increasing percentage of biodiesel will increase fuel density, so B20 density reach (856.2 kg/m³).

Regarding the values of the cloud point, it can be clear that B100 has more cloud point (5°C) than B5 and B20 that are (0°C and 1°C) respectively. These values are in the range of the ASTM D2500 value that determined the range from -3°C to 12°C, while the value of cloud point for petroleum diesel is close to (-3°C). It may be said that when the fuel has a high density, it has a high cloud point due to the increase in carbon content in the fuel.

The current study found out that the flash point for B100 was (192°C), which is in the range of the ASTM D93 standard that determined it (more than 130°C) While the value for blended samples with petroleum diesel is decreased to (70°C) for B20, and (68°C) for B5 which is in the range of ASTM D93 standard that determined it (more than 52°C) for blends. These results confirmed that the value of flashpoint for the blends is very close to the flashpoint for petroleum diesel (68°C), this means that the blend with the specific ratio B5 and B20 has no clear effect on the petroleum diesel flash point, WCO biodiesel recorded the value of gross calorific value to be 39.803 MJ/kg, which is lower than the petroleum diesel value that take range (45.62-46.48 MJ/kg). This value is acceptable since it is within the standard recommended range for ASTM that must be >35 MJ/kg. While the heating value of B5= 45.412 MJ/kg, B20= 44.936 MJ/kg. It is clearly seen that when the amount of blend with petroleum diesel increases, the heating value is increasing, so B5 has more value than B20 that is because petroleum diesel has a high gross calorific value, and due to the different in chemical composition since B5 has more amount of a mixture of naphthene and aromatic types of hydrocarbon compounds that comes from petroleum diesel,

while B20 has more amount of oxygenated hydrocarbon that comes from biodiesel [33].

Regarding the final fuel properties CN, it is seen that the value of B100 is 51.2, which is in the range determines from ASTM D613 that indicates the acceptable value is equal or more than 47. While EN ISO 5165 determines that the cetane number must be at min 51. It is seen that the study value is also acceptable in the EN standard. The cetane number value for B5 is 57.8, B20 is 53.6, and these two values are in the ASTM D613 range that indicates the acceptable value minimum is 40. The cetane number for petroleum diesel is must be 51 at minimum. Therefore, the CN value will increase in the blend fuel when the amount of blends with petroleum diesel increases.

Finally, the current study confirmed that the physical properties for biodiesel (B100) based on the current work are consist with the previous studies as seen in Table 7.

Table 7: Summary of the physical properties for biodiesel (B100)

Study	Density (ρ) Kg/m ³	Kinematic Viscosity (ν = μ/ρ) @40°C mm ² /Sec (cSt)	Flash Point °C	Cloud Point °C	Cetane Number	Heating Value (MJ)/Kg
The current work	884.3@15°C	5.92	192	5	51.2	HHV=39.803
Al-Hasan [16]	886.8@20°C	4.683	178	7	48.32	LHV=37.64
Banihani [6]	860@15°C	7.8	135	5	49 (cetane index)	-
Aworanti et al. [30]	863@32°C	4.1	164	-	-	-
Sahar et al. [19]	874@15°C	5.83	-	10.5	51.48	37.2
Devaraj et al. [21]	893@30°C	3	150	3	-	-

6. Conclusions

- The value of FFA must be determined before the trans-esterification process is done since the number of frying increases its value.
- The produced biodiesel has some different physical properties from petroleum diesel due to the difference in chemical composition.
- Biodiesel has higher density, viscosity, flash point, and cloud point than petroleum diesel.
- Biodiesel has the lowest gross specific energy value.
- The CN value for biodiesel is less than the values for both B5 and B20 blends fuel.

- Blends B5, B20 give different physical properties from both biodiesel and petroleum diesel, but their properties are still in the standard range for ASTM 7467.
- The high viscosity problem of the biodiesel fuel B100 can be solved by increasing the amount of petroleum diesel blends with biodiesel. Consequently, this will solve the high-density problem, cold flow properties like cloud point, and increase the heating value.

7. Limitations and Recommendations

One of the main limitations of this study that didn't measure some of physical properties of produced biodiesel, and blend fuels like (copper corrosion, total sulfur content, carbon residue) because the devices are not available for the researchers. In addition, the investigations of performance and emissions of internal combustion in diesel engine were not able to be measured because the diesel engine is not available for the researchers.

This study recommended the following points:

1. The researchers may try to prepare different percentage blend biodiesel with petroleum diesel to make a clear picture about the differences in the physical properties of these blends.
2. The researchers recommend studying more physical properties for biodiesel.
3. This study recommends investigating the performance and emissions of internal combustion in diesel engine also to study the effect of used biodiesel in noise, level sound, vibration occurrence on the engine.
4. More work must be conducted for monitoring and maintaining biodiesel quality against degradation during long-term storage.

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