

Production and Characterization of Biodiesel from Recycled wasted Cooking Oil collected from some Libyan restaurants.

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Abstract

The global energy crisis and the environmental impact of fossil fuel use have accelerated the search for renewable alternatives. This study focuses on producing biodiesel from recycled used cooking oil (UCO) through transesterification using methanol and ethanol with potassium hydroxide (KOH) as a catalyst. Different concentrations of KOH (1.5%, 2.5%, and 3.5%) were tested to optimize yield and quality. Physical and chemical properties such as density, viscosity, flash point, free fatty acid content, and moisture were analyzed according to ASTM standards. The results demonstrated that sunflower oil produced the best biodiesel yield and quality, while corn oil produced satisfactory results, and palm oil exhibited poor conversion due to high free fatty acid content. Ethanol-based reactions generally yielded biodiesel with higher clarity and stability. This research confirms that recycling used cooking oil into biodiesel offers an environmentally friendly and sustainable solution to waste management and renewable energy production.

Keywords

Biodiesel; Used Cooking Oil; Transesterification; Methanol; Ethanol; Renewable Energy.

1. Introduction

With the ever-increasing energy demands across the globe and depletion of the existing fossil fuel energy resources, the need for renewable and sustainable energy sources has intensified. One of the alternative fuels that have been considered is biodiesel since it offers several benefits including being biodegradable, non-toxic, and having fewer emission problems when compared to traditional diesel fuel (Jihad, 2024).

As per Awad et al., biodiesel refers to mono-alkyl esters made from long chain fatty acids using renewable lipid feedstock materials such as vegetable oils, animal fats, and used frying oils. Of all the sources available, WCO has received a great deal of interest due to its cheapness and availability. The use of WCO helps reduce the cost of production of biodiesel and also helps avoid pollution associated with the improper disposal of used oils (López et al., 2015). In addition, it helps avoid the issue of competition between food oils and biodiesel production (López et al., 2015). Transesterification is the predominant technique used in biodiesel production, where triglycerides react with an alcohol (methanol) in the presence of a catalyst to produce biodiesel (fatty acid methyl esters) and glycerin as a byproduct (Shunaia & Jazie, 2023).

Several factors affect the efficiency of the transesterification process, including the mole ratio between the alcohol and oil, the amount of the catalyst used, the reaction temperature, and the duration of the reaction (Awad et al., 2024).

As such, this investigation will be directed towards the synthesis and analysis of biodiesel obtained from waste cooking oil retrieved from selected Libyan restaurants. The objective is to assess the effectiveness of the transesterification reaction and also to investigate the physical and chemical attributes like density, viscosity, and acid number for evaluating the potential use of the biodiesel as diesel fuel. Biodiesel production is relatively new in Libya, which heavily relies on fossil fuels and requires sustainable energy sources. Prior studies in Libya have considered alternative raw materials such as jojoba oil; nevertheless, waste cooking oil has been poorly exploited (Altaher & Abdulla, 2019).

In view of the large amounts of used cooking oil produced by the restaurants in Libyan cities, biodiesel production from this raw material would be highly effective for both waste utilization and energy generation.

2. Materials and Methods

Used cooking oil was collected from some Libyan restaurants (sun flower, palm, corn) filtered, and pre-treated to remove moisture and impurities. Transesterification reactions were conducted using methanol and ethanol separately, with catalyst concentrations of 1.5%, 2.5%, and 3.5% by weight of oil. The reaction mixtures were maintained at 60°C and stirred continuously for 15 minutes. After separation and purification, the biodiesel was characterized for density, viscosity, free fatty acid (FFA) content, flash point, pH, moisture, and soap content.

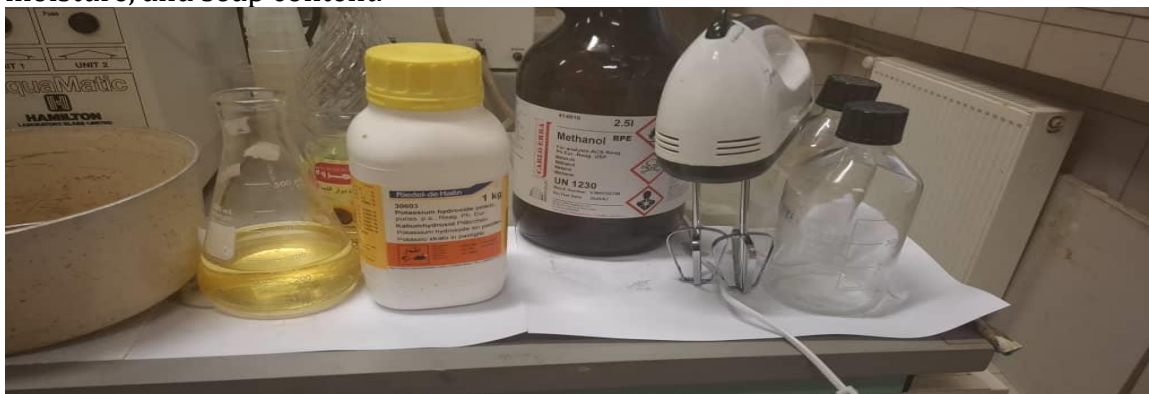


Figure (1) Materials and equipment: Produce biodiesel

3. Results and Discussion

3.1. Produce biodiesel by using methanol:

3.1.1. The results below show

biodiesel made from different types of oil when Koh 1.5% of oil weight, the methanol ratio is 1:5 of oil weight = 50ml:

Table (1) Biodiesel made from methanol when Koh 1.5%

Type of oil	Weight of oil in(gm.)	Biodiesel in(ml)	Glycerol in (ml)
corn	214	250	45
Sunflower	218	250	0
palm	214	-	200

3.1.2. The results below show biodiesel made from different types of oil when Koh 2.5% of oil weight, the methanol ratio is 1:5 of oil weight=50ml:

Table (2) Biodiesel made from methanol when Koh 2.5%

Type of oil	Weight of oil in(gm.)	Biodiesel in(ml)	Glycerol in (ml)
corn	214	200	60
Sunflower	218	245	10
palm	214	-	250

3.1.3. The results below show biodiesel made from different types of oil when Koh 3.5% of oil weight, the methanol ratio is 1:5 of oil weight=50ml:

Table (3) Biodiesel made from methanol when Koh 3.5%

Type of oil	Weight of oil in(gm.)	Biodiesel in(ml)	Glycerol in (ml)
corn	214	150	80
Sunflower	218	150	85
palm	214	-	275

3.1.4. The results below show biodiesel made from different types of oil when Koh 1.5% of oil weight, the ethanol ratio is 1:5 of oil weight=50ml:

Table (4) Biodiesel made from ethanol when Koh 1.5%

Type of oil	Weight of oil in(gm.)	Biodiesel in(ml)	Glycerol in (ml)
corn	214	300	-
Sunflower	218	250	-
palm	214	250	-

3.1.5. The results below show biodiesel made from different types of oil when Koh 2.5% of oil weight, the Ethanol ratio is 1:5 of oil weight = 50ml:

Table (5) Biodiesel made from ethanol when Koh 2.5%

Type of oil	Weight of oil in(gm.)	Biodiesel in(ml)	Glycerol in (ml)
corn	214	270	-
Sunflower	218	260	-
palm	214	260	-

3.1.6. The results below show biodiesel made from different types of oil When Koh 3.5% of oil weight, the ethanol ratio is 1:5 of oil weight = 50ml:

Table (6) Biodiesel made from ethanol when Koh 3.5%

Type of oil	Weight of oil in(gm.)	Biodiesel in(ml)	Glycerol in (ml)
corn	214	245	-
Sunflower	218	250	-
palm	214	225	-

3.2. Test the characterization of the produced biodiesel from used oil;

3.2.1. Density Test for Biodiesel Results:

The results of biodiesel density are shown in the table below, where A is 1.5%, B is 2.5% and C is 3.5% of oil weight.

Table (7) Density Test for Biodiesel Results

Bio diesel source	A density in(g/ml)	B density in(g/ml)	C density in(g/ml)
Corn(m)	0.62	0.63	0.52
Corn(E)	0.55	0.6	0.6
Sunflower(m)	0.52	0.52	0.53
Sunflower(E)	0.6	0.55	0.53
Palm(m)	-	-	-
Palm(E)	0.52	0.5	0.5

3.2.2. Kinematic Viscosity Test results:

The results of Viscosity biodiesel shown in table below where A is 1.5%, B is 2.5% and C is 3.5% of oil weight.

Table (8) Kinematic Viscosity Test results

Bio diesel source	A	B	C
Corn(m)	4.5	4.1	3.9
Corn(E)	4.8	4.3	4.1
Sunflower(m)	4.4	4	3.8
Sunflower(E)	4.6	4.2	4
Palm(m)	-	-	-
Palm(E)	5.4	5	4.6

3.2.3. Dynamic Viscosity Test results

The results of Viscosity biodiesel shown in table below where A is 1.5%, B is 2.5% and C is 3.5% of oil weight.

Table (9) Dynamic Viscosity Test results

Bio diesel source	A	B	C
Corn(m)	2.79	2.58	2.03
Corn(E)	2.64	2.58	2.46
Sunflower(m)	2.29	2.08	2.01
Sunflower(E)	2.76	2.31	2.12
Palm(m)	-	-	-
Palm(E)	2.81	2.51	2.30

3.2.4. Free fatty acid test:

The results of the biodiesel free fatty acid test are shown in the table below, where A is 1.5%, B is 2.5%, and C is 3.5% of oil weight.

Table (10) free fatty acid test results

Bio diesel source	A	B	C
Corn(m)	0.2%	0.3%	0.3%
Corn(E)	1%	0.9%	0.9%
Sunflower(m)	0.5%	0.3%	0.3%
Sunflower(E)	0.9%	1%	1%
Palm(m)	-	-	-
Palm(E)	2.18%	1%	1%

3.2.5. Flash point test:

The results of the Flash point content test shown in table below, where A is 1.5%, B is 2.5% and C is 3.5% of oil weight

Table (11) Flash point test results

Bio diesel source	A	B	C
Corn(m)	117	113	110
Corn(E)	103	107	112
Sunflower(m)	100	102	105
Sunflower(E)	105	100	110
Palm(m)	-	-	-
Palm(E)	132	130	120

3.2.6. Moisture content test:

The results of the biodiesel Moisture content test are shown in the table below, where A is 1.5%, B is 2.5%, and C is 3.5% of oil weight

Table(12)Moisture content test

Bio diesel source	A	B	C
Corn(m)	8%	15%	2%
Corn(E)	37%	45%	24%
Sunflower(m)	30%	6%	10%
Sunflower(E)	31%	28%	33%
Palm(m)	-	-	-
Palm(E)	24%	22%	40%

3.2.7. PH test:

Table (13) pH test for methanol biodiesel:

Type of oil	1.5%	2.5%	3.5%
corn	7.9	7.4	6.8
sunflower	8.1	8.1	8.3

Table (14) pH test for ethanol biodiesel

Type of oil	1.5%	2.5%	3.5%
corn	8.6	9.2	9.1
sunflower	8.6	8.7	8.8
palm	8.9	8.9	8.8

3.2.8. Soap content:

The results show that biodiesel made from methanol only, which give foam as shown below:

Table (15) Soap content test results

Type of oil	1.5%	2.5%	3.5%
Corn(mm)	-	1	1
Sunflower(mm)	2	3	5
palm(mm)	-	-	1

3.2.9. Detection of Excess Free Glycerin in Biodiesel by Visual Sedimentation

The results of the biodiesel Free Glycerin test are shown in the table below, where A is 1.5%, B is 2.5% and C is 3.5% of oil weight

Table (16) Detection of Excess Free Glycerin in Biodiesel

Bio diesel source	A	B	C
Corn(m)	No glycerol	No glycerol	No glycerol
Corn(E)	No glycerol	No glycerol	No glycerol
Sunflower(m)	No glycerol	No glycerol	No glycerol
Sunflower(E)	No glycerol	No glycerol	No glycerol
Palm(m)	All of the samples become glycerol	All of the samples become glycerol	All of the samples become glycerol
Palm(E)	No glycerol	Few layers of glycerol about 5mm	Few layer of glycerol about 5mm

3.2.10. Clarity Test for Biodiesel Results:

The results of biodiesel Clarity test are shown in table below where A is 1.5%, B is 2.5% and C is 3.5% of oil weight

Table (17) Clarity Test for Biodiesel Results

Bio diesel source	A	B	C
Corn(m)	Slight haze, clearer	Slight haze	Slight haze
Corn(E)	clear	clear	Mostly clear
Sunflower(m)	Clear and bright	Clear and bright	clear
Sunflower(E)	Crystal clear	Crystal clear	Crystal clear
Palm(m)	-	-	-
Palm(E)	cloudy	cloudy	Opaque dark

3.2.11. Haze Test for Biodiesel results:

The results of the biodiesel Haze test are shown in table below where A is 1.5%, B is 2.5% and C is 3.5% of oil weight

Table (18) Haze Test for Biodiesel results

Bio diesel source	A	B	C
Corn(m)	Light haze	Light haze	Light haze
Corn(E)	None	None	Very light haze
Sunflower(m)	None	None	None
Sunflower(E)	None	None	None
Palm(m)	-	-	-
Palm(E)	Moderate haze	Moderate haze	Heavy haze

3.2.12. Water Contamination Test (Separation Test):

The results of the biodiesel water contamination test are shown in table below where A is 1.5%, B is 2.5% and C is 3.5% of oil weight

Table (19) Water Contamination Test (Separation Test):

Bio diesel source	Separation	Interpretation of results	quality
corn	clear	Very low contamination	high
Sunflower	moderate	Acceptable	Medium to high
palm	Poor (no separation)	Likely contamination	low

4. Discussion

The yield and characterization of biodiesel from different vegetable oils using both methanol and ethanol as alcohols and KOH as a catalyst demonstrated here revealed some significant observations that are consistent with and in some ways contrary to previous literature.

4.1. Biodiesel Yield

The highest biodiesel yield was achieved using corn oil and ethanol (300 mL at 1.5% KOH), as shown in Chart (2) whereas palm oil never produced biodiesel when methanol was used—likely due to its high free fatty acid (FFA) level. High FFA levels may cause the formation of soap upon base-catalyzed transesterification, which hinders phase separation (Leung et al., 2010). This agrees with the literature, where oils with FFA > 2% are noted to be unsuitable for base catalysis unless already esterified (Knothe et al., 2005). Sunflower oil performed best in every experiment with yields of up to 250 mL of biodiesel with no or minimal glycerol separation issues as shown in Chart (1), which is indicative of a good profile for trans esterification. This also comes in line with studies such as Rashid and Anwar (2008), who achieved over 90% yield from sunflower oil under similar conditions as shown below.

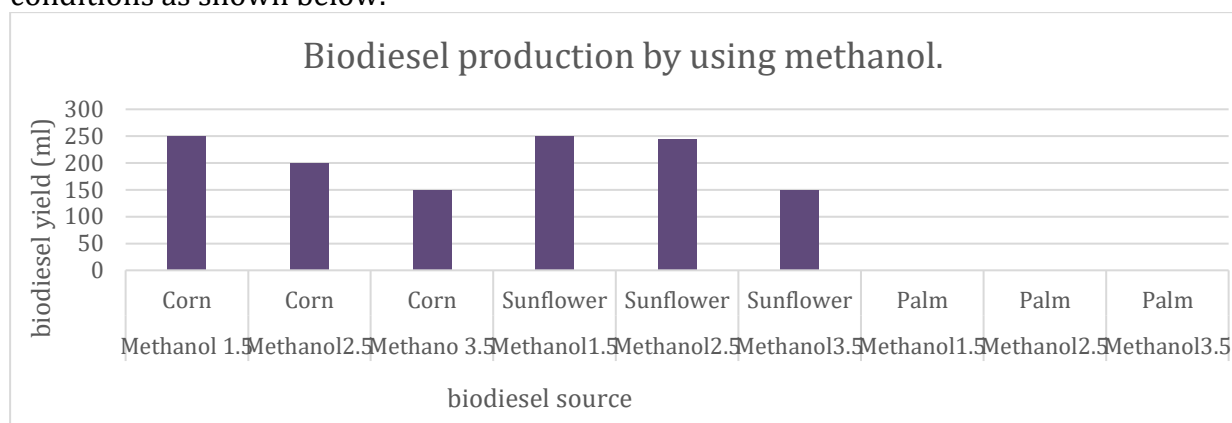


Chart (1) Biodiesel production by using methanol

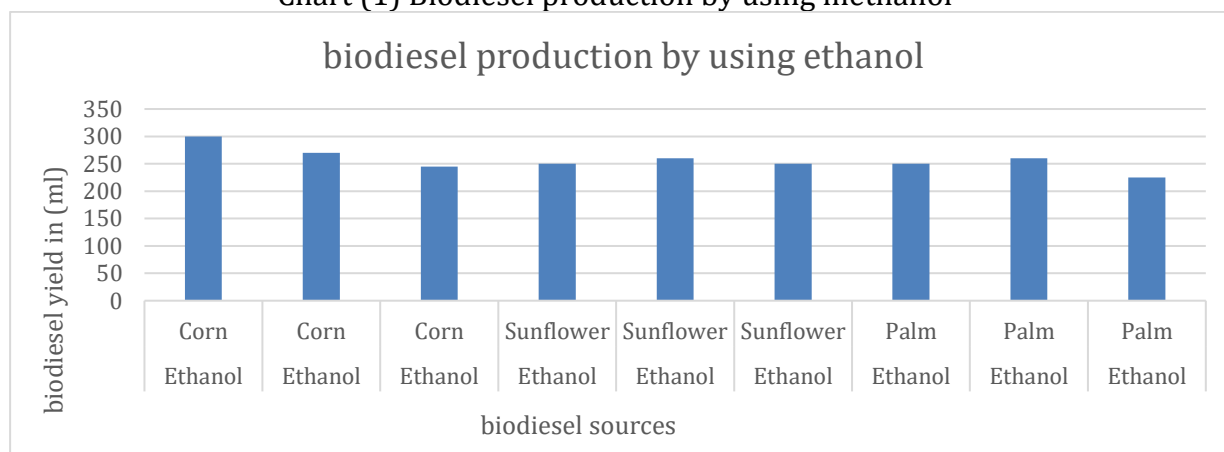


Chart (2) Biodiesel production by using ethanol

4.2. Density

The density of the product biodiesel was 0.50–0.63 g/mL as present in Chart (3). According to ASTM D6751, a biodiesel density range of 0.86–0.90 g/mL is acceptable. The readings acquired are much less than this, and it is an indicator of measuring errors, remaining unreacted alcohol, or ineffective trans esterification. The low densities can also be an indicator of high concentrations of ethanol/methanol in the product due to poor purification.

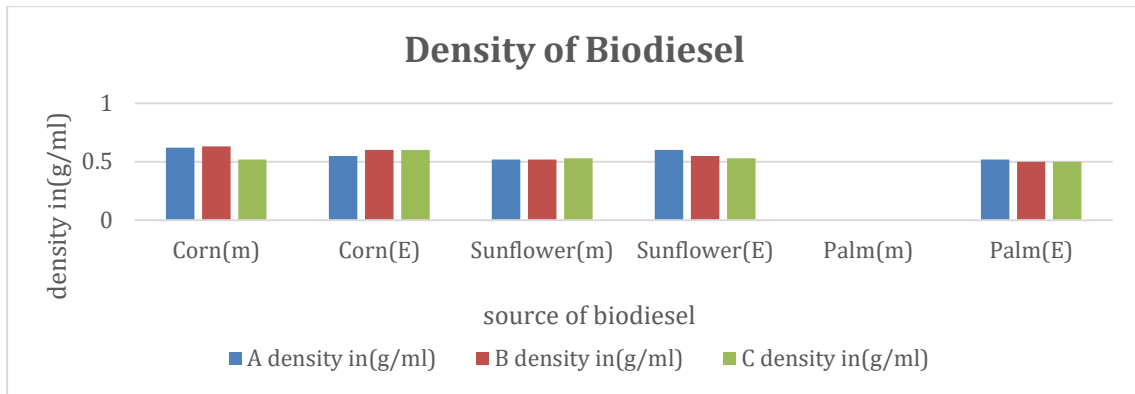


Chart (3) Density of Biodiesel

4.3. Viscosity

Kinematic viscosities were between 3.8–5.4 mm²/s and within the ASTM D6751 range of 1.9–6.0 mm²/s. Biodiesels from corn and sunflower had ideal viscosities, especially with ethanol. Palm oil biodiesel (ethanol) showed the maximum viscosity (5.4 mm²/s) as installer in chart (4) and (5), as expected due to its saturated fatty acid content. According to Moser (2009), saturated fats are known to produce biodiesel of higher viscosity.

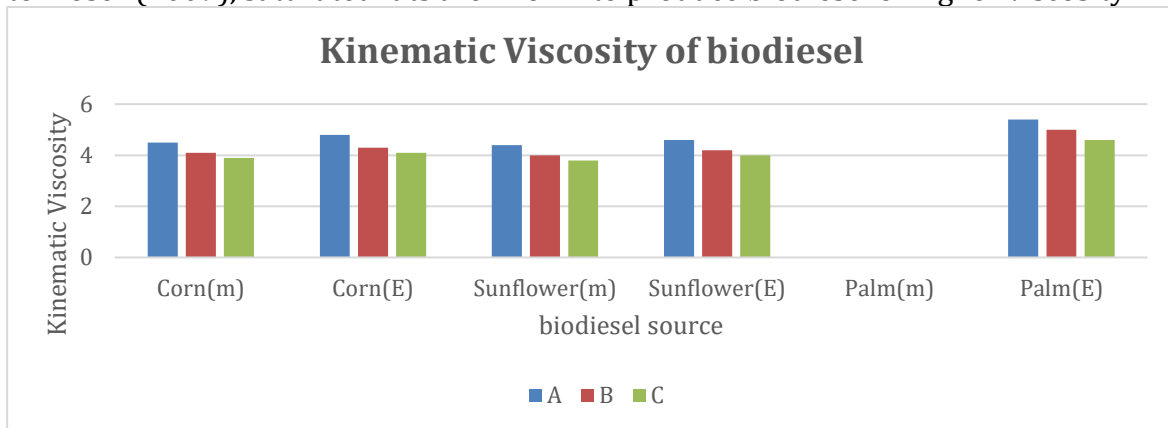


chart (4) Kinematic Viscosity of biodiesel

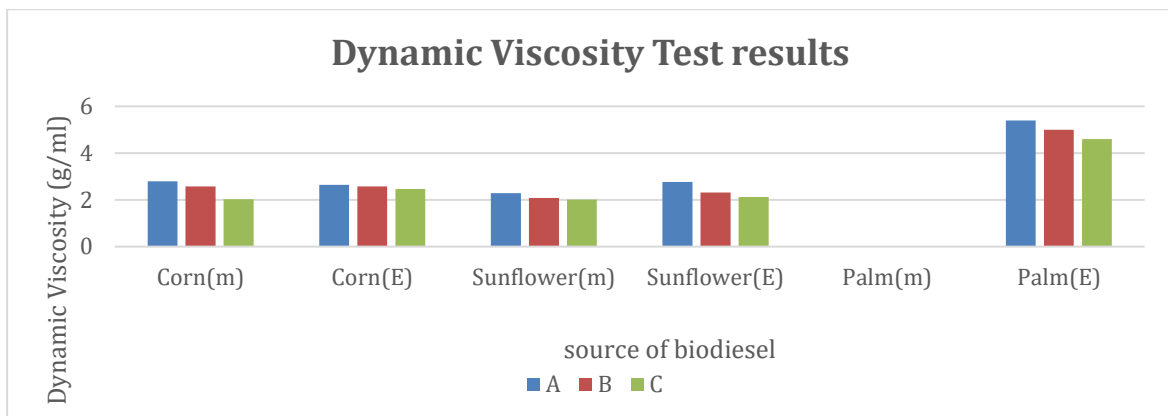


chart (5) dynamic Viscosity of biodiesel

4.4. Free Fatty Acids (FFA)

The palm oil biodiesel showed the highest FFA value (up to 2.18%), as shown in figure (3) indicating lower conversion due to soap formation. Ethanol would be less reactive than methanol, but with corn and sunflower oil, ethanol worked better—maybe due to its greater solubility in non-polar oils and greater molar ratio consumed. Previous studies

(Zhang et al., 2003) confirm that high FFA content requires acid pretreatment for efficient transesterification, which was not conducted here.



Figure (2) Free Fatty Acids results of biodiesel

4.5. Flash Point

Flash point temperatures ranged from 100–132°C. All the samples exceeded the minimum flash point specified for biodiesel as shown in Chart (6) (at least 93°C as per EN 14214). Palm oil biodiesel registered the highest flash points, reflecting lower volatility and enhanced safety of handling. This finding aligns with Demirbas (2009), which reported higher flash points in biodiesel from saturated fats.

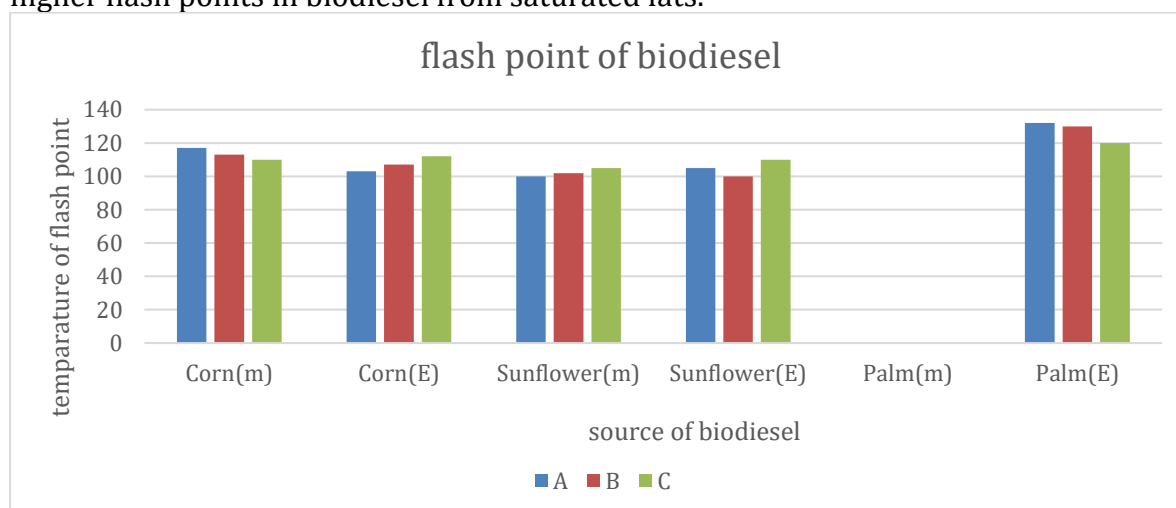


Chart (6) flash point of biodiesel

4.6. Moisture Content

Moisture content was not acceptable for ethanol-based biodiesels, particularly from corn (as much as 45%). High moisture is indicative of poor drying after washing or poor separation, which can promote microbial growth and lower engine performance. Moisture in typical biodiesel should not exceed 500 ppm (EN 14214). Ethanol is hygroscopic, so this might have resulted in the high moisture.



Figure (3) Moisture Content test equipment

4.7. PH Test

Corn methanol biodiesel became more acidic (pH range from 7.9 to 6.8) with higher catalyst concentration, while sunflower was alkaline. Ethanol-based biodiesel had a higher and consistent pH overall, especially for corn and palm oils. Palm ethanol biodiesel maintained a stable pH at around 8.9, which suggests great neutralization and potential fuel stability.

4.8. Soap Content

Soap formation was evident in methanol-based biodiesel. The greatest foam was evident in sunflower oil at 3.5% KOH as shown in Figure (5) and chart (7), indicating higher soap content 3mm insulator in (Jihad, 2024).

(López et al., 2015 (Shunaia & Jazie, 2023).

(Awad et al., 2024). (Altaher & Abdulla, 2019). Knothe et al., 2005 Rashid and Anwar (2008 ASTM D6751 o Moser (2009), (Zhang et al., 2003) EN 14214). table (15). Corn oil had minimal soap as shown in Figure (5), and palm oil had hardly any soap formation. Ethanol-based biodiesel did not have any foam, which indicates lower saponification and superior washing.

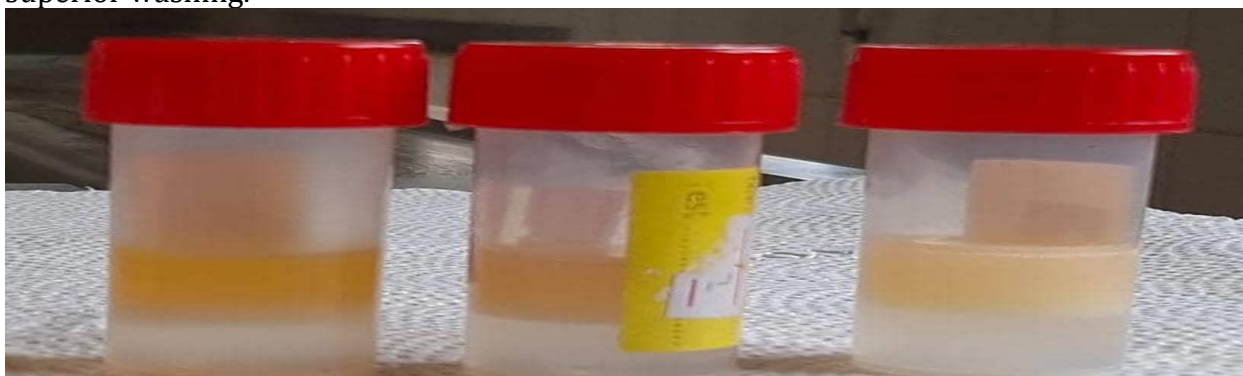


Figure (4) Biodiesel made from Corn and methanol



Figure (5) Biodiesel made from sunflower and methanol

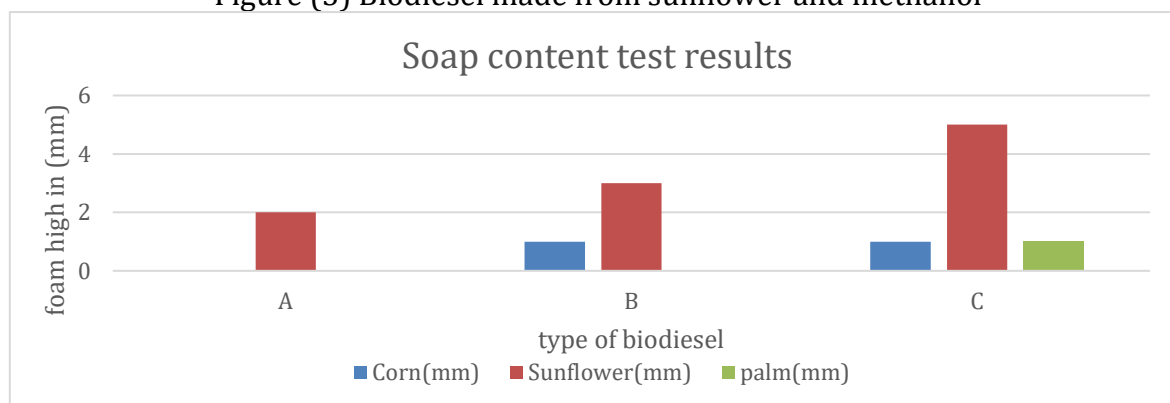


Chart (7) Soap content test results

4.9. Free Glycerin Test

All the samples of methanol-based palm biodiesel were totally converted to glycerol, as present in Figure (6) indicating a failed trans esterification reaction. Ethanol-based palm biodiesel was upgraded but contained visible glycerol layers (~5mm) as shown below.



Figure (6) Free Glycerin Test of palm biodiesel

Corn and sunflower biodiesel of both alcohols contained no visible glycerol, indicating successful conversion and upgraded fuel quality.

4.10. Clarity Test

Sunflower oil biodiesel, especially with ethanol, was most transparent, uniformly crystal clear at all catalyst levels. Corn biodiesel was clear and slightly foggy in 3.5% concentration in ethanol, but with ethanol. Palm oil biodiesel was cloudy to opaque, suggesting poor separation or contamination. Ethanol improved clarity in general as installer below in Figure (7) .



Figure (7) biodiesel clarity test.

4.2.11. Haze Test

Sunflower biodiesel was haze-free in all cases with excellent purification. Corn oil biodiesel had light haze in methanol and traces in ethanol. Palm oil biodiesel had medium to heavy haze, particularly with ethanol. Haze formation correlated with poor separation and moisture as present in Figure (7).

4.12. Water Contamination

Palm oil biodiesel exhibited high water absorption and phase instability as installer Figure (9), indicative of poor quality, but corn oil biodiesel (ethanol and methanol) exhibited clear separation as installer Figure (10) whereas sunflower biodiesel give good separation on 1.5% and 2.5% only as present in Figure (8), Sunflower biodiesel is very good but may require some minor polishing. Indicative of high quality as shown in photos below.



Figure (8) Sunflower Water Contamination



Figure (9) Palm Water Contamination

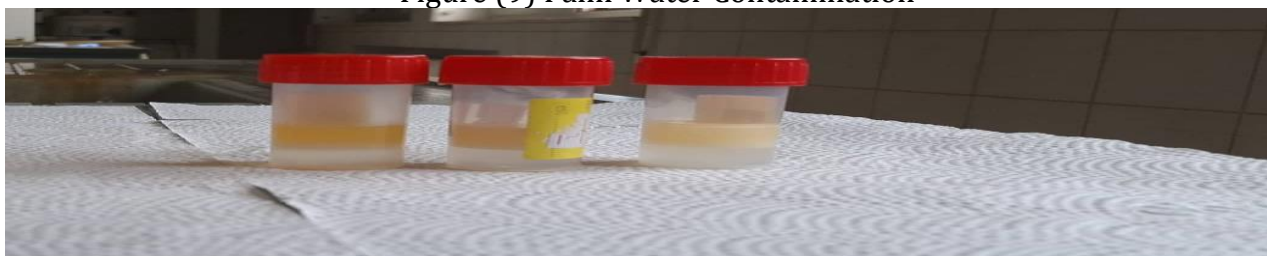


Figure (10) Corn Water Contamination

4. Conclusion

The results confirm that the type of feedstock, alcohol, and catalyst concentration have a significant impact on the yield and quality of biodiesel. Sunflower oil, particularly when combined with ethanol and 1.5–2.5% KOH, yields high-quality biodiesel with desirable physicochemical properties. Corn oil also showed good potential, while palm oil requires pretreatment to reduce free fatty acid levels. Recycling used cooking oil into biodiesel is a practical approach to reduce pollution, conserve resources, and support sustainable energy development.

5. Recommendations

1. Use sunflower oil for optimal biodiesel yield and quality.
2. Prefer ethanol as an alcohol for cleaner biodiesel production.
3. Maintain catalyst concentration between 1.5%–2.5% for balanced yield and purity.
4. Ensure thorough washing and drying of biodiesel to remove impurities.
5. Implement large-scale recycling programs to promote environmental sustainability.

6. References

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