

SYNTHESIS AND CHARACTERIZATION OF BIODIESEL DERIVED FROM WASTE COCONUT OIL AND MUSTARD OIL BLENDS THROUGH BASE- CATALYZED TRANSESTERIFICATION PROCESS

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ABSTRACT

Fossil fuels were created millions of years ago and are a one-time benefit whose supplies will certainly decline. Thus, for years, people have been trying to find alternatives for producing sustainable energy and found that oils, which are produced from vegetables, can be an ideal remedy for producing sustainable energy. Scientists all over the world are trying to bring the best outcome possible from the vegetable oils. This article focuses on the biodiesel made from the coconut and mustard oil blend by highlighting its production method, various properties, engine performance, and environmental safety. Mustard oil, which is rich in monounsaturated fatty acids, and coconut oil, high in saturated fats, combine with each other to produce biodiesel. Both the mustard seed and the coconut are readily available in the Indian sub-continent. Therefore, the biodiesel promotes sustainability and energy security. Transesterification with alkaline catalyst (NaOH) technique for producing biodiesel was used. At first the properties of biodiesel achieved from coconut oil and biodiesel from mustard oil separately were studied. Where the data were found to be close to the research that had been done before. Then the properties of biodiesel of their blend in with 25% CNO ratio and 50% CNO ratio were studied. Blended samples illustrated intermediate characteristics for different ratios. The 25% coconut oil blend (1:3 CNO:MO) displayed density $0.897 \text{ g}\cdot\text{mL}^{-1}$, calorific value $41.22 \text{ kJ}\cdot\text{g}^{-1}$, flash point $176.25 \text{ }^\circ\text{C}$, viscosity $4.71 \text{ mm}^2\cdot\text{s}^{-1}$, cloud point 5.6°C , and pour point -2.4°C . On the other hand, the 50% coconut oil blend (1:1 CNO:MO) showed density $0.886 \text{ g}\cdot\text{mL}^{-1}$, calorific value $40.506 \text{ kJ}\cdot\text{g}^{-1}$, flash point $172.5 \text{ }^\circ\text{C}$, viscosity $5.41 \text{ mm}^2\cdot\text{s}^{-1}$, cloud point 8.0°C , and pour point 4.3°C . The 25% coconut oil blend was better because it contains a higher calorific value and better cold flow properties with a lower pour point, which indicates it will remain fluid in colder climates. Though it has lower viscosity, it is still within a functional range for diesel engines. Higher flash point also helps to provide safer handling. Overall, mustard and coconut oil diesel blend highlight a promising solution for renewable energy. But further research should be conducted with more optimized ratio, more controlled conditions and minimized emissions to improve its efficiency. Furthermore, the corrosivity with different metals and performance in cold climate temperatures with many other things should be studied before making it commercial.

Keywords: Fossil fuels, biodiesel, transesterification, calorific value, pour point.

1. INTRODUCTION

Energy is an essential resource for human civilization. It is important for supporting economic progress and achieving sustainable development. But energy nowadays is one of the most global crises because fossil fuel, we use as a source of energy, is being used up rapidly. It is known that, fossil fuels are made from the fossils of ancient plants, animals, and microorganisms. As a result, it takes millions of years for these fuels to form. That's why fossil fuels are non-renewable energy sources (Huang et al., 2012). It is studied that in 2030, the world's need for energy will be 50% higher than the current. But the world's infrastructure depends much on petroleum products as there are no better alternatives found (Shelare et al., 2023). Besides, the large amount of carbon dioxide produced during their combustion contributes greatly to global warming, which leads to many harmful effects. In addition, pollutants such as sulfur oxides lead to acid rain, which can reduce crop productivity. Moreover, a large number of oil spills—amounting to about 1,190 thousand tons between 1970 and 1990—have severely damaged nearby land and aquatic ecosystems (Masudi et al., 2022).

Thus, Biodiesel has emerged as a significant alternative fuel for diesel engines in recent years. The process of producing biodiesel from vegetable oil is quite easy and has various environmental benefits (Thirumarimurugan et al., 2012). Besides, due to rising crude oil prices, the reduction of fossil fuels, and growing environmental concerns, the use of vegetable and animal fats to make biodiesel has recently gained popularity. Biodiesel is one kind of diesel fuel that comes from renewable sources like vegetable oils and animal fats. As it is biodegradable and nontoxic, it is said to be environment friendly (Ma & Hanna, 1999). Moreover, it contains low sulfur as well as good aromatic content (Neupane, 2022). Biodiesel can be produced from various kinds of edible and non-edible vegetable oils such as castor oil, cottonseed oil, mahua, karanja, coconut oil, jatropha curcas, and rice bran oil. These oils are suitable materials for the production of biodiesel because they are either readily available in excess or belong to the non-edible category (Bajpai & Tyagi, 2006). Also, the animal fat and cooking oil waste have also been applied as biodiesel sources (Valente et al., 2011).

Though biodiesel production and use from single vegetable oils have been widely studied, only few research has aimed at biodiesel blends made from combinations of different vegetable oils. By performing an examination of biodiesel blends made from coconut and mustard oils, this paper fulfills that gap, which is done by examining their characteristics and potential as economical, sustainable substitutes to regular diesel fuel (Ahmed et al., 2024). Some oils have few uses in their original form due to their chemical structure. If biodiesel blend is used, this problem can be eradicated. Although oil blending does not change the structure of triacyl glycerol, it gives the producer more ability to personalize the product to get certain useful qualities or provide required nutrients. Many Oils that are commonly used such as coconut or palm oil are enriched in saturated fatty acids. On the contrary, mustard, sesame and groundnut oils are enriched in mono-saturated fats and polyunsaturated fatty acids (PUFA). Thus, suitable blending of the oils mentioned above can increase the quality of PUFA (Prasanth Kumar et al., 2009). While compared with regular diesel, some blends have been found to lower emissions of carbon monoxide and nitrogen oxides, which is good for the environment. By blending different oils, such as mustard and coconut oil, the viscosity of the biodiesel can be reduced, improving its atomization and flow properties in engines (Wahyudi et al., 2020). Biodiesel produced from biodiesel blends is observed to reduce the hydrocarbon (HC), Carbon monoxide (CO) and other matter emissions up to 38.55% with higher blends (Masera & Hossain, 2021).

Bangladesh is rich in mustard seed production and every year the production of mustard seed in Bangladesh is higher than its demand (Alam & Rahman, 2013). Also, as Bangladesh has suitable climate and it is in a coastal region, coconut is being cultivated all over the country since long before. This study investigates the characteristics of coconut and mustard oil blends and biodiesel produced from different ratio of coconut and mustard oil. This research explores important parameters of these vegetable oil blends such as density, viscosity, flash point, pour point, cloud point, which can directly influence the engine performance. This study focuses on giving a valuable insight that could result into more efficient, environment friendly and cost-effective biodiesel production method. It provides

us the opportunity to research further about this most important phenomenon which can ensure a sustainable energy and also addressing the global energy crisis.

2. METHODOLOGY

2.1 Materials: Oil collection & catalyst preparation

The waste vegetable oils (coconut and mustard) were collected from the local market and then filtered to remove the unwanted particles. After that the catalyst NaOH and reagent methanol were taken from the Corrosion Lab, KUET. The catalyst NaOH was grinded to make fine particles and 1% (w/w) of it was added to the methanol to make the catalyst-reagent mixture.

2.2 Experimental setup and procedure

2.2.1 Blending

In the present work, two oil blends were made by mixing coconut oil (CNO) and mustard oil (MO) in the proportion of 25% and 50% CNO. Blending of two oils was performed by mixing with a mechanical stirrer at 60°C. The required quantities of oils were mixed well for 20 minutes in a beaker maintained at 60°C. Then the blends were cooled to room temperature and were transferred to small size jars, covered with screw cap lids and stored at room temperature (Prasanth Kumar et al., 2009).

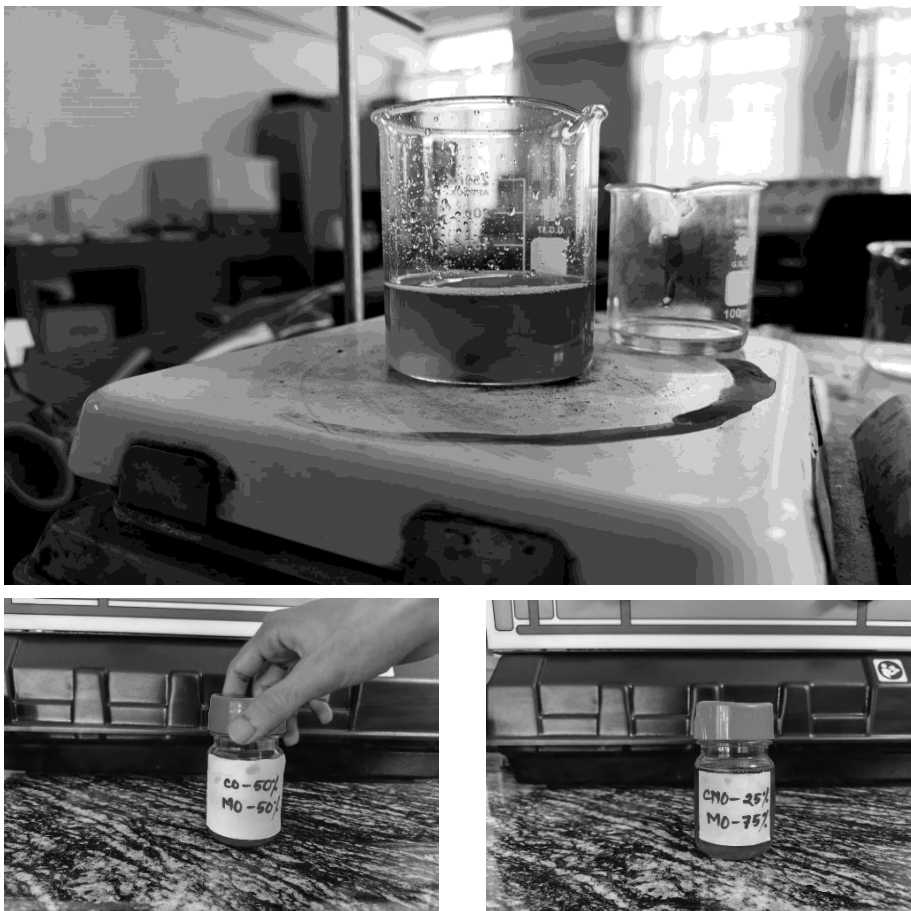


Figure 1: Blending and preparation of sample from waste coconut and mustard oil

2.2.2 Transesterification

The process was done in a 500 mL beaker with a mechanical stirrer. Firstly, 200 mL sample oil was taken in a beaker and was heated up to 60°C by a heater and a thermometer was used to measure the temperature. Then the methanol-NaOH solution was added gently at 2 minutes intervals for 10 minutes to the heated oil and heated constantly with a range of about (60-65) °C. In the meantime, the sample was stirred continuously by a mechanical stirrer at 250-300 rpm for about 60 minutes. During that process, the transesterification reaction occurred between the sample oil and methanol with the help of the catalyst NaOH. After 60 minutes of heating and stirring, the sample was kept 24 hours at room temperature for cooling. During that time the transesterification reaction occurred properly and produced methyl ester (biodiesel) and glycerin which were two layers in the beaker. The upper layer was methyl ester (biodiesel) and the lower layer was glycerin (Figure 3). Then the methyl ester was separated in another beaker, added distilled water and stirred properly to eliminate the residual methanol, soap, glycerol, catalyst residues and other impurities. Thus, the final sample of biodiesel was produced (Çetinkaya & Karaosmanoğlu, 2004). The workflow is summarized in Figure 3.



Figure 2: Visual appearance of biodiesel and glycerol layer

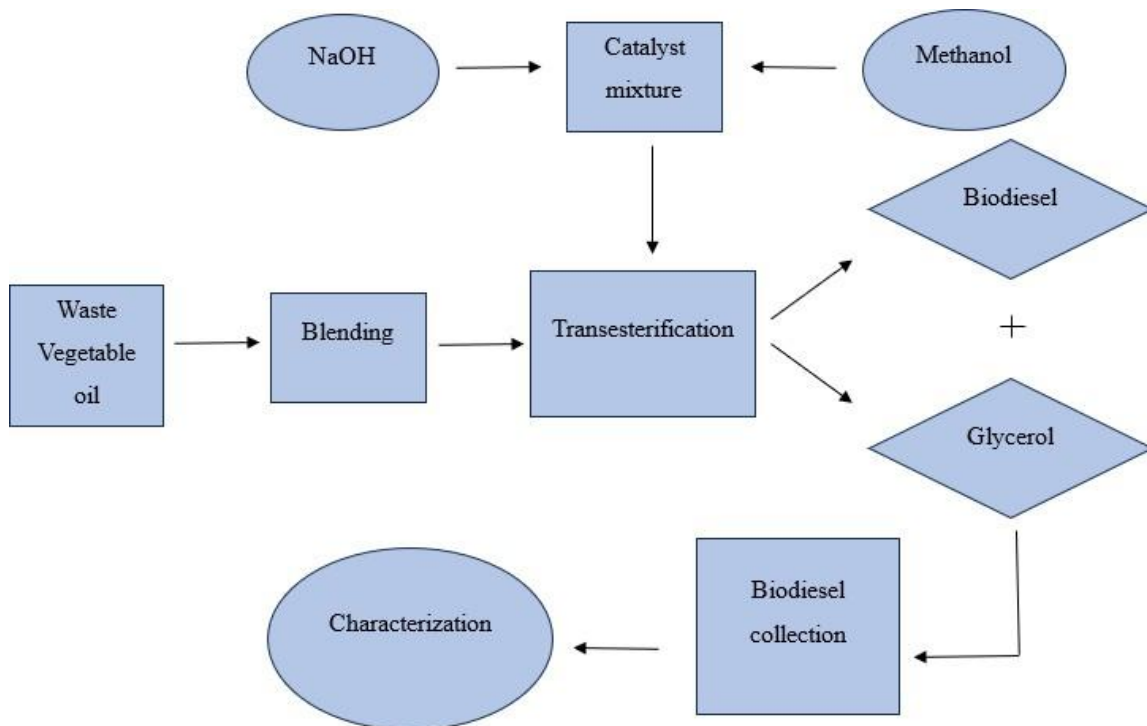


Figure 3: Flow diagram of the experiment

2.3 Product characterization:

The physicochemical and instrumental methods of analysis were used to evaluate the quality of the biodiesel made from a combination of coconut and mustard oils. The characterization aimed to compare the obtained biodiesel properties with the standard specifications. The physical properties analyzed included density, kinematic viscosity, calorific value and flash point, which are important indicators of fuel performance and stability. The density and viscosity were measured at room temperature using a digital densitometer and a capillary viscometer respectively, to assess the flow characteristics of the biodiesel. Both the calorific value & flash point of our sample biodiesel were tested respectively with CAL3K-S Bomb Calorimeter and Flash Point Tester (Koehler K16273) in the Corrosion lab, Department of Chemical Engineering, KUET.

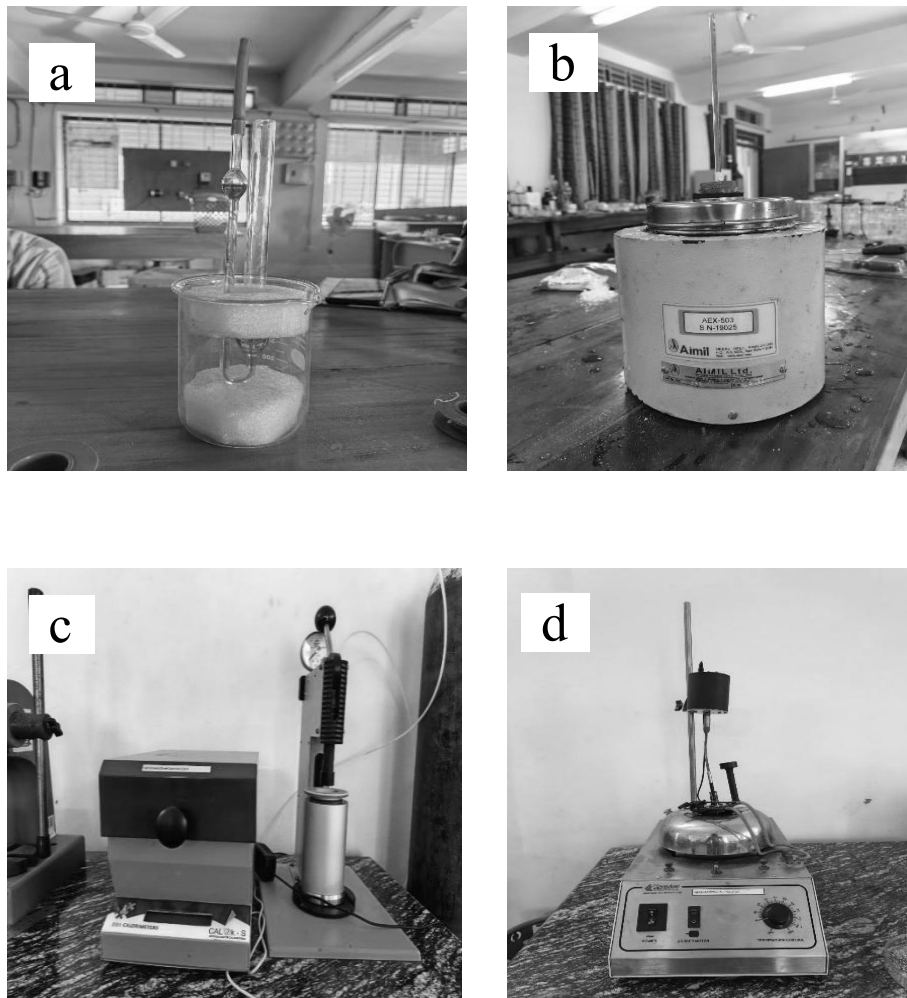


Figure 4: Evaluation of biodiesel from blended oil: (a) Kinematic viscosity, (b) Cloud point and pour point, (c) Flash Point, (d) Calorific value

3. RESULT AND DISCUSSION

Biodiesel properties are primarily determined by the fatty acid composition of the pure oils. In this study, biodiesel was produced from two different oils – Coconut oil (CNO) and Mustard oil (MO) and from their blends in two different proportions: 1. 25% CNO + 75% MO, 2. 50% CNO + 50% MO. These ratios were chosen to observe the impact of saturation, to optimize viscosity vs cold flow (cloud point, pour point) properties and also to see the engine compatibility with the biodiesel produced. Coconut oil is more saturated compared to other vegetable oils. The experimented data of these blend ratios give a measure that how much saturation affects different properties of the biodiesel produced. Saturated oil generally increases the viscosity and decreases the cold flow properties. These blend ratios are aimed to be sufficient at viscosity, cloud and pour point. Ultimately, these blend ratios were selected to produce biodiesel that can be used as suitable fuel for engine use, and increase the safety measurement.

3.1 Properties of pure biodiesels (100% Mustard and 100% Coconut)

Figure 5 shows the properties of the coconut oil and mustard oil-based biodiesel with respect to typical data for regular biodiesel. Mustard biodiesel, however, has a higher density (0.902 g/mL), slightly more than both the normal ceiling limit of 0.9 and the coconut biodiesel's density (0.872 g/mL). Greater density of mustard biodiesel may be due to storage of long-chain unsaturated esters and lesser in coconut biodiesel may occur because of medium chain saturated ester.

The calorific value of mustard biodiesel (41.85 kJ/g) was higher compared to coconut biodiesel (39.68 kJ/g) suggesting better energy content and combustion efficiency. This is in agreement with the higher carbon content and degree of unsaturation in mustard oil. Flash point shows safety characteristic of the two fuels, where mustard biodiesel (178.5°C) and coconut biodiesel (170°C), both lies well above the minimum requirement (>130°C). The higher flash point of mustard biodiesel indicates better thermal stability and less volatility.

The kinematic viscosity of coconut biodiesel (6.83 mm²/s) is slightly higher than the standard range (1.9–6.0 mm²/s), but the mustard biodiesel (4.32 mm²/s) aligns well with the standard values. A high viscosity of coconut biodiesel was found, which may be related to the incomplete conversion of methyl esters or to saturated fatty esters that might affect the atomization mechanism upon injection. For cold-flow behaviour, cloud point of coconut biodiesel was 10.2°C and pour point is 6.0°C, however mustard biodiesel had considerably lower values (4.8°C and –3.6°C, respectively). These results show that mustard biodiesel is more suitable for cooling applications because of higher unsaturation compared to coconut biodiesel.

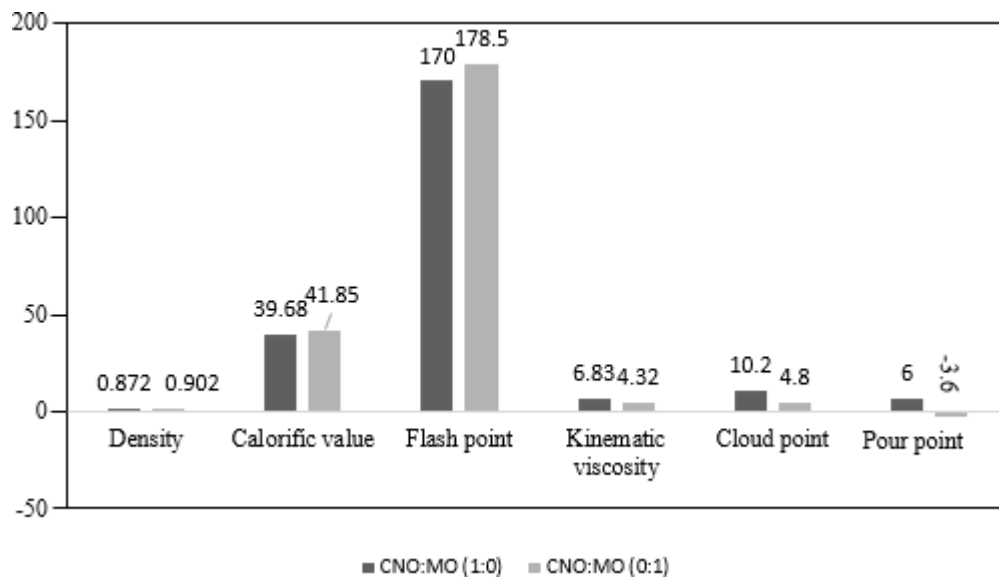


Figure 5: Comparison between different properties of biodiesel produced from coconut and mustard oil

3.2 Properties of blended biodiesel

Table 1: Experimented properties of blended biodiesel

Sample	Density, ρ (g/mL)	Calorific value (kJ/g)	Flash point ($^{\circ}$ C)	Kinematic Viscosity, ν (mm^2/s)	Cloud point ($^{\circ}$ C)	Pour point ($^{\circ}$ C)
Coconut+ Mustard oil (1:3 or 25% CNO)	0.897	41.220	176.3	4.71	5.6	-2.4
Coconut+ Mustard oil (1:1 or 50% CNO)	0.886	40.506	172.5	5.41	8	4.3

These experimented data show that blending two oils have an influence on the properties of the biofuel produced from the blended oils. The test results show a clear pattern that when two oils such as mustard and coconut oil are mixed, the biodiesel produced from the blend has properties that are somewhere at the middle ground.

3.2.1 Density trends and implications

Density of biodiesel is generally higher than that of diesel and it mostly depends upon its purity, fatty acid composition. This is the reason why biodiesel specific gravity changes a lot according to the contamination. Biodiesel density has a profound impact on various fuel characteristics average dimension of particle size as well cetane number, viscosity, heating value, combustion and also affects the quality of atomization (Barabas & Todoru, 2011). The density of the samples was observed to decrease gradually as the fraction of coconut oil was increased. The value of the density dropped from 0.902 g/mL for pure mustard biodiesel to 0.872 g/mL for pure coconut biodiesel.

The value of densities continues to decrease with increasing coconut portion. The values were 0.897 g/mL and 0.886 g/mL for the 25% and 50% CNO blends, respectively. This result arises because biodiesel produced from coconut consists generally a shorter and saturated fatty acid methyl ester (FAMES) such as methyl laurate and methyl myristate, which are lighter and have less intermolecular attraction than the longer unsaturated FAMES in mustard biodiesel (methyl oleate, linoleate, erucate). Moreover, the decrease in density indicates shifting toward less compact molecular structures as the CNO percentage increases.

Lower density can lead to a slight increase in volumetric fuel consumption as engine injection systems meter fuel by volume. However, this characteristic also helps to improve fuel atomization and combustion efficiency. Therefore, the net effect of this property change is considered moderate, and no significant damage to overall usability is expected. The density of blended biodiesels can be found in between pure coconut and mustard biodiesel. The 25% CNO blend provides a reasonable value that is optimal between energy content and the atomization of fuel. Coconut biodiesel with lower density has better atomization and mustard biodiesel having higher densities gives better fuel economy, so the 25% CNO blend achieves the greatest overall performance.

3.2.2 Calorific value (energy content)

Calorific value (heating value) is the amount of energy emitted by complete combustion of a unit quantity of biodiesel, which is burned and then cooled to the initial temperature of the combustible mixture (Sivaramakrishnan, 2011). The calorific value showed low but consistent decline as the fraction of the CNO was increased. The calorific value measured for biodiesel produced from pure coconut and mustard oil ranged from 39.68 kJ/g to 41.85 kJ/g, respectively. The blends biodiesel showed calorific value of 41.22 kJ/g for 25% CNO and 40.506 kJ/g for 50% CNO.

These results show the energy difference between long-chain unsaturated and short-chain saturated esters. Mustard biodiesel contains more energy per gram due to the higher carbon-hydrogen ratio. In contrast, biodiesel produced from coconut oil shows slightly less energy upon combustion process as it has shorter carbon chain and saturated molecules which are hard to break.

Mustard biodiesel has the highest calorific value due to long chain unsaturated esters, followed by pure coconut biodiesel. The mixtures show the intermediate values that align well with mustard's energy density. Therefore, the 25% mixture shows the best combustion and maximum energy for all the samples.

3.2.3 Flash point and storage safety

The flash point of biodiesel is an important measurement of fuel volatility and safety. It is the lowest temperature at which the fuel gives off enough vapor to ignite momentarily when exposed to an ignition source, like a spark or flame. All the samples in this experiment displayed high flash points ranging from 170-179°C, which is significantly above the conventional diesel (~60°C). It increases the safe nature of the biodiesel produced and also confirms non-volatility of the biodiesel.

The experimented data displays that as the coconut fraction was increased, the flash point gradually decreased (from 178.5°C to 170°C). This is because of the presence of slightly more volatile medium-chain methyl esters in coconut oil. Despite this, 50% CNO blend (flash point 172.5°C) also exceeds the ASTM D6751 minimum requirement of 93°C which ensures the required safety for storage and transport.

3.2.4 Kinematic viscosity

Kinematic viscosity is one of the most important fuel properties that has an influence over atomization, efficiency of combustion and engine performance. In this study, the kinematic viscosity of biodiesel produced from pure mustard oil and coconut oil and from their blend containing 25% and 50% CNO was determined.

The results show a gradual increase in viscosity as the coconut fraction is increased. Mustard biodiesel is mainly composed of long-chain unsaturated fatty acid methyl esters, such as methyl oleate, linoleate which showed the lowest viscosity (4.32 mm²/s). On the other hand, coconut biodiesel which is rich in medium-chain saturated esters like methyl laurate gave the highest value of 8.23 mm²/s because of stronger intermolecular attractions among the saturated molecules. The blended fuels demonstrated intermediate viscosities- for 25% CNO the value was 4.71 mm²/s and for 50% CNO it was 5.41 mm²/s.

High viscosity results in operational problems including engine compatibility (Xu & Hanna, 2009). Higher viscosity fuels produce larger spray droplets, which oppose atomization and make the combustion slower. The 50% blend (5.41 mm²/s) is thicker and may cause incomplete burning. Among the tested samples, 25% CNO blend showed the lowest value of viscosity which ensures enough lubricity, stable flow and engine compatibility.

3.2.5 Cloud point and Pour point

Pour point is the temperature at which a wax begins to form and crystals begin to grow and adhere together sufficiently to prevent free flow of the fluid when the container of fuel is tipped or rested on a horizontal surface. The diesel fuel being by nature, starts at a low temperature limit can no longer be used, while the biodiesel has a higher cloud point to allow its use in acceptable conditions. The cloud and pour points are primarily related to the nature of oil, the feedstock from which they were processed for biodiesel preparation (Canakci & Sanli, 2008). The cloud and pour point rose as the CNO content was increased. For pure mustard biodiesel, the cloud and pour points were 4.8°C and -3.6°C respectively, whereas for coconut biodiesel, the values increased to 10.2°C and 6.0°C. The values of the blended biodiesel were in the intermediate range. This is attributed to the fact that the percentage of saturated FAMES in coconut biodiesel is high, and the crystallization becomes easier at moderate temperatures.

The 25% CNO blend has cloud point 5.6 °C, which is lower than the cloud point of 50% blend (8 °C) and are less in comparison to that of pure coconut biodiesel. The latter makes the formulation more usable in cold conditions and at the same time stable to fuel. In that case, 25% CNO is better for moderate to cooler climates. The 25% CNO mixture has a pour point of -2.4 °C, which is better than that of the 50% blend (4.3 °C). This shows at lower temperatures the 25% blend remains as fluid and

is easier to pump when cold. Due to the low coconut content, its effect is inadequate for crystallization; thus 25% CNO is a good choice with regard to the cold-flow performance.

4. CONCLUSIONS

As mankind is experiencing that the consumption of fossil fuels around the world has become very vast and necessary because of rapid industrialization and deforestation. As a result, industrialisers and entrepreneurs need more eco-friendly and comparatively cheaper sources of diesel to run the important machinery or other equipment's in industries, mills, ships engines, aero plane or jet planes and other locomotives. The experiment show's that most of the criteria to make an effective source of fuel have been fulfilled because of the tests we did in the lab. The main purpose of the experiment was to differentiate the properties (fame yield, density, viscosity, flash point, calorific value, cloud point, pour point) of biodiesel which is derived from mustard oil-coconut oil blend in different molar ratio to the particular biodiesel we got from mustard oil and coconut oil. If we analyze the viscosity then the blend reduces the viscosity, increasing atomization. But the flash point and pour point improve due to the blend which is a positive part of this test. From the biodiesel we got from the blend, the combustion quality improves because it gets ignited and burned very smoothly rather than the single source. The process we used is the transesterification process which has many advantages and pros so that the production of biodiesel is done by this process (Gameiro et al., 2015).

The properties of the biodiesel blends were compared with the ASTM biodiesel property values which were selected as ASTM D6751 standards. The values were very close and give an improved balanced biodiesel overview which may be helpful and resourceful for future researchers. Comparing with the ASTM standards ensures quality assurance of the product, leading to better engine compatibility. Also, it helps to measure the environmental hazards at any kind of vegetable oil or feedstock blend. The performance consistency remains linear by taking notes from the ASTM standard and very safe for all kinds of research fields (Veljkovic et al., 2006).

The natural oils are too much thick so after doing transesterification the viscosity of the oil reduces make it suitable for usage in a diesel engine. It also converts large methyl esters into smaller esters which makes it very comfortable to start combustion in a diesel engine. It also produces a second layer of glycerol which a valuable by-product that can be use in further production of miscellaneous uses. The experiment shows the importance of different vegetable oils which can be used to enhance the combustion quality and reduce environmental hazard. This experiment paves the way to encourage the researchers to make more contributions to produce biodiesel from livestock, domestic waste-feedstocks, biochar and many other sources which can be very significant to reduce dependence on fossil fuels and reduce carbon emissions in the environment, making the world a better place to reside.

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DECLARATION OF USE OF AI

The authors declare that AI tools were used only to improve the language and clarity of the manuscript. AI tools were not used in the research design, methodology, data analysis, or interpretation of results. All scientific content and conclusions are the original work of the authors, who reviewed and approved the final manuscript.

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