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MgO Nanoparticles Inpactcastor Oilbiodiesel's Viscosity, Density, and Specific Gravity

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ABSTRACT
The study addresses concerns over the eventual depletion of petroleum by focusing on biodiesel derived from castor oil, a non-edible vegetable oil rich in ricinoleic acid. This renewable alternative offers significant environmental benefits compared to conventional diesel, including biodegradability, lower toxicity, and reduced greenhouse gas emissions. The research centers on optimizing the transesterification process of castor oil into biodiesel, exploring parameters such as alcohol-to-oil ratio and catalyst concentration to maximize yield and quality. A notable aspect of the study involves the incorporation of MgO nanoparticles into transesterified castor oil to enhance its viscosity, density, and specific gravity. The nanoparticles, ranging from 0.2% to 1.0% concentration, were analyzed using scanning electron microscopy (SEM) for surface morphology and X-ray fluorescence (XRF) spectroscopy for purity assessment of the oxide. Results indicate that even at a low concentration (0.2%), MgO nanoparticles significantly improve the physical properties of the biodiesel, suggesting an optimal concentration for fluid enhancement. Overall, the research contributes to sustainable biofuel development by leveraging non-edible vegetable oils like castor oil. By characterizing and ensuring the quality of the produced biodiesel against standard specifications, the study supports its practical application as a cleaner and more environmentally responsible fuel alternative. This advancement underscores ongoing efforts to reduce dependency on finite fossil fuel resources while promoting energy security and environmental stewardship in the transportation sector.

Keywords:
Biodiesel,
Castor oil,
Greenhouse,
Transesterification, SEM,
XRF.

INTRODUCTION

As it is well-known, transportation is almost entirely dependent onfossil-based fuels (> 99.9%) such as diesel, gasoline fuel, compressed natural gas (CNG) and liquefied petroleum gas (LPG) (Foroutan et al., 2023). However, the availability of fossil-based fuels in the immediate future is a question in the minds (Kennedy & Anthony, 2023). This is because the reserves of them are going to an end (Atadashi et al., 2013). Besides it, many harmful exhaust gases are released into the atmosphere while burning the fossil-fuels in the internal combustion engines (ICEs). For instance, 2.9 kg of greenhouse gas emissions are releasing into the atmosphere with the burning of only 1-liter diesel fuel (Sajjad et al., 2022). According to 2018 data, the transportation sector is responsible for 20% of the world's total energy consumption, 23% of total carbon dioxide (CO_2) emissions and 14% of total greenhouse gas emissions (Hosseinzadeh-Bandbafha et al., 2018).

Consequently, there is a necessity to adopt a cleaner, green, and environmentally friendly tactic for a sustainable environment, andthe extant and future generations of humans benefit that being devoid of any environmental pollution. Hence, the use of plant-based materials for the production of renewable fuels has been heralded by many researchers because of the several advantages they portend (Karki et al., 2021).

The most widely used method for the synthesis of biodiesel from edible and non-edible renewable biomass remains the trans- esterification reaction that involves the use of excess alcohol. A homogeneous mixture is formed during the reaction process consisting of specific biodiesel, alcohol, and glycerol (Ağbulut et al., 2020). Industrial production of biodiesel is usually hindered due to component separation challenges in the homogeneous mixture system (Sajjad et al., 2022). Other challenges include understanding the phenomena associated with the equilibrium behavior of the homogeneous mixture when the alcohol transits from the raffinate glycerol phase to the extract biodiesel phase during alcohol regeneration (Rashid, 2023). Essentially, differences in density are mostly linked to the immiscibility of the biodiesel and glycerol phases and thus, separation of the two-phase components requires greater time, resources, energy, and capital investment for a continuous biodiesel production and processing plant(Muhammad & Chandra, 2022). In this regard, the separation and purification of biodiesel from glycerol become the limiting step in the manufacture of biodiesel which requires the development of viable options and far-reaching research (Kumar et al., 2023). These choices enhance the design options and optimization objectives for emerging novel biodiesel production processes (Foroutan et al., 2023).

Ricinus communis commonly called castor oil plant is a bean seed from the Euphorbiaceae family. The plants grow in the tropicswith heights of about 10–13 m or about 30–40 feet. This tropical environment has a dual season that encourages the young plant to sprout year in and out. The leaves of the plants are fanlike with a beautiful lobed palmate feature consisting of 12 leaflets with spined-bristle red-bronze group bean fruits (Kennedy & Anthony, 2023).

This study investigates; using experimental and theoretical assessment, the phenomena linked with the separation and purification of biodiesel produced from Ricinus communis seed oil; elucidating the biodiesel components distribution in the homogeneous mixture after transesterification reaction at different investigated temperatures; evaluating the properties of the oil as a suitable substrate for biodiesel production and assessment of the produced biodiesel in comparison with global standards; and finally, evaluating the potential environmental benefit (s) of the biodiesel as a renewable energy source for greenhouse pollution reduction as against fossil energy utilization.

MATERIALS AND METHODS

Materials and Chemicals

The materials and reagents used in carrying out the research are as follows: crude castor oil, 8 % sodium hydroxide (NaOH), 64 % citric acid ($C_6H_8O_7$, purity: 99.7 %), MgOnano particless, activated carbon, acetone, and distilled water (H_2O).

Equipment

The equipment's used in carrying out this study are: magnetic stirrer with thermostatically controlled rotary hot plate (IKA C-MAG HS10), Brookfield Digital viscometer {Brookfield, RVDV-I}, thermometer, measuring cylinder, Cheng Sang Vacuum oven (MA 0-30L), Digital weight balance (AND model GT2000 EC), beaker, 24 cm filter paper, funnel, Digital stop watch, sampling bottles, spatula.

Figure 1. Transesterification processe

Methodology

Sample Purification (esterification)

The crude castor oil was purified through the following procedure; 200 ml of the castor oil was measured using measuring cylinder; the oil was pre-heated to 70ºC using hot magnet stirrer with thermometer. 1.5 ml citric acid was measured and added to the heated oil sample and continuously heated and stirred for 15 minutes at 70ºC .4g of 8% NaOH (by dissolving in 100 ml of distilled water) was then be added to the oil and continuously heated and stirred for 15 minutes at 70ºC. The mixture was then transferred to the vacuum oven where it was heated at 85ºC for 30 minutes. Then the mixture was taken back to hot magnetic stirrer and heated to 70ºC after which a 2g 0f silicone reagent was added while it was being heated and stirred for 30 minutes. Then the temperature was increased to 85ºC and 4g of activated carbon was added to each 100 ml of the oil sample, heated and stirred for 30 minutes. Then the mixture was separated using filter paper.

Nano-fluids Preparation

The MgO Nano-particles powder was purchased from Sky Spring Nanomaterials, Inc., U. S. A, the size of the nanoparticles is 10-20nm and the surface was modified with Epoxy Group and it's dispersible as mentioned by the company. Nano-fluids are prepared by two step process. The volume concentration of 0.2%, 0.4%, 0.6%, 0.8%, and 1.0% of powdered nanoparticles and purified castor oil was made respectively. To make the MgOnanoparticles more stable and remain more dispersed, each sample was stirred for 3-4 hours using magnetic stirrer, then the samples were taken for analysis.

X-ray fluorescence
XRF stands for X-ray fluorescence. It is a non-destructive analytical technique used to determine the elemental composition of a material. X-ray fluorescence spectrometers use X-rays to identify the elements present in a sample.

Samples Measurement
Viscosity
Viscosity, resistance of a fluid (liquid or gas) to a change in shape, or movement of neighboring portions relative to one another. Viscosity denotes opposition to flow. Thereciprocal of the viscosity is called the fluidity, a measure of the ease of flow. Molasses, for example, has a greater viscosity than water. Because part of a fluid that is forced to move carries along to some extent adjacent parts, viscosity may be thought of as internal friction between the molecules; such friction opposes the development of velocity differences within a fluid. Viscosity is a major factor in determining the forces that must be overcome when fluids are used in lubrication and transported in pipelines. It controls the liquid flow in such processes as spraying, injection molding, and surface coating. For many fluids the tangential, or shearing, stress that causes flow is directly proportional to the rate of shear strain, or rate of deformation, that results. In other words, the shear stress divided by the rate of shear strain is constant for a given fluid at a fixed temperature. This constant is called thedynamic, or absolute, viscosity and often simply the viscosity. Fluids that behave in this way are calledNewtonianfluids in honor ofSirIsaacNewton, who first formulated this mathematical description of viscosity. Digital viscometer will be use examine the viscosity of the oil in this work.

Density
Density is the measurement of how tightly a material is packed together. It is defined as the mass per unit volume. Density (ρ) has the relation of.

$$\rho = \frac{M}{V} \quad (1)$$

Where: ρ is the density, m is the mass of the object and V is the volume of the object.

Specific gravity
The specific gravity of a substance is the ratio of the density of the substance to the density of a reference substance. The most commonly used reference substance is water at 4 degrees Celsius, which has a density of 1 g/cm3.

$$S.G = \frac{\text{Mass of oil}}{\text{Mass of equal volume of water}} \text{ or } \frac{\text{Density of oil}}{\text{Density of water}} \quad (2)$$

Results and Discussions
Result of xrf of MgO nanoparticle

Table 1: XRF of MgO nanoparticle

Oxide	Fe_2O_2	Ni_2O	CuO	ZnO	Ta_2O_5	Na_2O	MgO	Al_2O_3	SiO_2	P_2O_2	SO	Cl	CaO	TiO	LOI
Perc. Com.(%)	.10708	.00146	.00589	.00203	.0331	.088	95.1510	.6731	1.2565	.01008	.1408	.0649	.4570	.02332	1.895

From the foregoing data received in table1, the magnesium oxide nano particles has the purity of 95.15%. While the remaining oxide compounds are found to be impurities.

XRF analysis provides qualitative and quantitative data. In this case, the Percentage Composition (%)" column represents the weight percentage of each element. LOI (Loss on Ignition) refers to the weight loss of the sample due to heating. It may indicate the presence of volatile compounds (e.g., water, CO_2) in the material compound.

Scanning Electron Microscope (SEM)
Figure 2 demonstrate the phase morphology for based magnesium oxide nano particle**.** It shows from a scanning electron microscope micrographs, the sample possess the poly grains nature.

Furthermore, each of the precursor of MgO was chemically analyzed by using the Energy Dispersive X-ray Fluorescence analyses as shown in figure2 all the measure elements were in oxide form.

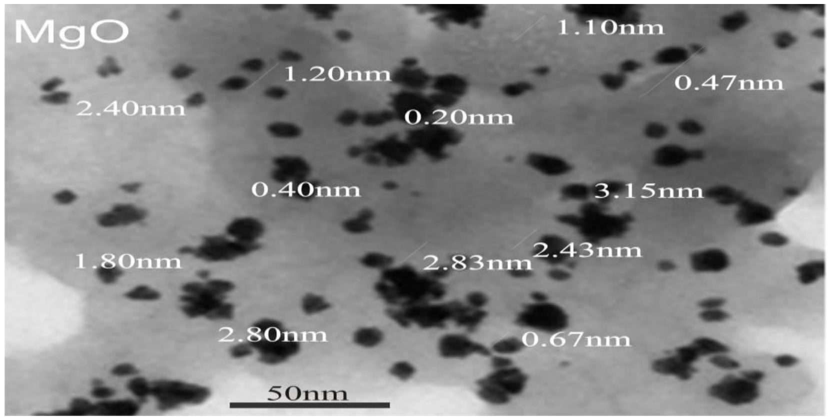

Figure 2: SEM with EDX of MgO nanoparticle

Viscosity

The viscosity of crude castor oil was determined using digital viscometer at a temperature 10^0C to 100^0C, Toque Speed: 50RPM, and Accuracy: 6^0C to 30^0C the table below is the result obtained.

Table 2. viscosity of crude castor oil

S/N	1	2	3	4	5	6	7	8	9	10
Temp. (^{0}C)	10	20	30	40	50	60	70	80	90	100
Viscosity(Cp)	22.91	19.80	12.28	11.32	9.83	9.00	8.41	7.01	7.34	6.02

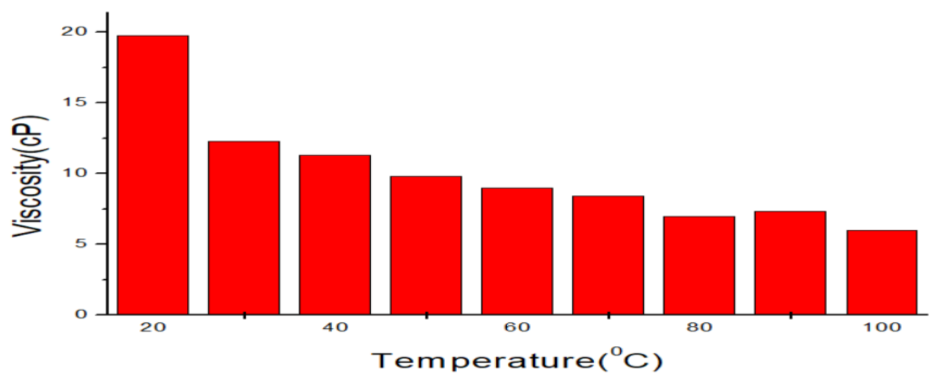

Figure 3: Viscosity of crude castor oil

The Figure 3 is a bar graph that shows the viscosity of crude castor oil at different temperatures. The x-axis of the graph is labeled "Temperature (°C)" and the y-axis is labeled "Viscosity (Cp)". The bars on the figure 3 are labeled with the viscosity of the oil at each temperature. For example, The Figure 3 shows that the viscosity of crude castor oil decreases as the temperature increases. This is because the oil molecules are more closely packed together at lower temperatures, which makes it more difficult for them to flow. As the temperature increases, the oil molecules move more apart, which makes it easier for them to flow and thus reduces the viscosity of the oil.

Viscosity of esterified oil

The viscosity of esterified castor oil was determined using digital viscometer at a temperature 10^0C to 100^0C, Toque Speed: 50RPM, and Accuracy: 6^0C to 30^0C the table 3 below is the result obtained.

Table 3: Viscosity of esterified castor

S/ N	1	2	3	4	5	6	7	8	9	10
Temp. (^{0}C)	10	20	30	40	50	60	70	80	90	100
Viscosity(Cp)	18.11	16.81	11.23	9.48	8.00	8.80	7.81	7.01	6.34	5.02

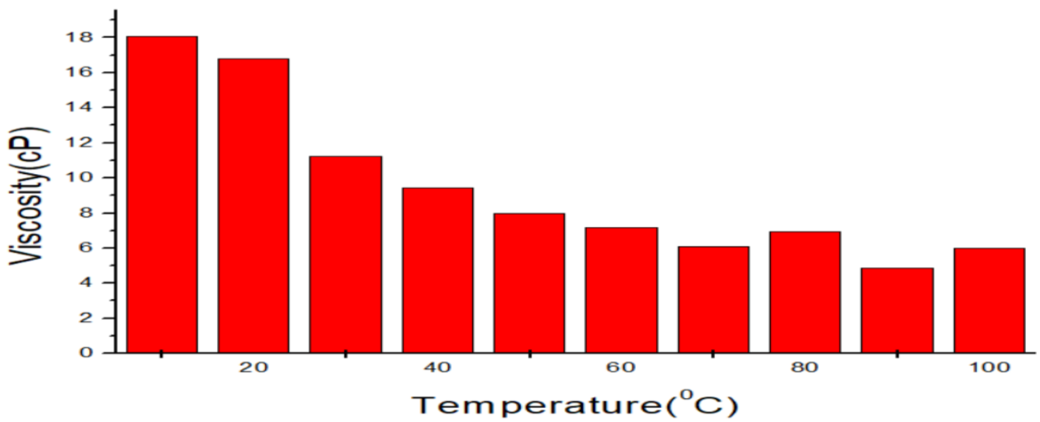

Figure 4: Viscosity of Esterified castor

Viscosity of transesterified oil

The viscosity of esterified castor oil was determined using digital viscometer at a temperature 10^{0}C to 100^{0}C, Toque Speed: 50RPM, and Accuracy: 6^{0}C to 30^{0}C the table below is the result obtained.

Table 4. Viscosity of transesterified oil

S/ N	1	2	3	4	5	6	7	8	9	10
Temp. (^{0}C)	10	20	30	40	50	60	70	80	90	100
Viscosity(Cp)	13.42	12.23	7.72	6.20	5.88	5.29	5.00	4.20	2.81	1.70

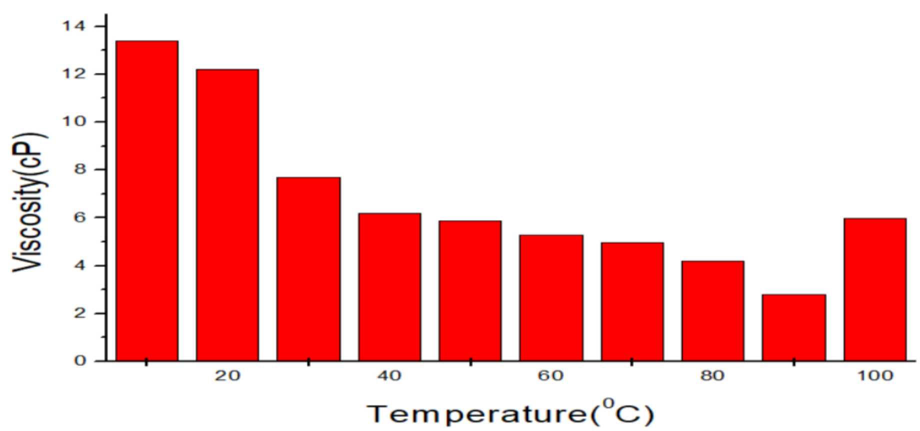

Figure 5: Viscosity of Transesterified

The Figure 5 shows that the viscosity of transesterified castor oil decreases as the temperature increases. In other words, the hotter the oil, the thinner it is. This is a typical characteristic of most fluids. The y-axis of the Figure 5 is labeled Viscosity (Cps). Cp stands for centipoise, a unit of dynamic viscosity. The x-axis of the Figure 5 is labeled Temperature (°C).

The data points on the graph show that the viscosity of esterified castor oil is about 18 Cps at 20 degrees Celsius, and about 4 Cps at 100 degrees Celsius.

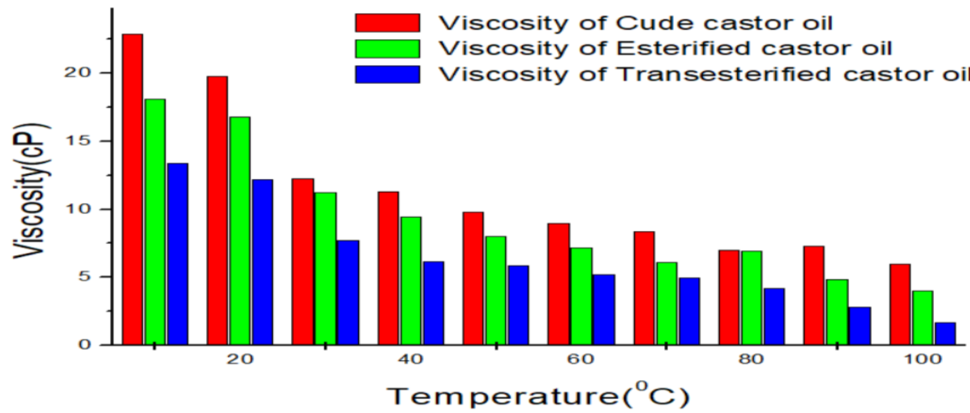

Figure 6: Viscosity of Crude, Esterified and transesterified castor oil

The Figure 6 shows the viscosity of crude, esterified, and transesterified castor oil at different temperatures. Viscosity is a measure of a fluid's resistance to flow. Higher viscosity fluids are thicker and flow more slowly than lower viscosity fluids.The Figure 6 shows that crude castor oil has the highest viscosity, followed by transesterified castor oil, and then esterified castor oil. This means that crude castor oil is the thickest and flows the slowest, while esterified castor oil is the thinnest and flows the fastest.

The viscosity of all three oils decreases as the temperature increases. This is because as the temperature increases, the molecules in the oil have more energy and are able to move around more easily. This makes the oil less viscous and easier to flow.

Table 5: Viscosity of transesterified castor oil (Biodiesel) doped by MgO nanoparticle

S/ N	Temp. (^{0}C)	0.0% MgO(Cp)	0.2% MgO(Cp)	0.4% MgO(Cp)	0.6% MgO(Cp)	0.8% MgO(Cp)	1.0% MgO(Cp)
1	10	13.42	12.59	9.00	10.46	12.23	11.54
2	20	10.23	11.90	9.21	10.30	11.69	10.52
3	30	7.72	10.54	6.00	10.00	11.10	10.01
4	40	6.20	11.10	5.50	8.31	10.31	9.67
5	50	5.88	11.31	5.78	8.50	9.43	8.48
6	60	5.21	10.93	4.34	7.45	9.00	8.01
7	70	5.00	10.31	4.31	6.00	7.43	8.78
8	80	4.20	9.15	4.89	9.50	6.36	7.34
9	90	2.81	8.II	4.01	8.11	6.01	7.13
10	100	1.70	7.97	3.00	6.21	5.02	7.89

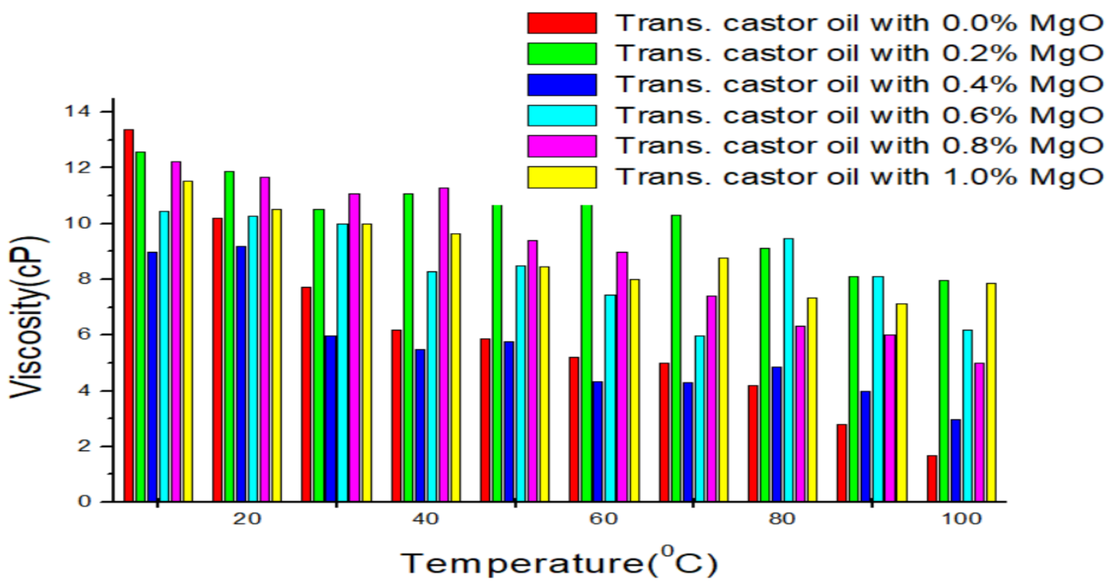

Figure 7: Viscosity of Transesterified castor oil doped with 0.0%, 0.2%, 0.4%, 0.6%, 0.8% and 1.0% MgO nanoparticle

The Figure 7 shows the viscosity of transesterified castor oil that has been doped with varying amounts of magnesium oxide (MgO) nano particle. The x-axis of the Figure 7 is labeled Temperature (°C) and the y-axis is labeled Viscosity (Cp). There are six lines on the Figure 7, each representing a different MgO concentration. The lines increase in viscosity as the MgO concentration increases. From bottom to top, the lines represent the following MgO concentrations. For all six concentrations, the viscosity of the transesterified castor oil increases as the temperature increases.In general, doping a liquid with nanoparticles can increase its viscosity. This is because the nanoparticles interfere with the movement of the liquid molecules, making it harder for the liquid to flow. In the case of transesterified castor oil, it is possible that the MgO nanoparticles are causing the oil to become more viscous.

Result of density

The density of the samples is calculated as was describe in the literature and the result is summarized on the Table 6. The table shows the density of crude, esterified, and transesterified castor oil, along with densities of biodiesel and diesel standards for comparison. Density is a measure of how much mass is in a certain volume. In simpler terms, it's how heavy something is for its size.The table shows that crude castor oil has the lowest density (0.82 kg/m^3), while transesterified castor oil has the highest (0.87 kg/m^3). Biodiesel and diesel standards have densities of 0.88 kg/m^3 and 0.85 kg/m^3, respectively.It was observed that the density of castor oil increases as it goes through the purification and transesterification processes. This means that the processed oil becomes denser or heavier for its size.

Table 6: Result of density

S/N	Sample	Density (g/cm^3)	Density (kg/m^3)
1	Crudecastor oil	0.82	820.00
2	Purified castor oil	0.84	840.00
3	Transesterified castor oil	0.87	870.00
4	Biodiesel standard	0.88	880.00
5	Diesel standard	0.85	850.00

Table 7: shows the density of Transesterified castor oil doped by MgO nanoparticle

MgO(%)	0.0	0.2	0.4	0.6	0.8	1.0
Density (Kg/m^3)	820	850	860	880	910	940

The Table 7 shows that the density of the transesterified castor oil increases as the percentage of MgO doping increases. For example, the density of the undoped castor oil (0% MgO) is 820 kg/m^3, while the density of the castor oil doped with 1.0% MgO is 940 kg/m^3.

Result of Specific Gravity

The specific gravity of the samples is calculated as was describe in the literature and the result is summarized on the Table 8. The table shows that crude castor oil has the highest specific gravity (0.952), followed by purified castor oil (0.945), and then transesterified castor oil (biodiesel) (0.911). Biodiesel standards are listed from 0.903 to 0.921, and diesel standards are listed from 0.82 to 0.95.In general, the higher the specific gravity, the denser the substance. So, crude castor oil is the densest type of castor oil in the table, and biodiesel is the least dense.The specific gravity of castor oil can vary depending on the source of the oil and how it is processed.

The specific gravity of castor oil is important for some industrial applications, such as the production of biodiesel.Biodiesel is a type of fuel that is made from vegetable oils or animal fats. It is a renewable and biodegradable fuel that can be used in place of diesel fuel.

Table 8: Result of Specific gravity

S/N	**Sample**	**Specific gravity**
1	Crude Castor oil	0.952
2	Purified Castor oil	0.945
3	Transesterified Castor oil	0.911
4	Biodiesel standard	0.903 to 0.921
5	Diesel standard	0.82 to 0.95

Table 9: Specific gravity of the MgO nanoparticle

MgO (%)	0.0	0.2	0.4	0.6	0.8	1.0
Specific gravity	0.911	0.912	0.914	0.915	0.918	0.990

The Table 9 below shows the density of Transesterified castor oil doped by MgO nano particle.

CrudeOil: The specific gravity of the crude oil is around 0.85-0.86, which is less dense than water.

Esterified Oil: Esterified oil shows a slight increase in specific gravity compared to crude oil, ranging from 0.875 to 0.885.

Biodiesel (Transesterified Oil): Biodiesel has the highest specific gravity among the three fuels, ranging from 0.89 to 0.900. This indicates it's denser than both crude and esterified oil, but still slightly less dense than water.The table also shows that doping all three fuels with MgO increases their specific gravity. This means adding MgO makes the fuels denser.

Denser fuels can have some advantages in terms of engine performance and efficiency. However, there may be trade-offs depending on the specific engine design. It's important to consult the engine manufacturer's recommendations for appropriate fuel types.

CONCLUSION

The dynamic viscosity of diesel and biodiesel can vary depending on the temperature and specific composition of the biodiesel. However, ASTM D6751 is the standard specification for biodiesel fuel. According to this standard, the dynamic viscosity of diesel at 40^0C should be between 2.5 and 3.02 cP, while that of biodiesel is between 1.9 and 6.0 cP. Also, according to the standard, the density of the fuel diesel is 850.00 kg/m3, and that of biodiesel is 880 kg/m^3. Also, the specific gravityty of diesel is between 0.82 and 0.95. The viscosity at 40 and 100^0C observed in this work is similar to that of the diesel and biodiesel standards; likewise, the viscosity of transesterified castor oil (biodiesel) doped by MgO nanoparticles at 40^0C is 5.50 cP, which is similar to that of the biodiesel standard. Also, the density of transesterified castor oil was observed to be 870 kg/m^3, and that of transesterified castor oil doped with 0.4% MgO nanoparticles was observed to be 879 kg/m^3, which is close to that of the biodiesel standard. The specific gravity study in this work is 0.911, which is also within the range of the biodiesel standard, and that of the transesterified castor oil doped with 0.4% MgO nanoparticles is 0.94, which is also within the range of the biodiesel standard value. Biodiesel doped with MgO nanoparticles has several potential advantages, which improved the combustion and act as catalysts, by enhancing the combustion process of the biodiesel. In the same vein the doping of MgO nanoparticles has reduced the harmfulemissions and increased the efficiency processes. This leads to the reduction of carbon monoxide and hydrocarbons respectively from the environment. This contributes to cleaner burning and potentially less air pollution, as well as enhanced fuel properties because doping biodiesel with MgO nanoparticles may improve its viscosity and density, making it behave more similarly to conventional diesel fuel. This can lead to better fuel injection and atomization, improving engine performance, and increased stability because the nanoparticles may improve the oxidative stability of biodiesel, meaning it resists degradation over time. This can be beneficial for storage and transportation. Therefore, biodiesel doped with MgO nanoparticles is a promising development for alternative fuels. It has the potential to improve engine performance, reduce emissions, and enhance the overall usability of biodiesel. However, it's important to note that research on this topic is ongoing. More studies are needed to fully understand the long-term effects and optimize the use of MgO nanoparticles in biodiesel.

REFERENCE

Ağbulut, Ü., Karagöz, M., Sarıdemir, S., & Öztürk, A. (2020). Impact of various metal-oxide based nanoparticles and biodiesel blends on the combustion, performance, emission, vibration and noise characteristics of a CI engine. *Fuel*, *270*. https://doi.org/10.1016/j.fuel.2020.117521

Atadashi, I. M., Aroua, M. K., Aziz, A. R. A., & Sulaiman, N. M. N. (2013). Journal of Industrial and Engineering Chemistry The effects of catalysts in biodiesel production : A review. *Journal of Industrial and Engineering Chemistry*, *19*(1), 14–26. https://doi.org/10.1016/j.jiec.2012.07.009

Foroutan, R., Peighambardoust, S. J., Mohammadi, R., Peighambardoust, S. H., & Ramavandi, B. (2023). Jou rna lP. *Environmental Technology & Innovation*, 103307. https://doi.org/10.1016/j.eti.2023.103307

Hosseinzadeh-Bandbafha, H., Tabatabaei, M., Aghbashlo, M., Khanali, M., & Demirbas, A. (2018). A comprehensive review on the environmental impacts of diesel/biodiesel additives. In *Energy Conversion and Management* (Vol. 174, pp. 579–614). Elsevier Ltd. https://doi.org/10.1016/j.enconman.2018.08.050

Karki, B., Dhobi, S. H., Karki, B., Dhobi, S. H., & Dhobi, I. (2021). Optical properties of Transparent Liquid: Water, Oils, and Honey. *J. Mater. Environ. Sci*, *2021*(12), 12. http://www.jmaterenvironsci.com

Kennedy, K., & Anthony, O. (2023). Heliyon Experimental and theoretical assessment of phenomena linked with separation and purification of biodiesel from Ricinus communis seed oil. *Heliyon*, *9*(6), e16536. https://doi.org/10.1016/j.heliyon.2023.e16536

Kumar, A., Rawat, N., Trivedi, J., & Singh, R. (2023). Bioresource Technology Reports Biodiesel production using novel solvent from agricultural crop Cannabis sativa L . and Sapium sebiferum L . and their fuel properties characterisation using blends. *Bioresource Technology Reports*, *23*(May), 101555. https://doi.org/10.1016/j.biteb.2023.101555

Muhammad, M. B., & Chandra, R. (2022). Turning neem leaves anti-microbial substrate to methane-producing co-substrate for the generation of clean and affordable electricity through biogas : A case study. *Sustainable Energy Technologies and Assessments*, *52*(PA), 101982. https://doi.org/10.1016/j.seta.2022.101982

Rashid, A. Bin. (2023). *Review Article Utilization of Nanotechnology and Nanomaterials in Biodiesel Production and Property Enhancement*. *2023*.

Sajjad, N., Orfali, R., Perveen, S., Rehman, S., Sultan, A., Akhtar, T., & Nazir, A. (2022). *Biodiesel Production from Alkali-Catalyzed Transesterification of Tamarindus indica Seed Oil and Optimization of Process Conditions*. *27*(10). https://doi.org/10.3390/molecules27103230

Ağbulut, Ü., Karagöz, M., Sarıdemir, S., & Öztürk, A. (2020). Impact of various metal-oxide based nanoparticles and biodiesel blends on the combustion, performance, emission, vibration and noise characteristics of a CI engine. *Fuel*, *270*. https://doi.org/10.1016/j.fuel.2020.117521

Atadashi, I. M., Aroua, M. K., Aziz, A. R. A., & Sulaiman, N. M. N. (2013). Journal of Industrial and Engineering Chemistry The effects of catalysts in biodiesel production : A review. *Journal of Industrial and Engineering Chemistry*, *19*(1), 14–26. https://doi.org/10.1016/j.jiec.2012.07.009

Foroutan, R., Peighambardoust, S. J., Mohammadi, R., Peighambardoust, S. H., & Ramavandi, B. (2023). Jou rna lP. *Environmental Technology & Innovation*, 103307. https://doi.org/10.1016/j.eti.2023.103307

Hosseinzadeh-Bandbafha, H., Tabatabaei, M., Aghbashlo, M., Khanali, M., & Demirbas, A. (2018). A comprehensive review on the environmental impacts of diesel/biodiesel additives. In *Energy Conversion and Management* (Vol. 174, pp. 579–614). Elsevier Ltd. https://doi.org/10.1016/j.enconman.2018.08.050

Karki, B., Dhobi, S. H., Karki, B., Dhobi, S. H., & Dhobi, I. (2021). Optical properties of Transparent Liquid: Water, Oils, and Honey. *J. Mater. Environ. Sci*, *2021*(12), 12. http://www.jmaterenvironsci.com

Kennedy, K., & Anthony, O. (2023). Heliyon Experimental and theoretical assessment of phenomena linked with separation and purification of biodiesel from Ricinus communis seed oil. *Heliyon*, *9*(6), e16536. https://doi.org/10.1016/j.heliyon.2023.e16536

Kumar, A., Rawat, N., Trivedi, J., & Singh, R. (2023). Bioresource Technology Reports Biodiesel production using novel solvent from agricultural crop Cannabis sativa L . and Sapium sebiferum L . and their fuel properties characterisation using blends. *Bioresource Technology Reports*, *23*(May), 101555. https://doi.org/10.1016/j.biteb.2023.101555

Muhammad, M. B., & Chandra, R. (2022). Turning neem leaves anti-microbial substrate to methane-producing co-substrate for the generation of clean and affordable electricity through biogas : A case study. *Sustainable Energy Technologies and Assessments*, *52*(PA), 101982. https://doi.org/10.1016/j.seta.2022.101982

Rashid, A. Bin. (2023). *Review Article Utilization of Nanotechnology and Nanomaterials in Biodiesel Production and Property Enhancement*. *2023*.

Sajjad, N., Orfali, R., Perveen, S., Rehman, S., Sultan, A., Akhtar, T., & Nazir, A. (2022). *Biodiesel Production from Alkali-Catalyzed Transesterification of Tamarindus indica Seed Oil and Optimization of Process Conditions*. *27*(10). https://doi.org/10.3390/molecules27103230