International Journal in Physical and Applied Sciences
Volume 11 Issue 10, October 2024 ISSN: 2394-5710 Impact Factor: 8.657
Journal Homepage: http://ijmr.net.in, Email: irjmss@gmail.com
Double-Blind Peer Reviewed Refereed Open Access International Journal

EFFECTS OF MGO NANOPARTICLES ON THE RHEOLOGICAL PROPERTIES OF TRANS – ESTERIFIED OLIVE OIL

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ABSTRACT

Biodiesel is a renewable, biodegradable, and environmentally friendly fuel that offers an energy-efficient alternative to fossil fuels without compromising engine performance. It addresses the dual challenges of fossil fuel depletion and environmental degradation. This study focused on examining the impact of MgO nanoparticles on the rheological properties of trans – esterified olive oil. The crude olive oil was purified, trans-esterified, and MgO nanoparticles were added to the trans – esterified oil in concentrations ranging from 0.2% to 1.0%, in intervals of 0.2%. X-ray fluorescence (XRF) and scanning electron microscopy (SEM) were employed to analyse the surface morphology and internal structure of the nanoparticles. The results revealed that a concentration of 0.6% MgO nanoparticles significantly improved the rheological properties of the biodiesel. Thus, it was concluded that the optimal concentration of MgO nanoparticles for enhancing the properties of the nanofluid is 0.6%.

Keywords: Biodiesel production, MgO nanoparticles, Rheological properties, Trans-esterified olive oil, Nanofluids optimization

INTRODUCTION

Biodiesel is increasingly being recognized as an environmentally friendly fuel, and its market demand is expected to surge as a viable renewable energy source in the near future. This mono alkyl ester, derived from vegetable or animal sources, can be blended with diesel fuel to produce similar characteristics while reducing exhaust emissions [1-20]. However, the primary challenges associated with vegetable oils are their high viscosity and low volatility, which lead to suboptimal combustion in diesel engines. Transesterification effectively lowers the viscosity of biodiesel for lubrication and enhances its other properties [21-30].

Lubricants play a crucial role in various industries by reducing friction in machinery and materials. In 2020, global lubricant consumption reached approximately 39 million metric tons, with a projected growth rate of 1.2% over the next decade [13]. Petroleum-based oils constitute about 85% of all lubricants used worldwide, and their extensive use has significantly harmed the environment. Key issues arise from improper usage, leading to surface and groundwater contamination, air pollution, soil degradation, and consequent contamination of agricultural products and food. Heightened environmental concerns and stricter regulations regarding pollution will drive the demand for renewable and biodegradable lubricants [31-37].

The introduction of nanoparticles into lubricating oils is anticipated to enhance oxidative stability, reduce friction coefficients, and increase the load-bearing capacity of mechanical components. Several mechanisms, including the ball bearing effect, protective film mending effect, and polishing effect, have been proposed to explain the lubrication and rheological improvements of nanoparticle-suspended lubricating oils [38]. These effects can be categorized into two main types: the direct impact of nanoparticles on lubrication enhancement and their secondary effect on surface improvement [14,38].

Recent studies have shown that nanoparticles serve as innovative additives in diesel and biodiesel fuels, reducing exhaust emissions while improving engine performance. Many researchers are focusing on using nano-additives to modify fuel properties and enhance performance and emission characteristics [31-40]. Given the stringent emission regulations governing pollutants produced by compression ignition (CI) engines, fuel additives can alter various fuel properties, including density, sulphur concentration, and volatility, all of which influence emissions.

The potential for nanoparticle addition as a secondary energy carrier has been shown to enhance combustion properties, prompting investigations into the practicality of using these modified fuels in diesel engines. Commonly used metal oxides such as Cu, Fe, Ce, Pt, B, Al, and Co have been employed as additives in diesel and biodiesel fuel blends [32-36, 38-49]. Studies have indicated that cerium nano-additives can influence size distribution and composition of particulate matter (PM), improving efficiency and impacting physicochemical properties and emissions. Furthermore, the catalytic activity of CeO_2 nanoparticles, attributed to their high surface area, has been linked to enhanced fuel efficiency and reduced emissions [50-52].

Despite these advancements, the effects of MgO nanoparticles on the rheological properties of biodiesel derived from olive oil have not yet been explored. This study aims to investigate how MgO nanoparticles affect the rheological properties of olive-based biodiesel. The incorporation of nanoparticles is expected to enhance the performance characteristics of vegetable oils, and even a small addition of MgO nanoparticles may improve some rheological features of the fuel.

METHODOLOGY

X – ray Fluorescence (XRF)

The characterization of MgO nanoparticles using X-ray fluorescence was conducted at the central laboratory of Umaru Musa Yar'adua University in Katsina. The analysis was performed with an ARL QUANT'X EDXRF Analyzer (S/N 9952120) to determine the percentage concentration of the oxide present in the nanoparticle sample used for this research.

Scanning Electron Microscopy (SEM)

The surface morphology of the MgO nanoparticles was examined using a multipurpose Scanning Electron Microscope (SEM) PHENOM PROXMVE016477830 at Umaru Musa Yar'adua University in Katsina. A small amount of the sample powder was placed onto carbon tape affixed to the holder. Excess powder was then removed using an air gun to leave only a few particles on the tape. Subsequently, the sample was placed in the SEM chamber for analysis. The SEM was operated at 10 kV, and images of the sample were captured at a magnification of X100.

Infrared Spectral Analysis

The Fourier Transform Infrared (FT-IR) spectroscopy instrument was employed to identify the functional groups present in the sample. A liquid sample was prepared in the form of a thin film by placing it between two potassium bromide discs made from single crystals. A drop of the liquid was applied to one disc, which was then covered with the second disc, effectively spreading the sample into a thin film. The analysis was conducted at the National Research Institute for Chemical Technology (NARICT) in Zaria.

Sample Purification

The purification of the olive oil was carried out through several steps. First, 200 ml of olive oil was measured using a measuring cylinder and pre-heated to 70 °C with a hot magnetic stirrer equipped with a thermometer. Next, 1.5 cc of citric acid was measured and added to the heated oil, which was continuously stirred for 15 minutes at 70 °C. Following this, 4 ml of 8% NaOH (prepared by dissolving 8 g of NaOH in 100 ml of distilled water) was introduced to the oil and heated while stirring for an additional 15 minutes at the same temperature. The mixture was then transferred to a vacuum oven, where it was heated to 85 °C for 30 minutes. Afterward, the liquid was returned to the hot magnetic stirrer and heated again to 70 °C before adding 2 g of a silicon reagent, stirring for 30 minutes. The temperature was subsequently raised to 85 °C, and 4 grams of activated carbon were added for every 100 millilitres of the oil sample. This mixture was then heated and agitated for another 30 minutes before being separated using filter paper.

Trans – esterification

A sample of 60 g of crude oil was measured into a 250 ml conical flask and heated while stirring to a temperature of 60 – 65 °C using a hot magnetic stirrer. Meanwhile, 0.6 g of NaOH was measured with an electronic balance and dissolved in 21 ml of methanol, which was then heated for 60 minutes with stirring on the hot magnetic plate. After maintaining a consistent temperature of 65 °C for an hour, the mixture was transferred into a separating funnel via a glass funnel. It was allowed to cool for about 40 minutes, during which two distinct liquid layers formed: the upper layer being biodiesel and the lower layer consisting of triglyceride fatty acids. The biodiesel was then carefully separated from the byproduct.

Nano – fluid Preparation

The MgO nanoparticle powder was obtained from Sky Spring Nanomaterials, Inc. in the U.S.A. The nanoparticles measure between 10-20 nm in size and are modified with an epoxy group for enhanced dispersibility, as stated by the manufacturer. The preparation of nanofluids involved a two-step process, where volume concentrations of 0.2%, 0.4%, 0.6%, 0.8%, and 1% of the powdered nanoparticles were mixed with purified oil. To ensure greater stability and dispersion of the nanoparticles, each sample was stirred for 3-4 hours using a magnetic stirrer before being taken for analysis.

Measurement of Viscosity

Viscosity was determined using a Brookfield viscometer set to a speed of 50 rpm with a spindle size of 2, as only a small amount of the sample was needed for measurement. The detailed procedure for measuring viscosity is as follows: the sample was poured into a beaker, the spindle was secured in place, and the machine was activated. The angular speed was selected on the viscometer, and the viscosity reading was taken and recorded. This procedure was then repeated for the purified sample.

RESULTS AND DISCUSSIONS

SEM

Figure 1 below displays the scanning electron microscope image of the MgO nanoparticles. The image reveals that the oxide exhibits a white, irregular morphology characterized by a cloudy structure.

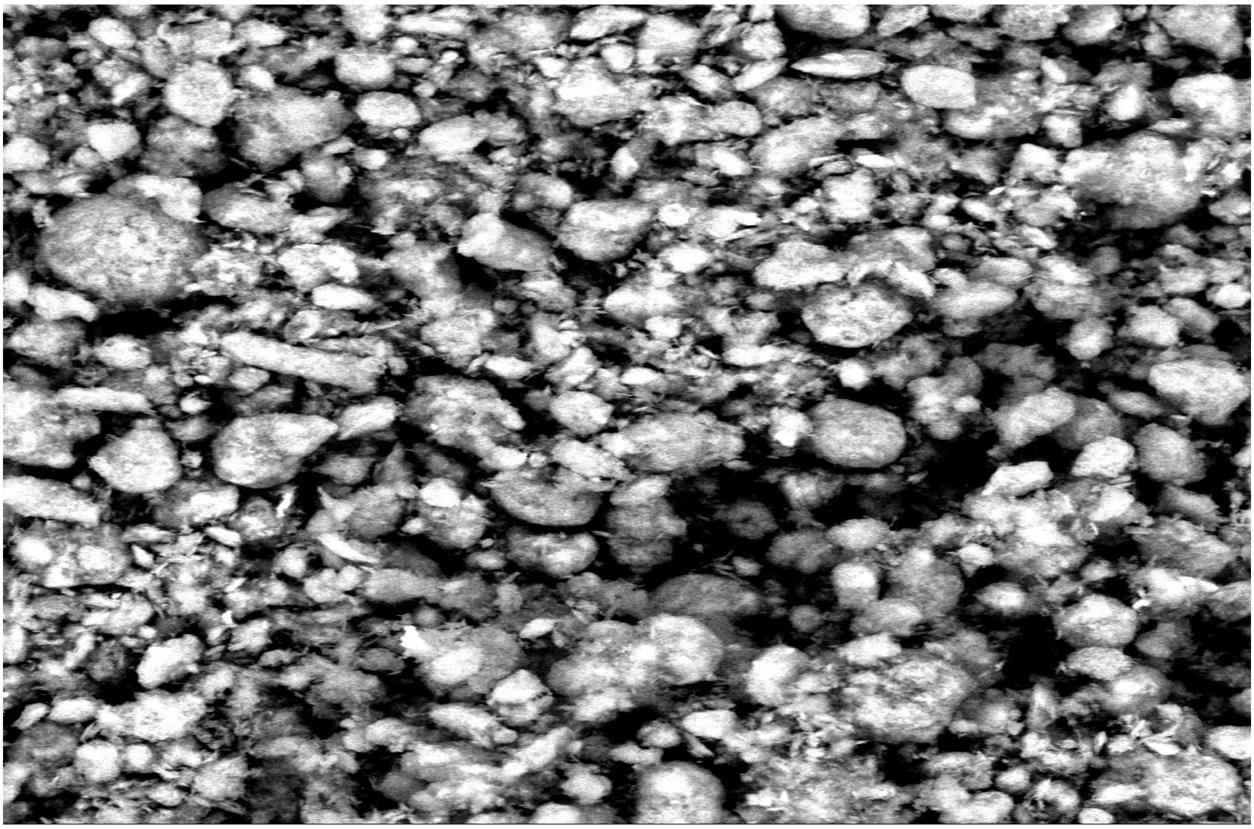

Figure 1: SEM of MgO

XRF

The X-ray fluorescence (XRF) analysis of the MgO nanoparticles was performed to examine the percentage concentration of the various compounds in the sample utilized for this research, with the results presented in Table 1 below. The table indicates that MgO has the highest concentration at 92.4%, followed by SiO_2 at 2.49%. In contrast, NiO has the lowest concentration in the sample.

Table 1: Percentage Concentration of The Sample Element

Element	MgO	SiO_2	CaO	SO_3	Al_2O_3	P_2O_5	K_2O	Cl	La_2O_3	NiO
Conc. (%)	92.4	2.49	2.20	0.86	0.69	0.47	0.38	0.28	0.06	0.05

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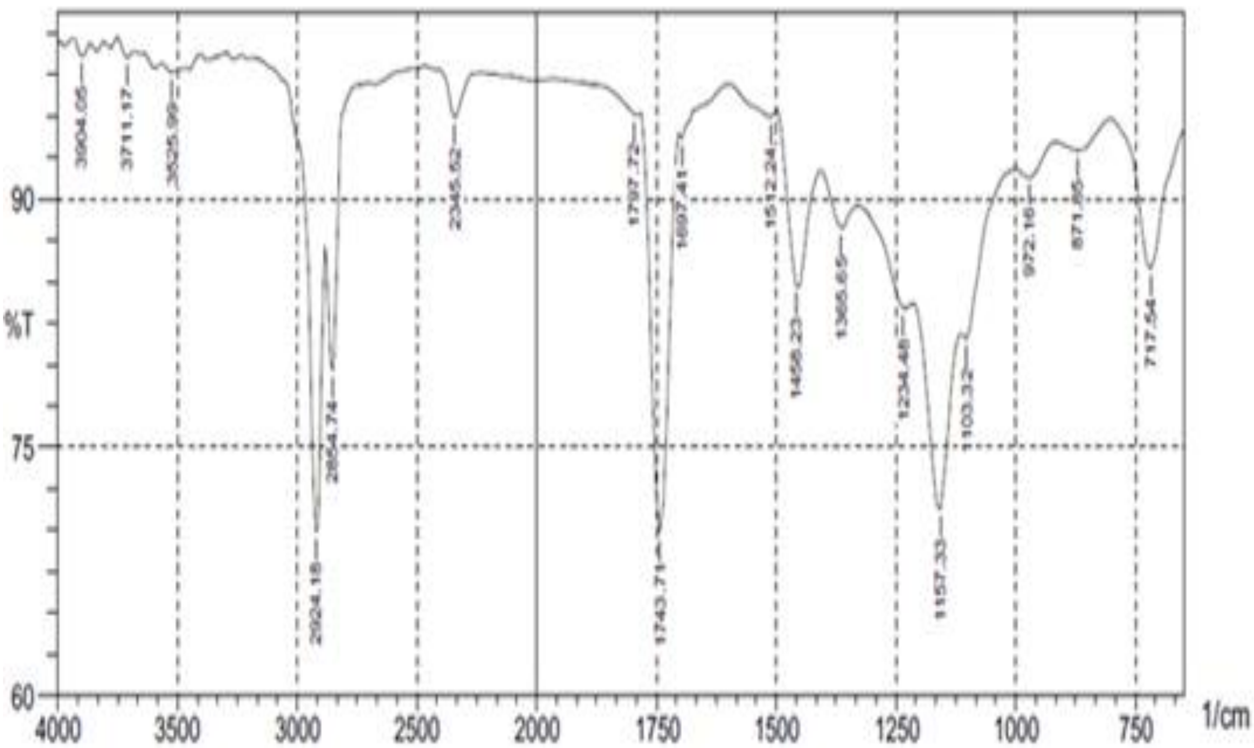
Figure 2 displays the FTIR spectrum showing transmittance (%) plotted against the wave number (cm^{-1}), reflecting the amount of light absorbed by specific molecules in the trans – esterified olive oil. According to Ismail et al. (2022), the bands with peaks between 650 and 1400 cm^{-1} and 1500 to 1800 cm^{-1} correspond to the C-O and C=O bonds, respectively, indicating the presence of ester (biodiesel) or ether groups in the sample. Additionally, the peaks between 2700 and 3000 cm^{-1} relate to C-H stretching, while those from 3000 to 3700 cm^{-1} correspond to the OH bond. Consequently, the ester was identified at the peaks of 717.54, 1157.33, and 1743.71.

Figure 2: FTIR of Trans – esterified Olive Oil



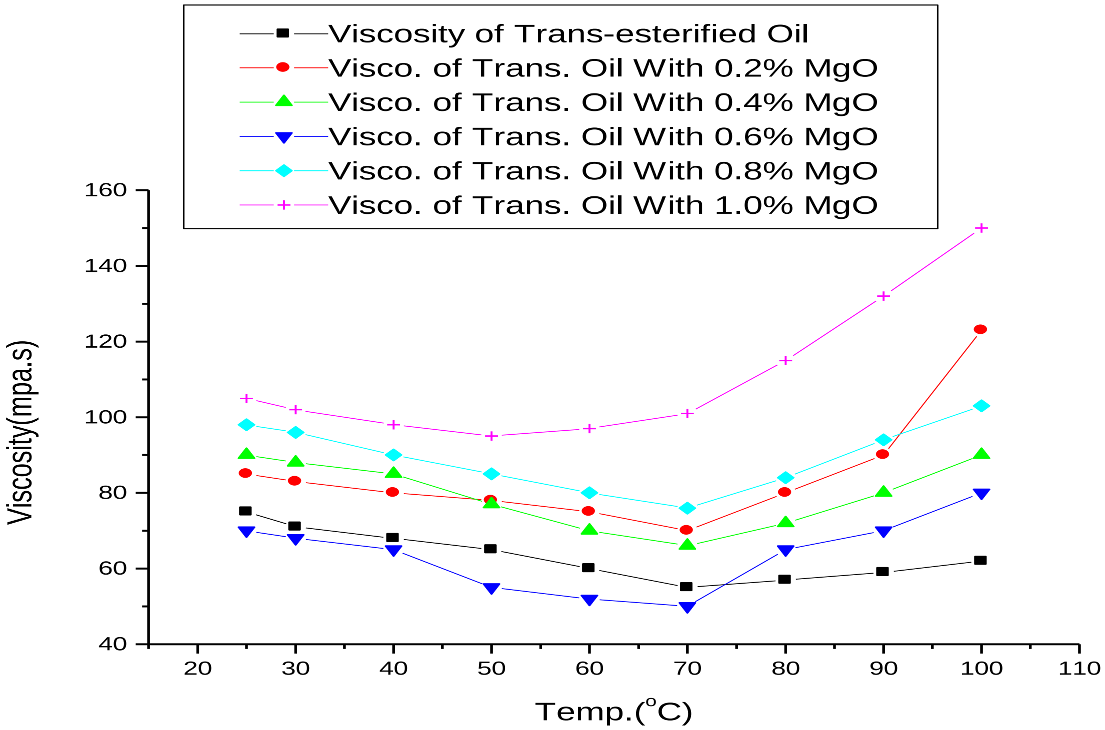


Figure 3: Viscosity Versus Temperature of Trans – esterified Olive Oil With Varied Concentration of MgO

Viscosity is recognized as the most critical parameter in biodiesel specifications, as it influences both the liquid flow capacity and the fuel atomization process within the injection system [21]. The transesterification of fatty acids leads to a reduction in viscosity while simultaneously enhancing volatility [22-35]. These characteristics facilitate engine operation and minimize waste production, such as coal and sludge. Additionally, viscosity analysis is vital for assessing the quality and purity of biodiesel; contaminants like residual soaps, unreacted glycerides, and oxidative degradation products can increase fluid viscosity, which can be indirectly evaluated by measuring viscosity at 70 °C [36-41]. Consequently, lower viscosity values of biofuels compared to crude oil indicate higher conversion efficiency of fatty acids into methyl esters.

Figure 3 illustrates the rheological behaviour of olive oil biodiesel across a temperature range of 20°C to 100°C with the addition of nanoparticles at concentrations of 0.2 wt% to 1.0 wt%. This temperature range was chosen to evaluate the flow performance of the olive biofuel during the heating cycle, allowing for detailed observation of flow characteristics under varying conditions. The rheograms in Figure 3 exhibited a significant surge with the incorporation of nanoparticles, displaying a slightly nonlinear trend on logarithmic scales when comparing temperature to viscosity [41-52]. As the temperature increased, viscosity values decreased; similarly, viscosity reduced with higher nanoparticle concentrations. Notably, viscosity increased progressively and significantly between 70°C and 100°C. The lowest viscosity value was recorded with the addition of 0.6 wt% MgO nanoparticles at 70°C, attributed to increased thermal motion among the biofuel components, which diminished the intermolecular forces and reduced flow resistance. Dynamic viscosity is a crucial physical property for various industrial processes, including fluid flow systems, heat exchangers, and pumping machines. It directly relates the applied nanoparticles to the velocity gradient, influencing the physical properties of the fuel. This finding is consistent with results reported by Ghannam [23]. A fluid is classified as Newtonian when its viscosity remains constant and is independent of shear rate at a specific temperature. Conversely, non-Newtonian fluids exhibit varying viscosity; if viscosity changes over time, they are termed thixotropic or rheopectic. If viscosity remains constant over time, they may be categorized as pseudoplastic, dilatant, plastic, or Bingham plastic.

CONCLUSION

The aim of this study is to examine the effects of MgO nanoparticles on the rheological properties of trans – esterified olive oil. The physical and chemical characteristics of the MgO nanoparticles were analysed using SEM, XRF, and XRD techniques. The SEM images reveal that the nanoparticles exhibit a white, irregular morphology with a cloudy structure. XRF analysis indicated that MgO comprises the highest percentage in the sample at 92.4%, followed by SiO_2 at 2.49%, while NiO shows the lowest percentage.

The viscosity values were observed to increase with rising temperature; conversely, viscosity decreased with the addition of nanoparticles. Notably, viscosity increased progressively and significantly when heated between 70°C and 100°C. The lowest viscosity was recorded with the addition of 0.6 wt% MgO nanoparticles at 70°C. This reduction can be attributed to the enhanced thermal motion of the biofuel components, which alleviated the intermolecular forces between the fuel molecules and decreased flow resistance. Therefore, it can be concluded that the optimal concentration of MgO to be used as an additive is 0.6 wt%.

Acknowledgement

The authors would like to acknowledge the financial support of Tertiary Education Trust Fund (TETFund) for sponsoring this research and the Directorate for Research and Development Federal University of Education, Kano for facilitating the process of accessing the research grant.

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