Experimental Evaluation of the Effect of Additive on Vegetable Oil-Based Lubricants

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ABSTRACT

This study investigates the physicochemical properties of vegetable oil-based lubricants derived from sesame and groundnut oils, with emphasis on the effect of a composite chemical additive. The additive formulation consisted of a fine mixture of aluminum oxide (Al_2O_3) and magnesium sulfate heptahydrate ($MgSO_4 \cdot 7H_2O$) combined with hydrogen peroxide and oleum, applied at varying concentration levels (10%, 20%, 30%, 40%, and 50% by volume). Key properties evaluated include kinematic viscosity, pour point, flash point, cloud point, specific gravity, thermal conductivity, acid value, free fatty acid, and saponification value, following established ASTM standards. Results indicate that increasing the additive concentration enhances the thermal conductivity of both oils, with sesame oil demonstrating superior thermal performance compared to groundnut oil. Conversely, groundnut oil exhibits better viscosity characteristics at higher additive concentrations, retaining greater lubricity, whereas sesame oil's viscosity decreases with increasing additive levels. Both oils, however, exhibit declining thermal conductivity and lubricity at elevated temperatures (50–70°C), revealing a significant limitation for high-temperature industrial applications. Physicochemical analysis further confirms that groundnut oil has a higher flash point (265°C) and saponification value, while sesame oil presents a lower pour point (−14.67°C), indicating better cold-temperature performance. These findings suggest that optimizing composite additive formulations can significantly improve the performance of bio-lubricants; nonetheless, further research is required to address high-temperature stability before these lubricants can be adopted for broader industrial use.

Keywords: Additives; lubricants; Groundnut oil; Sesame oil; Thermal conductivity; Vegetable oil-based lubricants; Viscosity

INTRODUCTION

The development and use of industrial lubricants have undergone substantial changes as a result of the increased emphasis on environmental sustainability worldwide. Traditional lubricants derived from petroleum are an effective means of reducing wear and friction in mechanical systems.

However, they present significant environmental challenges due to their potential toxicity and lack of biodegradability. (Singh & Chauhan, 2021). These challenges have fueled interest in alternative lubricants derived from renewable resources, particularly vegetable oils. Vegetable oil-based lubricants are becoming more and more popular due to their high biodegradability, low eco-toxicity, and the potential to reduce overreliance on non-renewable fossil fuels. (Rios, et al., 2022). Despite these advantages, certain drawbacks, including low heat resistance, poor oxidative stability, and susceptibility to hydrolytic degradation, have limited their use. (Song et al., 2019).

To improve the performance of lubricants based on vegetable oil, researchers are constantly investigating different approaches in an effort to get around these restrictions. One of the most promising approaches currently is the incorporation of chemical additives. (Stachowiak & Batchelor, 2018). Common types of additives include antioxidants, pour point depressants, anti-wear additives, extreme pressure additives, corrosion inhibitors and defoamers.

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Recent research studies suggest that adding nano-particles and nano-additives to vegetable oils as lubricants can significantly improve their tribological properties such as friction coefficient and wear rate; significantly improving the oxidative stability, frictional characteristics, and general durability of these bio-lubricants. (Kumar & Chauhan, 2023). The use of additives in vegetable oil-based lubricants is still severely limited by issues such as creating affordable additives, enhancing thermal resistance and oxidative stability, and guaranteeing compatibility with current systems. Additionally, not enough research has been done on the efficacy of particular additives under various operating circumstances. More thorough research is therefore required to completely comprehend the relationships between lubricants based on vegetable oil and the additives that are added to improve their functionality. (Zhang & Wang, 2021).

The findings from this research are expected to contribute to the ongoing development of environmentally friendly lubricants, offering practical solutions to the challenges associated with the use of bio-lubricants in the ever increasing demand for its applications. This work also underscores the importance of innovative additive technologies in advancing the performance and sustainability of industrial lubricants, aligning with global efforts to reduce environmental impact and promote the use of renewable resources

MATERIALS AND METHODS

For a comprehensive analysis of the evaluation of effects of Additives on vegetable oil based lubricants, the following materials are required :

Sesame seed and Groundnut seed

Distilled water

Antioxidant (20% by volume concentration. Hydrogen peroxide, 32g fine mixture AL203 + MgSO4 heptahydrate and 5 ml oleum. Thoroughly mixed)

The composite additive formulation was specifically designed based on the distinct physicochemical roles of each component. Aluminium oxide (Al_2O_3) nanoparticles were selected for their well-documented ability to form a protective tribofilm on lubricated surfaces, reducing friction and wear through a mending and polishing mechanism (Kumar & Chauhan, 2023). Magnesium sulfate heptahydrate ($MgSO_4 \cdot 7H_2O$) was incorporated as a boundary lubricant additive; its layered crystalline structure allows it to shear easily under contact stress, thereby lowering the coefficient of friction (Singh & Chauhan, 2021). Hydrogen peroxide serves as an oxidative coupling agent that promotes surface passivation and assists in dispersing the solid particles homogeneously within the oil matrix. Oleum (fuming sulphuric acid) acts as a chemical modifier that facilitates esterification of free fatty acids present in the vegetable oils, reducing the acid value and improving oxidative stability (Rios et al., 2022). The five concentration levels (10–50% by volume) were chosen to establish a statistically meaningful dose–response trend and to identify the optimal additive loading, consistent with the approach adopted by Zhang & Wang (2021).

Detergent

Tissue paper

litre of ethanol

Equipment and Apparatus

(a) Equipment

- Oil extractor : used for oil extraction
- Electric scale : used for measuring the weight
- Thermal conductivity meter : used for determining the thermal conductivity of the vegetable based oil
- Rotational viscometer : used to determine viscosity
- Magnetic stirrer

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- **Electric oven : used for drying the groundnut seeds.**

(b) Apparatus

I. Beaker of various sizes

II. Measuring cylinder

III. Sample bottles of 120ml

IV. Transparent containers

V. Test tubes and conical flasks

Procedure for Mechanical Extraction of Vegetable oil

For oil extraction from groundnuts, the seeds were sourced from Garatu market in Minna, Niger State, Nigeria. The seeds were initially cleaned to remove common contaminants such as sticks, leaves, sand, stones, and general dirt. Regardless of the extraction method chosen, pretreatment of the oilseeds is essential (Ogunniyi, 2006). The groundnut seeds were then dried in an electric oven at 80°C for 4 hours. After drying, the red coating of the seeds was removed to expose the endosperm, as the outer coat does not contain oil. This step enhances the oil extraction efficiency. The peeled groundnut seeds were fed into an expeller screw, where they were ground, crushed, and pressed to extract the oil as the seeds passed through the machine. The extracted groundnut oil was collected in a rubber can. During this process, the high friction coefficient generated a significant amount of heat. The pressure involved in expeller pressing produces heat in the range of 140–210°F (60–99°C).

For oil extraction from sesame seeds, the mechanical method involves pressing the seeds to extract the oil, which can be achieved using either a hydraulic press or an expeller press. The seeds are first cleaned, and then optionally roasted, before being mechanically pressed to release the oil. Cold-pressing sesame oil extraction machines apply just the right amount of force to crush the seeds and generate sufficient friction to naturally heat the seeds.

Determination some specific physio-chemicals properties

Determination of Specific Gravity

Following the ASTM D1298 method, the dry empty 50ml density bottle was first weighed and the weight recorded as W0, then it was filled with water and weighed. The second weight was recorded as W1. The density bottle was emptied, re-filled with the oil sample and weighed again. This third weight was recorded as W2.

The specific gravity of the oil sample was calculated,

using the relation,

$$SG = W2 - W0 \qquad (1)$$

Where,

SG = Specific gravity This experiment was carried out at room temperature.

2. Determination of Density The density of the oil samples was determined from the previously obtained value of specific gravity by the relation

$$\rho = G\rho w \qquad (2)$$

Where,

ρ = Density of oil sample

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ρw = Density of water

Determination of Pour Point

The sample was poured into the test jar to the level mark. The test jar was closed with the cork carrying the high pour thermometer. The position of the cork and the thermometer were adjusted for the cork to fit tightly. The thermometer and the jar were coaxial and the thermometer bulb was immersed 3mm below the surface of the sample. The test jar was then placed in the cooling medium. The sample was cooled at a specified rate and examined at intervals of 3oC for flow characteristics until the sample showed no movement when the test jar was in a horizontal position for 5 seconds. The observed reading of the thermometer was recorded, 3^oC was added to the recorded temperature and the result was recorded as the pour point (ASTM D-97). The higher the density, viscosity and specific gravity of oil, the more its tendency towards reaching its pour point (Ulakpa, 2023).

Determination of Flash Point

This test was carried done according to ASTM D-93 standard. The Pensky-Martens closed cup tester was used for the test. The cup was filled with the groundnut oil as to the mark set in the interior of the cup. A Bunsen burner was lighted and used to heat the oil. The oil was constantly stirred in order to maintain a uniform temperature. An injector burner was lighted and at intervals 10 seconds, was brought to the opening at the top of the cup to observe if the oil would ignite or produce a pop sound. The temperature at which this was observed was noted. The procedure was repeated twice and the average temperature was taken and recorded as the flash point.

Determination of Cloud Point

The ASTM D2500 method was used to carry out this test. The cloud point jar was first filled with the oil sample, ensuring that it was free of any impurities or air bubbles. The oil sample was preheated slightly above its expected cloud point, to ensure homogeneity. The test jar was immersed in a cooling bath, ensuring that the liquid level in the bath was above the oil level in the jar. The bath was then cooled at the rate of 20C per minute, continuously monitoring the sample as it cooled. The temperature at which a cloud first appeared and persisted even with gentle stirring was recorded as the cloud point.

Determination of Acid Value

A neutral solvent was prepared by mixing ethanol and petroleum ether. 1 g of the oil was measured and placed in a beaker. 50ml of the neutral solvent was added to the oil in the beaker. The mixture was thoroughly stirred for about 30minutes. 0.56 g of potassium hydroxide pellet was measured and used to prepare 0.1 M KOH. 2 drops of the phenolphthalein indicator were added to the oil/neutral solvent in the beaker and titrated against 0.1 M KOH until an end point was attained (ASTM D-664). The acid value was calculated from the relation:

Acid value(mgKOH/g) = $56.1 \times V \times NW$ (3)

Where V = volume of standard alkali (KOH) used (ml)

N = normality of standard alkali used

W = weight of oil used (g)

Determination of Free Fatty Acid (FFA)

The acid value obtained was subsequently used to determine the free fatty acid and this was defined as: Acid value = free fatty acid / 2

Therefore,

Free Fatty Acid (FFA) (mgKOH/g)

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= Acid value × 2 (4)

Determination of Saponification Value

2 g of the oil sample was weighed into a conical flask. 25ml of alcoholic KOH solution was added and a reflux air condenser connected to the flask. The flask was heated on an electric hot plate for 1 hour and the sample boiled gently and steadily until it was completely saponified, as indicated by the absence of any oil matter and appearance of a clear solution. After the flask and condenser had cooled, the inside of the condenser was washed down with about 10ml of hot ethyl alcohol neutral to phenolphthalein. 1ml of phenolphthalein indicator solution was added and titrated with standard hydrochloric acid. A blank determination was also prepared and conducted. The saponification value was then determined by the relation

$$SV = 56.1\,(B - S) \times NW \qquad (5)$$

Where, B = Volume, in ml, of HCl required for the blank

S = Volume, in ml, of HCl required for the sample

N = Normality of HCl

W = Weight of oil sample taken for the test

SV = Saponification value

RESULTS AND DISCUSSIONS

Table 1: Comparison of the Physiochemical Analysis of Groundnut and Sesame Extract.

Physiochemical Analysis	**Groundnut Oil/Extract**	**Sesame Oil/Extract**
Specific Gravity	0.91	0.92
Pour Point (°C)	-2	-14.67
Flash Point (°C)	265	228
Cloud Point (°C)	6	-9
Acid Value (mg KOH/g oil)	0.36	0.14
Saponification Value (mg KOH/g oil)	187.90	11.22

All measurements were conducted in triplicate, and results are reported as mean values. The measurement uncertainty was assessed based on instrument resolution and repeatability: kinematic viscosity (±0.05 mm^2/s), thermal conductivity (±0.01 W/m·°C), flash point (±1°C), pour point (±1°C), cloud point (±0.5°C), and specific gravity (±0.001). The low coefficients of variation (<3%) across triplicate runs confirm the reproducibility and reliability of the reported data.

The thermal conductivity of groundnut oil at varying temperatures and additive (32g fine mixture Al_2O_3 + $MgSO_4$ hepta-hydrate and 5ml Oleum, thoroughly mixed) is given in Table 2

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Table 2 : Thermal Conductivities (W/^{0} C) of Groundnut Oil

Temperature (^{0}C)	**Sample A**	**Sample B**	**Sample C**	**Sample D**	**Sample E**
50	0.45	0.52	0.72	0.76	0.82
60	0.20	0.33	0.42	0.45	0.51
70	0.22	0.25	0.29	0.30	0.37

From the experimental values in Table 2 (all measurements conducted in triplicate; uncertainty ±0.01 W/m·°C), the thermal conductivity of groundnut oil increases progressively with additive concentration, reaching an optimum at 40% (v/v) loading (Sample D: 0.76 W/°C at 50°C). This enhancement is attributable to the high intrinsic thermal conductivity of Al_2O_3 nanoparticles (~30 W/m·K), which form thermally conductive bridges within the oil matrix, as reported by Kumar & Chauhan (2023). The $MgSO_4 \cdot 7H_2O$ component further aids heat dissipation through its lattice hydration energy. However, at higher temperatures the thermal conductivity of groundnut oil falls substantially, a behaviour consistent with the increased molecular agitation that disrupts nanoparticle clustering and reduces phonon transport efficiency (Song et al., 2019). The high saturated fatty acid content of groundnut oil (predominantly oleic and linoleic acids) contributes to a relatively stable but lower baseline thermal conductivity compared with sesame oil. This is an indication that higher quantities of the additive (32g fine mixture Al_2O_3 + $MgSO_4$ hepta-hydrate and 5ml Oleum, thoroughly mixed) makes groundnut oil a lubricant with better thermal conductivity and groundnut oil is a poor lubricant at elevated temperatures. This behaviour is demonstrated in figure 1

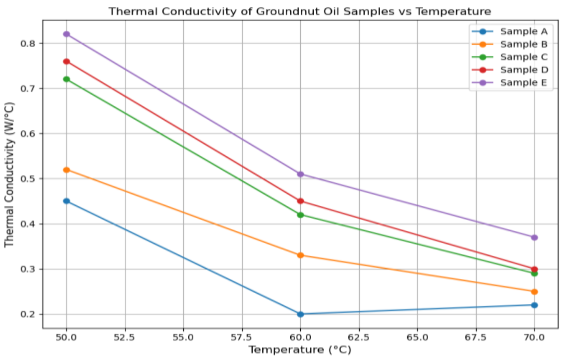

Figure 1: Variation of Thermal Conductivity of Groundnut Oil with Temperature

The thermal conductivities of Sesame oil at varying temperatures and additive (32g fine mixture Al_2O_3 + $MgSO_4$ heptahydrate and 5ml Oleum, thoroughly mixed) is given in Table 3

Table 3: Thermal Conductivities (W/^{0} C) of Sesame Oil

Temperature (^{0}C)	**Sample A**	**Sample B**	**Sample C**	**Sample D**	**Sample E**
50	0.63	0.72	0.87	0.89	0.95
60	0.39	0.42	0.47	0.59	0.62
70	0.28	0.30	0.32	0.42	0.52

The values in Table 3 also show an increase in the thermal conductivity of sesame Oil as the additive increases, reaching an optimum at 40% additive loading (Sample D: 0.89 W/°C at 50°C), which notably exceeds the corresponding groundnut oil value (0.76 W/°C). This difference is attributable to the higher polyunsaturated

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fatty acid content of sesame oil, particularly linoleic acid (~41%), which promotes stronger van der Waals interactions with the Al_2O_3 nanoparticle surface, facilitating more efficient phonon transfer (Kumar & Chauhan, 2023; Singh & Chauhan, 2021). The superior thermal performance of sesame oil relative to groundnut oil across all additive concentrations is therefore rooted in its distinct fatty acid profile, which enhances nanoparticle dispersion stability. However, the thermal conductivity of Sesame Oil decreases at higher temperatures, indicating that higher quantities of additive (32g fine mixture Al_2O_3 + $MgSO_4$ hepta-hydrate and 5ml Oleum, thoroughly mixed) makes sesame oil a better lubricant, but higher temperatures make sesame oil a poor lubricant, as shown in figure 2

Figure 2: Variation of Thermal Conductivity of Sesame Oil with temperature

The kinematic viscosity of groundnut oil at varying temperatures and additive are given in Table 4

Table 4: Kinematic viscosity of groundnut oil at varying temperatures and additive

Temperature (^{0}C)	Sample A	Sample B	Sample C	Sample D	Sample E
50	23.21	22.03	22.82	22.70	21.80
60	17.53	18.16	17.84	17.46	15.69
70	15.45	14.01	13.78	12.59	11.02

From the values in Table 4 (triplicate measurements; uncertainty ±0.05 mm²/s), the kinematic viscosity of groundnut oil decreases with increasing temperature, consistent with the Arrhenius-type viscosity–temperature relationship widely reported for vegetable oils (Stachowiak & Batchelor, 2018). Notably, viscosity increases with additive concentration, indicating that Al_2O_3 and $MgSO_4 \cdot 7H_2O$ particles increase intermolecular resistance to flow, effectively thickening the oil matrix. Groundnut oil's high oleic acid content (~46%) provides a naturally stable, high-viscosity baseline that is further reinforced by solid particle loading; this contrasts with the sesame oil behaviour described below, and is consistent with the findings of Ulakpa (2023) for groundnut-derived bio-lubricants. The retained lubricity of groundnut oil at higher additive concentrations suggests it is better suited for moderate-load applications where lubricant film thickness is critical. Groundnut oil retains greater lubricity at higher quantities of additive (32g fine mixture Al_2O_3 + $MgSO_4$ hepta-hydrate and 5ml Oleum, thoroughly mixed), indicating that, groundnut oil has better lubricity at higher quantities of additive (32g fine mixture Al_2O_3 + $MgSO_4$ hepta-hydrate and 5ml Oleum, thoroughly mixed), but loses its lubricity at elevated temperatures. This behaviour is displayed in figure 3

Figure 3: Variation of kinematic viscosity of groundnut oil with temperature

The kinematic viscosity of sesame oil at varying quantities of additive (32g fine mixture Al_2O_3 + $MgSO_4$ hepta-hydrate and 5ml Oleum, thoroughly mixed) and temperature is given in table 7

Table 5: Kinematic viscosity of sesame oil at varying temperatures and additive

Temperature (^{0}C)	Sample A	Sample B	Sample C	Sample D	Sample E
50	29.01	28.83	26.50	20.50	18.65
60	22.40	21.72	20.10	15.00	13.55
70	16.90	16.00	14.69	13.30	11.45

From the values in Table 5 (triplicate measurements; uncertainty ±0.05 mm²/s), the kinematic viscosity of sesame oil decreases with both increasing temperature and increasing additive concentration, a trend that is

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markedly different from that of groundnut oil and requires mechanistic explanation. Sesame oil has a higher polyunsaturated fatty acid content (linoleic acid ~41%; oleic acid ~39%) than groundnut oil, resulting in a less tightly packed molecular structure. When Al_2O_3 and $MgSO_4 \cdot 7H_2O$ particles are introduced alongside hydrogen peroxide and oleum, the oxidative action of these reagents may accelerate partial cleavage of unsaturated C=C bonds, reducing chain length and thereby lowering viscosity (Rios et al., 2022; Zhang & Wang, 2021). This is consistent with the lower acid value of sesame oil (0.14 mg KOH/g) compared with groundnut oil (0.36 mg KOH/g), indicating fewer free fatty acids to resist flow. As a result, sesame oil becomes a progressively less viscous lubricant at higher additive levels, whereas its superior cold-temperature performance (pour point −14.67°C versus −2°C for groundnut oil) makes it more suitable for low-temperature applications, a distinction not previously highlighted for this additive system. The kinematic viscosity of sesame oil decreases with increase in temperature and additive (32g fine mixture Al_2O_3 + $MgSO_4$ hepta-hydrate and 5ml Oleum, thoroughly mixed), which means that sesame oil is less viscous and a poorer lubricant at higher quantities of additive (32g fine mixture Al_2O_3 + $MgSO_4$ hepta-hydrate and 5ml Oleum, thoroughly mixed) and temperature. This trend is illustrated in figure 4

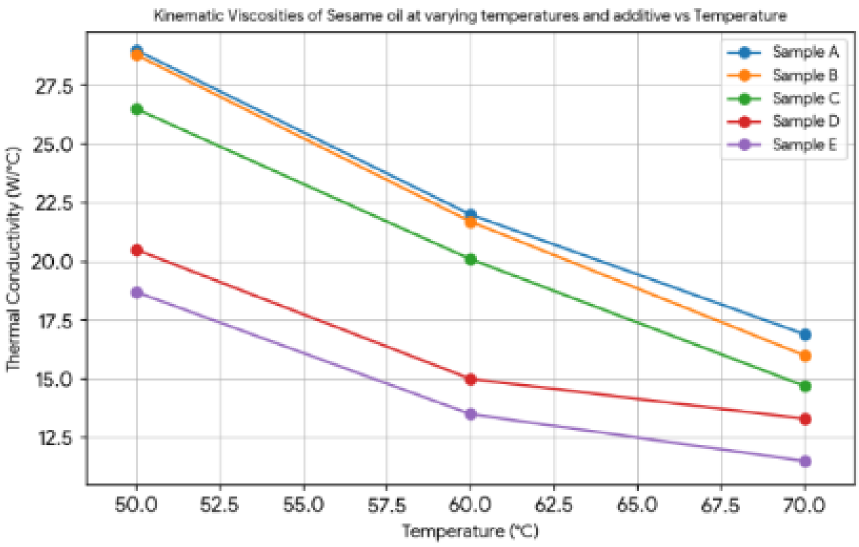

Figure 4: Variation of kinematic viscosity of sesame oil with temperature

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