

# Nano-additives to improve the Flow and Thermal Properties of Different Oils

Thesis submitted to  
**The Maharaja Sayajirao University of Baroda**  
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in  
**APPLIED CHEMISTRY**

Submitted by  
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# Summary

Of the thesis entitled

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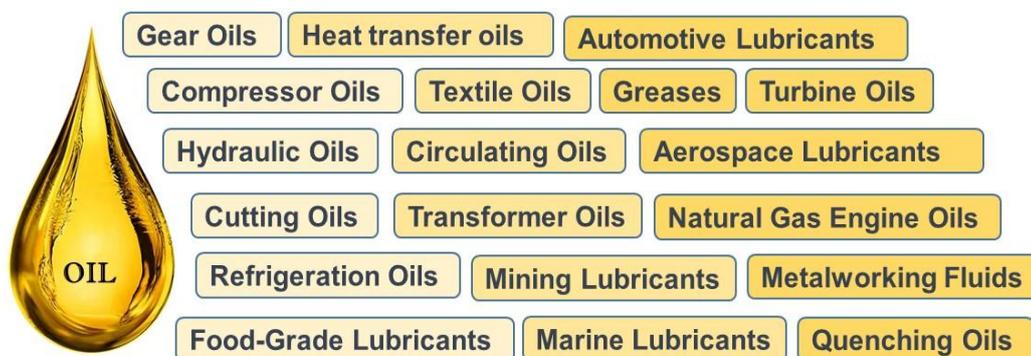
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## Nano-additives to improve the flow and thermal properties of different oils

Oils, specifically industrial oils (IOs) play a crucial role as essential fluids employed across diverse applications in various industries[1]. These oils are formulated to meet the specific requirements of different machinery and equipment, providing necessary lubrication, protection, and performance enhancement[2,3]. From heavy-duty manufacturing to automotive applications, IOs play a critical role in ensuring the smooth operation of industrial manufacturing[4]. These oils are used as lubricants in the manufacturing industry for a variety of equipment, such as presses, pumps, and machine tools. They help to reduce friction and wear, thereby improving the longevity and performance of machinery[5]. The use of IOs also helps to minimize downtime, maintenance costs, and energy consumption in manufacturing operations, thereby increasing productivity and profitability. Engine oils, transmission fluids, and hydraulic fluids are also examples of IOs used in automotive applications. These oils help to protect engine parts from wear and tear, reduce friction, and ensure the smooth operation of various components in the vehicle. Not only that, industrial oils are used in construction applications like heavy equipment, cranes, and hydraulic systems. These oils are specifically designed to provide high levels of lubrication and protection in extreme operating conditions, such as high temperatures and heavy loads[6].

In addition to the above applications, IOs are also used in other industries, such as the food and beverage industry, pharmaceuticals, and electronics manufacturing. In the food and beverage industry, industrial oils are used for lubrication and corrosion protection in food processing and packaging equipment. In the pharmaceutical industry, they are utilized for smoothing of pharmaceutical processing equipment. In the electronics manufacturing industry, IOs are used for cooling and lubrication of cutting and drilling machines used in printed circuit board manufacturing[7,8].



**Figure 1:** Types of IOs based on various applications[9]

Overall, the application of IOs is diverse and essential in various industries (Figure 1). These oils provide critical lubrication and protection for machinery and equipment, thereby ensuring the smooth and efficient operation of industrial processes and therefore, the demand for more specialized IOs with specific properties is very much increasing, and research and development in this area will play a critical role in it [4].

The sources of industrial oils are diverse, ranging from traditional vegetable and animal oils to modern synthetic and biofuel alternatives.

**Table 1:** Sources of IOs [10]

No.	Source Type	Examples
1	Vegetable oils	Olive oil, Sunflower oil, Soybean oil, Castor oil, Palm oil
2	Animal oils	Lard, Tallow, Fish oil, Cod liver oil
3	Mineral oils	Mineral oil, Petrolatum
4	Essential oils	Lavender oil, Peppermint oil, Tea tree oil
5	Synthetic oils	Synthetic motor oils, PAO oils, PEG oils
6	Fish oils	Cod liver oil, Salmon oil
7	Biofuels	Biodiesel, Algal oil
8	Fruit oils	Avocado oil, Mango seed oil, Passion fruit oil
9	Nut oils	Almond oil, Walnut oil, Hazelnut oil
10	Seed oils	Flaxseed oil, Sesame oil, Pumpkin seed oil
11	Herb oils	Basil oil, Rosemary oil, Thyme oil
12	Fungi oils	Mushroom oil

Vegetable oils, extracted from plant sources like seeds and fruits, include widely used varieties such as soybean and palm oil. Animal oils, derived from fats and tissues, find applications in various industrial sectors. Mineral oils, a product of petroleum refining, contribute significantly to industrial lubrication. Essential oils are known for their aromatic and therapeutic properties, offer very distinct applications. The emergence of synthetic oils and biofuels represents advancements in engineering oils tailored to specific industrial needs. Table 1 shows the diverse sources contributing to the formation of IOs [1, 3].

**Nano-additives**, also known as nanomaterial additives, are substances that consist of nanoscale particles or structures and are added to various materials to impart specific properties or enhance their performance. Nano-additives typically have at least one dimension at the nanometer scale, which is in the range of 1 to 100 nm. Nanoparticles, nanotubes, nanofibers, and nanoclays are commonly used as nano-additives. These additives play a crucial role in various industrial applications due to their unique properties and the

ability to enhance the performance of materials and products. When nano-additives are dispersed evenly in a base fluid like water, oils, or ethylene glycol, they create nanofluids. Nanofluids, a cutting-edge class of fluids, have gained significant popularity in research due to their unique properties and transformative potential. The nanoparticles confer exceptional thermal and rheological properties on the nanofluid, enhancing its heat transfer efficiency and flow characteristics. This heightened performance is attributed to the nanoparticles' large surface area, which facilitates improved thermal conductivity and fluid stability [9].

The use of nanofluids can significantly reduce engine wear and increase fuel efficiency. The nanoparticles form a protective layer on the engine surfaces, reducing friction and minimizing wear [11]. Additionally, the increased thermal stability of the oil prevents the formation of deposits and sludge, reducing the risk of engine damage. In hydraulic fluids, nano-additives can improve the lubricant's ability to withstand high-pressure and high-temperature conditions. The nanoparticles improve the fluid's shear strength, preventing it from breaking down under extreme conditions[12]. Similarly, in transmission fluids, the use of nano-additives can improve the fluid's ability to withstand high temperatures and pressures, reducing wear and extending the life of the transmission system [13]. Overall, the use of nano-additives in different oils as nanofluid has significant potential to enhance their performance properties and extend the life of mechanical systems. Researchers are exploring their applications in areas such as heat exchangers, electronics cooling, and automotive systems to address challenges related to thermal management and energy efficiency. The versatility and promising performance of nanofluids have propelled them to the forefront of scientific investigation and practical implementation[14].

The present research aims to study the performance characteristics of different oils by focusing on flow properties through rheology studies and thermal properties, i.e., thermal conductivity, in the presence of nano-additives. The approach involves the synthesis and evaluation of various nanofluids, wherein nano-additives are dispersed within base oils. The investigation mainly focuses on understanding the effects of specific nano-additives, namely alumina, zinc oxide, graphene nanoplatelets, and multiwalled carbon nanotubes, when introduced into distinctive base oils like castor oil and synthetic engine oil. Notably, castor oil, a non-edible fatty oil with a unique hydroxyl group structure, serves as a distinctive base fluid for synthesizing castor oil-based nanofluids. Recognizing its distinct properties, such as lubricative qualities, dielectric functionality, and heat transfer potential, castor oil proves to be an intriguing candidate for nanofluid development. In parallel, India's expansive two-wheeler automotive market underscores the critical role of engine oil, elevating the

significance of synthetic oils. Notably, 10W-30 synthetic engine oil emerges as a standout choice due to its remarkable versatility, delivering optimal performance across a diverse temperature range. This synthetic oil's inherent compatibility with nanoparticle dispersion is the driving force behind its selection for nanofluid research.

The study employs sophisticated characterization techniques, such as scanning electron microscopy (SEM), X-ray diffraction (XRD), and energy dispersive X-ray spectroscopy (EDX), to analyze the structural and chemical composition of the developed nano-additives. The hydrothermal method was employed to synthesize metal oxide based nano-additives. The probe-sonication method was used in the nanofluid development process to make sure that the nano-additives were evenly distributed in the base oils. A rheometer was used to measure the rheological properties of the synthesized nanofluids, and a thermal conductivity meter was used to measure their thermal conductivity. These analyses provide insights into the impact of nano-additives on the flow and thermal properties of the oils, which contribute valuable data to the broader understanding of IO applications.

In order to meet all the objectives of the present work, the contents of the thesis are summarized into seven chapters.

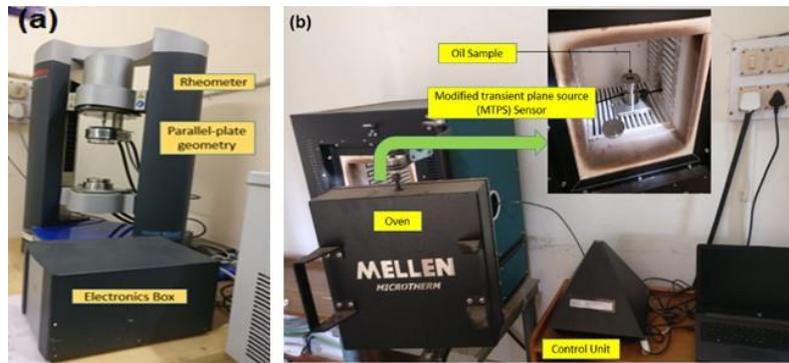
## **Chapter 1: General Introduction**

The present chapter covers the introduction of industrial oils (IOs) and their role in various applications. The chapter mainly focuses on two types of lubricating oils, such as castor oil (COs) and engine oil (EOs), for nanofluid synthesis. Various nano-additives and their potency in industrial applications have been described. The relevant research outputs in the area of the present work have been provided.

## **Chapter 2: Materials and Methods**

This chapter discusses the use of two different base oils for the synthesis of nanofluids: castor oil (COs) and engine oil (EOs). The complete procedure for extracting non-edible castor oil from oil-bearing seeds is explained. The physical and chemical characteristics of the extracted non-edible COs are provided and examined in detail. These characteristics include the saponification value, acid value, iodine value, specific gravity, hydroxyl number, and chemical composition. Simultaneously, the commercially available synthetic engine oil (EOs) of 10W-30 grade undergoes comprehensive evaluations for viscosity, pour point, flash point, and specific gravity. Furthermore, methodologies for rheological analysis and thermal conductivity analysis are briefly described to provide insights into the flow behavior and thermal properties of the fluids under investigation.

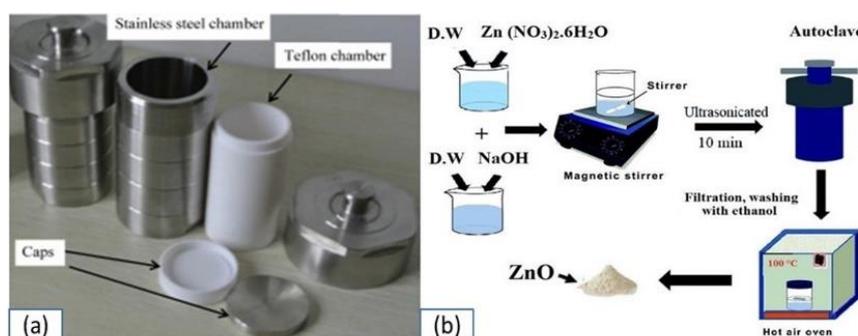
Moreover, rheometer and thermal conductivity meter instruments working principle explained in depth.



**Figure 2:** (a) Rotational rheometer (HAAKE MARS, Thermo scientific) and (b) Thermal conductivity analyzer (Trident, C-Therm Technologies) by using modified transient plane source (MTPS) technique

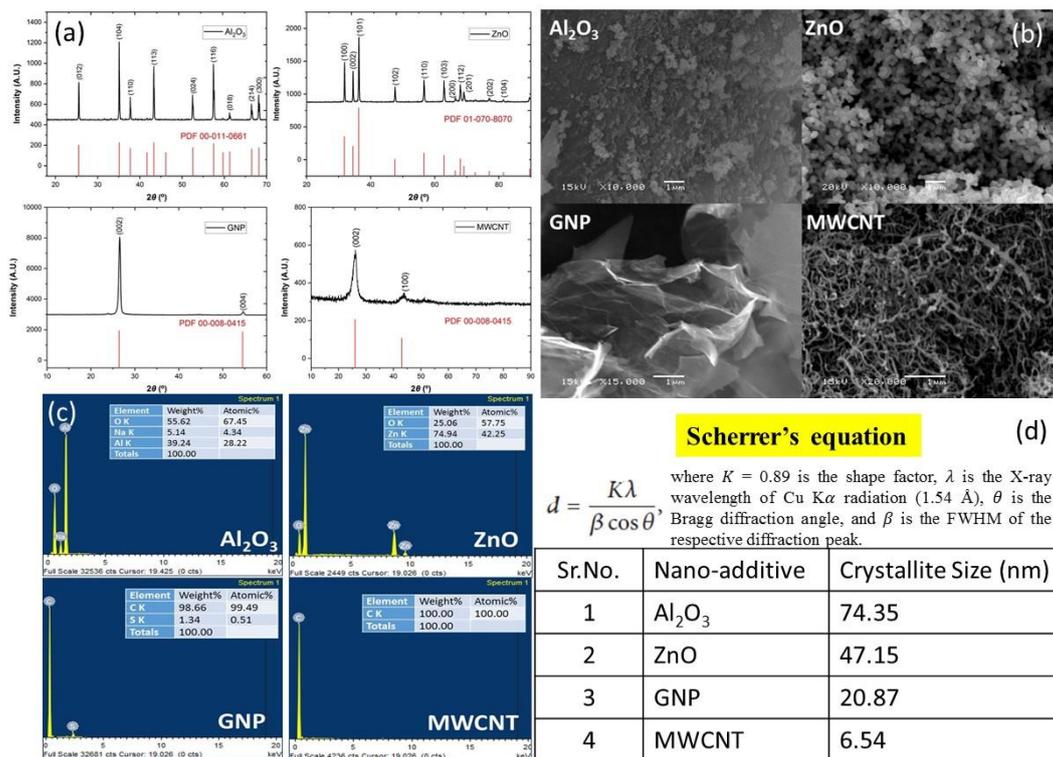
### Chapter 3: Nano-additives for development of Castor oil and Engine oil-based Nanofluids

For the development of COs and EOs based nanofluids, four different types of nano-additives have been chosen. Two important nano-additives Graphene nanoplatelets (GNP) and Multiwalled carbon nanotubes (MWCNT) were procured from Sigma-Aldrich (USA). The metal oxide based nano-additives: Alumina ( $\text{Al}_2\text{O}_3$ ) and Zinc oxide (ZnO), were typically synthesized through hydrothermal method. In a typical ZnO nano-additive hydrothermal synthesis, 10 mL of zinc nitrate  $\text{Zn}(\text{NO}_3)_2 \cdot 6\text{H}_2\text{O}$  (0.1 M) solution and 10 mL NaOH aqueous solution were vigorous stirring for 30min, and the slurry solutions were poured into Teflon lined autoclaves and hydrothermally heated at  $180^\circ\text{C}$  for 24 hours. The yield was washed with water then followed by ethanol, centrifuged and dried in an oven at overnight. Similarly,  $\text{Al}_2\text{O}_3$  nano-additives were synthesized using aluminum nitrate  $\text{Al}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$  as starting material and followed the procedure of ZnO nanoparticles.



**Figure 3:**(a)Hydrothermal PTFE reactor with SS container, (b) Hydrothermal method for ZnO nano-additive synthesis

Here, the synthesized and purchased nano-additives were characterized by sophisticated characterization techniques, such as Scanning Electron Microscopy (SEM), X-ray Diffraction (XRD), and Energy Dispersive X-ray Spectroscopy (EDX), to analyze the structural and chemical composition of the developed nano-additives. Crystallite size less than 100 nm for all additives suggested the nanocrystalline nature and considered as nano-additives. The results of this chapter demonstrate that the developed additives can be used as nano-additives for the nano-fluid preparation to improve flow and thermal properties of base fluids.



**Figure 4:**(a) X-ray Diffraction (XRD), (b) Scanning Electron Microscopy (SEM), (c) Energy Dispersive X-ray Spectroscopy (EDX) and (d) Crystallite Size determination using Scherrer's equation of developed nano-additives: Al<sub>2</sub>O<sub>3</sub>, ZnO, GNP and MWCNT.

## Chapter 4: Castor oil-based nanofluids containing Al<sub>2</sub>O<sub>3</sub>, ZnO, GNP and MWCNT nano-additives

Following CO-based nanofluids prepared by dispersing nano-additives.

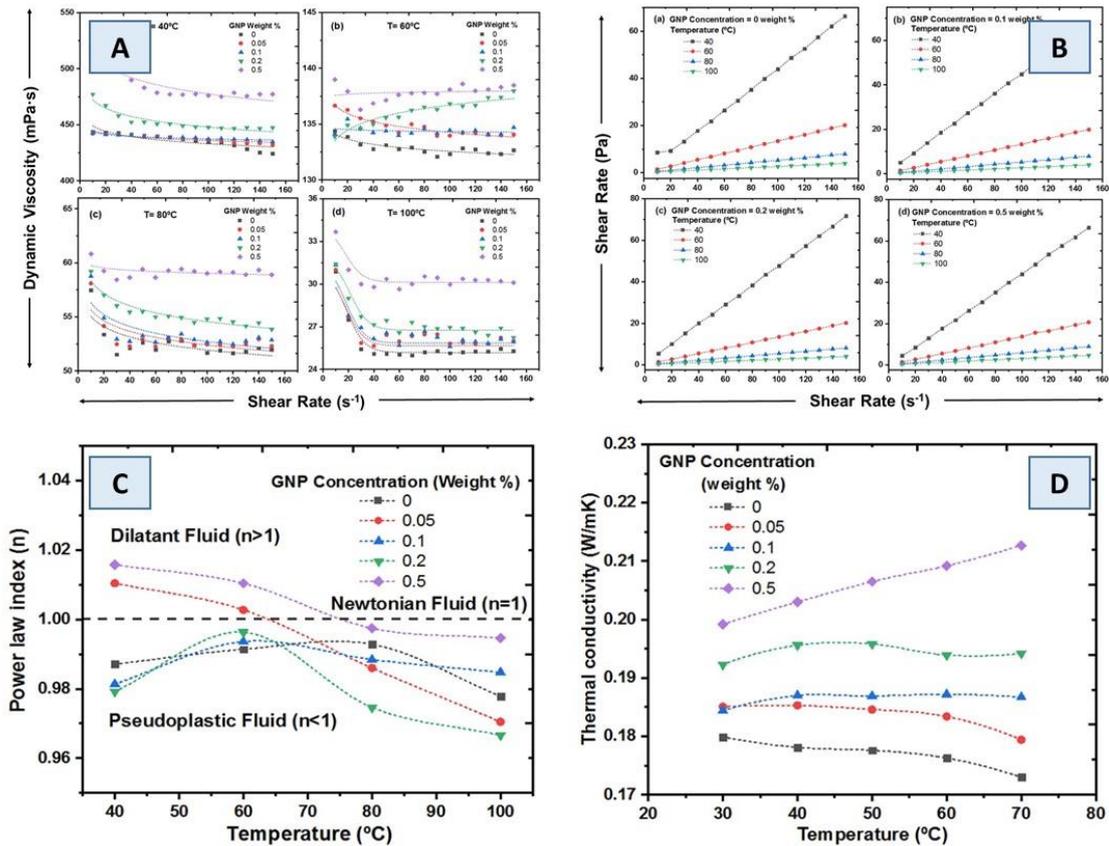
1. CO-based nanofluid containing ZnO nano-additives
2. CO-based nanofluid containing Al<sub>2</sub>O<sub>3</sub> nano-additives
3. CO-based nanofluid containing GNP nano-additives
4. CO-based nanofluid containing MWCNT nano-additives

The nanofluid samples were prepared by adding nano-additives powder into pure CO by a double-step procedure. Homogeneous CO-based nanofluids were obtained by using a high-power ultra-sonication probe having a 500-watt output power and a 20 kHz frequency power supply.

In this chapter, a systematic exploration was undertaken to elucidate the rheological attributes of both base CO and CO-based nanofluids, encompassing CO/Al<sub>2</sub>O<sub>3</sub>, CO/ZnO, CO/GNP, and CO/MWCNT nanoformulations. The study explored dynamic viscosity under varying nano-additive concentrations (0.05, 0.1, 0.2, 0.5 weight %), shear rates, and temperatures. The primary focus on comprehended the impact of nano-additive weight percentage and temperature on the dynamic viscosity and thermal conductivity of all COs nanofluids, with potential applications as lubricating oils. To ascertain the flow behavior, whether it adheres to Newtonian or non-Newtonian flow, the Ostwald-de-Waele (OdW) model was employed using Equation (2):

$$\tau = m \cdot \gamma^n \dots\dots\dots (2)$$

Where  $\tau$  is shear stress,  $\gamma$  is shear rate,  $m$  is the consistency index, and  $n$  is the power law index. Power law curve fitting was applied to the shear stress against shear rate curve to determine the values of  $m$  and  $n$ . As showed in figure 6, results revealed non-linear viscosity trends at lower shear rates, linear behavior at higher shear rates, and a slight shear-thinning effect with increased GNP nano-additive concentration. Similarly, comprehensive flow behavior analyses were conducted for all other nanofluids, elucidating their distinct rheological characteristics. The study underscored the enhanced thermal conductivity of CO/GNP nanofluids compared to pure CO and other CO-based nanofluids, emphasizing their potential in improving heat transfer performance.



**Figure 5:**(A) Effect of shear rate on dynamic viscosity of CO/GNP nanofluids at different mass fraction, (B) Shear stress against shear rate at various temperature for CO/GNP nanofluids (C) Power law index for different solid mass fractions and temperature for CO/GNP nanofluids, (D) Thermal conductivity of CO/GNP nanofluids

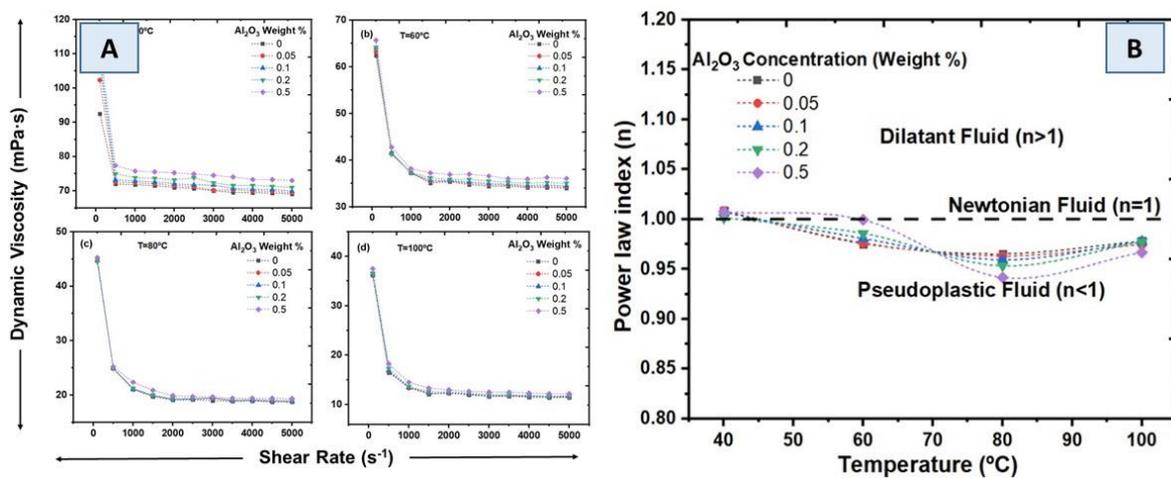
## Chapter 5: Engine oil-based nanofluids containing Al<sub>2</sub>O<sub>3</sub>, ZnO, GNP and MWCNT nano-additives

Following EO-based nanofluids prepared by dispersing nano-additives.

1. EO-based nanofluid containing ZnO nano-additives
2. EO-based nanofluid containing Al<sub>2</sub>O<sub>3</sub> nano-additives
3. EO-based nanofluid containing GNP nano-additives
4. EO-based nanofluid containing MWCNT nano-additives

The nanofluid samples were prepared by adding nano-additives powder into EO of synthetic grade (10W-30) by a double-step procedure. Homogeneous EO-based nanofluids were obtained by using a high-power ultra-sonication probe having a 500-watt output power and a 20 kHz frequency power supply.

A systematic study was done in parallel to find out more about the flow properties of 10W-30 grade synthetic EO and its nanofluid counterparts, including EO/Al<sub>2</sub>O<sub>3</sub>, EO/ZnO, EO/GNP, and EO/MWCNT compounds. The investigation focused on dynamic viscosity under varied nano-additive concentrations (0.05, 0.1, 0.2, 0.5 weight %), shear rates, and temperatures, with a primary emphasis on comprehending the influence of nano-additive weight percentage and temperature on the dynamic viscosity and thermal conductivity of all EO-based nanofluids, offering potential applications in lubricating systems. Employing the Ostwald-de-Waele (OdW) model with Equation (1), where  $\tau$  represents shear stress,  $\dot{\gamma}$  is shear rate,  $m$  is the consistency index, and  $n$  is the power law index, enabled the determination of  $m$  and  $n$  values through power law curve fitting. In the same way, a full study of the flow behavior of all the other nanofluids was carried out, which showed how their unique rheological properties work. The study highlighted the augmented thermal conductivity of EO/GNP nanofluids compared to pure EO and other EO nanofluids, accentuating their potential for enhancing heat transfer performance in diverse applications.



**Figure 6:**(A) Effect of shear rate on dynamic viscosity of EO/Al<sub>2</sub>O<sub>3</sub> nanofluids at different mass fraction, (B) Power law index for different solid mass fractions and temperature for EO/Al<sub>2</sub>O<sub>3</sub> nanofluids

## Chapter 6: Summary and Conclusions

The thesis ends with a summary of all the reported work and general conclusions drawn from the investigations.

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