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Enhancement of Thermophysical Properties of SAE20W40 Using Low Concentration Nanoparticles

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Abstract

Engine oils are the lifeblood of any internal combustion engine, playing a crucial role in lubricating, cooling, and protecting its moving parts. They come in various formulations and viscosities, tailored to meet the specific needs of different engines. From enhancing performance to ensuring longevity, understanding engine oil types, properties, and functions is essential for maintaining a healthy and efficient engine. Given the high-strength properties of graphene-based nanoparticles, this study compares and analyzes the thermophysical performance of the commonly used SAE20W40 oil in automobile engines with Reduced Graphene Oxide (RGO) and Carboxyl Graphene (CG) mono and hybrid nanoparticles of 0.001% and 0.005%, respectively. This study aims to enhance the thermophysical properties of the SAE 20W40 oil and improve engine performance and the oil's life span.

Keywords: *Carboxyl Graphene (CG), Dynamic Viscosity, Reduced Graphene Oxide (RGO), SAE20W40, Thermal Conductivity*

1.0 Introduction

Areas with high contact loads widely utilize lubricants to reduce friction and wear on equipment, thereby extending machine life. Wear is the primary cause of most mechanical failures in machines, and mechanical friction accounts for about 30% of machine energy consumption. Lubricant bases receive tiny amounts of additives to enhance system performance and reduce wear and friction. Environmental restrictions have restricted the applications of traditional additives, such as phosphorus or chlorine. To solve this issue, some researchers are currently investigating the application of nanoparticles as a novel kind of lubricant additive. Moreover, nanoparticles typically increase lubricant tribological properties and are ecologically benign. The most commonly used nanoparticles in tribological applications are carbon and metallic-based[1]. Nanotechnology is a rapidly developing technology that has drastically changed several sectors. Because of this, scientists have attempted to apply various facets of this technology to every branch of science and engineering[2]. Since fluid mechanics and heat transfer may both profit from nanotechnology benefits, these two fields are among its most significant applications[3]. The oil and heat transfer industries typically employ nanofluids, leveraging nanotechnology advantages to optimize a variety of engineering systems[4]. The automotive and mechanical industries frequently use lubricants to increase efficiency. The most often used lubricants are hydraulic and engine oils[5]. Nanoparticles remarkably large specific surface area in comparison to their dimensions enhances the qualities of nanofluids, reduces flow route clogging and sedimentation, and boosts stability and improvement. Researchers have studied and employed

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nanofluids in potential applications such as electrical, nuclear, and automotive systems due to their idealized thermophysical behavior[6]. Because of better thermal and lubricating capabilities, carbon nanoparticles based on nano-lubricants are a viable choice for use as lubricant additives. Their eco-friendly and non-toxic properties broaden their potential applications as lubricant additives[7]. The two types of carbon nanotubes (single-wall and multi-wall) are shown schematically in Figure 1(a)[8]. Graphene sheets, carbon onions, and inorganic fullerenes make up the walls. Inorganic fullerenes, often known as carbon nanotubes, are nested structures, or lamellar structures, that are mostly employed as solid lubricants. Single graphite sheets are gradually exfoliated or unwound from the periphery when they are deformed by shear and strain. Their nanoscale size is the exclusive benefit of the closed structure over the equivalent lamellar one. The structures of carbon allotropes, which are primarily in charge of their diverse properties, are depicted in Figure 1 b[8]. Whereas graphene is a thick sheet with only one layer, graphite contains many layers. Fullerene has a spherical form and is numbered 60, 70, or 540 depending on how many carbon atoms are in its structure. Researchers have reduced wear, friction, corrosion, oxidation, and scuffing in automotive lubricants by using carbon-based nanoparticles.

Reduced graphene oxide has a heterogeneous structure made up of a basal plane that resembles graphene and is additionally decorated with structural defects and populated with areas containing oxidized chemical groups; it shares mechanical, optoelectronic, and conductive properties with pristine graphene. Due to its graphene-like characteristics, reduced graphene oxide is a highly sought-after material for numerous sensory, biological, environmental, or catalytic applications, as well as optoelectronic and storage devices[9].

A vast amount of theoretical and experimental literature on many facets of graphene functionalization has surfaced in a brief amount of time. Even phrases like "carboxylate graphene oxide" and "carboxyl graphene" seem to have become more common lately[10]. Carboxyl hydrophilic groups on the surface of Carboxyl Graphene (CG), a type of graphene oxide nanomaterials, make it more soluble in water than Graphene Oxide (GO). The CG has a carboxyl content of 5%, a single layer ratio of around 99%, and a diameter of between 50 and 200

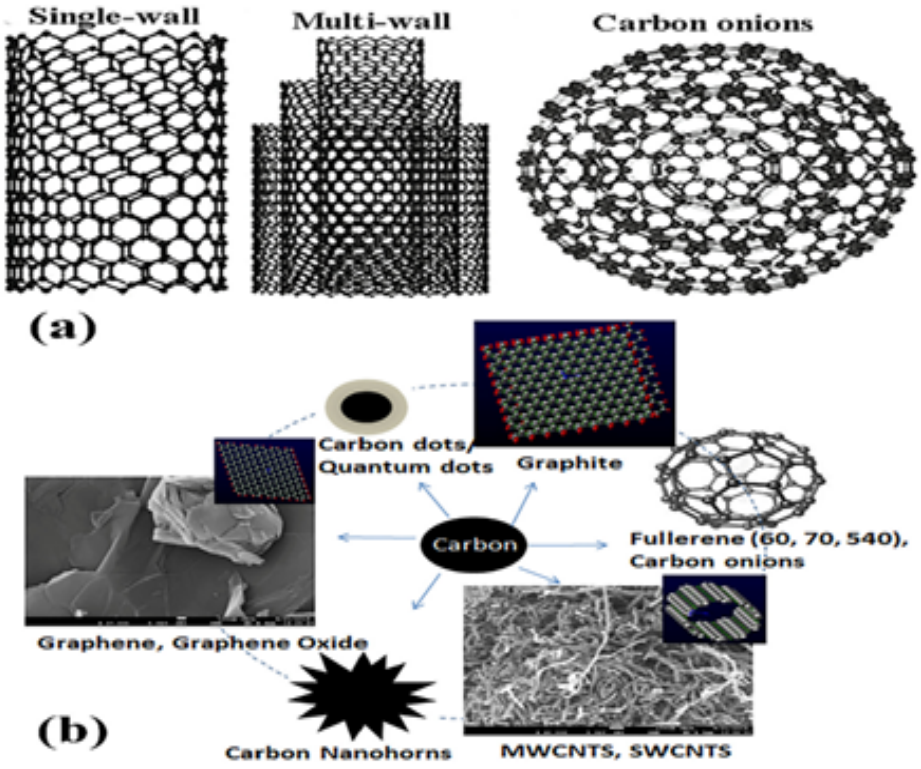


Figure 1. Schematic representation of the structure of carbon nanomaterials[8].

nm. The wide application of CG in biology, catalysis, sensors, and detection is a result of its remarkable properties[11].

2.0 Methodology

2.1 SEM and EDX Analysis

Used the SEM images to understand the shape, size, and aggregation of nanoparticles, which are crucial parameters affecting their properties and applications. We also used EDX to determine the elemental composition of the nanoparticles and to detect any impurities present in the sample. Figures 2 and 3 present the SEM images of reduced graphene oxide and carboxyl graphene, respectively, at different magnifications. Table 1 indicates the detailed thermophysical properties of RGO and CG nanoparticles.

The EDX test performed on both the nanoparticles provided us with information regarding the purity of the sample. Figure 4 (a) and (b) display the obtained results for reduced graphene oxide and carboxyl graphene, respectively. Table 2 depicts the detailed variation of the carbon and oxygen content present in the RGO and CG nanoparticles.

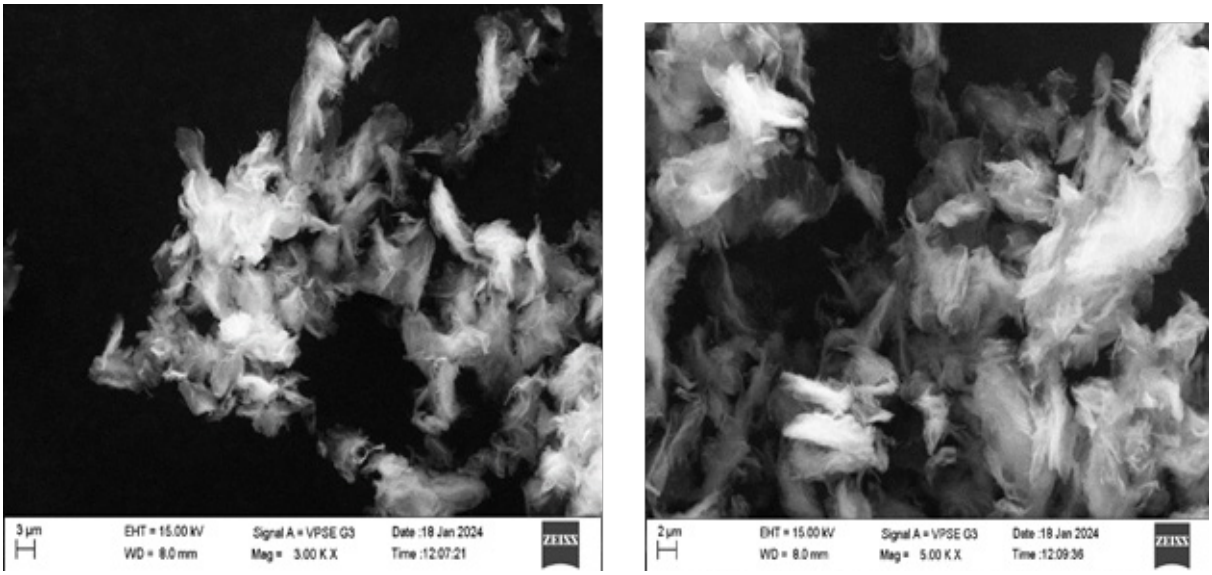


Figure 2. SEM Images of Reduced Graphene Oxide (RGO).

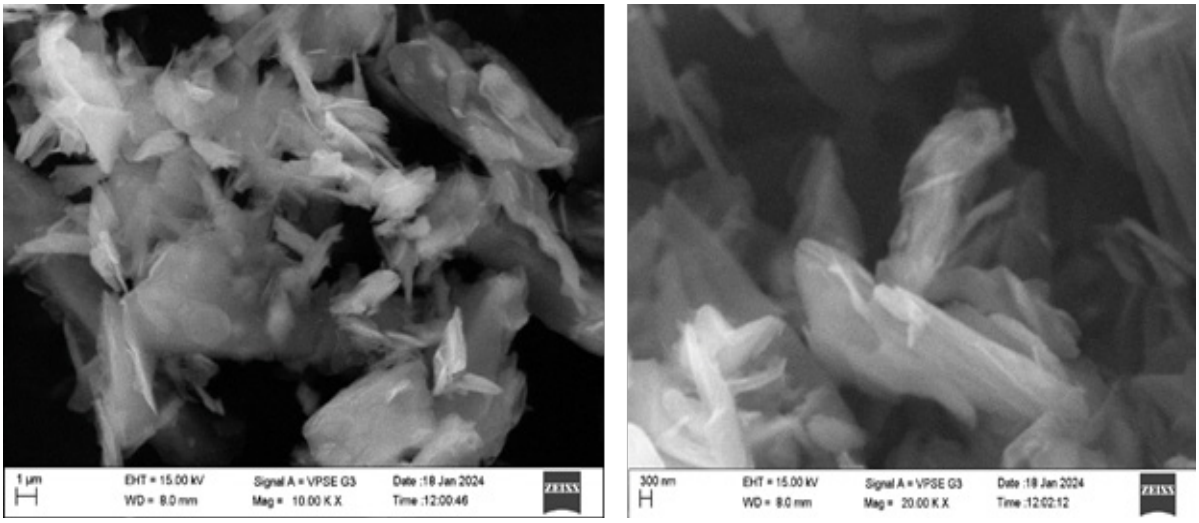


Figure 3. SEM Images of Carboxyl Graphene (CG).

Table 1. Thermo physical properties of RGO and CG

Parameter	RGO	CG
Particle Average size in nm	2	2.5
Density, ρ in kg/m^3	250	240
Thermal Conductivity, k in W/m-K	2800	2800
Specific Heat, Cp in J/kg K	730	730
Colour	Black	Dark Grey
Morphology	Sheet	
Purity	99%	

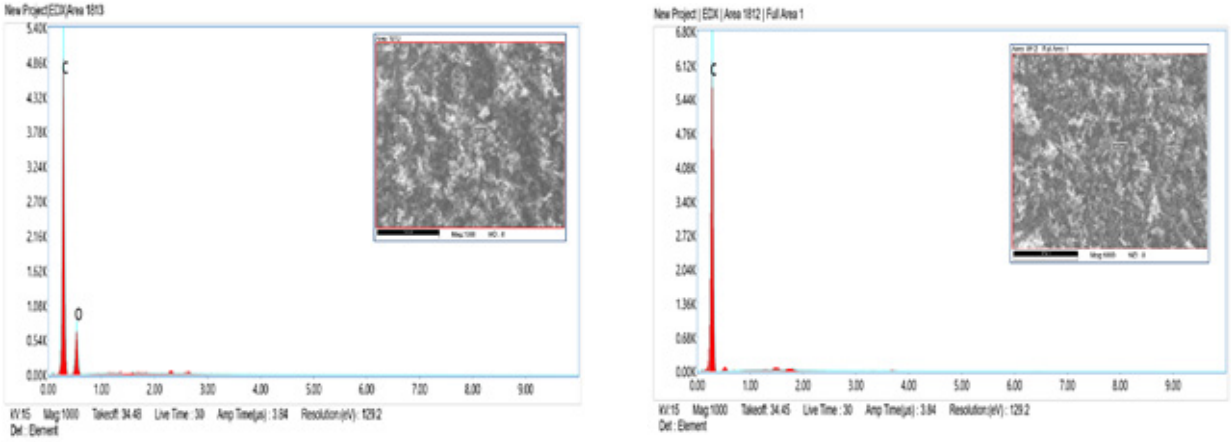


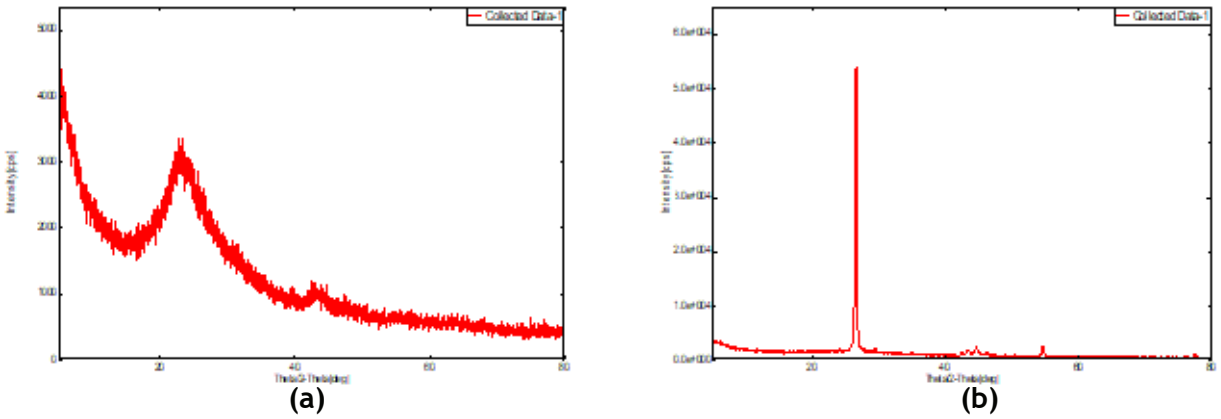
Figure 4. EDX analysis of **(a)** RGO **(b)** CG.

Table 2. EDX Analysis Report

RGO		CG	
C (K) **O (K)**		**C (K)**	**O (K)**
Elements by weight %			
75.8	24.2	98.5	1.5
Elements by Atomic %			
80.7	19.3	99.4	0.6

2.2 XRD Analysis

The size of the crystalline domains, or crystallite size, in samples of nanoparticles can be usefully determined using XRD. Examining the broadening of diffraction peaks allows us to calculate the average size of the crystalline domains of the nanoparticles. This is critical for evaluating the material's nanoscale structure and refining synthesis procedures to regulate particle size. Figure 5 (a) and (b) show the average crystalline size of the reduced graphene oxide and carboxyl graphene, respectively.



(a) **(b)**

Figure 5. XRD result of **(a)** RGO and **(b)** CG.

2.3 Preparation of Nanofluids

The creation of nanofluids is an essential first step in experimental research. This study prepares SAE20W40-RGO and CG nanofluid using a two-step procedure. Compared to a one-step procedure, the two-step method is the most practical and cost-effective way to prepare a stable nanofluid[12]. The two-step preparation method first synthesizes or extracts the nanoparticles independently from the base fluid. Various processes, such as chemical synthesis, the sol-gel method, and physical procedures like grinding or laser ablation, create nanoparticles in this step. The two-step approach is typically favored over the one-step method for nanofluid synthesis due to its superior cost-effectiveness, scalability, and flexibility. In the two-step procedure, nanoparticles are initially manufactured independently utilizing existing techniques and subsequently distributed into the base fluid. This allows enhanced control of nanoparticle characteristics, including dimensions and shape, while preventing issues such as aggregation or oxidation during synthesis. The two-step technique provides greater variety in the selection and customization of various nanoparticles and base fluids, rendering it appropriate for diverse applications, whereas the one-step method integrates synthesis and dispersion, potentially constraining process control and scalability. The intended uses and characteristics of the nanofluid dictate the kind of nanoparticles employed. First, obtain the nanoparticles and then disperse them throughout the base fluid to create a nanofluid. This dispersion technique requires careful monitoring to produce consistent and stable suspensions. An electronic scale is used to weigh the nanoparticles as shown in Figure 6 (a) (the least count is 0.01 mg), and the particles are then dispersed evenly throughout the base fluid (SAE20W40 = 6 liters). As shown in Figure 6 (b), we transfer the nanofluid to an ultrasonic bath-type sonicator (45 liters, 480 W of power, 37 kHz of frequency, and 230 volts and 50 Hz of input



(a) Weighing balance. **(b)** Sonicator. **(c)** Nanofluid.

Figure 6. Preparation of Nanofluid.

supply AC) to obtain a stable nanofluid. To improve stability, the fluid is sonicated for almost three hours. As shown in Figure 6 (c), we then transfer the sonicated samples to separate containers.

The volume concentration for the proportion of nanoparticles to be added to prepare the nanofluid was calculated using the below relationship[12]:

$$\phi = \left[\frac{W_{np}/\rho_{np}}{\frac{W_{np}}{\rho_{np}} + \frac{W_{bf}}{\rho_{bf}}}\right] X\ 100$$

3.0 Test Carried Out

The study aims to assess the improvement in thermophysical characteristics such as flash and fire point, thermal conductivity, and viscosity in both pure fresh SAE20W40 lubrication oil and oil-containing hybrid nanoparticles of RGO and CG at 0.001 and 0.005 vol. %[13].

3.1 Flash and Fire Point

One well-known device for doing these experiments is the Able-Pensky flash and fire point apparatus, as shown in Figure 7. A metal test cup, an oil bath, a thermometer, and a manually operated ignition source- typically a tiny flame or electric spark- make up the device. The sample oil (in this case, SAE20W40) is poured into the cup, and the oil bath guarantees that the sample is heated evenly.

The test cup is filled with the oil sample and then submerged in the oil bath. The sample undergoes heating at an exact controlled pace of 5 to 6 °C per minute. The igniter routinely exposes the oil surface as the temperature rises. The lowest temperature at which vapor ignites and produces a visible flash on the oil's surface is known as the flash point. The thermometer is used to precisely record this temperature.

The oil sample is heated further once the flash point is established until the temperature rises even higher. The temperature is increased by sporadically applying the ignition source. When the oil vapors ignite and continue to burn for at least five seconds, the fire point is attained. The SAE20W40 oil reaches its burning point at this temperature. The flash and fire point tests provide important information about the thermal stability and safety of SAE20W40 oil. The Able-Pensky apparatus is a preferred method in both industrial and research contexts because it guarantees precision and reliability. These findings aid in establishing the operational bounds and security measures required while using this kind of lubricating oil in diverse applications.

3.2 Viscosity

When assessing the performance of lubricating oils such as SAE20W40, one of the most important parameters is the oil viscosity, which is a measurement of its resistance to flow. One popular tool for figuring out the kinematic viscosity of petroleum compounds is the Redwood Viscometer, as shown in Figure 8. The experimental process for utilizing a Redwood viscometer to measure the viscosity of SAE 20W40 oil is described below. The oil sample (SAE20W40), a thermometer, a timer, and a Redwood viscometer are among the equipment needed for this experiment. The Redwood Viscometer consists of a collecting flask to measure the oil flow, a heating bath



Figure 7. Open Cup Flas/Fire point apparatus.



Figure 8. Redwood Viscometer.



Figure 9. Thermal conductivity of liquid apparatus.

to maintain a consistent temperature, and a cylindrical cup with a bottom opening. Make sure the viscometer is clear of any leftover oil and clean it before beginning the experiment. Following the standard, fill the viscometer's water bath to the appropriate level and heat it to the required test temperature, typically 30°C or 100°C[5]. In another container, the oil sample is warmed to the same temperature.

The kinematic viscosity in Stokes (St) is then determined using the average time that was recorded, utilizing a Redwood Viscometer-specific formula or standard conversion table. Understanding the viscosity value at the test temperature sheds light on the properties of the oil's flow under operating circumstances.

The viscosity of SAE20W40 oil may be accurately measured with this experiment, which is important for guaranteeing its compatibility for a variety of applications. This is especially true for engines, where maintaining proper lubrication is essential for longevity and performance. A simple and efficient way to evaluate this crucial feature is by using the redwood viscometer[14].

3.3 Thermal Conductivity

Thermal conductivity refers to the ability of engine oil to conduct heat. This characteristic is essential for preserving the ideal engine temperature since it effectively transfers heat away from important parts. Oils with higher thermal conductivity[14] dissipate heat more efficiently, thereby improving engine longevity and performance. To increase thermal conductivity and guarantee that engines run within acceptable temperature limits, manufacturers frequently add additives to their oil formulations.

Figure 9 indicates the pictorial view of the apparatuses used to determine the thermal conductivity of the oil samples. The objective is to determine the thermal conductivity of SAE20W40 oil and various nanofluids. The procedure involves setting up the necessary electrical and water connections for the instrument, activating the control panel by switching on the power and console and adjusting the voltage within a range of 70-80 volts. The cooling water supply through the water jacket is initiated, and temperatures are recorded at different points until a steady state is reached. The experiment is repeated for different heater inputs. Upon completion, the voltage is reduced to the minimum, the heater and main switches are turned off, and the water flow through the water jacket is allowed for a period before stopping it.

4.0 Results and Discussions

The results obtained through the experiments conducted for the fresh SAE20W40 lubricating oil and oil with 0.001 and 0.005 vol. % hybrid nanoparticles are listed below in Table 3.

4.1 Flash and Fire Point Temperatures

The temperature at which lubricating oil produces enough vapor to ignite in the presence of an ignition source is known as the flash point of the oil, and it is an important characteristic. Incorporating nanoparticles

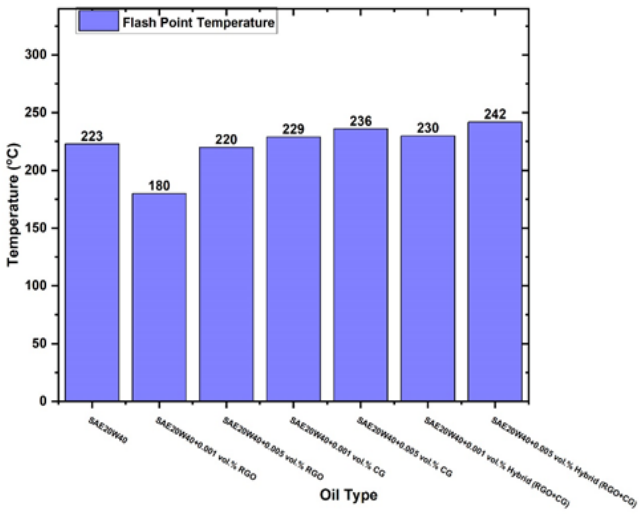


Figure 10. Flash point temperature of SAE20W40 oil with nanoparticles.

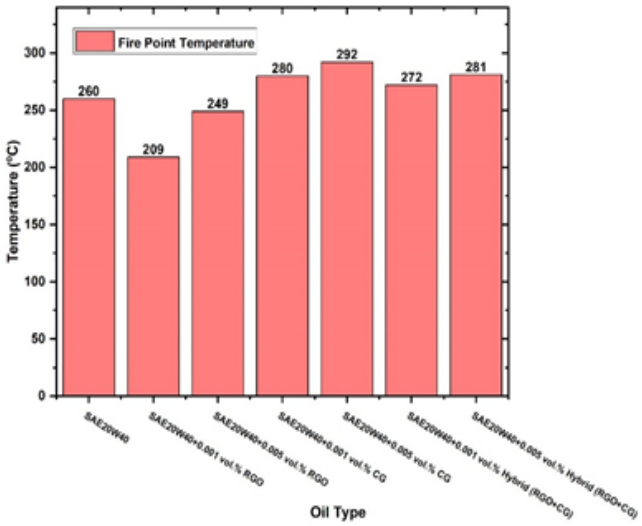


Figure 11. Fire point temperature of SAE20W40 oil with nanoparticles.

into lubricating oils to improve their performance attributes has attracted a lot of attention lately. This study looks into what happens to the flash point of SAE20W40 lubricating oil when hybrid nanoparticles of Reduced Graphene Oxide (RGO) and Carboxyl Graphene (CG) are added to it. Due to increased thermal stability and decreased volatility, adding hybrid nanoparticles of reduced graphene and carboxyl graphene to SAE20W40 lubricating oil is anticipated to raise the oil's flash point. Several variables, including nanoparticle concentration, dispersion quality, and interaction with the base oil, affect how much of an improvement there is. To find the best formulations and fully understand how these additives affect the performance and safety of lubricants, large-scale experiments are needed. This is needed even though preliminary studies and theoretical considerations support these benefits.

Figure 10 indicates that the hybrid nanoparticles of 0.005 vol.% exhibit the highest flash point temperature of 242 ^{O}C and the lowest flash point temperature of 180 ^{O}C for 0.001 vol.% of RGO nanoparticles. From experimental results, it is evident that the addition of RGO nanoparticles of 0.001 vol.% reduces the flashpoint temperature compared to pure oil and then increases with increasing the vol.% of nanoparticles. However, the addition of CG nanoparticles increases the flash point temperature.

From Figure 11, it is observed that the addition of RGO nanoparticles of 0.001 and 0.005 vol. % concentrations decrease the fire point temperature but CG nanoparticles increase the fire point temperature. The addition of RGO nanoparticles of 0.001 and 0.005 vol.% exhibits 209 and 249 ^{o}C and CG nanoparticles exhibit 280 and 292 ^{O}C. Similarly, at corresponding concentrations, RGO and CG nanoparticles display fire point temperatures of 272 and 281, respectively.

The enhancement of flash and fire point temperatures of SAE20W40 oil by the incorporation of carboxyl and reduced graphene nanoparticles has substantial practical advantages, particularly in augmenting the safety and efficacy of lubricants under elevated temperature conditions. An elevated flash and fire point signifies enhanced resistance to ignition, which is essential in engines or machinery functioning under harsh circumstances. This results in diminished fire risks and enhanced thermal stability, facilitating more efficient operation, prolonged oil longevity, and superior protection of engine components. These improvements are especially beneficial in automotive, aerospace, and industrial sectors where elevated heat and pressure are prevalent, leading to enhanced operating safety and diminished maintenance expenses.

4.2 Viscosity

Figure 12 depicts the experimental outcomes of the impact of RGO and CG mono and hybrid nanoparticles

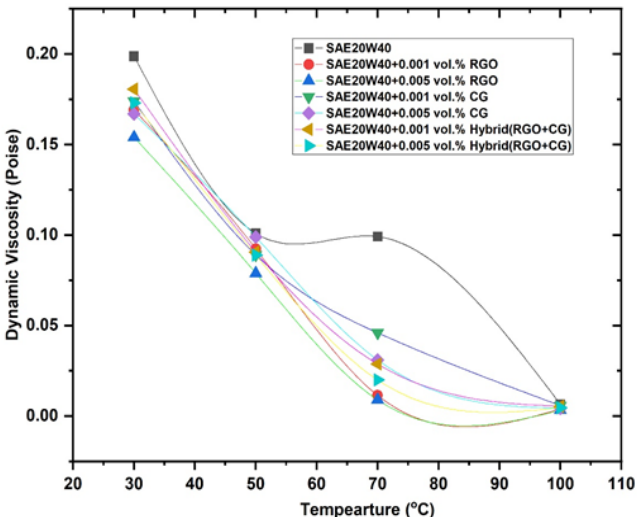


Figure 12. Dynamic viscosity variation with temperature.

of 0.001 and 0.005 vol.% and variation of the temperature on the dynamic viscosity of the SAE20W40 oil.

The results clearly show that the dynamic viscosity of pure SAE20W40 ranges from 0.1988 to 0.0064 poise at a temperature range of 30 to 100 ^{O}C. When 0.001 and 0.005 vol.% of RGO nanoparticles are added to oil, the viscosity decreases from 0.1691 to 0.0039 and from 0.167 to 0.0042 poises, respectively, at the corresponding temperatures. In the same pattern, the CG nanoparticles also reduce the viscosity by 0.174 to 0.0052 and 0.167 to 0.0042 poise respectively, for 0.001 and 0.005 vol.% with the temperature ranges from 30 to 100 ^{O}C. The addition of hybrid nanoparticles leads to an increase in viscosity compared to monoparticles. The 0.001 vol.% shows 0.1806 to 0.0053 poise and the 0.005 vol.% exhibits 0.173 to 0.0046 poise.

RGO and CG nanoparticles can intercalate between oil molecules due to their tiny size and large surface area, which lowers internal friction and viscosity as a result. These nanoparticles can minimize shear stress in the oil by forming a thin lubricating coating on metal surfaces. This leads to a decrease in flow resistance and a further reduction in viscosity. Graphene-based nanoparticles can break up the long-range molecular connections in the oil, making the fluid less cohesive and more prone to shearing, thereby reducing viscosity. By increasing the oil thermal conductivity, graphene nanoparticles improve heat dissipation. Under working conditions, this may cause the oil temperature to drop, which would reduce its viscosity.

The decrease in viscosity of SAE20W40 oil resulting from the incorporation of carboxyl and reduced graphene nanoparticles has significant real-time consequences for enhancing the efficiency of lubricants in mechanical systems. Decreased viscosity results in less internal friction, facilitating smoother fluid flow, minimizing energy loss, and enhancing fuel economy in engines. This is especially advantageous in cold-start scenarios when elevated viscosity may obstruct lubrication. Moreover, decreased viscosity improves thermal dissipation and minimizes wear on moving components, hence prolonging the longevity of engine parts. In industrial and automotive applications, this can lead to enhanced performance, decreased fuel consumption, and diminished maintenance expenses, hence increasing the reliability and efficiency of machines under diverse operating situations.

4.3 Thermal Conductivity

The test results in Figure 13 illustrate the effects of adding 0.001 and 0.005 vol.% RGO and CG mono and hybrid nanoparticles to SAE20W40 oil, as well as the heat conductivity.

The fresh SAE20W40 oil shows a thermal conductivity of 0.145 w/m K. Adding 0.001 and 0.005 vol.% of RGO nanoparticles boosts the thermal conductivity by 0.2678 and 0.5892 w/m K, respectively. Similarly, CG nanoparticles exhibit thermal conductivity values of 0.2565 and 0.5678 w/m K for the corresponding

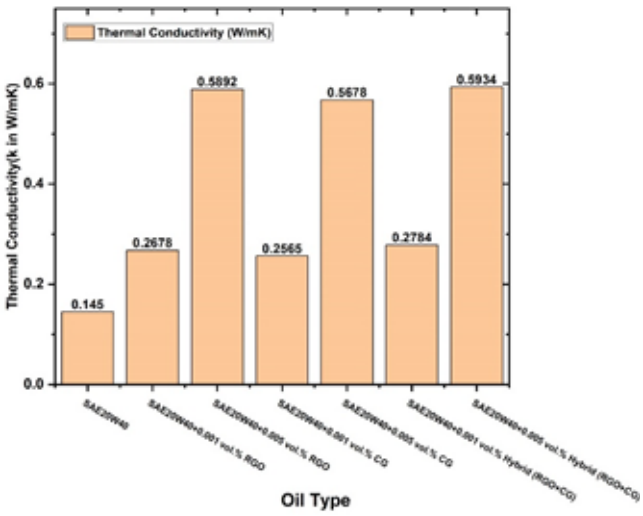


Figure 13. Variation of thermal conductivity.

concentrations. At the same concentrations, the addition of RGO nanoparticles to oil shows greater thermal conductivity than CG nanoparticles. But compared to mono nanoparticles, hybrid particles exhibit the highest improvement in the thermal conductivity of 0.2784 and 0.5934 w/m K for the same volume concentrations.

The addition of mono and hybrid Carboxyl Graphene (CG) and Reduced Graphene Oxide (RGO) nanoparticles at volumes of 0.001 and 0.005, respectively, resulted in an increase in thermal conductivity. Because of their inherent high heat conductivity, RGO and CG are similar. These nanoparticles, when disseminated in the oil, open thermal channels that facilitate more effective heat transport throughout the fluid. The inclusion of nanoparticles introduces more phonon carriers into the oil, which can raise the phonon mean free path and enhance heat conduction through the fluid. If you use both RGO and CG nanoparticles together instead of just one, their different structures and properties can work together to make the thermal conductivity much better.

The enhancement of thermal conductivity in SAE20W40 oil with the incorporation of carboxyl and reduced graphene nanoparticles is significantly advantageous for real-time applications, especially in heat management for engines and machines. Improved thermal conductivity enables the oil to disperse heat more effectively, reducing overheating and maintaining more stable operating temperatures. This results in enhanced cooling efficiency, essential for averting thermal deterioration of the oil and minimizing the likelihood of engine or component failure under elevated temperature circumstances. In automotive and industrial applications, improved heat dissipation enhances overall efficiency, prolongs lubricant lifespan, and sustains maximum performance, even under rigorous operating circumstances.

5.0 Conclusions

Based on the experimental data and analysis carried out using fresh SAE20W40 and oil with mano and hybrid RGO and CG nanoparticles of 0.001 and 0.005 vol% concentrations, the following conclusions are drawn:

- The addition of mono RGO nanoparticles into SAE20W40 leads to a reduction in the flash point temperatures to 180 and 220 °C and the fire point temperatures to 209 and 249 °C for 0.001 and 0.005 vol. % respectively.
- The addition of mono CG nanoparticles into SAE20W40 leads to an increase in the flash point temperatures to 229 and 236 °C and fire point temperatures of 280 and 292 °C, respectively for 0.001 and 0.005 vol. % concentrations.
- The addition of hybrid nanoparticles with concentrations of 0.001 and 0.005 vol% leads to an increase in the flash point temperatures to 230 and 242 °C and the fire point temperatures to 272 and 281 °C, respectively.
- The hybrid RGO and CG nanoparticles, with a volume percentage of 0.005, exhibit the highest flash and fire point temperatures, measuring 242 and 281 °C.
- The addition of RGO and CG nanoparticles leads to a decrease in the viscosity of the oil. RGO nanoparticles of 0.005 vol.% concentration exhibit the lowest average dynamic viscosity of 06125 poise.
- The addition of mono and hybrid nanoparticles leads to an increase in thermal conductivity. When it comes to thermal conductivity, hybrid nanoparticles at 0.005 vol.% have the best value at 0.5934 w/m K, while mono RGO nanoparticles at 0.001 vol.% have the worst at 0.2678 w/m K.

6.0 Acknowledgement

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Nomenclature

RGO- Reduced Graphene Oxide
CG- Carboxyl Graphene
EDX- Energy dispersive X-ray
SEM- Scanning electron microscope
XRD- X-ray diffraction
W_{np}- Weight of Nanoparticles (kg)
W_{bf}- Weight of Base Fluid (kg)
ρ_{np}- Density of Nanoparticles (kg/m^3)
ρ_{bf}- Density of Base Fluid (kg/m^3)
ϕ- Volume Fraction (vol.%)
SAE- Society of Automotive Engineers.