Performance Of R134a Vapour Compression Refrigeration System by Using Gr and Al2o3 Hybrid Nano Lubricants

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ABSTRACT

Nowadays, in many developing countries like India they are facing the shortage of energy. The Refrigeration system has become the major consumer of energy for many industrial as well as household applications. So, it is the need to enhance the energy efficiency of the refrigeration systems. Performance of the refrigeration system can be improved either by increasing the rate of heat absorption in evaporator or by reducing the compressor power. Use of efficient lubricant oil can help to remove the heat generated in the compression process which leads to less power consumption. Development in Nanotechnology makes it possible to develop a new class of lubricant called nanolubricant, in which nanoparticles are added in base lubricant oil to enhance the thermal properties. The two step technique with ultrasonic agitation force is used to synthesise stable nanolubricant. The present study investigates the performance of an R-134a refrigerant vapour compression refrigeration system using nanolubricant with different volume concentrations (0.05%, 0.075%, 0.1% and 0.2%) of Graphene/Aluminium nanoparticles to mineral oil (MO) experimentally. The result shows maximum enhancement in COP approximately as 85% for 0.075 % volume fraction Nano lubricant as compared to base fluid. Use of nanolubricant saves approximately 27% compressor power.

I.INTRODUCTION

In recent years, the quest for enhancing the efficiency of refrigeration systems while reducing their environmental footprint has led to the exploration of advanced materials and technologies. One promising avenue is the use of hybrid nano-lubricants, which are engineered by combiningnanoparticles with conventional lubricants to improve the thermal and tribological properties ofthe system. This study focuses on the introduction of Graphene (Gr) and Aluminum Oxide (Al_2O_3) hybrid nano-lubricants into the R134a vapour compression refrigeration system. R134a, a widely used refrigerant, has been under scrutiny due to its global warming potential, making the search for efficiency improvements all the more critical.

Graphene, a two-dimensional material with exceptional thermal conductivity, and Aluminum Oxide, known for its stability and wear resistance, are hypothesized to synergistically enhance the lubricant's performance. When dispersed in the compressor oil, these nanoparticles are expected to form a protective layer on the metal surfaces, reducing friction and wear. Additionally, their high thermal conductivity could improve heat transfer characteristics of thelubricant, potentially leading to enhanced overall efficiency of the refrigeration cycle.

This study aims to systematically investigate the effects of Gr/Al_2O_3 hybrid nano-lubricants onthe performance of an R134a vapour compression refrigeration system. Parameters of interest include the system's coefficient of performance (COP), energy consumption, compressor wear,and heat transfer characteristics. By comprehensively examining these aspects, the research seeks to provide insights into the viability of employing hybrid nanolubricants as a means to achieve more sustainable and efficient refrigeration technologies.

1.1 Graphene nanoparticles:

Graphene is a single layer of carbon atoms arranged in a two-dimensional honeycomb lattice. It has attracted immense attention from various scientific communities due to its exceptional electrical, thermal, and mechanical properties. When we talk about graphene nanoparticles, weare generally referring to small pieces of graphene or graphene oxide that have dimensions in the nanometer range. These nanoparticles inherit some of the remarkable properties of graphenebut also exhibit unique characteristics due to their nanoscale dimensions.

1.1.1 Theoretical Foundations of Graphene Nanoparticles

The theory behind graphene nanoparticles largely stems from the properties of graphene itself, combined with principles from nanoscience. Here are some key theoretical aspects:

1.1.2 Quantum Confinement

When graphene is reduced to nanoparticle size, it exhibits quantum confinement effects. This means that the electronic properties of the nanoparticles can be significantly different from bulkgraphene. For example, graphene quantum dots (a type of graphene nanoparticle) can exhibit size-dependent optical and electronic properties due to quantum confinement.

1.1.3 Surface Effects

In nanoparticles, the surface-to-volume ratio is very high. Therefore, the properties of graphenenanoparticles are strongly influenced by their surface. This can lead to enhanced reactivity and interactions with other materials, making graphene nanoparticles particularly useful for applications in catalysis, sensors, and energy storage.

1.1.4 Edge States

Graphene nanoparticles have a significant amount of edge relative to their volume. The properties of graphene edges can differ markedly from the graphene plane due to the presence of dangling bonds and the potential for different hybridizations of carbon atoms. Edge states can influence the electronic, magnetic, and chemical properties of graphene nanoparticles.

1.1.5 Mechanical Properties

Theoretical studies based on the mechanical properties of graphene suggest that graphene nanoparticles would retain the high strength and flexibility of bulk graphene. However, the presence of edges and possible defects can introduce variability in these properties at the nanoscale.

1.1.6 Electrical and Thermal Conductivity

Graphene's remarkable electrical and thermal conductivity is expected to influence the properties of its nanoparticles, although the exact nature of this influence can depend on the nanoparticle's shape, size, and specific structure (e.g., presence of defects, layer stacking).

1.1.7 Applications Based on Theoretical Insights

The unique theoretical aspects of graphene nanoparticles have paved the way for a wide range of applications:

- **Energy Storage**: Utilizing the high surface area and electrical conductivity forsupercapacitors and batteries.
- **Catalysis**: The high surface reactivity makes them excellent catalysts or catalystsupports.
- **Biomedical Applications**: Quantum dots for imaging, drug delivery, and photothermal therapy, leveraging their optical properties and biocompatibility.
- **Sensors**: High sensitivity to environmental changes due to the large surface area and electronic properties.
- **Composite Materials**: Improving mechanical, thermal, and electrical properties ofmaterials.

Despite their potential, there are challenges in the synthesis, characterization, and integration of graphene nanoparticles into applications. Controlling the size, shape, and surface chemistry of nanoparticles remains a significant challenge. Additionally, understanding the toxicity and environmental impact of these nanoparticles is crucial for their safe use, especially in biomedical applications. Future research is likely to focus on addressing these challenges, developing scalable and sustainable synthesis methods, and further exploring the theoretical underpinnings of graphene nanoparticles to unlock new applications.

1.2 Aluminum oxide (Al2O3) nanoparticles:

Aluminum oxide (Al2O3) nanoparticles, also known as alumina nanoparticles, are a form of aluminum oxide that is characterized by its small particle size, typically less than 100 nanometers. Due to their nanoscale dimensions, these particles exhibit unique physical and chemical properties compared to bulk aluminum oxide, making them of great interest across a wide range of scientific and industrial fields. The theory surrounding aluminum oxide nanoparticles encompasses aspects of their synthesis, structure, properties, and applications.

1.2.1 Synthesis

Aluminum oxide nanoparticles can be synthesized through various methods, including sol-gel processes, hydrothermal methods, laser ablation, and ball milling. The choice of synthesis method can affect the purity, particle size, morphology, and crystalline phase of the nanoparticles. The sol-gel process, for example, is popular for its control over the chemical composition and uniformity of the nanoparticles produced.

1.2.2 Structure and Properties

The structure of aluminum oxide nanoparticles is defined by their crystallography and surface morphology. Alumina exists in several crystalline phases, with the most stable and common being the α-phase (alpha phase). The nanoparticles can exhibit different phases such as γAl2O3 (gamma), δ-Al2O3 (delta), and θ-Al2O3 (theta), each with unique properties. The nanoscale size of these particles significantly influences their melting point, mechanical strength, chemicalreactivity, and optical properties due to the increased surface area-tovolume ratio and quantumeffects.

1.2.3 Mechanical Properties

Aluminum oxide nanoparticles are known for their hardness and mechanical strength. They can significantly enhance the mechanical properties of composite materials, including increased tensile strength and scratch resistance.

1.2.4 Thermal Properties

These nanoparticles have high thermal stability and are excellent thermal conductors, making them useful in thermal interface materials, heat transfer fluids, and refractory materials.

1.2.5 Optical Properties

The bandgap of aluminum oxide nanoparticles can be influenced by their size, which affects their optical properties. This makes them suitable for applications in UV-absorbent materials and coatings.

1.2.6 Chemical Properties

Al2O3 nanoparticles exhibit high chemical stability, resistance to corrosion, and are inert in most environmental conditions. Their surface properties can be modified to increase reactivity or to provide specific surface functionalities for targeted applications.

1.2.7 Applications

The unique properties of aluminum oxide nanoparticles have led to their use in a variety of applications:

- **Ceramics and Composite Materials**: Strengthening matrices and improving thermalproperties.
- **Coatings**: Protective coatings against corrosion and wear, UV-blocking coatings.
- **Electronics and Photonics**: As insulators, in photonic devices, or in improving the thermal management of electronic devices.
- **Biomedical Field**: In drug delivery systems, due to their biocompatibility and ability to be functionalized for targeting specific sites within the body.
- **Catalysis**: As supports for catalysts, benefiting from their large surface area and thermalstability.

Despite their potential, the use of aluminum oxide nanoparticles poses several challenges, including ensuring uniform dispersion in composite materials, controlling the phase and morphology during synthesis, and addressing health and environmental concerns related to nanoparticle exposure. Future research is directed towards overcoming these challenges, developing greener synthesis methods, and exploring new applications enabled by the unique properties of Al2O3 nanoparticles. Understanding and manipulating the surface chemistry of these nanoparticles remains a crucial area of study to expand their application in catalysis, biomedical applications, and beyond.

1.3 R134a Refrigerant

R134a, chemically known as 1, 1, 1, 2-Tetrafluoroethane (CF3CH2F), is a hydrofluorocarbon (HFC) refrigerant that has been widely used in various refrigeration and air conditioning systems. It gained prominence as a replacement for chlorofluorocarbon (CFC) refrigerants, suchas R12 (CFC-12), due to its significantly lower ozone depletion potential (ODP). While R134aitself does not deplete the ozone layer, it is a potent greenhouse gas with a relatively high global warming potential (GWP), leading to its gradual phase-down under global environmental agreements like the Kigali Amendment to the Montreal Protocol.

1.3.1 Basic Properties

- **Non-ozone depleting:** R134a has an ODP of 0, making it environmentally preferable toCFCs in terms of ozone layer impact.
- **Global Warming Potential (GWP):** Although it's better for the ozone layer, R134a hasa high GWP, contributing to climate change concerns.
- **Non-flammable:** This makes it safe to use in a wide range of applications withoutsignificant risk of fire or explosion.
- **Chemical Stability:** R134a is chemically stable, which is advantageous for long-termuse in systems

without degrading.

• **Thermodynamic Properties:** It offers efficient cooling capabilities, making it suitablefor medium- to high-temperature refrigeration applications.

1.3.2 Theoretical Aspects of R134a in Refrigeration Systems

The operation of R134a in refrigeration and air conditioning systems is based on the principles of the vapour-compression cycle, which includes four primary processes: evaporation, compression, condensation, and expansion.

1. **Evaporation:** Inside the evaporator coil, R134a absorbs heat from the surrounding environment, causing it to evaporate and thus producing a cooling effect.
2. **Compression:** The evaporated R134a is then compressed by the compressor, which increases its pressure and temperature, turning it into a hot, high-pressure gas.
3. **Condensation:** This hot gas then flows through the condenser coil, where it releases its heat to the outside environment and condenses into a high-pressure liquid.
4. **Expansion:** Finally, the high-pressure liquid passes through an expansion valve, where its pressure is reduced. As the pressure decreases, the temperature also drops, and the cycle begins anew.

1.3.3 Environmental Impact and Regulations

The widespread use of R134a has raised concerns due to its global warming potential. R134a's GWP is considerably high, meaning that its release into the atmosphere contributes to climate change. As a result, there has been a push towards finding alternative refrigerants with lower GWP. In many regions, regulations have been put in place to phase down the use of high-GWPrefrigerants, including R134a, in favour of alternatives such as HFO-1234yf (with a significantly lower GWP) for automotive air conditioning and other next-generation refrigerantsfor various applications.

1.3.4 Alternatives and Future Directions

The shift away from R134a due to its environmental impact has led to the development and adoption of alternative refrigerants. These include hydrofluoroolefins (HFOs), such as HFO1234yf, and natural refrigerants like CO2 (R-744) and hydrocarbons (e.g., R-600a, isobutane). Each of these alternatives has its own set of properties, advantages, and challenges,particularly concerning efficiency, safety, and environmental impact.

In conclusion, while R134a has played a crucial role in refrigeration and air conditioning systems due to its efficiency and safety profile, its environmental drawbacks are leading to its phasedown and the search for more sustainable alternatives. The on-going development in refrigeration technology continues to balance the need for efficient cooling solutions with environmental sustainability.

II. LITERATURE REVIEW

R. Santhana Krishnan et al. [1] this paper deals with the analysis and feasibility of nanolubricants in vapour compression refrigeration system. Refrigeration system has become one of the major energy consumers and hence in the present scenario of depleting resources, it is the need of the hour to enhance the energy efficiency of the refrigeration systems. This project incorporates nano-particles in lubricants which help in increasing the heat transfer characteristics of the refrigeration system hence decreasing the work done by the compressor. The refrigerant used is R134a as it has zero ozone depletion potential and is environmentfriendly. The lubricant used was Poly-Oil Ester (POE). The various nanoparticles used are Al2O3, SiO2, ZrO2 and CNT. The nano-particles were suspended into the lubricant by means of ultrasonification and magnetic stirring to disperse the nanoparticles uniformly in the system.

M. Kranthikumar et al. [2] in the working cycle of vapour compression cycle, a liquid knownas refrigerant is used to absorb and release the latent heat at the evaporator and condenser respectively. A refrigerant contains the chlorofluorocarbons (CFCs) and hydro - chlorofluorocarbons (HCFCs). The presence of chlorofluorocarbons (CFCs) and hydro chlorofluorocarbons (HCFCs) in the refrigerants have adverse effects on our environment by contributing towards ozone layer depletion and Green House effect. With recent government regulations and Kyoto protocol curtaining to the use of substances which contribute to global warming and ozone depletion. Conventional refrigerants such as R11, R22, R12, etc., which contributes global warming and ozone depletion are to be replaced by the environment friendlyrefrigerants. Hence, this project has put forth efforts to eliminate these adverse effects by using suitable eco- friendly refrigerants in refrigeration and air conditioning systems. In this work, refrigeration system works on simple vapour compression refrigeration cycle and uses R410a as a refrigerant. To enhance the performance of the VCR cycle, ZNO nano particles are mixed with compressor lubricant oil. The zinc oxide (ZnO) nano particles at particle mass fractions of0.8%, with particle sizes of 30nm to 40nm are dispersed in 100ml of POE oil. The thermal properties of nanofluids are measured and the results show that the thermal conductivity of thenano lubricant increases with the increase in the percentage concentration of zno nano particles. Now, the obtain nano lubricant is dumped in the compressor of air conditioning system and readings are noted. Results showed that the average compressor work reduced, this ultimately resulted in an increase in COP due to the addition of nanoparticles in the lubricating oil.

Gudlavalleti VVS Vara Prasad et al. [3] this article represents an experimental investigationaccomplished to examine the impact of magnetic field on liquid channel of nano lubricant (CuO& PAG oil) equipped VCR system. These effects on energy economics in VCR system. By employing magnetic field to fluid flow, atomization of the fluid will takes place and reduces the specific volume of the fluid molecules. This drop in specific volume of fluid molecules results to loses its viscosity that decreases the input compressing power required by compressor,also increases heat changing rates in evaporator and condenser in behalf of raised mass flow rates of the refrigerant. Addition of nano particles to the lubricating oil of compressor enhances heat changing rates in ejector (i.e. condenser) and evaporator & by reducing frictional power leads to rise in mechanical efficiency. By this experimental study, an improvement in the performance of VCR system was noticed and the occupancy of best level of magnetic field in the presence of different volumetric compositions (0.01%, 0.015%, 0.02%, and 0.025%) of CuOnano particles to PAG oil observed. Finally by combining both magnetic and lubrication effects,the coefficient of performance of system enhanced up to 25.14% for refrigerant R134a at fourthmagnetic pair among all five magnetic pairs (each 11,800 Gauss), by the application of magnetic field to liquid channel with 0.025% volumetric addition of copper-oxide nano particles (APS: 40-80 nm) to the compressor lubricating oil (PAG oil), when compared to simple VCR.

K. Dilip Kumar et al. [4] in this work, the Al2O3 nano-oil is proposed as a promising lubricantto enhance the performance of vapour compression refrigerator compressor. The stability of Al2O3 nanoparticles in the oil is investigated experimentally. It was confirmed that the nanoparticles steadily suspended in the mineral oil at a stationary condition for long period of time. The application of the nano-oil with specific concentrations of 1.5%, 1.7% and 1.9 %(bymass fraction) were added in the compressor oil. The VCRS performance with the nanoparticles was then investigated using energy consumption tests. The result shows the COP of system were improved by 19.14%, 21.6% & 11.22%, respectively, when the nano-oil was used insteadof pure oil.

Nilesh S. Desai and P.R.Patil [5] in this work, the SiO2 nano-oil is proposed as a promising lubricant to enhance the performance of vapour compression refrigerator compressor. The stability of SiO2 nanoparticles in the oil is investigated experimentally. It was confirmed that the nanoparticles steadily suspended in the mineral oil at a stationary condition for long periodof time. The application of the nano-oil with specific concentrations of 1%, 2% and 2.5 %(by mass fraction) were added in the compressor oil. The VCRS performance with the nanoparticles was then investigated using energy consumption tests. The result shows the COP of system were improved by 7.61%, 14.05% & 11.90%, respectively, when the nano-oil was used insteadof pure oil.

K. Veera Raghavulu & N. Govindha Rasu [6] the impact of refrigeration on the environmentis considered as an important problem in the research community. This phenomenon necessitates the need to improve the performance of refrigeration systems coupled with reduced environmental impacts. Previous researches revealed the use of additive combined lubricants that tend to improve the performance of Vapour Compression Refrigeration system (VCR). Thecurrent study experimentally investigated graphene Nano lubricant additives in VCR. The graphene oil nanoparticles, of different volume concentrations, i.e., 0.025–- 0.15, were suspended in Polyester oil (POE). The researcher hypothesizes that the use of graphene nanoparticles with lubricants tends to improve the performance of VCR systems. Thermal conductivity, viscosity, and friction coefficient were calculated experimentally. The optimum volume concentration was identified during when the minimum friction coefficient was also obtained. The performance of the VCR system was also correlated with a base lubricant (POE oil). The results showed better performance in terms of heat removal rate, work input to the compressor and Coefficient of Performance (COP). The COP of the VCR system got enhancedupto ~29%. Therefore, it can be inferred that the graphene lubricant additives achieved higher performance than the base oil (POE) and it can be considered as a better replacement for base oil. Future researchers are recommended to use other such promising organic additives to improve the performance of VCR systems, and reduce the impact of refrigeration systems on the environment.

A. Senthilkumar et al. [7] in this research the evaluation of performance of R600a vapour compression system was investigated using CuO/Al 2O3 hybrid nano lubricants. Three differenthybrid nano lubricants concentrations of 0.2, 0.4 and 0.6 g/L were considered for this study with70 g of R600a refrigerant. The experiment was conducted for the analysis of various important parameters such as coefficient of performance, refrigeration effect and compressor power consumption, pull down of refrigerator and transmittance of both mineral oil without nanoparticles and nano doped mineral oil while using CuO/Al 2 O 3 hybrid nanoparticles withthe lubricant. The study was done with R600a refrigeration system and can be employed as better replacement for pure mineral refrigeration system. Addition of CuO/Al 2 O 3 hybrid nanoparticles in to a compressor lubricating oil resulted in enhanced coefficient of performanceup to 27% from 1.17 to 1.6 and increase in cooling capacity up to 20% from 160 to 200 W andreduction in power utilized by the compressor up to 24% from 158 to 120 W in comparison with the R600a system without nano lubricants. CuO/Al 2 O 3 hybrid nano lubricant refrigeratorcan be employed as better substitute for R134a refrigerator.

D. G. Subhedar et al. [8] in many developing countries like India they are facing the shortage of energy. The Refrigeration system has become the major consumer of energy for many industrial as well as household applications. So, it is the need to enhance the energy efficiency of the refrigeration systems. Performance of the refrigeration system can be improved either byincreasing the rate of heat absorption in evaporator or by reducing the compressor power. Use of efficient lubricant oil can help to remove the heat generated in the compression process whichleads to less power consumption. Development in Nanotechnology makes it possible to developa new class of lubricant called nano-lubricant, in which nanoparticles are added in base lubricantoil to enhance the thermal properties. The two step technique with ultrasonic agitation force is used to synthesise stable nano-lubricant. The present study investigates the performance of an R-134a refrigerant vapour compression refrigeration system using nanolubricant with differentvolume concentrations (0.05%, 0.075%, 0.1% and 0.2%) of Al_2O_3 to mineral oil (MO) experimentally. The result shows maximum enhancement in COP approximately as 85% for 0.075 % volume fraction Nano lubricant as compared to base fluid. Use of nano-lubricant saves approximately 27% compressor power.

Pico et al. [9] two different mass concentrations of diamond nanoparticles were utilized as nano-lubricants. The parameters concentrated are refrigeration effect, coefficient of performance and power consumption. With addition of diamond nanoparticles there is an enhancement in COP by 4% and 8%. The improved cooling effect of refrigeration setup with nano-lubricants was around 7% with highest mass concentration of diamond nanoparticles.

Babarinde et al. [10] examined R600a refrigerator performance with MWCNT taken as nanolubricant which is used as supplement for R134a system. Using MWCNT-nanolubricant concentrations resulted in better COP value ranges between 2.6 to 2.9 with 0.4 g/L and 0.6 g/L for refrigerant mass charges of 60 g. The maximum refrigeration effect of 0.1893 kW resulted with 0.4 g/L and 60 g refrigerant mass charge. The decrease in consumption of compressor power of 0.0639 kW obtained for 0.6 g/L and 60 g of refrigerant mass charge.

Adelekan et al. [11] determined refrigeration effect, COP, Work of compression and test is conducted to bring down temperature of R600a/TiO_2 system. Using 40 g of R600a with 0.1 g/L-TiO_2 mixture resulted in enhanced COP value of 4.99 and highest value of cooling effect as 290.83 kJ/kg. The lowest compressor work was attained using nanoparticles. In R32 refrigerator diamond nano-lubricants was utilized to perform experiments which determines thermal and tribological performance. In this system diamond nano-lubricants at two various mass quantities of 0.1% and 0.5% was employed. The refrigerator performance is studied by conducting experiment with nano-lubricants. Wear test has been performed to determine the performance of compressor under less quantity of lubrication condition.

Pico et al. [12] in R32 refrigerator diamond nano-lubricants was utilized to perform experimentswhich determine thermal and tribological performance. In this system diamond nano-lubricants at two various mass quantities of 0.1% and 0.5% was employed. The refrigerator performance is studied by conducting experiment with nano-lubricants. Wear test has been performed to determine the performance of compressor under less quantity of lubrication condition. The refrigeration effect and COP of refrigerator enhanced by 5.0% and 0.5. The friction and wear reduced to a value of approximately 4% and 30% with addition of 0.1% and 0.5% diamond nanoparticles

Jatinder et al. [13] three different mass quantity of R600a refrigerant and various concentrations of titanium oxide nano-lubricant was examined and then made comparison with working of refrigerator with LPG as refrigerant. The impact of titanium oxide nanolubricant thermo physical properties was explored. The refrigeration effect and coefficient of performance was elevated up to value of 17.39% and 62.54%. The R600a refrigerator resultedwith improved performance than LPG based refrigerator.

Anish et al. [14] used CuO/Al 2 O 3 -R22 as nano-refrigerant and evaluated the performance. Using this nano refrigerant resulted in better performance and heat transfer rate and reduction in power consumption. With 0.05% concentration of nano-particles the C.O.P value increased from 0.58 to 0.62.

Sanukrishna and Jose Prakash [15] the experiment was carried out with TiO_2 -PAG nanolubricant and thermal and rheological effects were investigated. From the findings it can be observed that there is an enhancement in thermal conductivity of 1.38 and in viscosity valuewhich is 10 times more than pure refrigerant with 0.8% and 0.6% volume fraction.

Saravanan and Vijayan [16] used Al_2O_3 / TiO_2 nano composite nanoparticles in R134a household refrigerator. The experiment was conducted with different nano composite compositions. From the results the better performance was obtained with composite nanolubricants. With nanoparticles there is enhancement in COP to 2.33 and less energy utilizedup to 92.2 W.

Babarinde et al. [17] enhanced R600a system efficiency with graphene nano-lubricants. Graphene nano-lubricants concentration of three different samples 0.2, 0.4 and 0.6 g/L andthree different R600a mass quantities of 50, 60 and 70 g were used. R600a with 60 g and graphene nano-lubricant quantity of 0.2 g/L gave maximum COP of 3.2.

Narayanasarma and Kuzhiveli [18] assessed the energy efficiency of POE/SiO_2 nanolubricant refrigeration system. The various properties like thermal, tribological, rheological, polyolester (POE) oil with SiO_2 nanoparticles is used as nano-lubricant in compressors. The properties got enhanced using nano-lubricants in refrigeration system. The 0.15% of POE oil the compressor life may be extended. Graphene nano-lubricants with various concentrations were implementedin isobutene refrigerator. Nano-lubricants concentration of 0.2, 0.4 and finally 0.6 g/L has beentaken. The quantity of R600a refrigerant taken for analysis as (40, 50 and 70 g). After conducting experiments, the compressor consumes lower value of power 65 W and temperatureinside cabin is – 12 °C. The power per ton of refrigeration value obtained was 5.22 and enhancedCOP of 0.76 was achieved using 70 g of R600a and graphene quantity of 0 g/L.

Krishna Sabareesh et al. [19] has performed experiment in VCR system with TiO_2 nanoparticles. The coefficient of performance was enhanced up to 1.43 and about 17% with TiO_2 nanoparticles. In comparison to the current literature, the different CuO/Al_2O_3 nanolubricants concentrations were utilized in R600a refrigerator. The experiment was performed to increase the refrigerator performance.

Adelekhan et al. [20] conducted experiment in R600a refrigeration system with Tio_2 nanolubricants concentrations. The power utilized by the system was lowered by 6.2% with 0.2 g/L compared to 0 g/L nano-lubricant system. The COP of the system improved to a range value of 3.23–4.03. Test rig with Tio2 nano-lubricants resulted in higher discharge temperature of about 6–24%. LPG refrigerator performance with various mineral oil and titanium concentrations were examined. With 0.4 g/L nano- lubricant concentration and 40 g of refrigerant mass charge resulted in enhanced COP of 2.8.

Adelekan et al. [21] the compressor consumed less power of 21 W with 70 g of LPG with 0.2 or 0.4 g/L nano-lubricants concentration and resulted in enhanced refrigerating effect of 65 W.In LPG refrigerator experiment was carried out with titanium oxide, silicon oxide and aluminium oxide nanoparticles at low concentration and diffused in mineral oil. Based on the results the conclusion was arrived that all nano-lubricant-based LPG has dropped evaporator air temperatures in comparison with pure mineral oil based LPG system. The compressor utilized less power of 13 and 12% with nano-lubricants composed of titanium oxide and silicon dioxide in comparison with LPG refrigerator which consumed more power.

Santhana Krishnan et al. [22] mainly focused on analysis and effectiveness of nanolubricants in R134a refrigerator. Energy consumption is one of the main problems in refrigeration systemand hence system efficiency has been increased. The various nanoparticles was employed in this experiment was Al_2O_3, SiO_2, ZrO_2 and CNT with POE lubricant. The COP value was improved to 1.73 by utilizing 0.60 g of SiO_2 added to quantity of 220 mL of POE.

Ohu nakin et al. [23] tested with various concentrations of SiO_2 nanoparticles using LPG refrigerant with mineral oil as lubricant. Results indicated that increase in COP value of 2.5 with 0.4 g/L nano-lubricant and 50 g of LPG. With 0.2 g/L SiO_2 /60 g of LPG resulted in COPvalue of 2.65 compared to R134a refrigeration system. The power utilized by compressor was
28.81 W using 0.2 g/L nano-lubricant/60 g of LPG and resulted in 39.21 W with 100 g of LPGrefrigerant.

Subramani et al. [24] considered various titanium oxide concentrations of nanoparticles in R134a refrigerator. Based on the experimental findings the nano-lubricants works usually and safely. The compressor power utilization was decreased by 15.4 %, while the COP was increased by 20%. The detailed summary of nano-lubricants, hybrid nanofluids and nano refrigerants effects and significance in vapour compression refrigeration system.

Haque et al. [25] Al_2O_3 and TiO_2 nanoparticles with different sizes were dispersed to polyolester (POE) oil in two various volume concentrations of 0.05 and 0.1 vol. %. By employing nano lubricants, the COP of refrigeration system was improved by 19% with 0.05%and 22% with 0.1% Al_2O_3 nanoparticles. The compressor consumed 27.73% and 14.19% less energy with Al_2O_3 and TiO_2 nanoparticles mixed with POE oil.

Yang et al. [26] carried out research by three various concentrations of 10, 20 and 30 mg/L of refrigerant oil with graphene nanosheets was prepared and used for experiment. By adopting graphene nanosheets resulted in increased freezing capacity of system up to 11.1% and using graphene nanosheets refrigerant oil concentrations of 10, 20 and 30 mg/L the energy consumedfor 24 h decreased by 15.4%, 19.2% and 20.3%.

Hamid et al. [27] made attempts to improve the single component nanofluids thermo physical properties. To improve the heat transfer performance the hybrid or composite nanofluids were developed. Titanium oxide and silicon dioxide nanoparticles are mixed with water and ethyleneglycol in ratio of 60:40. Nanofluids with titanium oxide and silicon dioxide enhance thermal conductivity up to 16% in comparison to the base fluids. With nanofluids, the dynamics viscosity was also increased.

Lou et al. [28] studied about isobutene and graphite nano lubricants which are applied to refrigerator to evaluate the performance. In the refrigerator, graphite nano lubricants of varyingmass fractions of 0, 0.05, 0.1, 0.2 and 0.5 % were used. Using graphite nano lubricant mass fractions of 0.05, 0.1, 0.2 and 0.5% resulted in energy consumption of 3.54%, 4.55%, 3.61%, and 0.64% and the pull-down time got reduced.

Nabil et al. [29] reviewed and performed experiments on hybrid nanofluids and hybrid nano lubricants which are made by combining two dissimilar nanoparticles and dispersed in base fluid. The hybrid nano-fluids/nano-lubricants possess better thermal properties compared to conventional nanofluids/nano-lubricants. This review gives detailed information about preparation methods, current progress, development and heat transfer characteristics of hybrid nano-lubricants and hybrid nanofluids. Hybrid nanofluids play a critical role in improving heattransfer. In this study titanium oxide and silicon dioxide in a mixture of water and ethylene glycol was considered to study the properties like thermal conductivity and dynamic viscosity.The thermal conductivity of titanium oxide and silicon dioxide nanofluids increased by 22% with increase in volume concentration of nanofluids.

Esfe et al. [30] employed hybrid nanofluids which contains single walled carbon nanotubes andmagnesium oxide nanoparticles and dispersed in to ethylene glycol. This research revealed the thermal conductivity measurement and used artificial neural network (ANN) modelling technique. The data which was obtained using hybrid nanofluids compared with single particle nanofluids. From analysis it was inferred that there is enhancement in thermal conductivity with 1% addition of volume fraction and proposed a correlation to understand thermal behaviour ofhybrid nanofluids.

III. MATERIALS AND METHODS

Mineral oil lubrication in refrigeration systems is a crucial component for ensuring the smooth operation and longevity of the system. Mineral oils are petroleum-based lubricants that have been used for many years in various types of refrigeration systems, especially those using CFC (chlorofluorocarbon) and HCFC (hydrochlorofluorocarbon) refrigerants. Their compatibility with these refrigerants, along with their lubricating properties, has made mineral oils the lubricant of choice in many traditional refrigeration systems. Compatibility: Mineral oils are highly compatible with traditional CFC and HCFC refrigerants, which make them a preferred choice for systems designed for these refrigerants. Lubrication Quality: They provide excellentlubrication to the moving parts of the refrigeration compressor, reducing wear and tear, and extending the life of the compressor. Chemical Stability: Mineral oils are chemically stable, which means they do not readily react with the refrigerants or the materials used in the construction of the refrigeration system, thus maintaining system integrity. Low Volatility: These oils have low volatility, reducing the risk of them being carried away with the refrigerantto other parts of the system where they could cause issues such as oil logging or reduced heat transfer efficiency. Hydrophobic Nature: Mineral oils are hydrophobic, meaning they do mix well with moisture. This characteristic can lead to the formation of acids if moisture enters the system, potentially causing corrosion and other issues. While the refrigeration industry evolves with a focus on environmental sustainability and efficiency, leading to the adoption of new refrigerants and lubricants, mineral oil remains an important lubricant for specific applications, especially in older systems. The selection of lubricants in refrigeration systems must consider factors such as refrigerant type, system design, and operational conditions to ensure optimal performance and longevity.

Mineral oil lubrication plays a critical role in the operation and longevity of refrigeration compressors. Refrigeration compressors are mechanical devices that compress refrigerant gas, playing a central part in the refrigeration cycle that cools air or liquids. The role of mineral oil in these compressors includes several key functions: Lubrication: The primary role of mineral oil in a refrigeration compressor is to lubricate moving parts such as pistons, bearings, and shafts. Proper lubrication reduces friction between these components, minimizing wear and extending the life of the compressor. Cooling: By circulating within the compressor, mineral oil absorbs heat generated from the compression process and friction, helping to cool the compressor's internal components. This is vital for preventing overheating and potential damage. Sealing: Mineral oil helps to maintain a good seal in the compression chamber, improving the efficiency of the compression cycle by reducing the leakage of refrigerant gas.

3.1 Synthesis of Nano lubricant

Synthesis of stable nano-lubricant is the crucial step in the experimental investigation. In the present study, the Gr/Al_2O_3 was used as additives in mineral oil (MO) to prepare nanolubricant. The Alumina and Graphene nanoparticles of size 20 nm. The thermo-physical properties of thenanoparticles and the mineral oil used are given in Tables 1, 2 and 3.

The preparation of nanolubricants typically involves dispersing nanoparticles in a base lubricant.Achieving a stable dispersion without agglomeration of nanoparticles is crucial for the effectiveuse of nanolubricants. Among various methods, the two-step method is the most widely used approach due to its simplicity, scalability, and versatility in terms of compatible materials and nanoparticles. Here's how it's generally done:

3.1.1 Nanoparticle Preparation

The first step is to obtain or prepare nanoparticles of the desired material. These nanoparticles can be metals, metal oxides, carbon nanotubes, graphene, or other materials with specific properties aimed at improving lubrication. The particles are typically prepared using processes like ball milling, sol-gel techniques, chemical vapour deposition, or purchased from suppliers as pre-synthesized powders. The key objectives are to control the size, shape, and surface characteristics of the nanoparticles, as these factors significantly influence the performance of the final nanolubricant.

3.1.2 Dispersing Nanoparticles in the Base Lubricant

Selection of Base Lubricant: The base lubricant (e.g., mineral oil, synthetic oil, vegetable oil)is chosen based on its compatibility with the system components, the working environment, and the type of nanoparticles used. **Dispersion of Nanoparticles**: The prepared nanoparticles are then dispersed into the base lubricant. This step is critical and can be challenging due to the natural tendency of nanoparticles to agglomerate. To achieve a stable dispersion, the process may involve: **High-Speed Stirring**: Mechanical stirring at high speeds can help distribute the nanoparticles evenly throughout the lubricant. **Ultrasonication**: This is a widely used technique where ultrasound energy is applied to the mixture to break up agglomerates and distribute the nanoparticles uniformly. The ultrasonic waves create microjets and cavitation bubbles in the liquid, promoting effective dispersion. **Use of Surfactants**: In some cases, surfactants (dispersing agents) are added to stabilize the dispersion. Surfactants can adsorb onto the surfaceof nanoparticles, preventing agglomeration by providing steric or electrostatic stabilization.

After preparation, the nanolubricant requires thorough analysis to ensure the stability and dispersion quality of the nanoparticles. Techniques like dynamic light scattering (DLS) can assess particle size distribution, while transmission electron microscopy (TEM) or scanning electron microscopy (SEM) can provide insights into the morphology and state of dispersion ofthe nanoparticles. Additionally, stability tests, often involving zeta potential measurements or sedimentation observation, are conducted to predict the long-term behavior of the nanolubricant.

The two-step method allows for considerable flexibility in the choice of nanoparticle materials and base lubricants, making it a popular approach for developing nanolubricants for awide range of applications, including vapor compression refrigeration system compressors. TheMineral Oil-Gr-Al_2O_3 nano-powder was characterized by using Scanning Electron Microscope(SEM). The particles were of spherical shape. The samples for the study were prepared by two- step method with Oleic acid as surfactant. Nano-lubricants were synthesized for four different Gr/Al_2O_3 nanoparticle volume concentrations (0.05%, 0.075%, 0.1%, 0.2%), as above 0.2% volume concentration, the coefficient of friction is increased. The required mass of aluminum oxide particles for each sample volume concentrations were calculated by using law of mixture relation and weighted by using highly precise Balance.

$$\% \text{ Volume Fraction of Al2O3} = \frac{\left[\frac{W_p}{\rho_p}\right]}{\left[\frac{W_p}{\rho_p} + \frac{V_{bf}}{\rho_{bf}}\right]}$$

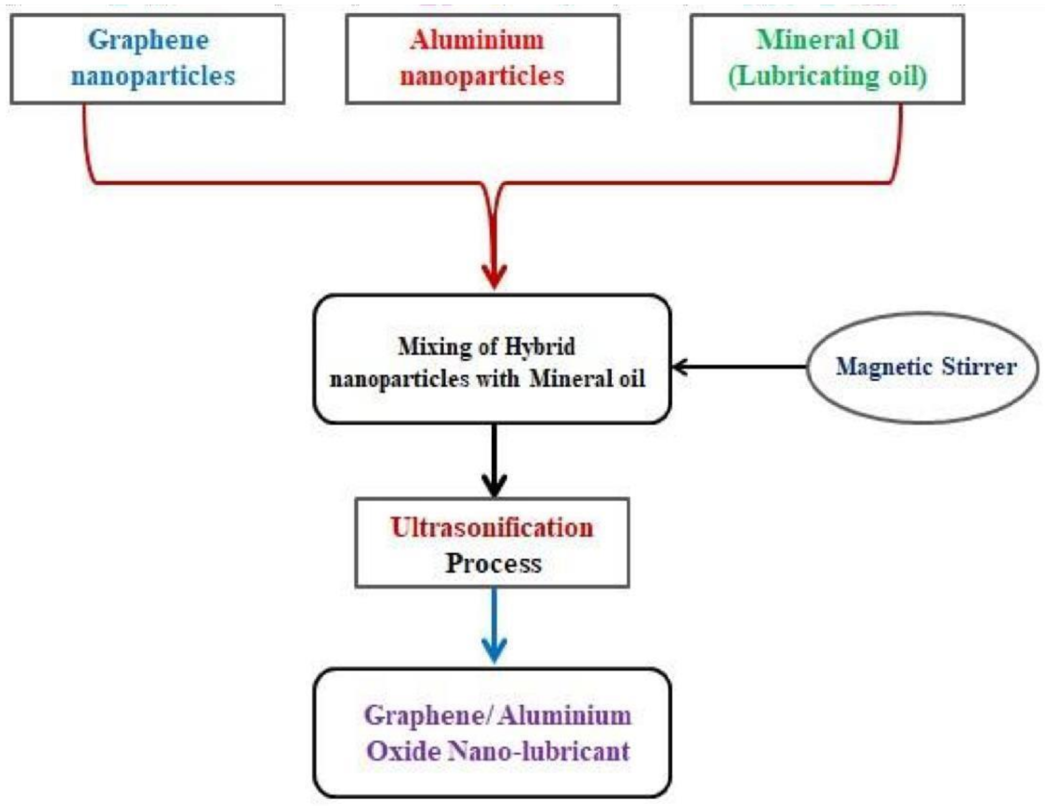

Figure.1: synthesis of nanoluricant flow chart

3.2 Magnetic Stirring is used in Nanolubrication Synthesis

Magnetic stirring is a widely used technique in various chemical synthesis processes, includingthe preparation of nanolubricants. Nanolubricants are nano-enhanced lubricating fluids that contain nanoparticles dispersed in a base lubricant. These nanoparticles can significantly improve the lubricant's thermal and mechanical properties, leading to reduced friction, wear, and energy consumption in mechanical systems. Uniform Dispersion of Nanoparticles: Magnetic stirring helps in achieving a uniform dispersion of nanoparticles within the base lubricant. The stirring action ensures that nanoparticles are evenly distributed throughout the liquid, preventing agglomeration (clumping together of particles). This is crucial for maintaining the stability and performance of nanolubricants. Synthesis of Nanoparticles: In some cases, magnetic stirring is involved in the synthesis of the nanoparticles themselves before they are added to the lubricant. For example, chemical reduction or sol-gel processes might require vigorous stirring to ensure proper chemical reactions and the formation of nanoparticles with desired sizes and shapes.

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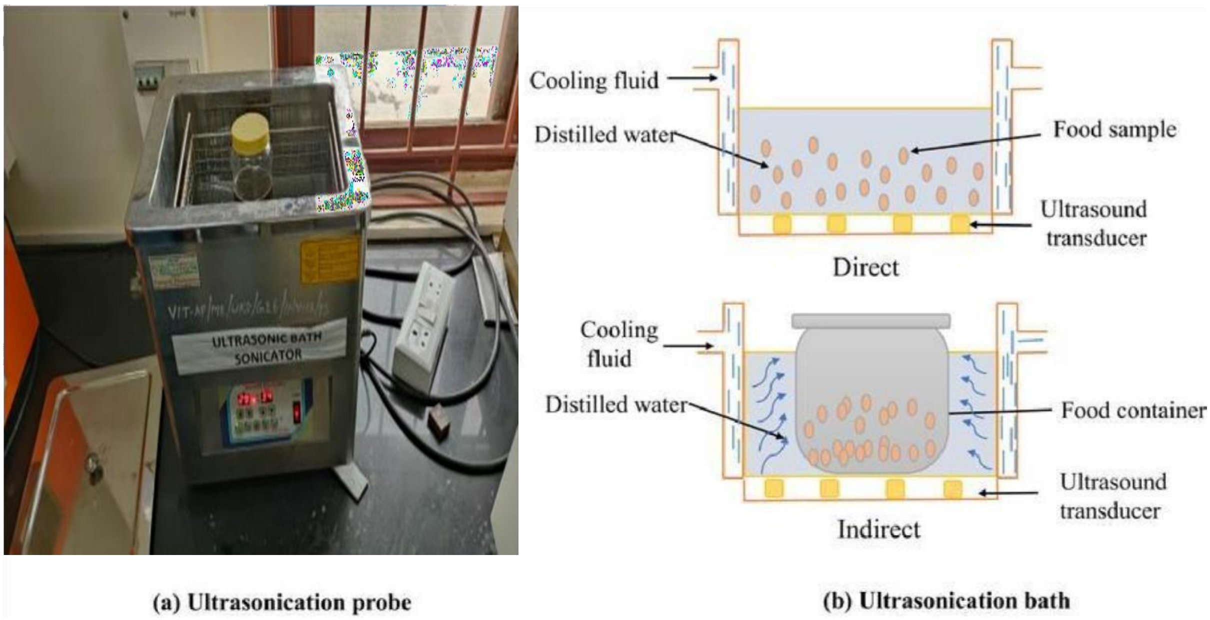
Figure.2: Magnetic Stirring

3.3 Ultra Sonication in Nanolubricant Synthesis

Ultra sonication is a powerful technique often employed in the synthesis and dispersion of nanolubricants, which are lubricants enhanced with nanoparticles to improve their performance. Nanolubricants have been gaining attention in various industries, including automotive, aerospace, and manufacturing, due to their potential to significantly reduce friction and wear, leading to enhanced energy efficiency and longer machinery life.

The process of ultra-sonication involves the use of high-frequency sound waves to agitate particles in a sample. This agitation can lead to the break-up of agglomerates and the dispersionof nanoparticles evenly throughout a liquid medium. In the context of nanolubrication, ultra sonication plays a crucial role in: **Dispersion of Nanoparticles:** Ensuring that nanoparticles areevenly dispersed within the base lubricant is critical. Nanoparticles tend to agglomerate due tovan der Waals forces and other interactions. Agglomerated particles would not provide the desired reduction in friction and may even cause increased wear. Ultra sonication breaks up these agglomerates, ensuring a uniform dispersion of nanoparticles. **Stability of Nanolubricants:** The stability of the nanolubricant is vital for its effective storage and use. Proper dispersion achieved through ultra-sonication can enhance the stability of the suspension, preventing the nanoparticles from settling over time. **Particle Size Reduction:** Ultra sonicationcan also help in reducing the size of the nanoparticles. Smaller particles have a larger surface area to volume ratio, which can potentially enhance the lubricating properties of the nanolubricant by providing a more effective barrier between sliding surfaces. **Selection of BaseLubricant and Nanoparticles:** The first step involves selecting the appropriate base lubricant (such as oil) and nanoparticles (such as graphene, Al_2O_3) based on the desired properties. **Preparation of Nanoparticle Dispersion:** The nanoparticles are dispersed in the base lubricant. The mixture might be premixed using mechanical stirring to achieve an initial dispersion. **Ultra Sonication:** The premixed nanolubricant is then subjected to ultra-sonication.

This process involves using an ultrasonic probe or bath that emits high-frequency sound waves, causing intense agitation and cavitation within the liquid. This step is crucial for breaking down nanoparticle agglomerates and achieving a stable, homogeneous nanolubricant. **PostProcessing:** After ultra-sonication, the nanolubricant may undergo additional steps such asfiltering, degassing, or further stability tests to ensure its quality and performance. **Characterization:** Finally, the synthesized nanolubricant is characterized for its physical and chemical properties, including particle size distribution, zeta potential (for stability analysis), viscosity, thermal conductivity, and tribological properties (friction and wear characteristics). Ultra sonication is a versatile and effective tool in the field of nanotechnology, particularly forthe synthesis and enhancement of nanolubricants. By ensuring the even dispersion of nanoparticles and enhancing the stability of the nanolubricant, ultra sonication helps in maximizing the performance benefits of nanolubricants across various applications.



(a) Ultrasonication probe (b) Ultrasonication bath

Figure.3: Ultra Sonication

To prepare stable nanolubricant, Sonics make VCX500 Probe sonicator (Figure.4) was used toapply ultrasonic agitation force. Sonication was done for 1 hour at frequency of 50 kHz to homogenise the one litre sample. A probe sonicator, also known as an ultrasonic homogenizer,plays a crucial role in the preparation of nanolubricants, particularly during the dispersion phaseof the two-step method. The main function of a probe sonicator is to apply ultrasonic energy to a liquid sample to create intense shearing forces. These forces are capable of breaking up particle agglomerates and dispersing nanoparticles uniformly throughout a base lubricant. Here's a closer look at how a probe sonicator works in the context of nanolubricant preparation**:**Ultrasonic Energy Generation: The probe sonicator operates by converting electrical energy into mechanical vibrations. These vibrations are generated by a piezoelectric transducer attached to the probe (or horn) of the sonicator. Cavitation: When the probe is submerged in theliquid lubricant containing nanoparticles and activated, it generates ultrasonic waves that propagate through the liquid, leading to the formation of microscopic bubbles or cavities. These bubbles grow until they can no longer absorb energy, at which point they collapse violently a process known as cavitation. Particle Dispersion and

Deagglomeration: The collapse of the cavitation bubbles generates intense local energy release, producing high shear forces and localized hot spots with extremely high temperatures and pressures. This environment is highly effective at breaking apart nanoparticle agglomerates and dispersing individual nanoparticles throughout the base lubricant. Temperature Control**:** The process generates significant heat, which can alter the properties of the lubricant or damage the nanoparticles. To mitigate this, probe sonication is often conducted in short bursts or pulses, with cooling periods in between, to manage the temperature rise. In summary, probe sonication is a powerful and versatile tool for the preparation of nanolubricants, enabling the effective dispersion of nanoparticles within a base lubricant to enhance its properties. However, careful attention to process parameters and material compatibility is essential to achieve optimal results and maintain the integrity of both the nanoparticles and the lubricant.

Figure.4: Probe sonicator

3.4 Characterization of Nanolubricant Table.1: properties of Al2O3 nano-powder

Property	Al2O3 nano-powder
Purity	99.9%
Average particle size	20 nm
Molecular weight	101.96 g/mol
Density	2.76 g/cm3
Thermal conductivity	237 W/m°K
Specific heat	880 J/Kg•°K
Conductivity [MS/m]	35

Table.2: properties of Mineral Oil

Property	Mineral oil
Viscosity @ 40°C	67.8 cSt
Viscosity index	93
Pour point	−46°C
Flash point	243°C
Density	865 kg/m^3
Boiling point	>300°C

Table.3: properties of Graphene nano-powder

Property	Graphene nano-powder
Melting point [◦C]	4620
Density [g/cm3]	1.1–1.5
Conductivity [MS/m]	100 (3 × Al)
Thermal conductivity [W/m.k]	4840
Thermal conductivity	35 W/m°K

Specific heat	760Kg•°K

3.4.1 Rheology

The investigation of Gr/Al_2O_3-mineral nanolubricant oil and its viscosity characteristics using a rheometer represents a specific application of nanotechnology in enhancing lubricant properties. Here, "Gr" stands for graphene, a material known for its exceptional strength, thermal conductivity, and lubrication properties, and "Al_2O_3" stands for aluminium oxide (alumina), which is recognized for its wear resistance and thermal stability. When these nanoparticles are dispersed in mineral oil, they form a hybrid nanofluid that could potentially offer superior lubrication performance compared to conventional lubricants. This nanolubricantis essentially a mineral oil base in which graphene and aluminium oxide nanoparticles are dispersed. Graphene particles contribute to the enhanced thermal conductivity and mechanical strength of the lubricant, while aluminium oxide particles add to the wear resistance and potentially improve the thermal stability of the mixture.

3.4.2 Viscosity Testing Using a Rheometer:

Viscosity measurement is crucial for evaluating the flow behaviour of lubricants under different conditions. A rheometer is an instrument designed to measure the rheological properties, including viscosity, of fluids and semi-solid materials. Here's how viscosity testing of Gr/ Al_2O_3-mineral nanolubricant oil might be conducted: **Sample Preparation:** The nanolubricantsample is prepared by dispersing a specific concentration of graphene and aluminium oxide nanoparticles in mineral oil. The dispersion process often involves mechanical stirring, ultrasonication, or other methods to ensure uniform distribution of nanoparticles. **Temperatureand Shear Rate Control:** The rheometer allows for precise control over the temperature and shear rate applied to the nanolubricant sample. This is important because the viscosity of lubricants can vary significantly with changes in temperature and under different shear conditions. **Viscosity Measurement:** The rheometer measures the resistance of the nanolubricant to flow under applied stress. By doing so, it can provide valuable data on how the viscosity changes with temperature, shear rate, and nanoparticle concentration. These measurements can be conducted over a range of temperatures and shear rates to simulate the operational conditions the lubricant would experience in a real-world application. **Analysis:** The data obtained from the rheometer are analysed to understand the flow behavior of the Gr/ Al_2O_3-mineral nanolubricant. Parameters such as shear-thinning or shear-thickening behavior, temperature sensitivity of the viscosity, and the impact of nanoparticle concentration on lubrication performance can be assessed. The Anton Paar viscometer show in the figure--.

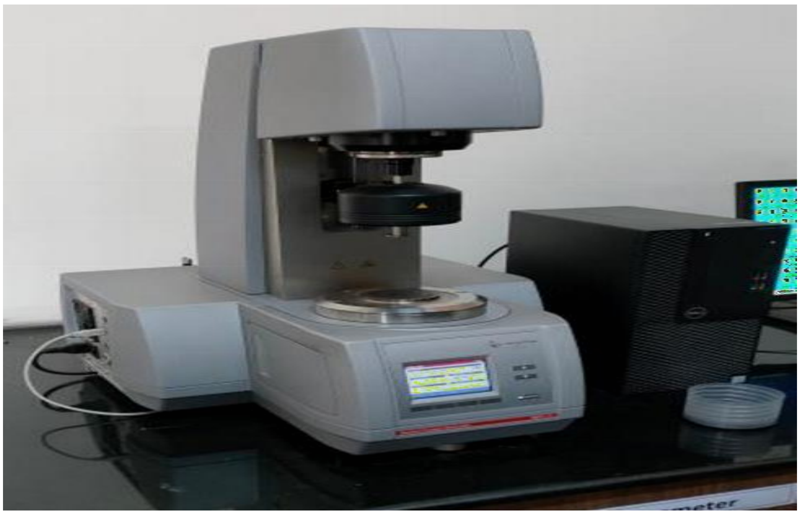


Figure.5: Rheometer

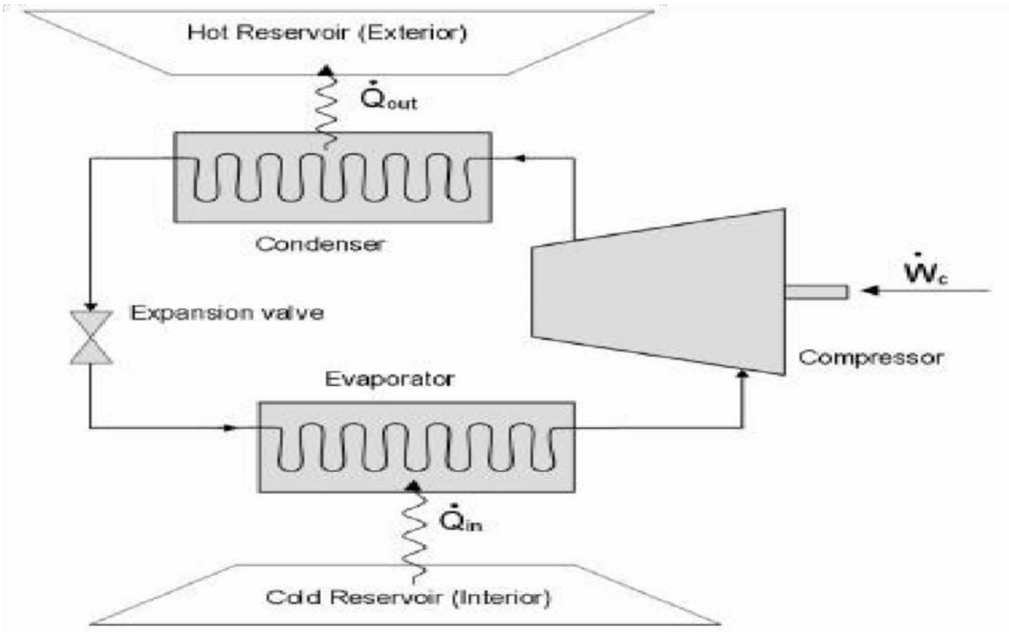
The viscosity characteristics of the Gr/Al_2O_3-mineral nanolubricant are critical for its application in vapor compression refrigeration systems or other machinery. Ideally, a lubricant should maintain sufficient fluidity at low temperatures for easy start up and form a robust lubricating film at high temperatures to protect against wear. Additionally, understanding how the viscosity responds to shear stress is vital for predicting the lubricant's performance under operating conditions. By examining the viscosity behavior of nanolubricants, researchers and engineers can tailor the composition and concentration of nanoparticles to achieve desired lubrication properties, thereby enhancing the efficiency, reliability, and lifespan of mechanicalsystems.

3.4.3 Procedure for SEM Analysis of Nanolubricants

Sample Preparation: Samples are prepared from the nanolubricant, often by depositing a small quantity on a suitable substrate or by directly preparing a wear scar for analysis. **Imaging:**
The sample is placed in the SEM chamber, and images are taken at various magnifications to observe the distribution, morphology, and interaction of nanoparticles within the lubricant or on the wear surfaces. **Analysis:** The collected images are analysed to assess the parameters of interest, such as particle size distribution, dispersion quality, and wear characteristics. SEM analysis of nanolubricants provides a wealth of information that is critical for optimizing their formulation and understanding their performance characteristics. By enabling detailed observation of nanoparticles and their interactions within lubricants, SEM helps in the development of more effective and reliable nanolubrication systems.

3.5 Experimental Test

3.5.1 vapour-compression refrigeration (VCR) system



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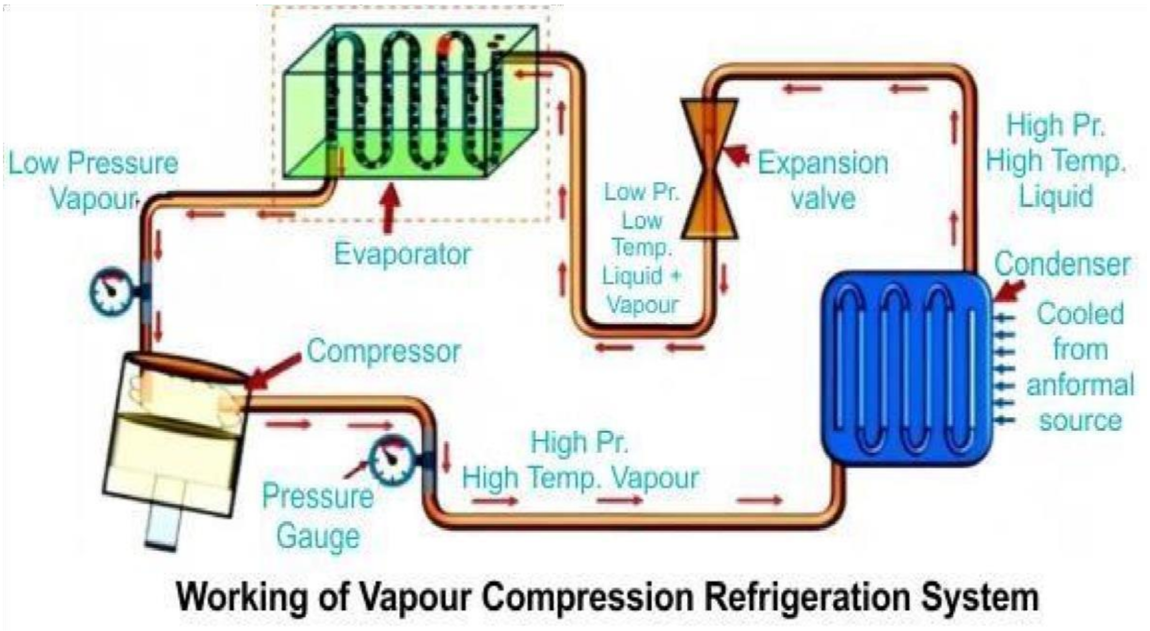


Figure.6: vapour-compression refrigeration (VCR) system line diagram

The vapour-compression refrigeration (VCR) system is a widely used method for cooling environments and preserving food and medicine, among other applications. It operates on the basic principle of phase change of the refrigerant within a closed system, moving heat from oneplace to another. The system mainly consists of four components: the compressor, condenser, expansion device, and evaporator. Here's how it works, step by step:

1. **Compression:** The cycle starts with the refrigerant in vapour form at a low pressure andtemperature. This vapour is drawn into the compressor, where its pressure and temperature are significantly increased. The compressor is the driving force of the refrigerant through the system.

2. **Condensation:** The high-pressure, high-temperature vapour then flows into the condenser. Here, the refrigerant releases its heat to the surroundings (outside air, water, or another medium). As it loses heat, the refrigerant condenses into a highpressure liquid. The process of condensation is typically aided by fans or cooling water to removethe heat more efficiently.

3. **Expansion:** Next, the high-pressure liquid refrigerant moves to the expansion device, which can be a capillary tube, thermostatic expansion valve, or electronic expansion valve, among others. This device restricts the flow of the refrigerant, causing a sudden drop in pressure as the refrigerant passes through. This abrupt pressure reduction results in a portion of the liquid refrigerant evaporating instantly, significantly lowering its temperature.

4. **Evaporation:** The cold, low-pressure liquid refrigerant then enters the evaporator, where it absorbs heat from the environment to be cooled (such as the interior of a refrigerator or the rooms of a building through air handling units). As it absorbs heat, the refrigerant evaporates, turning back into a low-pressure vapour. This process effectively removes heat from the area, lowering its temperature.

5. **Return to Compression:** The low-pressure vapour is then sucked back into thecompressor, and the cycle repeats.

3.5.2 Types of Refrigeration Compressors

1. Reciprocating Compressors (Piston Compressors)

These are one of the most widely used technologies for commercial and industrial applications. They feature a piston and cylinder arrangement like the automotive engine. The refrigerant inside the cylinder gets compressed by the reciprocating motion of the piston. These compressors are capable of compressing gases to high pressures and support continuous operation. There are three types of reciprocating compressors: hermetically sealed semihermetically sealed and open type.

2. Screw Compressors

These compressors have a pair of meshing screws in between them where the refrigerant gets compressed. They can produce high pressure for a small quantity of gas. They pass refrigerantvapour through screw spindles which compress the gas.

3. Scroll Compressors

This technology comprises two interleaved scrolls. One of these scrolls is fixed and the other orbits eccentrically without rotating. The refrigerant is then compressed in the small gaps whichare created during its motion. These compressors are widely in use as they have a relatively lowrate of leakage and provide high efficiency.

4. Rotary Compressors

Rotary Compressors feature two rotating elements, like gears, between which the refrigerant iscompressed. These compressors can pump the refrigerant to lower or moderate condensing pressures and thus are able to handle small volumes of gas and produce lesser pressure.

5. Centrifugal Compressors

These compressors possess impellers or the blowers that can handle large quantities of gas. The beauty of the vapour-compression refrigeration system lies in its ability to transfer heat from acooler environment (inside the refrigerator or building) to a warmer environment (outside), which is counterintuitive but incredibly effective for cooling. This cycle is highly efficient andcan be adapted to various scales, from small household appliances to large industrial chillers.

Figure.7: Experimental set up

The potential of Gr/Al_2O_3-Mineral Oil (MO) nanolubricant in 0.5 tons capacity R134aMObased vapour compression refrigeration system was studied using the test setup as shown in Figure 5.The test setup consists of a Kirloskar make hermetically sealed compressor, finned tube air- cooled condenser, expansion devices, evaporator tank inbuilt with cooling coils to cool the water. The calibrated J-type thermocouples were used to record the temperature of refrigerant at the inlet and outlet of the condenser, evaporator and water tank. Two pressure gauges were used to measure condenser and evaporator pressure. The energy metre having a constant of 3200 Rev/Kwh was used to find the power consumption of the R134a-MO-based vapour compression refrigeration system. The rate of power consumption by compressor was calculated by recording the time required by the energy metre for 10 revolutions. The water wasfilled in the evaporator tank.

$$Refrigerating\ Effect = Q = \frac{m\ Cp\ \Delta T}{t}$$

$$Compressor\ Work\ Input = P = \frac{n\ 3600}{t\ K}$$

$$COP = \frac{Q}{P}$$

The experimentation was carried out at 1.71, 1.9, 2.4, 3.0 and 3.9 LPM water flow rate through the tank for different samples of compressor lubricant. The mass flow rate of water was measured by using the measuring cylinder. The coefficient of performance (COP) of the VCR system was calculated by using the amount of heat removal rate in the water tank and power consumption by the compressor. Equations 2, 3 and 4 were used to find the heat absorbed in theevaporator section, power input to run the compressor and COP.

3.5.3 Role of 134a refrigerant in vapour compression refrigeration system

R-134a, chemically known as 1,1,1,2-Tetrafluoroethane, plays a critical role in vapour compression refrigeration systems, particularly in applications ranging from automotive air conditioning to commercial and domestic refrigeration units. Its adoption was primarily driven by the need to replace older refrigerants like R-12 (dichlorodifluoromethane) due to environmental concerns, specifically their potential to deplete the ozone layer and contribute to global warming. R-134a is a hydro fluorocarbon (HFC), which, while still a greenhouse gas, does not deplete the ozone layer.

3.5.4 Role in the Refrigeration Cycle:

In the context of a vapor compression refrigeration system, R-134a serves as the working fluid that undergoes phase changes to absorb and release heat, thereby enabling the refrigeration cycle. Here's a brief overview of its role throughout the cycle: **Compression:** Initially, R-134a is in a low-pressure vapor state. The compressor increases its pressure, causing the temperature of R-134a to rise significantly above the ambient temperature. **Condensation:** In its highpressure, high-temperature vapour state, R-134a flows through the condenser coils. Here, it releases its heat to the surroundings (air or water). As it loses heat, it condenses into a highpressure liquid. The ability of R-134a to efficiently release heat during condensation is crucial for the effectiveness of the refrigeration cycle. **Expansion:** The highpressure liquid R- 134a then passes through an expansion device (such as a capillary tube or expansion valve), where its pressure is abruptly reduced. This sudden pressure drop causes a portion of the liquidto evaporate immediately, cooling the remaining liquid significantly due to the latent heat of vaporization. **Evaporation:** The cold, low-pressure R-134a liquid then enters the evaporator coils. Here, it absorbs heat from the environment to be cooled (like the interior of a refrigerator or a room). This absorption process causes the R-134a to evaporate, turning back into a vapor while removing heat from the surrounding area, effectively lowering its temperature. **Return to Compression:** The low-pressure R-134a vapour is then drawn back into the compressor, completing the cycle.

3.5.5 Advantages of R-134a:

- **Ozone-Friendly:** R-134a does not contribute to ozone depletion, making it environmentally preferable to older refrigerants like R-12.
- **Compatibility:** It can be used in existing R-12 systems with some modifications, makingit a versatile replacement option.
- **Safety:** R-134a is non-toxic and non-flammable under normal conditions, offering a safe choice for various applications.
- **Efficiency:** It provides efficient cooling performance, suitable for a wide range oftemperatures and pressures in refrigeration and air conditioning systems.

3.5.6 Environmental Impact:

While R-134a is ozone-friendly, it is a potent greenhouse gas with a global warming potential (GWP) significantly higher than CO_2. This has led to efforts to phase down its use under globalagreements like the Kigali Amendment to the Montreal Protocol, in favour of refrigerants with lower GWPs. Alternatives include HFOs (hydrofluoroolefins) and natural refrigerants like CO_2 and propane, which offer lower global warming potentials and are becoming increasingly popular in new systems.

3.5.7 Role of mineral oil in compressor in vapour compression refrigeration system

Mineral oil in a vapor compression refrigeration system plays several crucial roles, particularly within the compressor, which is the heart of the system. The primary functions of mineral oil in the compressor are lubrication, cooling, sealing, and protecting against wear and corrosion.

Let's delve into each of these roles in more detail:

Lubrication:

Reducing Friction: The most important role of mineral oil is to lubricate the moving parts of the compressor, such as pistons, cylinders, bearings, and rotors. This reduces friction betweenthese components, ensuring smooth operation and preventing excessive wear.

Heat Reduction: By reducing friction, mineral oil also helps in reducing the heat generated bythe moving parts within the compressor. This is crucial for maintaining the efficiency and longevity of the compressor.

Cooling:

Heat Absorption: Besides lubrication, mineral oil absorbs heat generated during the compression process. This helps in controlling the temperature of the compressor, preventing overheating, which can lead to breakdowns or reduced efficiency.

Heat Transfer: The circulating oil carries absorbed heat away from critical components and dissipates it, helping to maintain an optimal operating temperature within the compressor.

Sealing:

Enhancing Efficiency: Mineral oil helps in creating a better seal in the compression chamber.By filling gaps and coating the surfaces, it minimizes the leakage of refrigerant during compression, thus enhancing the efficiency of the compression cycle.

Protection:

Preventing Corrosion and Wear: The oil forms a protective barrier on metal surfaces, whichhelps in preventing corrosion caused by moisture or other corrosive substances. It also reduces wear and tear on moving parts, prolonging the life of the compressor.

Removing Contaminants: Mineral oil helps in suspending and carrying away contaminants and debris from critical areas, which are then removed through oil filters or separators. This keeps the internal components clean and reduces the risk of malfunctions.

Compatibility: An esential aspect to consider is the compatibility of mineral oil with the refrigerant used in the system. With traditional refrigerants like R-12, mineral oil was widely used due to its compatibility. However, with the introduction of newer refrigerants like R134a, the compatibility of mineral oil decreased, leading to the use of synthetic oils (e.g., polyolester(POE) oils) that are better suited for these applications. The choice of oil depends on the type of refrigerant, as well as the specific design and requirements of the refrigeration system.

In summary, mineral oil is integral to the efficient and reliable operation of compressors in vapor compression refrigeration systems. It reduces wear and tear on moving parts, helps in heat management, improves sealing, and protects against corrosion, thus ensuring the compressor operates smoothly and efficiently. However, the shift towards new refrigerants forenvironmental reasons has also necessitated the use of new lubricant types that are more compatible with these refrigerants.

3.5.7 Benefits of Nanoparticle-Enhanced Mineral Oil in Compressors

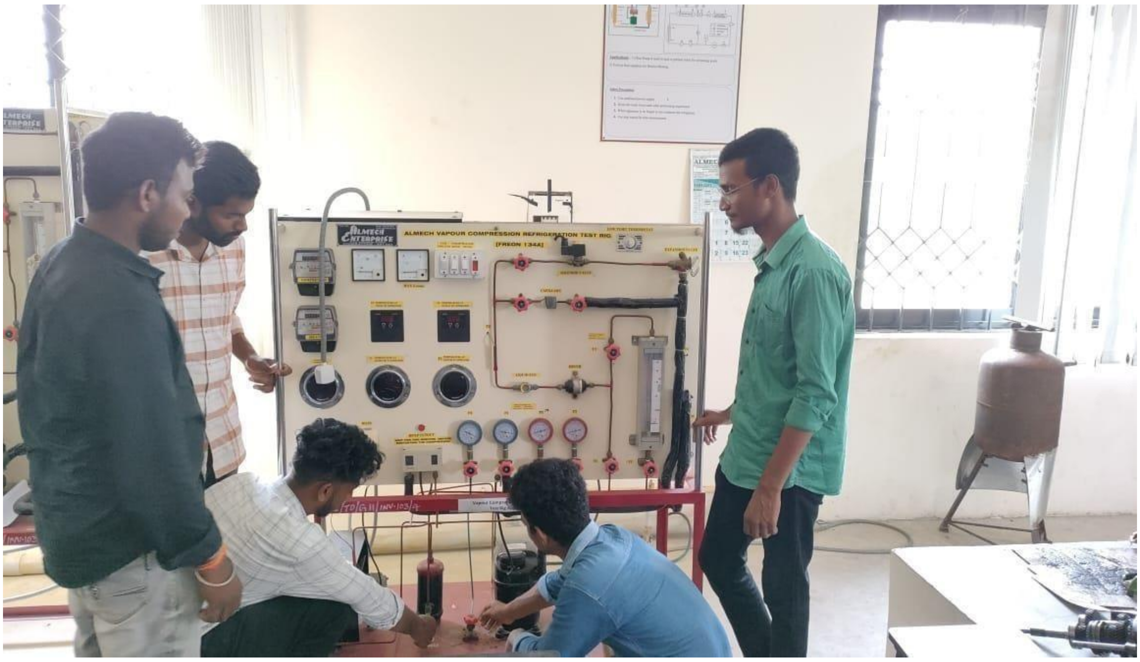
The integration of nanoparticles into mineral oil lubricants for compressors in vapor compression refrigeration systems is an innovative approach that seeks to enhance the performance and efficiency of the refrigeration cycle. Nanoparticles extremely small particles that measure in nanometres can significantly alter the physical and chemical properties of conventional lubricants when dispersed within them. These modified lubricants are often referred to as nano-lubricants.

1. **Improved Thermal Conductivity:** Nanoparticles can significantly increase the thermalconductivity of mineral oil. This enhanced thermal conductivity helps in better heat dissipationfrom the compressor, contributing to a reduction in operating temperatures and potentially extending the lifespan of the compressor and the refrigeration system.

2. **Enhanced Lubrication:** The addition of nanoparticles can improve the lubrication properties of mineral oil by filling microscopic gaps on surfaces, leading to a reduction in friction and wear on compressor components. This can result in smoother operation, reduced energy consumption, and an extended service life for the compressor.

3. **Increased Film Strength:** Nano-lubricants can form a more robust lubricating film on metal surfaces, which can bear higher loads without breaking down. This property is particularlybeneficial in preventing metal-to-metal contact within the compressor, further reducing wear and tear.

Incorporating nanoparticles into mineral oil lubricants for compressors represents a cuttingedge approach to improving refrigeration systems' efficiency and durability. On-going research and development in this field continue to uncover the full potential and address the challenges associated with nano-lubricants.



IV. RESULT AND DISCUSSION

4.1 characterization of nanolubricant:

Nanolubricants, incorporating nanoparticles in lubricating oils, have emerged as a promising technology for enhancing the performance of various mechanical systems, including the compressors in vapour compression refrigeration (VCR) systems. The use of Gr/Al_2O_3 nanolubricants in these compressors, we expecting based on the physical properties like viscosity, stabilization, SEM Analysis can lead to several benefits: Nanoparticles dispersed in the lubricant can fill in the microscopic irregularities on the surfaces of moving parts, leading to a smoother interface. This can significantly reduce friction and wear, enhancing the longevity of the compressor components. Gr/Al_2O_3 Nanolubricants can improve the thermal conductivity of the lubricating oil, facilitating better heat dissipation from the compressor. This can help in maintaining a lower operating temperature, which is beneficial for the compressor's efficiency and durability. The addition of nanoparticles Gr/Al_2O_3 can enhance the thermal and chemical stability of the lubricant, making it less prone to degradation at high temperatures or under mechanical stress. This can lead to longer lubricant life and reduced maintenance requirements. By reducing friction and improving heat transfer, nanolubricants can contribute to a reduction in the energy consumption of the compressor. This enhances the overall energy efficiency of the vapours compression refrigeration system. Properly engineered nanolubricants can be compatible with the existing refrigerants and compressor materials, offering additional protection against corrosion and oxidation, which can extend the service life of the compressor. The application of nanolubricants in VCR system compressors is an area of active research. On-going studies aim to optimize nanoparticle formulations for different types of compressors and operating conditions. As the technology matures, it is expected that nanolubricants will play an increasingly important role in enhancing the performance and efficiency of refrigeration systems.

4.1.2 Sedimentation capturing analysis

Sedimentation analysis is a critical method for assessing the stability of nanolubricants over time. It involves observing and measuring the extent to which nanoparticles settle out of the suspension and accumulate at the bottom of the container. For nanolubricants, long-term stability is desirable; nanoparticles should remain evenly dispersed within the lubricant to ensure consistent performance. Here's a basic outline of how you might conduct a sedimentation capturing analysis for a nanolubricant after 15 days: The sedimentation test was carried out to assure the stability of nanolubricant. From continuous inspection, the synthesisednanolubricant was visually stable or 2 weeks (Figure.8). No evidence of sedimentation was observed after 15 days. Sedimentation capturing analysis provides valuable insights into the long-term stability of nanolubricants, which is crucial for their practical application in industrial, automotive, or refrigeration systems. Identifying and addressing stability issues early can significantly enhance the performance and reliability of nanolubricant-enhanced systems. In the visual analysing we observe 0.10% and 0.20% concentration lubricant had less sedimentation.

Figure.8: Sedimentation capturing

4.1.3 Rheology for Viscosity Testing

The rheological properties, including the viscosity, of nanolubricants such as Gr/Al2O3 -based fluids, can indeed change significantly with the concentration of nanoparticles within the base lubricant. Generally, as the concentration of nanoparticles increases, the viscosity of the nanolubricant also increases. A good or ideal lubricant should have properties like high boiling point, high viscosity index, high viscosity, etc. At higher concentrations, nanoparticles have a greater likelihood of interacting with each other. These interactions can lead to an increased resistance to flow, manifesting as an increase in viscosity. For Gr/Al2O3 nanoparticles, their high surface area to volume ratios amplifies these effects, as the particles can create a network that hinders the movement of the base lubricant. It is observed that as the volume concentration of Gr/Al2O3 nanoparticles increases, the viscosity of lubricant also increases as compared to thepure mineral oil as shown in Figure 9. Anton Paar viscometer was used to measure the viscosity at room temperature. Compare to pure mineral oil the concentration at 0.1% of Gr/Al2O3 increases 29.41%, it's highly increases with 0.2% of Gr/Al2O3 is 43% compared with pure MO.

Table.4: Viscosity & Volume fraction values

Volume fraction (%)	Viscosity (cst)
0	65.5257
0.05	75.8263
0.075	81.6254
0.1	89.4213
0.2	120.226

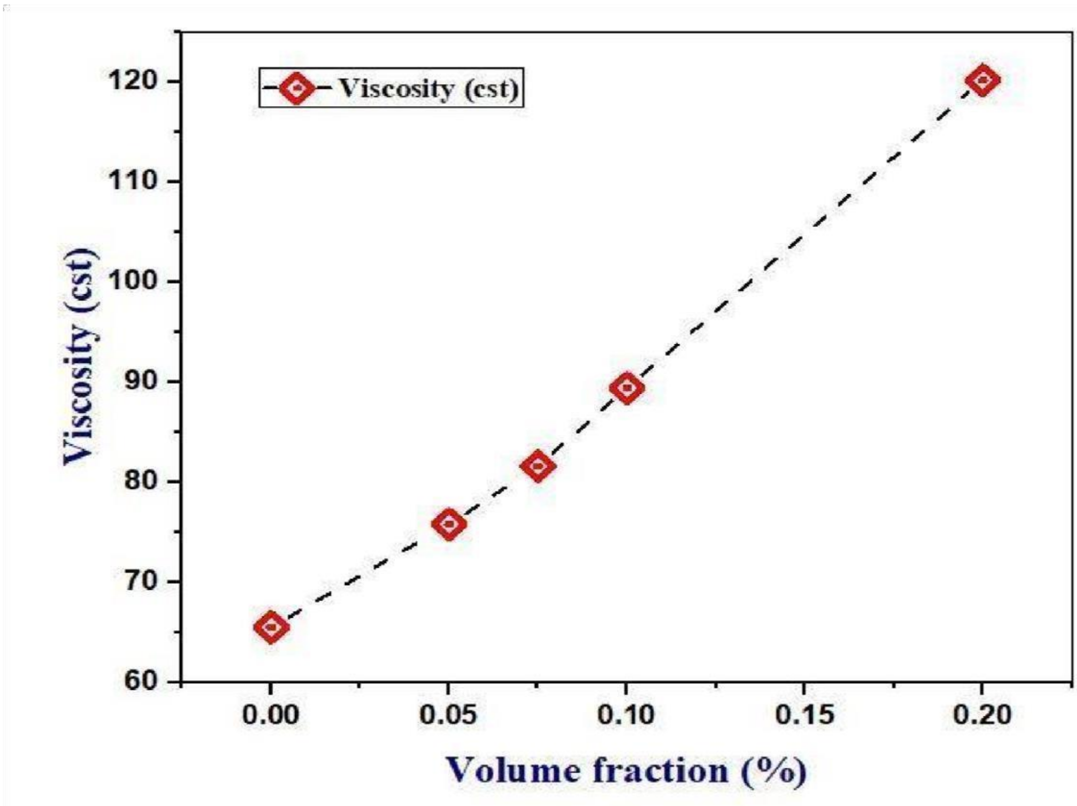


Figure.9: Viscosity Vs Volume fraction

A good or ideal lubricant should have properties like high boiling point, high viscosity index, high viscosity, etc. It is observed that as the volume concentration of Gr/Al_2O_3 nanoparticle increases, the viscosity and stability of lubricant also increases as compared to the pure mineraloil.

4.1.3 SEM analysis for Nanolubricant Testing

Scanning Electron Microscopy (SEM) plays a pivotal role in the analysis and testing of nanolubricants, providing critical insights into the morphology, distribution, and interaction of nanoparticles within the lubricant matrix. SEM is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. These electrons interact with atoms in the sample, producing various signals that contain information about the sample'ssurface topography and composition. Morphological Analysis: Nanoparticle Shape and Size:

SEM allows for the detailed observation of the shape and size of nanoparticles within nanolubricants. This is crucial because these parameters directly influence the tribological properties of the lubricant, affecting its ability to reduce friction and wear. Agglomeration State: It helps in assessing the state of nanoparticle agglomeration. Even dispersion is vital for the effective performance of nanolubricants, and SEM images can reveal whether the sonication or dispersion processes have been effective in breaking up agglomerates. Distribution Analysis: Homogeneity: SEM can be used to evaluate the homogeneity of the nanoparticle dispersion within the base lubricant. A uniform distribution of nanoparticles is essential for consistent performance across the entirety of the lubricated surface. Stability over Time: By comparing SEM images of nanolubricants taken over time, researchers can assess the stability of the dispersion. This is important for understanding how the nanolubricant might behave under storage conditions or within the operational life of the machinery.

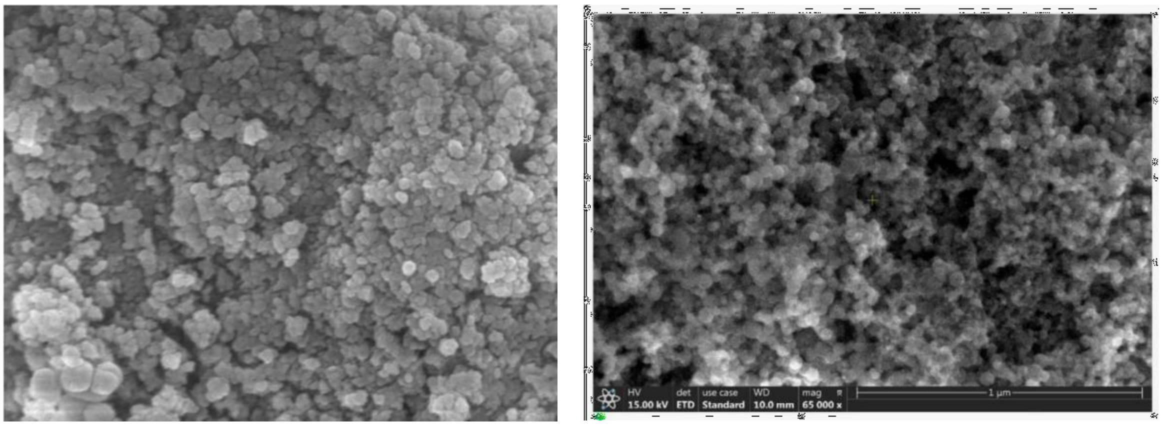


Figure.10: SEM image of the Al_2O_3 and Graphene nanoparticles

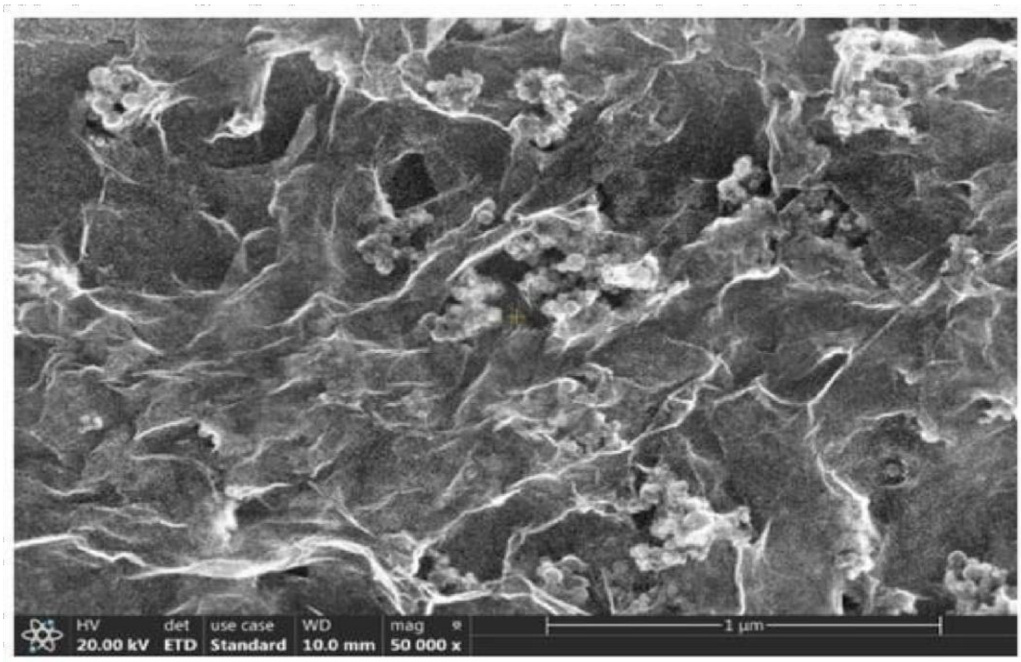


Figure.11: SEM image of the hybrid nanolubricant

4.2 Effect of nanolubricant on heat removal rate:

Heat removal rates at different volume concentrations. It is observed that, with the suspension of different volume concentrations, the heat transfer rate got increased to 0.10% after which thevalue got reduced. With the addition of nanoparticles, the thermal conductivity of graphene lubricant additives increased. This is because the nanoparticles triggered and increased the heatremoval rate. The graph also shows that the maximum heat removal rate was 0.366 kilowatts at0.10% volume concentration with 2400 rpm speed. The maximum percentage of heat removal increases to 8.9% at 0.2% volume concentration.

4.3 Performance of VCR

The performance of R134a/VCR system was carried out first with pure MO lubricant. That result was considered as reference to compare the performance of VCR system with nanolubricant. The experimentation was carried out with the same conditions for nanolubricant with different volume fractions. Figures 6 and 7 show the COP and input compressor power fordifferent volume fractions of Gr/ Al_2O_3.

Table 5: Co-efficient of Performance & volume fraction values

Volume fraction (%)	Co-efficient 0f Performance (COP)				
Flow Rate	4 LPM	3 LPM	2.5 LPM	2 LPM	1.5 LPM
0	2.47008	1.92722	1.58445	1.3986	1.11288
0.05	3.6388	3.31027	3.06732	2.48164	1.96731
0.075	3.83612	3.32183	3.10759	2.55039	2.00753
0.1	3.27625	2.86196	2.39052	2.11909	1.96195
0.2	3.23071	2.61646	2.38784	2.14498	1.87351

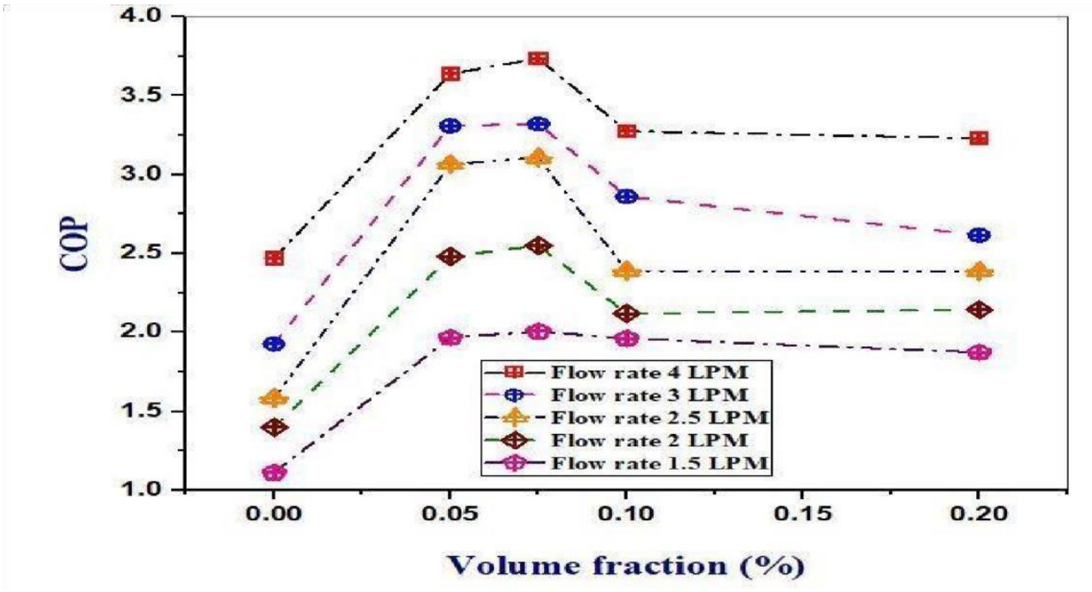


Figure.12: Co-efficient of Performance Vs volume fraction

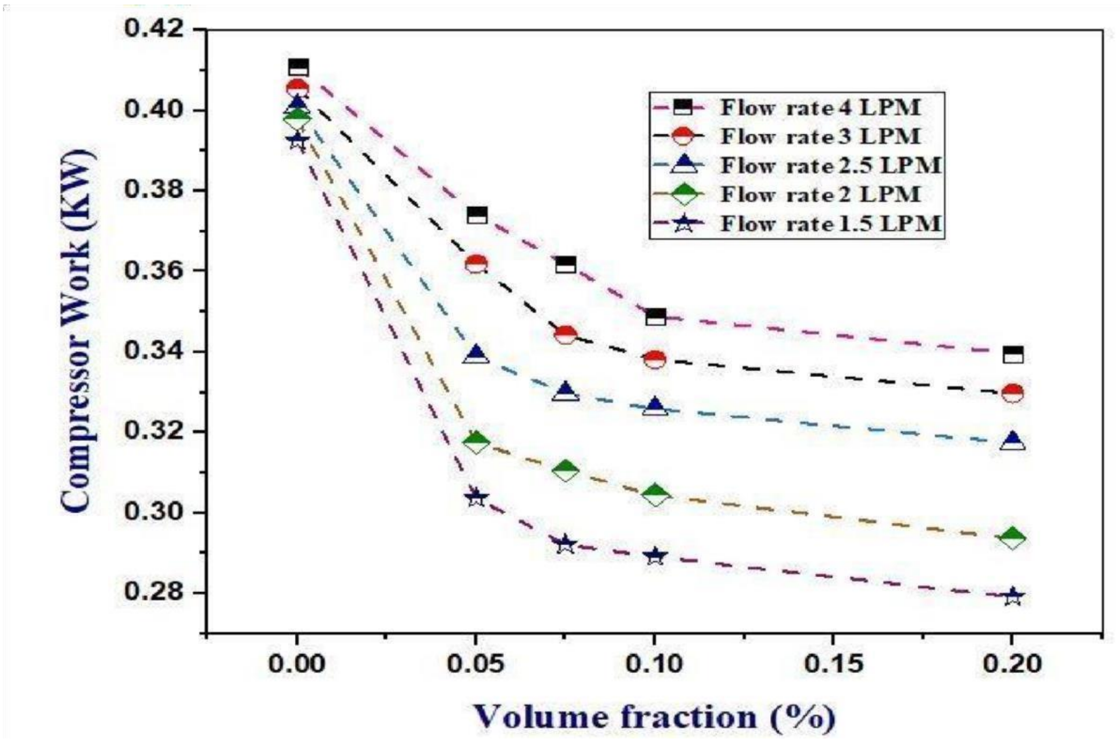
The variations of compressor work, when there is a change in volume concentration. It was inferred that the work of the compressor got reduced at optimum concentration, i.e., 0.10%. After 0.10% volume concentration, the compression work got increased as shown in the graph.The least point was measured at a speed of 800 rpm in the compressor, compared to all other speeds. The maximum amount of work got reduced, 21.7% occurred at 0.10% volume concentration with 2400 rpm in comparison with base oil. These findings can be corroborated with the results of who revealed that carbon nanofiber and graphene as additives improves the efficiency of the compressor pump.

Table.6: Compressor Work & volume fraction Values

Volume Fraction (%)	Compressor work				
Flow Rate	4 LPM	3 LPM	2.5 LPM	2 LPM	1.5 LMP
-0.019848	0.410894	0.405532	0400936	0.397872	0.392511
0.0412806	0.374128	0.361872	0.338894	0.317447	0.30366
0.0985319	0.361872	0.344255	0.329702	0.310553	0.29217

0.159537	0.348851	0.338128	0.325872	0.304426	0.289106
0.216773	0.33966	0.329702	0.317447	0.293702	0.279149

Figure.13: Compressor Work Vs volume fraction



By adding the nanoparticle in the mineral oil, with the thermal properties of lubricant, tribological characteristics also improved. Therefore, reduction in power required to run the compressor with the increase in the volume fraction of Gr/Al2O3 nanoparticles is observed. Thecompressor work required for Gr/Al2O3-MO nanolubricant base VCR system is lower than the pure MO system because of enhancement in the thermal and tribological properties. Nanolubricant reduces the compression temperature as well as coefficient of friction due to rolling action of the nanoparticles that reduces power required to run the compressor (Raina andAnand 2018). It is found that there is approximately 27% reduction in compressor power using 0.075% volume fraction Gr/Al2O3-MO nano lubricant in place of mineral oil. The coefficient of performance is increased with increasing volume fraction of Gr/Al2O3 nanoparticles due to enhancement in thermal conductivity of the nanolubricant. The highest COP 3.68 was observed at 0.075% volume concentration of Gr/Al2O3 nanoparticles. It is observed that there is approximately 85% increment in COP than base lubricant mineral oil. As in test rig hermeticallysealed compressor was used, in which partial amount of nano lubricant migrate with lubricant because of this refrigerating effect (RE) was also improved. So, increase in RE and reduction in compressor work causes increase in COP of VCR system. It is observed that above 0.075% volume concentration of Gr/Al2O3 in MO, the COP is decreasing and compressor work input isincreasing, because of increase in the friction coefficient.

IV.CONCLUSION

Using Gr/Al2O3-mineral nanolubricant oil in a vapor compression refrigeration system represents an advanced approach to enhancing the system's performance and efficiency. While I can't access or provide specific results from unpublished or specific research papers due to thenature of this platform, I can discuss the expected outcomes and potential benefits based on theproperties of such nanolubricants and their application in refrigeration systems. The integrationof graphene (Gr) and aluminum oxide (Al2O3) nanoparticles into mineral oil aims to leverage the unique properties of these nanomaterial's to improve lubrication, thermal conductivity, and system durability. While specific paper results on Gr/Al2O3-mineral nanolubricant oil used in vapor compression refrigeration systems would provide concrete data on performance enhancements, expected benefits based on the properties of these nanomaterial's include improved thermal conductivity, enhanced lubrication, reduced wear, and increased overall system efficiency. Future research and empirical studies will continue to clarify the extent of these benefits and help address the challenges associated with implementing nanotechnology in refrigeration systems. From this experimental investigation it is concluded that 0.075% volumefraction of the Gr/Al2O3 nanoparticles increases the heat absorption capacity in the evaporator section by 35% and reduces the work input for compression by 27% which shows 85% increment in COP of VCR system. It is also concluded that 0.075% is the optimum volume concentration of Gr/Al2O3-MO nanolubricant for VCR system.

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