



Experimental investigation of a vapour compression refrigeration system with TiO₂ and Al₂O₃ nano lubricants

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Abstract

Thermal conductivity significantly influences heat transfer efficiency. Conventional refrigerants in vapor compression refrigeration systems (VCRS) generally exhibit low thermal conductivity, limiting performance. To enhance heat transfer, researchers have explored the use of nanofluids. This study focuses on evaluating the reliability and performance of a VCRS using R134a refrigerant combined with Polyolester (POE) oil blended with TiO₂ and Al₂O₃ nanoparticles. The aim is to assess how these nano-lubricants influence thermal conductivity and improve overall system efficiency, offering a potential advancement in refrigeration technology. The system's overall performance analysis were carried out via the cooling capacity tests and energy intake examination. The results demonstrated that the system with nano lubricant achieved low work done in the compressor with better performance in the system. The results also indicate R134a with TiO₂ and CuO nano lubricant works normally and safely. The nano lubricants exhibited enhanced properties. The system nano lubricant exhibited considerable augmentation in COP due to significant reduction in power consumption and slight improvement in cooling effect.

Keywords: Thermal conductivity, Heat transfer, Nano fluids, Work done, Vapour compression refrigeration, Nanolubricant, POE oil, COP, R134a refrigerant

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Introduction

The process of extracting heat and sustaining optimum temperature is refrigeration. Refrigeration takes place in a closed system. As per Montreal Norms, the usage of chlorofluorocarbons has been completely banned due to high ozone depletion potential. Currently Hydrochlorofluorocarbons (HFCs) are used for most of the systems as they exhibit zero ODP and low GWP. The most predominantly used refrigeration system is VCR system, which consists of a compressor, condenser, expansion valve and an evaporator. A VCR cycle involves four process namely compression, condensation, expansion and evaporation. Currently HFCs like R-134a, R-404a are used for most of the practical applications due to zero ODP and less GWP. Mineral oils, Polyester oils, and PolyAlkyl Glycol oils are used as lubricants in refrigeration compressors to lubricate the moving components of compressor (Yağız, Özyilmaz and Özyilmaz, 2022). Nano Fluids tend to enhance the properties of the system in which they are used. There are solids in between 1-100nm. Addition of nano particles enhance thermophysical and tribological properties of the base fluid along with they are employed. Akhtar *et al.* conducted an exergy analysis on a vapor compression refrigeration system using R600a blended with graphene nanoparticles (GNs), revealing significant performance improvements. Graphene was mixed with isobutane in varying ratios and combined with mineral oil. A similar approach was used to evaluate total exergy loss. The results indicated that the R600a/GNs system outperformed pure R600a with mineral

oil in terms of energy, exergy, environmental, and economic aspects (Rajalakshmi *et al.*, 2024). Notably, the actual COP and exergy efficiency increased by 12.16% and 23.65%, respectively (Akhtar and Rajput, 2025). Babarinde *et al.* experimentally investigated the use of multi-walled carbon nanotubes (MWCNTs) with lubricating oil as a nanolubricant in a domestic refrigerator using R600a, replacing conventional oil (Mohammadi, Hosseinzadeh Sahaifi and Naji, 2021). The study employed MWCNT concentrations of 0.4–0.6 g/L and refrigerant charges of 50–60 g. Results showed reduced pull-down time and evaporator temperatures of -8°C and -11°C . The combination of 0.4 g/L MWCNTs and 50 g R600a achieved the lowest energy consumption. This setup improved refrigeration performance and reduced energy usage by 25.9%, 20.2%, and 13.7% at 50 g, 60 g, and 70 g charges, respectively, compared to conventional lubricant systems (Babarinde *et al.*, 2022). Vipin *et al.* investigated the influence of nano-lubricants on key performance aspects of a VCR system—such as cooling capacity, compressor energy use, discharge temperature, and COP—was evaluated. Tests at evaporator temperatures from -11°C to 1°C and condenser settings of 30°C and 34°C showed improved subcooling and up to a 6.5% COP increase with nanoparticle-enhanced oil (Nair, Parekh and Tailor, 2020). Gill Jatinder from their experimental work on refrigeration system gave the following findings. Varying the TiO_2 nanoparticle concentration in compressor lubricant significantly affected thermo-physical

properties. At 0.2 g/L TiO_2 concentration with R600a refrigerant, power consumption was 1.94–33.33% lower than the baseline LPG refrigerant. Additionally, this combination resulted in the lowest discharge temperatures across all R600a charges when compared to the baseline, enhancing overall system performance (Jatinder *et al.*, 2019). M.Z. Sharif et al reviewed the mechanisms by which nano-refrigerants and nano-lubricants enhance the performance of VCR system. Key factors include improved heat transfer, enhanced refrigerant-lubricant interaction, and superior tribological properties. These enhancements contribute to reduced compressor work and increased system efficiency. Specifically, nano-lubricants demonstrated significant tribological improvements, with a 32% reduction in coefficient of friction and a wear rate reduction of 13%. The combined effects of improved thermal properties and reduced mechanical losses led to an 11% reduction in compressor power consumption and a 24% increase in the coefficient of performance, highlighting the potential of nanotechnology in optimizing VCRS efficiency (Sharif *et al.*, 2018). The effect of Al_2O_3 nanoparticles on the performance of a vapor compression refrigeration system (VCRS) using R134a refrigerant, without requiring system modifications. Performance was evaluated through freeze capacity and energy intake tests. Results revealed that the Al_2O_3 -based nanofluid significantly improved system efficiency, enabling faster cooling and reduced energy use compared to conventional fluids. These findings confirmed the practicality of

incorporating nanoparticles into domestic refrigeration systems. To understand the cause of this improved thermal behavior (Lukić, 2019), the thermophysical properties of the nano-lubricant were subsequently examined, providing insight into the mechanisms driving the enhanced performance of the nanoparticle-infused working fluid (Ajayi *et al.*, 2019). D V Raghunatha Reddy et al in their experimental work inferred that refrigerants containing nano particles have a much greater thermal conductivity at low particle concentrations when compared with normally used refrigerant. In this review, they summarized the performance enhancement of vapour compression refrigeration system using Nano additive refrigerants pointed out by other researchers. Furthermore, scope and constraints of employing nano additives along with refrigeration system were also presented (Venugopal, 2018). P. Vithya, et al from their experimental study pointed out that the overall COP of a VCR system relies predominantly on the organization of the components, properties of the lubricant and refrigerant. The conventional ideal gas model offers limited accuracy over a broad range of conditions. This study introduces an analytical real gas model to more precisely evaluate heat transfer in the evaporator and the compressor's work output (Ibraheem, 2022). The improved model enables a more accurate determination of the system's coefficient of performance (COP), enhancing reliability in performance analysis (Venugopal, 2018). Sanukrishna S. S. et al. conducted an experimental study on a vapor compression refrigeration system

(VCRS) using R134a refrigerant with CuO–PAG oil nanolubricant. The addition of CuO nanoparticles to the base lubricant showed good stability and significantly reduced the energy consumption of the reciprocating compressor. Moreover, the use of the nanolubricant enhanced the heat transfer rates in both the condenser and evaporator, along with a notable improvement in the system's freezing capacity. The study concluded that incorporating nanoparticles as additives in refrigerants is a promising approach for developing energy-efficient refrigeration systems with improved thermal performance and reduced power usage (Sanukrishna, Vishnu and Jose Prakash, 2017). Nithyanandhadhass Kamaraj *et al.* investigated the reliability and COP of a vapor compression refrigeration system using R134a refrigerant with carbon black nanopowder blended in Polyolester (POE) or Mineral Oil (MO) as a nanolubricant (Chatterjee and Singh, 2023). The results confirmed that the system operated safely and efficiently with these combinations. The use of such nanolubricants notably reduced power consumption and enhanced overall system performance, making them suitable for refrigeration applications (Kamaraj and Babu, 2016). Vipin Nair, *et al.* from their experimental study, found that performance of the refrigeration system augments by the ingress of nanoparticles in the refrigerant. The enhanced conductivity of Nanorefrigerants is only partially responsible for an enhanced heat transfer coefficient (Nair, Tailor and Parekh, 2016). Sajith *et al.* studied the impact of Al₂O₃ and CuO nanoparticles in lubricant

oil, reporting a significant reduction in flash temperature and enhanced fluid stability, while maintaining the original lubrication properties without any detrimental effects (Sabareesh *et al.*, 2012). Peng *et al.* utilized sediment photograph capturing as a simple, cost-effective method to assess nanofluid stability. During preparation, some particles remain in the container, and comparing sediment images helps estimate sedimentation levels and evaluate the stability of nanolubricants effectively (Ding *et al.*, 2009). Mahbubul *et al.* examined the influence of viscosity on a fluid's thermophysical properties, noting its effect on pumping power and pressure drop, especially in laminar flow. They highlighted the limited research on nanolubricant viscosity, with most existing studies focusing on nanofluids using water or ethylene glycol (Mahbubul *et al.*, 2013). Youbi *et al.* (2008) delved into how lubricating oil affected refrigeration. When compared to regular POE oil lubricant, the author found that the nanoparticles in POE oil increase the rate of heat transfer because of their high thermal conductivity (Youbi-Idrissi and Bonjour, 2008). It is also inferred from literature survey that either by adding Nano fluids to normally used refrigerant or to a compressor lubricant, performance can be augmented and work done could be decreased. In this work, Titanium oxide and Aluminium oxide nano particles were blended with lubricating oil used in a vapour compression refrigeration system and the system was tested for performance. The properties of the nano lubricant was also studied.

Materials and Methods

Aluminum oxide nanoparticles were synthesized via hot plasma jet, while titanium oxide was produced from

Titanium IV Isopropoxide using HNO_3 . In this experimental work, following materials were used. The details of materials and methods used in this work are shown below in Table 1

Table 1: Materials and methods.

Refrigerant Used	R-134a
Type of Refrigeration System used	Vapour Compression Refrigeration System
Nano Particles Used	Aluminum Oxide (Al_2O_3) & Titanium Oxide (TiO_2).
Lubricating Oil used	Zed Plus Polyol Ester (POE) oil

The composition of different samples used as lubricant in refrigeration

compressor is shown in the below Table 4.1

Table 2: Nano lubricant sample composition.

Sample Number	POE oil (ml)	Al_2O_3 (ppm)	Al_2O_3 (g)	TiO_2 (ppm)	TiO_2 (g)
1	200	-	-	-	-
2	200	50	0.01g	-	-
3	200	100	0.02g	-	-
4	200	150	0.03g	-	-
5	200	-	-	50	0.01g
6	200	-	-	100	0.02g
7	200	-	-	150	0.03g

The Aluminium oxide and Titanium oxide particles were taken in the above proportions 50 ppm, 100 ppm and 150 ppm each respectively. Electronic weighing machine shown in Figure 1, is used for weighing particles, Bath type Ultrasonicator shown in Figure 2 is used for sonification of particles in oil and Magnetic stirrer shown in Figure 3 was employed for the stirring the lubricant.



Figure 1: Weighing balance.



Figure 2: Ultrasonicator.



Figure 3: Magnetic stirrer.

Experimental Setup

In this experimental work, the setup used for the experimental work is a refrigerator with a capacity of 175 litres, which is shown in Figure 4.



Figure 4: Experimental setup.

The specifications of experimental setup is shown in Table 2.

Table 2: Specifications of the experimental setup.

Capacity	175 Litres
Refrigerant Employed	R134a
Quantity Charged	0.120 kg
Type of Compressor	Hermetic Reciprocating
Quantity of Lubricating Oil	200 ml
Type of Condenser	Natural Convection Air Cooled

Experimental Test Procedure

The experimental up is placed in room with a temperature of 27°C. The compressor is filled with normal lubricating oil without nano particle. Refrigerant, R-134a is used as a working fluid. For varying evaporator temperatures, the conditions of temperature and pressure at suction line and discharge line are noted. Then power consumption by compressor is noted. The working fluid is evacuated by vacuum pump and the same procedure is repeated for all seven samples.

UV-Visible Spectrophotometer

Sedimentation of nanolubricants characterized by using a UV-Visible spectrophotometer. The UV-Visible spectrophotometer used here is SHIMADZU (UV-1601). 0.1 weight concentrations (%) of sample S1 to S7 nanolubricant were considered for of UV- Visible spectrophotometer analysis with pure R134 refrigerant.

Sediment Photograph Capturing

An orbital incubator shaker was used to prepare the different nano lubricant for Sedimentation photo. The Sedimentation photo capturing process involves the prepared samples to be allowed for sedimentation for seven days and the photo of the sedimentation was captured every once in 24 hours and the photographs would be analyzed.

Results and Discussions

The analysis of nanolubricant is performed by UV-Visible spectrophotometry, sediment photograph capturing, SEM and TEM. Considering observations, the various performance characteristics such as energy intake, cooling effect and COP, was calculated for all the lubricant samples. The results are plotted in a graph to compare the performance improvement of present domestic refrigerator with nano lubricants. The first lubricant sample without any nano particle composed only of POE oil. That is taken as base lubricant sample. The performance characteristics of nano lubricant second and third samples was compared with base line sample S1 separately at varying temperatures of evaporator. The performance characteristics of different samples of nano lubricant is compared

with first sample for varying evaporator temperatures.

Effect of on Lubricant Stability

The results mentioned below indicate; titania and alumina distribution in the images showing good stability in hybrid nanocomposite. Sample S5 had considerably lesser particle size bettering the individual POE+Al₂O₃, POE+ TiO₂ samples. Samples with wt% 0.1 of nano particle were in the size range of 21-40 nm and it was seen that the particles

aggregation was negligible even with extensive heating of the titania and alumina nanofluid. Particle sizes were monitored and visual inspection was done to evaluate the visual inspection at various thermal instances. Photograph shown below depicts Titania and alumina nanofluids without particles sedimentation for several days. In spite of some agglomerates and reduced dispersion observed in the TEM images as shown in Figure 5 the nanoparticles exhibited good stability.

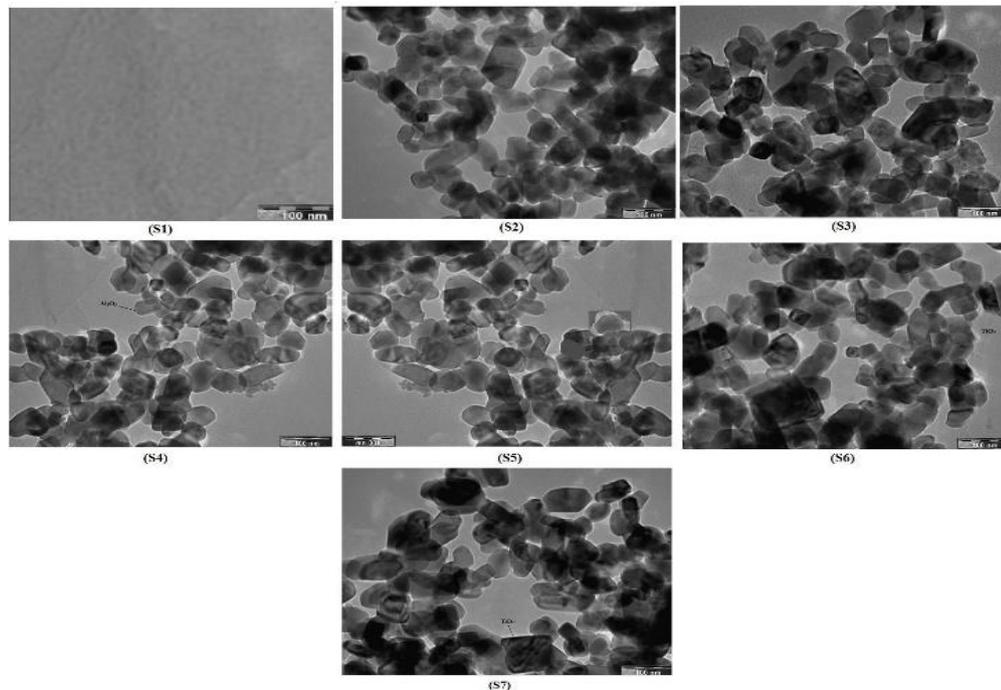


Figure 5: TEM images of aluminium oxide and titanium oxide nano particles.

The sedimentation was allowed to take place experimentally and photographs of the sedimentation process were captured at predetermined time interval. The inference of results shown that the ratio of sedimentation increases with the

augment in hybrid nanoparticle concentration till about 75 wt% concentration of TiO₂. The impact of concentrations on the sedimentation ratio of the nanofluid are shown in Figure 5.4

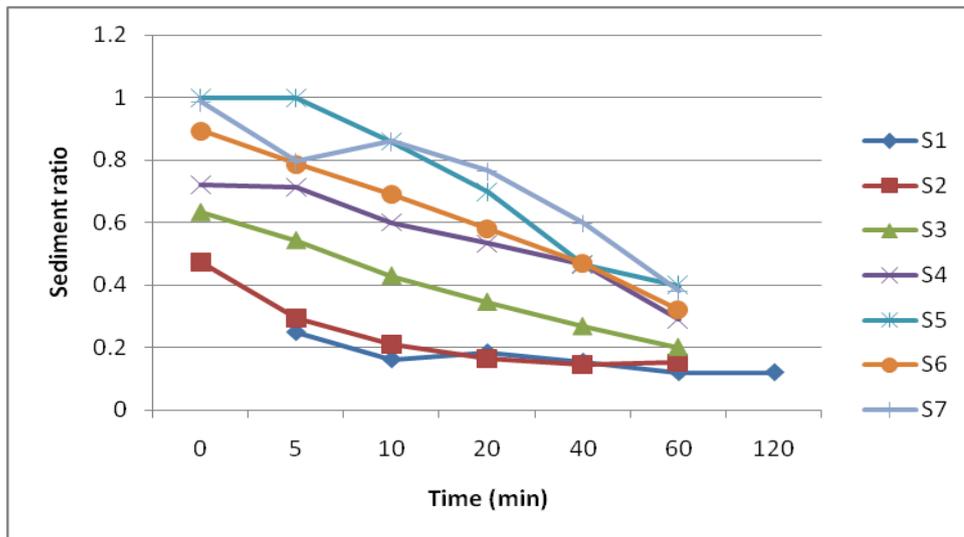


Figure 6: Sedimentation ratio of the nanofluid suspension observed after 2 hours.

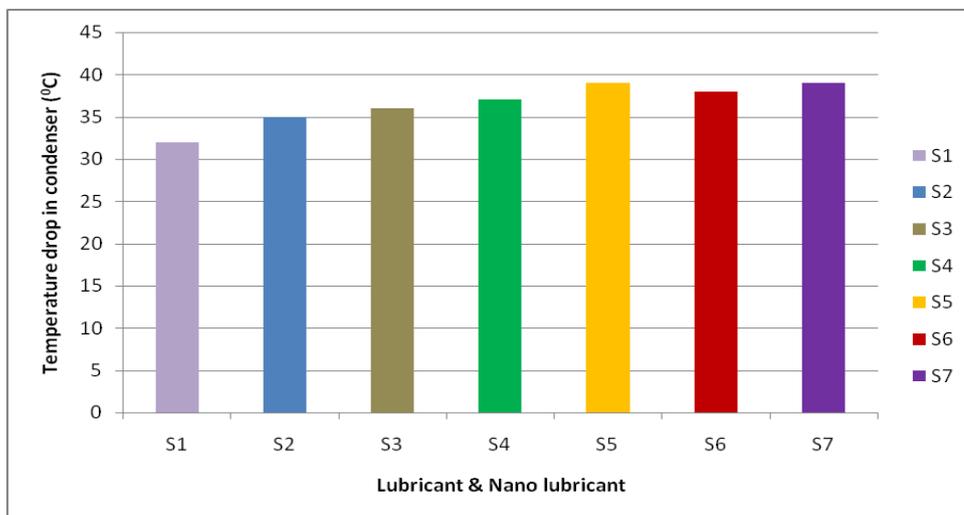


Figure 7: Temperature drop in condenser for nanolubricant at 3.4 LPH volume flow rate and at evaporator heat flux 35-36 0C.

The temperature drop for sample S1 (POE) was found to be 24.16°C, whereas the samples S2 (Al₂O₃ (50ppm) + POE), S3(Al₂O₃(100 ppm) + POE), S4, S5, S6 and S7 had temperature drops of 36.85 °C, 37.12 °C, 37.92 °C, 39 °C and 38.42 °C. Sample S2 to Sample S4 saw 13.4% to 16.7% increase in temperature drop while sample S5 exhibited 20 % and sample S6 showed 19% more temperature drop when compared to standard lubricant.

Thermal Conductivity of Nanolubricant

The thermal conductivity of nanolubricant was observed for corresponding temperature changes from 300 to 360°C as shown in Figure 8. The results suggest that the sample S1 to S7 with varying particle volume proportion (%) varied from lowest conductivity which was 1.083 more than conventional (POE) fluid to the maximum value recorded being around 2.29 times more than the conventional base (POE) fluid. The maximum conductivity was seen in sample S4 that is in the fraction of

150ppm Al_2O_3 . The sample S5 was marginally better than sample S7 which has a composition ratio of 150ppm.

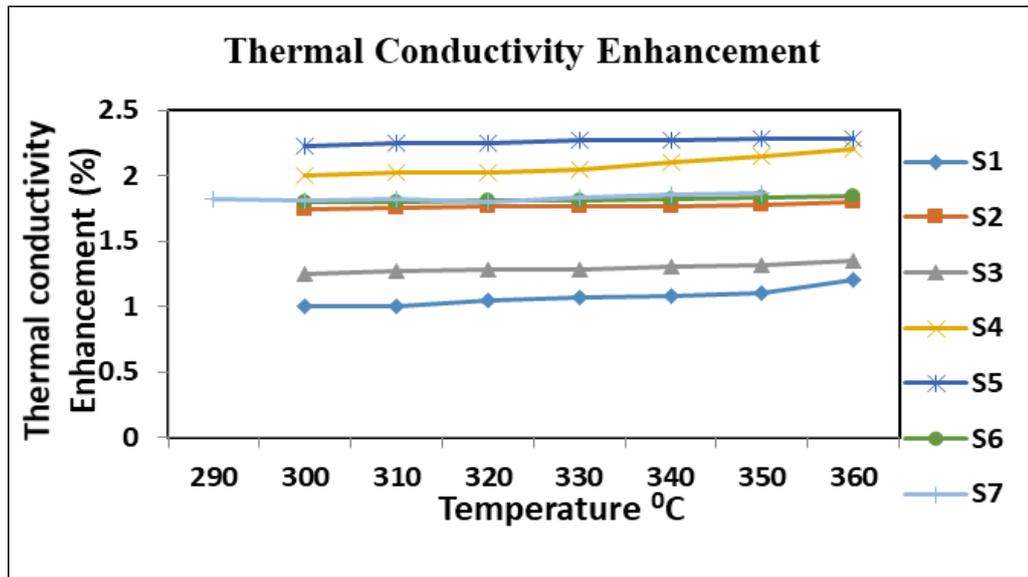


Figure 8: Comparison of thermal conductivity.

Figure 9 shows a comparative data with respect to viscosity for present work. The deviation between the measured

value and the suggested model was around 15%.

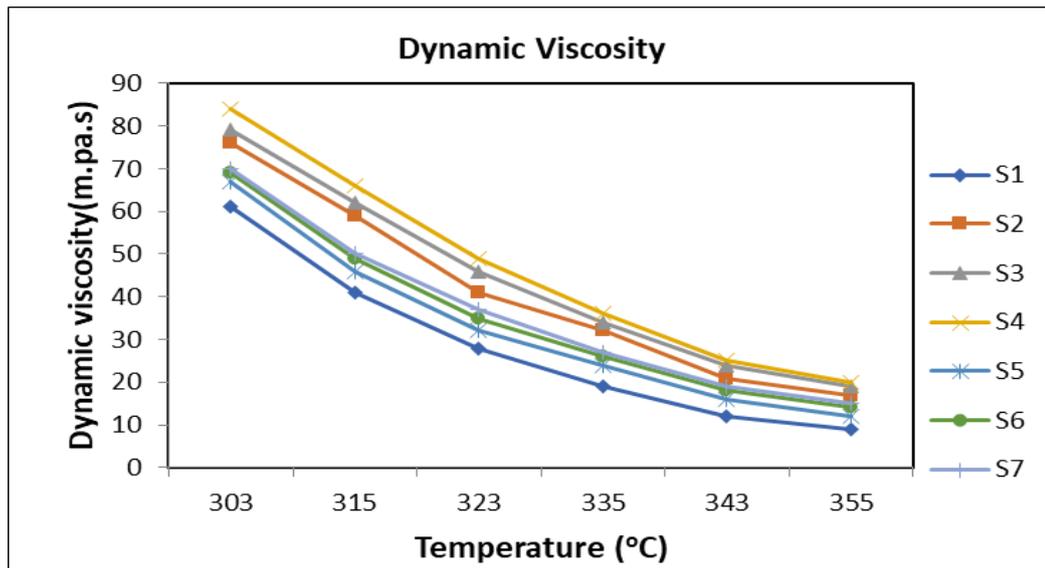


Figure 9: Viscosity of Al_2O_3 - TiO_2 /POE composite nanolubricant at various concentrations.

The friction coefficient of the samples are shown in Figure 10. The TiO_2 traces are detected on the surfaces due to their deposition in the surfaces during the experiment. The surface scratches on the

friction surface become shallower and smoother due to the boundary film comprising of organic compounds, Al, Ti and iron being formed.

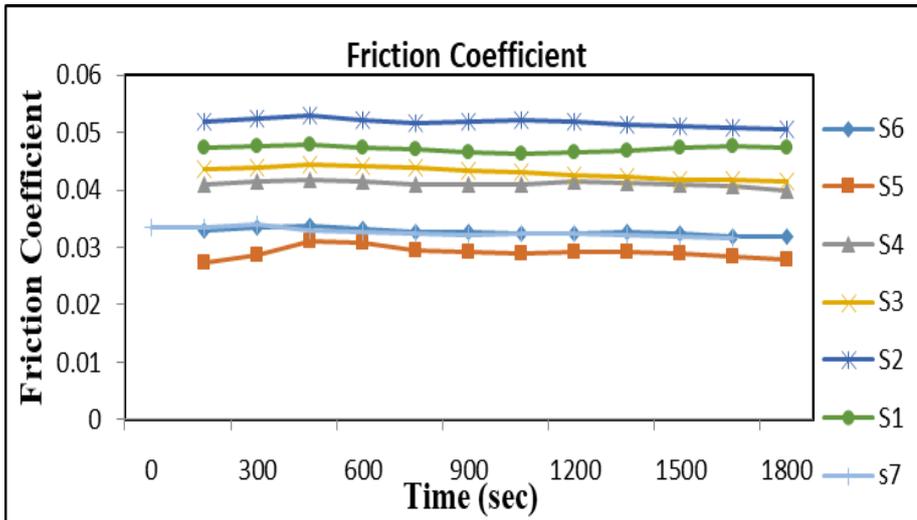


Figure 10: Friction coefficient with time for various lubricants.

The energy intake of the refrigerator with all lubricant samples at varying evaporator temperature is shown in the Figure 11. It is seen that with increase in

the proportion of nano particle, the energy consumption of compressor decreases.

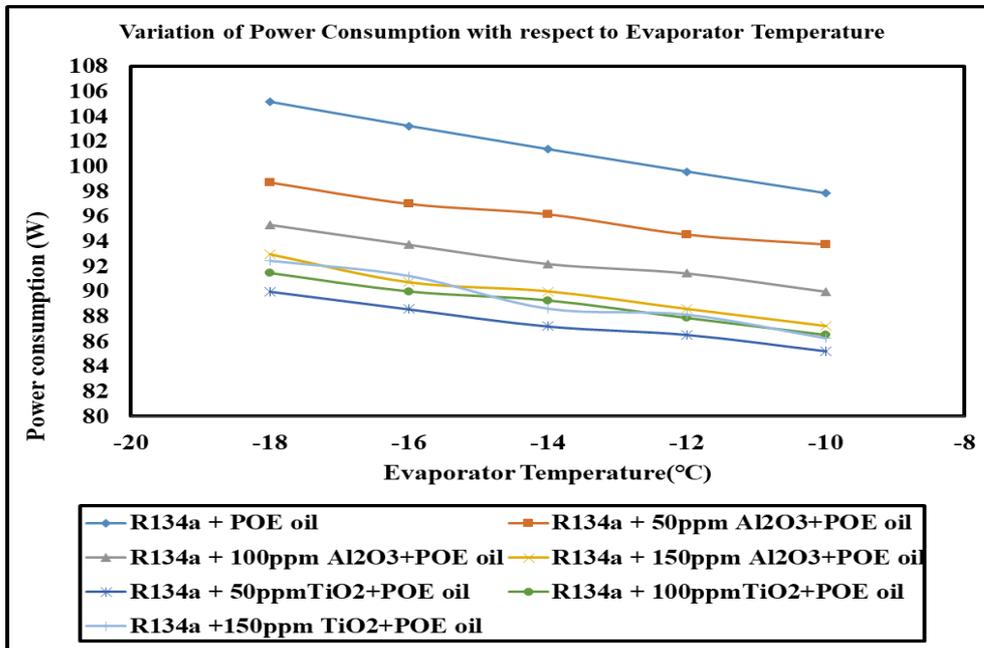


Figure 11: Energy consumption at varying temperatures of evaporator for the lubricant samples.

The Cooling Capacity of the refrigerator with different lubricant samples containing varying proportion of nano particles at varying evaporator temperature is shown in the Figure 12.

The cooling capacity of all nano composite lubricant samples showed a slight augmentation with the increase in proportion of nano particles.

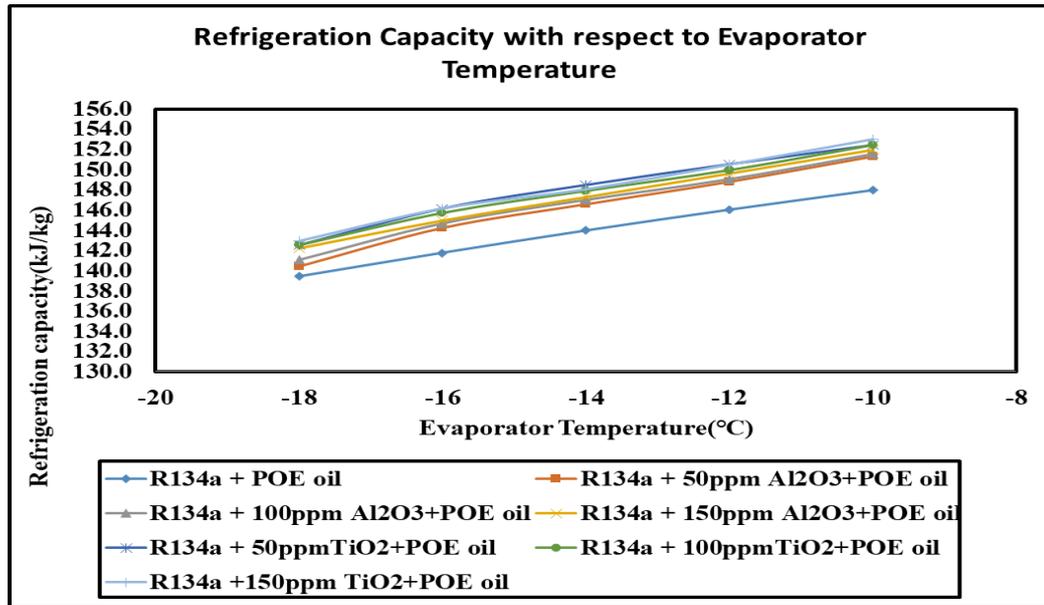


Figure 12: Cooling capacity at different evaporator temperature for the lubricant samples.

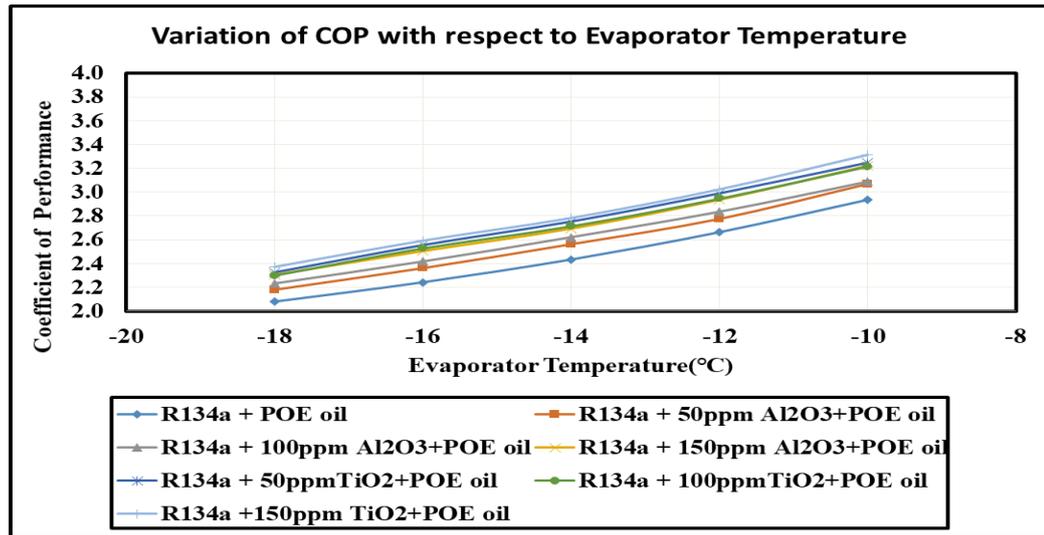


Figure 13: COP at varying evaporator temperature for the lubricant samples.

The Figure 13 displays the COP of the system with all lubricant samples at varying evaporator temperatures. The COP of all the nano composite lubricant samples fourth, fifth and sixth sample was high in comparison with first sample. The COP of fourth sample was augmented by 10.81%, 11.66%, 10.66%, 10.21% and 9.69% for varying evaporator temperatures of -18°C, -16°C, -14°C, -12°C and -10°C on comparison with lubricant sample without nano particle. The COP of nano lubricant

sample S4 enhanced by 5.57%, 5.90%, 4.98%, 5.70% and 4.88% at different evaporator temperature - 18°C, -16°C, -14°C, -12°C and -10°C on comparison with second sample. The COP of nano lubricant sample S5 enhanced by 4.34%, 5.83%, 5.09%, 5.46% and 5.14% at varying evaporator temperature - 18°C, -16°C, -14°C, -12°C and -10°C respectively on comparison with third sample. The COP of nano lubricant sample S6 augmented by 10.69%, 12.78%, 11.57%, 10.65% and 9.61% at

different evaporator temperature -18°C , -16°C , -14°C , -12°C and -10°C respectively on comparison with first sample. The COP of nano lubricant sample S7 enhanced by 5.44%, 6.97%, 5.84%, 6.12% and 4.8% at different evaporator temperature -18°C , -16°C , -14°C , -12°C and -10°C respectively on comparison with second sample. The COP of nano composite lubricant sample S7 enhanced by 3.22%, 4.71%, 3.62%, 3.96% and 4.19% at varying evaporator temperature -18°C , -16°C , -14°C , -12°C and -10°C on comparison with third sample.

Conclusion

The results of performance characteristics such as power consumption, COP, refrigeration capacity were studied and analyzed. The analysis of refrigerator with all samples of nano lubricants S2, S3, S4, S5, S6 and S7 was compared with first sample S1. Inferring from investigation and optimization analysis of refrigerator, the following effects on performance characteristics of the system were discussed the lubricant stability was tested by determining the agglomeration, dispersion using Transmission Electron Microscopy (TEM) images. The Sample S5 and S6 were observed to be better due to higher TiO_2 Content. Similarly the absorbance is tested UV-Vis Spectrophotometer to predict the stability and sample S4 and S7 were versatile and had enhance absorbance. The absorbance of sample fourth and sixth sample were around 10% and 8.5% more than that of first sample respectively. More temperature drop at the condenser suggests higher heat transfer rate. Temperature transfer between condenser

walls and the lubricant accounts for the effective refrigeration effect. This was tested for an ambient temperature at $300^{\circ}\text{C} \pm 20^{\circ}\text{C}$ for heat load in the range of $25-27^{\circ}\text{C}$ and $35-36^{\circ}\text{C}$. The sample S7 and S4 displayed a temperature drop of nearly 9% and 11% more than the standard sample S1 respectively. The factor that determines the overall performance of the complete system is thermal conductivity. The conductivity of nano lubricant is determined primarily by the nanoparticle concentration. Alignment and clustering of nanoparticles may result in nonlinear thermal conductivity. The filling of the gaps by Al_2O_3 nanoparticles between POE increases surface contact area improving thermal conductivity. Higher thermal conductivity of nanolubricants can be attributed to the Brownian movement phenomenon caused by fast moving nanoparticles with higher energy content. This was tested using thermal property analyzer for temperature changes from 300 to 3600C for all samples, the conductivity for Sample S4 was 0.155 W/mk and conductivity enhancement was around 2.25% more than that of sample S1. Similarly the conductivity for Sample S7 was 0.151 W/mk and around 2% more than that of sample S1. The power intake of system is a very critical parameter from a commercial point of view as well as the performance perspective. The overall performance of the coolant will determine optimize the energy intake, which is inversely proportional to the freezing capacity. Density, viscosity, Thermal conductivity, specific heat and tribological properties are factors that influence power consumption. The test results conclude that sample S5 and S7 has consume the lesser power by around

15% and 14% respectively when compared to sample S1, at any given vaporizer temperature. The COP relies on the thermal performance and physical properties of the lubricant. The system measures a COP of around 3.25 and 3.22 for samples S6 and S7 which is around 11% and 9% more than that of the pure POE lubricant (Sample S1) respectively. The cooling capacity of the system relies on effective heat transfer properties of the lubricant. The cooling load temperature is rapidly decreased when the heat transfer is more due to enhanced conductivity. It was seen that the sample S5 and S6 had refrigeration capacity of around 152.4 kJ/kg, due to the existence of nano additives in the optimized ratio. The Sample S1 displayed lower refrigeration capacity of around 148 kJ/kg, which was around 2.7% less than samples S7 and S6.

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