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Performance Reseach On Water Cooler With Silicon Nitride/Polyolester Nanolubricant

Mansoor Ahamed, S.M. Jameel Basha, B. Durga Prasad, Jakeer Hussain Shaik

Abstract: *Performance of vapour compression refrigeration depends on refrigeration effect and power utilization of the compressor. The present work focuses on reduction in power utilization of the compressor and enhancement in refrigeration effect with the supplement of silicon nitride (Si3N4) nanoparticles (NP) to the compressor lubricant polyolester (POE) oil. Also the performance of the water cooler has been compared with the addition of tetra butyl ammonia iodide (TBAI) surfactant to the nanolubricant. Thermophysical properties of the modified POE and POE/Si3N4NP/surfactant were found before experimentation to select the optimum concentration for the performance evaluation. Test results showed that the maximum thermal conductivity was improved by 31.06% for nanolubricant and 30.5% for nanolubricant with surfactant at 0.6% vol concentration. It is also seen that the viscosity has been enhanced maximum at 0.6% vol. concentration and for the same concentration the friction coefficient has been reduced by 7% and 11% for nanolubricant and nanolubricant with surfactant. Further the performance was evaluated with nanolubricant and nanolubricant/surfactant and the results were compared. It is found that the coefficient of performance (COP) has been enhanced by 36.39% and 29.6% for nanolubricant and nanolubricant/surfactant. Also the performance of the water cooler was investigated after 30 days and the results were in accordance with the initial results. Hence the experimentation shows that the addition of Si3N4 nanoadditives to the POE oil enhances the working of the water cooler.*

Index Terms: Coefficient Performance (COP), Nanoparticle, Nanolubricant, thermophysical properties

I. INTRODUCTION

The rapid growth in the utilization of refrigeration & air conditioning has led to technology advancements across the globe. Fossil fuels are depleting day by day and the compressor in the refrigeration and air conditioning systems consumes maximum power.

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* Correspondence Author
MD. Mansoor Ahamed*, Dept. of Mechanical Engineering, Jawaharlal Nehru Technological University Anantapur, Anantapur, Andhra Pradesh, India
S.M. Jameel Basha, Dept. of Mechanical Engineering, SKD Engineering College, Anantapur, Andhra Pradesh, India
B. Durga Prasad, Dept. of Mechanical Engineering, Jawaharlal Nehru Technological University Anantapur, Andhra Pradesh, India.
Jakeer Hussain Shaik, Dept. of Mechanical Engineering, KKR & KSR Institute of Technology & Sciences, Guntur, Andhra Pradesh, India.

Hence there is a thirst to nurture thermal systems which are energy efficient. In this scenario, nanotechnology is advancing rapidly which leads to new generation fluid called nanofluid. Nanolubricants are formulated by mixing nanoparticles of the range 1 – 102nm in the base fluid. Base fluid may be water, engine lubricant or compressor lubricant. Nanoparticle has a potential to enhance the thermophysical properties of the base oil which leads to improvement in the working vapour compression refrigeration system. Nanoparticle in the base oil leads to improvement in thermophysical properties which affects the enhancement in the functioning of refrigeration and air conditioning. Experiments illustrate that the improvement in the thermal conductivity of 4.6% at 1.5% weight concentration was noticed when Al2O3 nanoparticles were added to compressor lubricating oil [1]. Experimentation data reveal that the highest thermal conductivity is experiential up to 2.41% for 0.1% vol. conc. and temperature of 303 K with the addition of composite nanoparticles (Al2O3-SiO2/PAG oil) to the compressor lubricant oil [2]. Results proved that the friction coefficient of lubricant with TiO2 nanoparticles reduced by 32% at 0.01% volume concentration compares to lubricant without nano particle [3]. Experimental observations were found that with the addition of 0.1% weight concentration of boron nitride nanoparticles to the lubricant oil might considerably improve the anti friction characteristics of the base fluid [4].

The viscosity of Al2O3 nanolubricant at 1.0% weight concentration was found to be 30% to 40% higher than that of POE oil for temperature ranged from 0°C to 45°C [5]. Experimentation concludes that the maximum dynamic viscosity enhanced with the inclusion of composite nanoparticles (Al2O3-SiO2/PAG oil) to the compressor lubricant oil by 9.71% at 0.1% vol. concentration and temperature of 333 K [2].

Experimental results explain that the presence of graphite nanoparticles to the POE oil decreases the energy consumption by 4.55% at 0.1% Wt. concentration [6]. Based on the experimental readings, it is found that the compressor work reduced by 11% and Coefficient of Performance has been enhanced by 17% with the addition of TiO2 nanoparticles to the POE oil at 0.01% volume fraction [3]. Experimental results proved that the presence of nanoparticles to the oil has reduced the coefficient of friction up to 90% and concluded that that the nanolubricant has enhanced lubricating properties in comparison with pure oil [7].

Performance investigations were carried out with C60 nano oil and the results showed the COP has been enhanced by 5.26% to 5.3%incomparison with pure oil. Also they had observed the reduction in the shell temperature of the compressor by 3ºC to 5ºC which is acceptable and improves the stability of the lubricant [8]. The thermal conductivity of the nanolubricant depends on diverse factors like particle size, percentage concentration, type of fluid and sonication [9]. Experiment were conducted to study the performance of the refrigeration system by mixing Al2O3 nanoparticles to the mineral oil and found reduction in power utilization by 2.4% and COP has been enhanced by 4.4% at 0.1% by weight concentration and 60% R134a [10]. Solubility of nanolubricant with HFC refrigerant has been enhanced by the addition of TiO2 nanoparticles and also concludes that the performance of the refrigeration system has been enhanced by returning more oil to the compressor compare to the HFC and POE oil [11].

The main aim of this work is to study the effect of Si3N4 nanoparticles mixed in compressor oil on thermo-physical properties of nanolubricant and performance of water cooler using R134a refrigerant.

II. PREPARATION & STABILITY OF NANOLUBRICANT

Preparation and steadiness of nanolubricant is the focal step in this work. Nanoparticle and base oil used in this experimentation for the preparation of nanolubricants are silicon nitride (Si3N4) and compressor lubricant polyolester oil (POE). Table 1 shows the thermal and physical characteristics of Si3N4 nanoparticle and POE oil. Nanolubricants were prepared by two step method with nanoparticle concentration of 0.15%, 0.3%, 0.45% and 0.6% concentration. Similarly nanolubricant samples with 0.1% of TBAI surfactant were prepared for the same concentration. The required quantity of nanoparticles for the sample preparation is calculated by the law of mixture (Eq.1). All the samples were prepared by dispersing nanoparticles directly in the base POE oil and thoroughly stirred with magnetic stirrer for 1 hr followed by 2 hours of sonication for homogenization.

$$\varphi = \frac{\frac{m_{np}}{\rho_{np}}}{\frac{m_p}{\rho_p} + \frac{m_o}{\rho_o}} ----(1)$$

Table 1: Specifications of POE oil and Si3N4 nanoparticles

S.No.	Property	POE oil	Si3N4 (*)
1	Form	Liquid	Powder
2	Crystallographic form	---	Hexagonal
3	Size	---	30nm -40nm
4	Viscosity	30-34 cSt	---
5	Density	0.981g/ml	3.52g/ cm^3
6	Thermal Conductivity	0.137W/m k	43W/m-k
7	Specific Heat	1171j/kg k	1100j/kg-k
8	Operating Temperatures	70˚- 5000 F	1900ºC

(*) Specification provided by the supplier

III. STABILITY AND SIZE ASSESSMENT

Based on the results obtained from the thermophysical tests, the best concentration was identified as 0.6% and stability test was conducted for that concentration. Stability of nanoparticles in the base POE oil and POE oil + surfactant was observed by conducting dynamic light scattering test (DLS). Test was conducted for nanolubricant and nanolubricant/surfactant with time gap of 0hrs, 24hrs and 72hrs. From the experimental results as shown in the fig 1 & 2, it is observed that the size of the nanoparticles was found to be 20nm, 30nm and 40nm at 0hrs, 24hrs and 72hrs which is less than the size mentioned in the specification data supplied by the supplier and hence it is concluded that there is homogeneous stability and no clusters of the nanoparticles found in the base oil over a time period for both the samples. Quick sedimentation was seen after 72hrs and within 6hrs complete sedimentation occurred in case of nanolubricant and for nanolubricant with surfactant it took 14hrs for complete sedimentation. Also from the fig 1 the average size of the nanoparticles in the base POE oil was found to be in 20nm, 30nm, 40nm and 3μm corresponding to the time interval of 0hrs, 24hrs, 72hrs and 78hrs respectively. Similarly from fig 2 the size of nanoparticles in the base POE/TBAI surfactant was found 10nm, 20nm, 30nm and 3μm corresponding to the time interval of 0hrs, 24hrs, 72hrs and 96hrs. It is observed that the sedimentation of nanoparticles in nanolubricant is at the centre in the form of a cluster but in case of a surfactant mixed nanolubricant the sedimentation was observed uniform in the base oil.

IV. THERMO-PHYSICAL PROPERTY MEASUREMENT

Thermo-physical properties like thermal conductivity, viscosity and coefficient of friction were measured at different temperatures for pure POE oil, POE+Si3N4 nanolubricant and POE+Si3N4+TBAI nanolubricant. Electrical conductivity was also measured using electrical conductivity meter to avoid any winding short circuit.

A. Viscosity

The key parameter in the lubricating system is the viscosity of the oil. Compressor oil will not act as a good sealing agent for refrigerant in the compressor if the viscosity of the lubricant is too low and also the components of the compressor will quickly worn out due to friction. On the other side if the viscosity is high then it require more power to pump the oil and power consumption will increases. Hence it is required to identify the optimum concentration which improves the viscosity and performance of the system. In this work viscosity of the samples were measured at 0.15%, 0.3%, 0.45% and 0.6% concentration in the temperature range 20ºC - 50ºC using Brookfield viscometer.

B. Coefficient of friction

The pin on disc setup as shown in fig 4 comprises of a spherical surface pin and rotating circular disc. Pin and disc are positioned vertical with respect to the pin surface. The diameter of the pin is 10mm and the track radius is 80mm which rotates at uniform speed of 700 rpm. A load is applied on the pin with the arm or lever which makes the pin to be pressed with the disc.

It consists of data acquisition system and WINDUCOM software which provides the graphs and result values.

C. Thermal Conductivity

Thermal conductivity of the three samples (pure POE oil, Si3N4 nanolubricant and Si3N4 nanolubricant with TBAI surfactant) was measured with Decagon KD2 PRO thermal analyzer as shown in fig 5 for 0.15%, 0.3%, 0.45% and 0.6% volume concentrations at different temperatures. Various researchers [12], [13], [14], [15] had used KD 2 Pro thermal analyzer for the measurement of the thermal conductivity of the nanolubricants. This devise also meets the standards of the ASTM D5334 and IEEE 442-1981. The sensor probe used to measure the thermal conductivity was KS-1 having 5% precision within the range of 0.002 to 2W/m-K. Each time before measuring the sample the precision of the sensor was confirmed by measuring the standard fluid glycerin at 298.15K (0.281W/m-K which is within the standard value as mentioned in the literature). At least 3 readings were noted for each sample for reliability and thermal equilibrium at a specific temperature.

D. Measurement of electrical conductivity of nanolubricant:

An electrical conductivity meter (EC meter) revealed in fig 6 was used to determine the electrical conductivity for POE oil, Si3N4 nanolubricant and Si3N4 nanolubricant/TBAI surfactant. Electrical Conductivity is a measure of the potential of a substance/solution to accomplish an electric current (this electric current is passed by ions and the chemical transformation that happen in the solution). Since every particle has its own particular capacity to direct current, and subsequently assurance of the electrical conductivity is a quick and advantageous methods for assessing the concentration of ions in solution

V. EXPERIMENTAL SETUP

Experimentation was conducted on water cooler of 50 liter capacity fabricated as per the Indian standards. As similar to the normal water cooler, the components present are compressor, condenser, expansion valve and evaporator. Apart from the basic components it also includes the pressure gauges and thermocouples were incorporated where ever necessary to note down the pressures and temperatures which are required for performance evaluation. Experimental obtained pressure and temperatures were used to get enthalpy values from the property tables to evaluate the performance. The schematic figure of the experimental setup is shown in the fig 3.

Experimentation was repeated for POE oil, POE oil+Si3N4 nanolubricant and nanolubricant with surfactant. Performance of the water cooler was evaluated by calculating coefficient of performance (COP) at steady states. Coefficient of performance was evaluated at different loads (1lit, 5lit, 10lit and 15lit) for all the three samples. The actual power consumption was measured with clamp meter

VI. RESULTS AND DISCUSSIONS

A. Thermal property evaluation:

Fig. 8 illustrates the thermal conductivity of the POE oil, Si3N4/POE nanolubricant and Si3N4/POE/surfactant as a function of volume concentrations and temperature respectively. Experimental observations proved that the thermal conductivity of the Si3N4/POE nanolubricant and Si3N4/POE/surfactant nanolubricant enhanced with volume concentration and reduced with temperature rise but the decrement values are more than the pure POE oil. The maximum enhancement was found to be 31.6% and 30.5% at 0.6% volume concentration at 25±15ºC for Si3N4 nanolubricant and nanolubricant with surfactant in comparison with pure POE oil. It is also noticed from the results that the addition of surfactant has reduced the thermal conductivity compare to Si3N4 nanolubricant. The decrement of thermal conductivity is due to fact that the mean path between liquid molecules increases and accordingly the impact of molecules will be decreased as a result the thermal conductivity decreases with raise in temperature and addition of surfactant [15].

B. Viscosity:

Viscosity of the oil, Si3N4/POE nanolubricant and Si3N4/POE/surfactant as a function of volume concentrations and temperature was plotted in Fig. 7. The figure presents that the viscosity of the nanolubricant and nanolubricant with surfactant increases exponentially with the increase of volume concentration and decreases with the rise of temperature with respect to pure oil. Results showed that from 0.45% concentration viscosity has been reduced which indicated the non-Newtonian behavior of the lubricant [15]. This is due to fact that at higher concentration agglomeration of nanoparticles will be more. However, the nanolubricant likely to exhibit Newtonian behavior at up to 0.6% volume concentration and therefore for the experimentation a volume concentration 0f 0.6% was preferred. From figure 7(a) & (b) the maximum viscosity enhancement has been found 41.6%, 33.9%, 31.2% and 37.1% for Si3N4 nanolubricant in comparison with POE oil at 20ºC 30ºC, 40ºC and 50ºC for 0.6% volume concentration. Similarly the addition of surfactant also enhanced the viscosity of the nanolubricant by 34.9%, 39.4%, 38.1% and 32.6% for the same temperature and concentration. As suggested by [16], at high temperatures Brownian motion of the nanolubricants get intensified as a result the viscosity of the nanolubricant get decreases. Nanolubricant with high viscosity leads to extra load on the compressor and increases the pumping power [17].

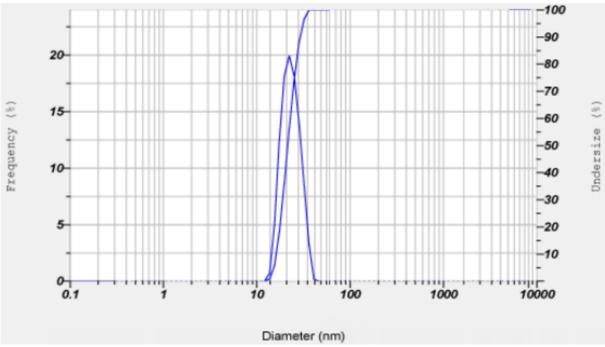
C. Coefficient of Friction

In order to analyze the effect of enhanced viscosity on the lubrication characteristics, an experiment were carried out on both the pure POE oil and the altered oil. The coefficient of friction of three samples was found by performing tests with a standard pin on disk tribometer in a controlled condition of 28±3ºC. In the experimentation, the frictional force was taken for a time period of 20 min, at intervals of 5 min. For each 5min, 0.15% concentration nanolubricant was added and the average value obtained was represented in the fig 12.

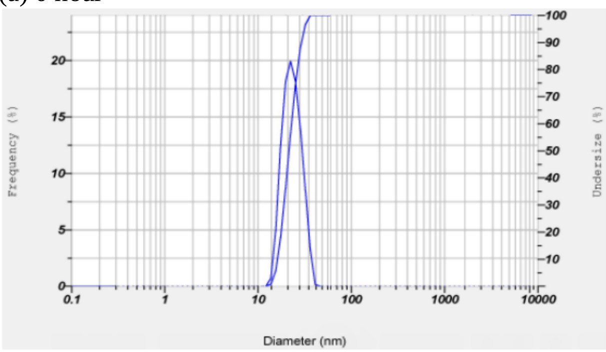
Results show that the coefficient of friction was increased initially with a rise in the volume fraction and reaches a least value at 0.6% volume fraction. Although the viscosities of the nanolubricants were increased with concentration as said before, it is found that the coefficient of friction keeps on increasing and reduces at 0.6% concentration. Results conclude that coefficient of friction is minimum at 0.6% concentration by 7% & 11% for both the samples and hence this concentration is suggested for the experimentation.

D. Measurement of electrical conductivity of nanolubricant:

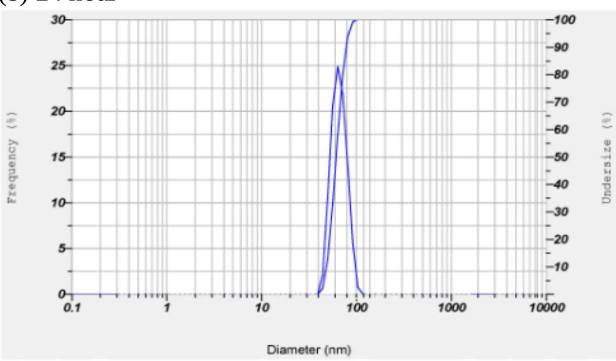
From the Table 2, it is found that the electrical conductivity values are decreased for the Si3N4 and Si3N4+ TBAI nanolubricants when compared with the electrical conductivities of pure POE oil. The maximum percentage decrease is found to be 27.27% and 24.1% for Si3N4 nanolubricant and Si3N4 nanolubricant/surfactant. Lesser the electrical conductivity value, longer the compressor life.



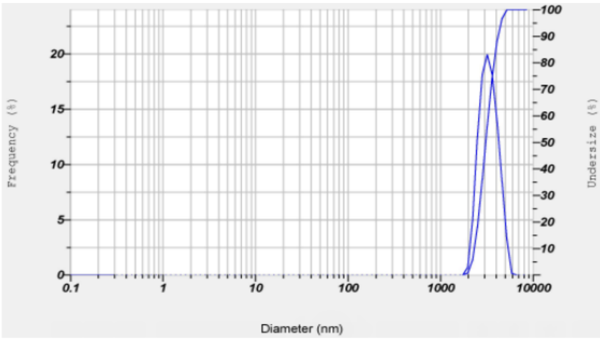
(a) 0 hour



(b) 24 hour

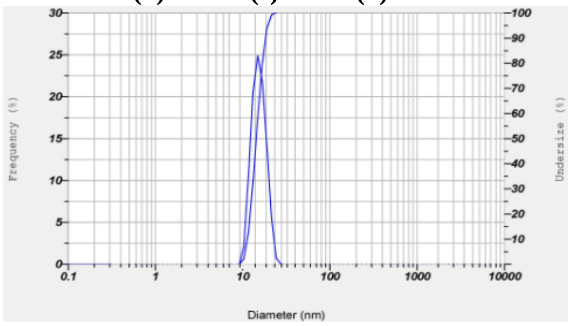


(c) 72 hour

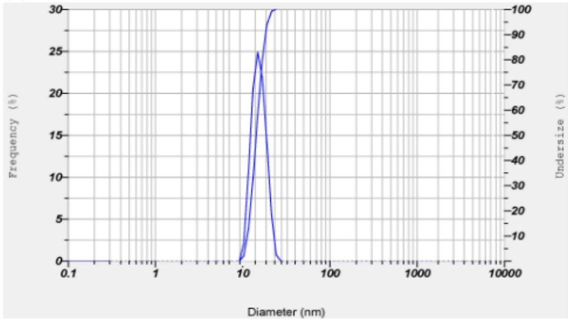


(d) 78 hour

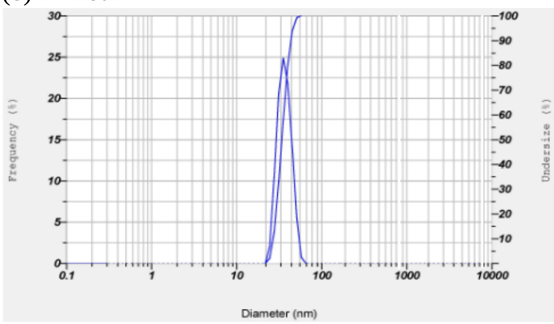
Fig 1: DLS image of Si3N4 nanolubricant at (a) 0 hrs (b) 24 hrs (c) 72hrs (d) 78 hrs



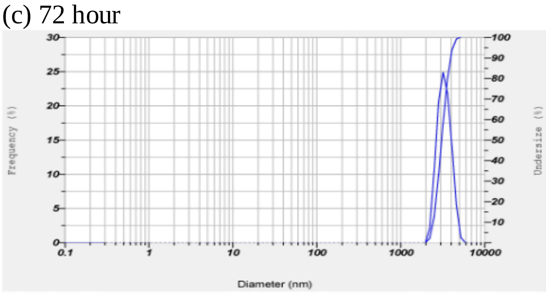
(a) 0 hour



(b) 24 hour



(c) 72 hour



(d) 96 hour

Fig 2: DLS image of Si3N4 nanolubricant at (a) 0 hrs (b) 24 hrs (c) 72hrs (d) 96 hrs

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Table 2 Electrical Conductivity Results

Sample	Pure POE oil	POE oil-Si3N4 nanolubricant	POE oil- Si3N4 nanolubricant + TBAI surfactant
Electrical conductivity (Siemens/meter)	38.5	28	29.2

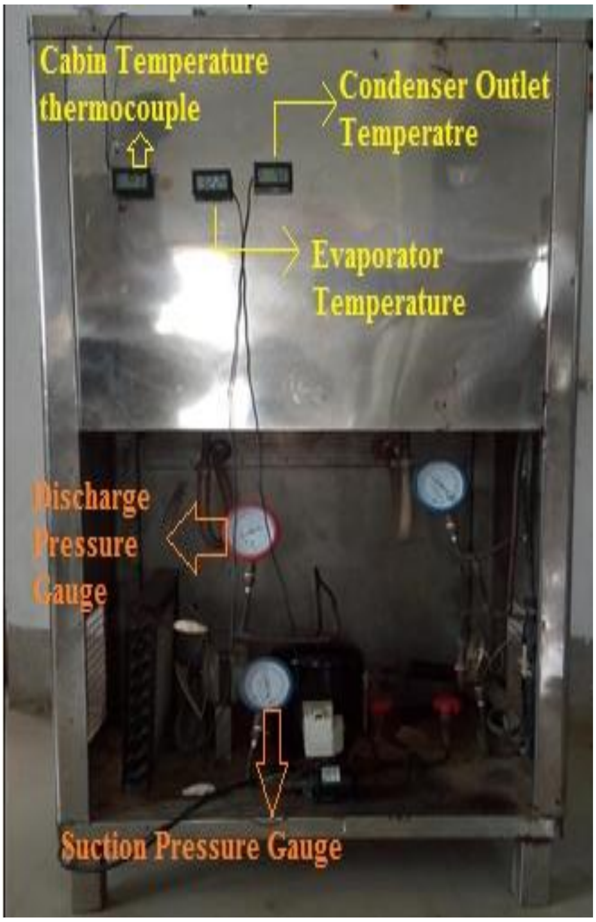


Fig 3: Experimental Setup

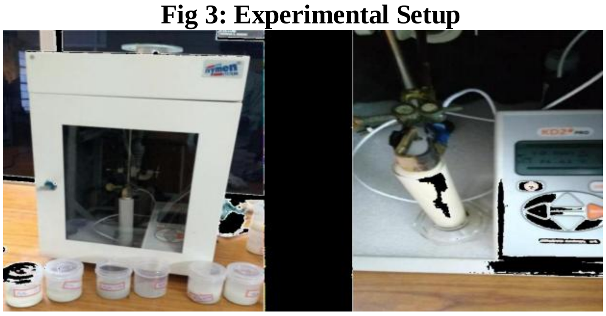


Fig 4: KD 2 Pro Thermal Analyser

Fig 5: Pin on Disc Tribotester

Fig 6: Electric Conductivity Meter

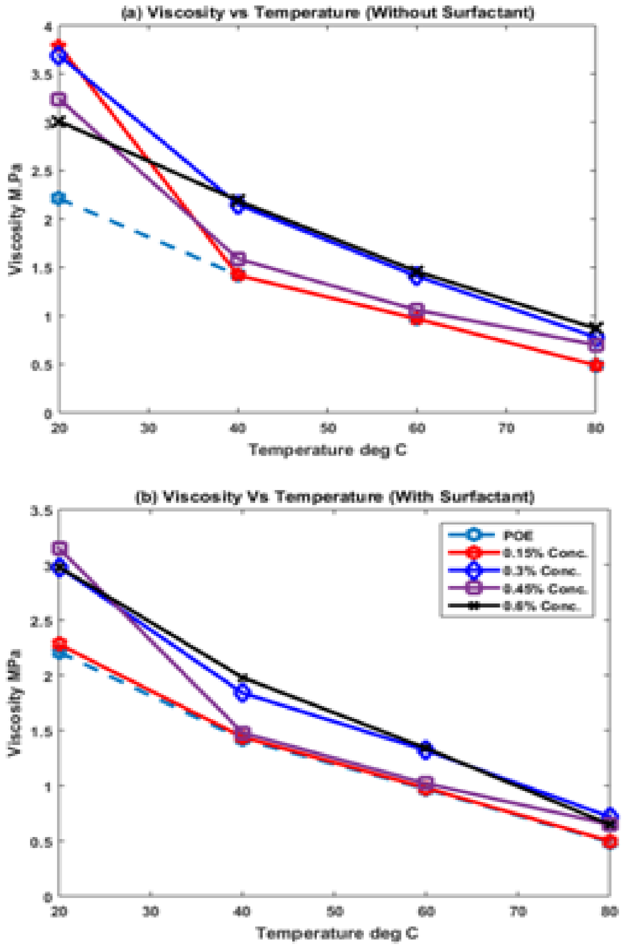
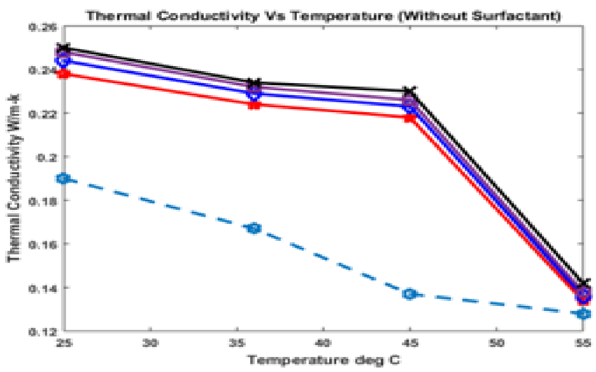
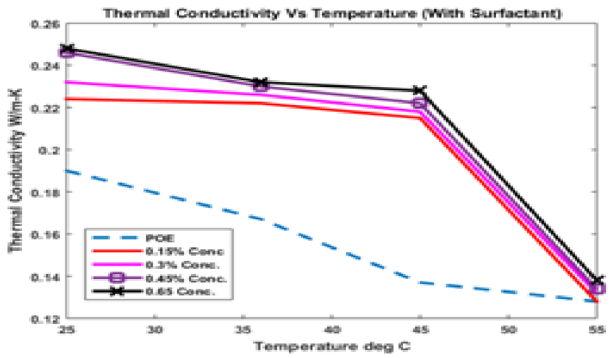
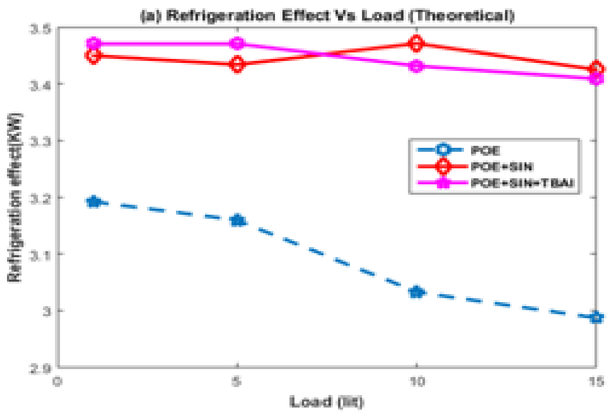


Fig: 7 Viscosity as function of temperature (a) Without surfactant (b) With surfactant





: 8 Thermal conductivity as a function of temperature (a) Without surfactant (b) With surfactant



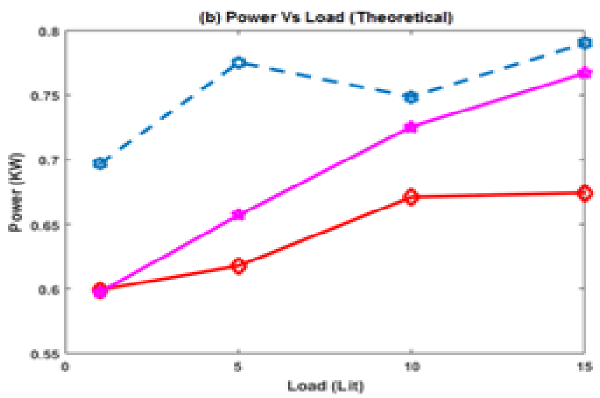
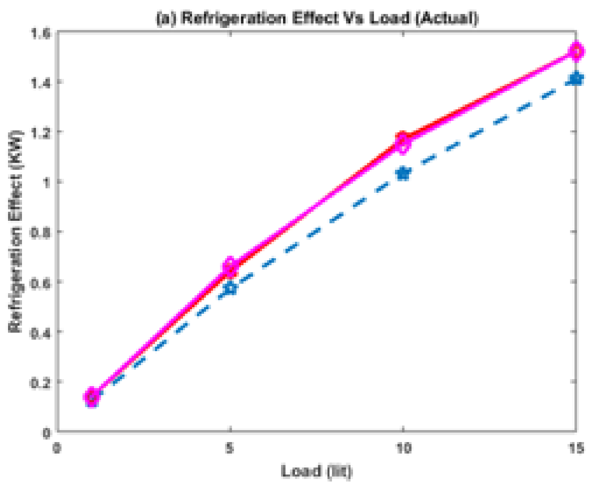


Fig: 9 (a) Theoretical Refrigeration effect as function of load (b) Theoretical Power Vs Load



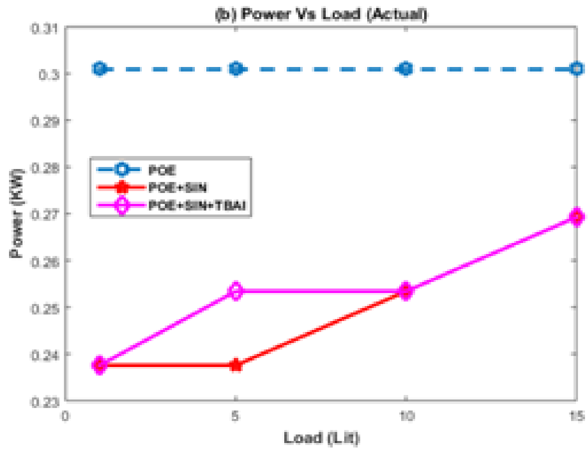
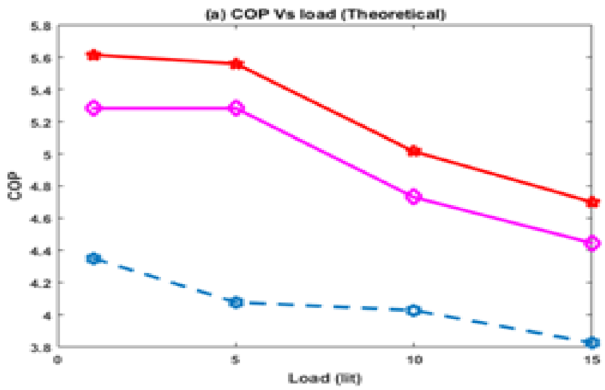


Fig: 10 (a) Actual Refrigeration effect as function of load (b) Actual Power Vs Load



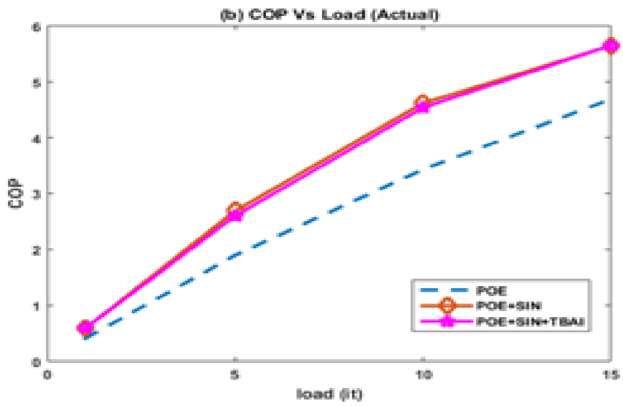


Fig: 11 (a) Theoretical COP as function of load (b) Actual COP Vs Load

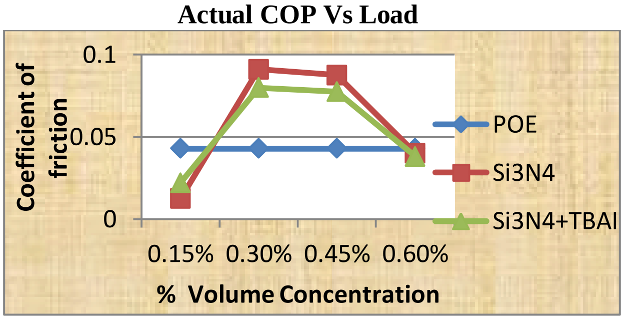


Fig: 12 Coefficient of friction as % volume concentration

Table 3 Experimental Uncertainties

S.No.	Measured Variable	Sensor Range	Uncertainty
1	Coolant temperature	PT-100- 200 to 500 °C	0.2 °C
2	Compressor temperatures	Type t thermocouple 15 – 150 °C	0.25 °C
3	Suction & Discharge pressure	Bourdon Type 0 – 10 bar	0.3 %
4	Input power analyzer to Compressor	10 – 100 A, 110 – 480 V	0.5W

E. Performance evaluation:

Performance investigations were conducted experimentally on water cooler with pure lubricant, nanolubricant and nanolubricant with surfactant. From the literature it is shown that the nanolubricant with higher thermal properties will affects more on the performance. Hence in this work, thermal property evaluation were made for the nanolubricant and nanolubricant with surfactant and found the maximum enhancement at 0.6% volume concentration for both the samples. All the experiments were conducted at steady state conditions for at least three times to avoid the errors in the measurements. The experimental uncertainties were mentioned in the table 3.

$$COP_T = \frac{h_1 - h_{f3}}{h_2 - h_1} ----(2)$$

$$COP_A = \frac{\dfrac{m_w C_p (t_{wi} - t_{wf})}{t}}{VICOS\phi} ----(3)$$

COP is influenced by refrigeration effect and compressor work which in turn depends on the operating conditions hence all the experiments were carried out approximately at the same temperature with ±4ºC. In this work theoretical COP and actual COP was examined at all temperature and loads using the following formula (Eq…). Fig 11 illustrates the comparison of COP for all the three samples at different loads. Experimental results proved that the COP has been enhanced with the presence of nanoadditives to the base POE oil. Both actual and theoretical COP has been enhanced by 29.06%, 36.39%, 24.52%, 22.85% and 21.43%, 29.6%, 17.46%, 16.19% corresponding to the load 1,5,10 and 15 liters in comparison with pure oil respectively.

Refrigeration effect of the cooling system at different loads was evaluated with pure POE oil and modified POE oil. Fig 9(a) &10(a) shows the enhancement comparison of refrigeration effects with the addition of Si3N4 nanoparticles and Si3N4 nanoparticles/surfactant for 0.6% volume concentration. In this work theoretical and actual refrigeration effects were estimated by using the eq (1) & (2). Results found that the refrigeration effect has been enhanced by 8.1%, 8.7%, 14%, 15% and 8.7%, 9.8%, 13.15%, 14.12% for Si3N4 nanolubricant and nanolubricant with surfactant respectively corresponding to the load 1,5,10 and 15 liters in comparison with pure oil. The enhancement is due to fact that the existence of high thermal conductivity nanoparticles in the oil+ refrigerant mixture can improve the heat transfer in the evaporator and the same has been stated by [15], [18] & [19]. Also subcooling of 4ºC to 6ºC has been observed for nanolubricants and nanolubricant/surfactant which is the indication of enhancement in the refrigeration effect. Power utilized by the compressor has been calculated at different loads with nanolubricant and nanolubricant/surfactant. Fig 9(b) & 10(b) shows the comparison of compressor power as a function of temperature. Results showed that the power consumption has been reduced by 14%, 20.3%, 10.3%, 14.67% and 14%, 15.24%, 3.088%, 2.92% corresponding to the load of 1,5,10and 15 lit in comparison with the system working with pure POE oil. In addition, it is also seen that the reduction in compressor pressures and temperature which leads to the reduction of stator windings temperature and consequently improves the efficiency, durability of the compressor [20]. The reduction is due to fact that the enhanced viscosity as shown in the fig7 leads to reduction in the friction coefficient which reduces the frictional loss and frictional heat of the compressor [6]. Also the high thermal conductivity of the nanolubricant allows the excess heat to escape from the compressor more easily [21].

VII. CONCLUSION

Experimental work was conducted to compare the performance of a water cooler by altering the compressor lubricating oil with Si3N4 nanoparticle and Si3N4 nanoadditives with TBAI surfactant for 0.6% by volume concentration. Also thermophysical properties were also evaluated to find the optimum concentration which has high thermophysical properties. From the viscosity results the optimum concentration for the experimentation was found to be 0.6% and also the coefficient of friction was found to be minimum by 7%, 11% and thermal conductivity has been increased by 31,6%, 30.5% for nanolubricant and nanolubricant/surfactant at the same concentration in comparison with POE oil. It is concluded that the performance of the water cooler has been increased with the addition of nanoparticles to the compressor lubricating oil. The experimental results showed that the COP of the water cooler has been enhanced by 36.39% and 29.6% at 10lit load for nanolubricant and nanolubricant/surfactant in contrast with the POE oil alone. The obtained results were validated by repeating the experiment after one month. The results obtained after one month were in accordance with the results before one month with ±5% variation in the performance.

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