PERFORMANCE INVESTIGATION AND EXERGY ANALYSIS OF VCRS OPERATED USING R600a REFRIGERANT AND NANOADDITIVE COMPRESSOR OIL

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ABSTRACT: Compression of vaporized refrigerant is the essential process of the refrigeration cycle which is performed by using a compressor. The amount of power consumed by a refrigeration system is governed by the work input given to its compressor, which also determines the COP of the system. By reducing the work input given to the compressor, the power consumption of refrigerator is reduced along with the improvement in its COP. Now a days, nanoparticles have emerged as the new generation additives in various working fluids because of their remarkable ability to improve the heat transfer, tribological and other thermo-physical properties of the base fluid. In such a vein, we propose a compressor oil based nanofluid prepared by dispersing nanoparticles into the conventional compressor oil. In the present study, four samples of nanoadditive compressor oil were prepared by dispersing the nanoparticles like Al_2O_3, TiO_2 and ZnO into the conventional mineral oil as a lubricant. The tribological properties of this four samples were studied, out of which one sample gave a better lubrication and heat transfer properties which are considered as one of the key parameters for reducing work input to the compressor, this can result in reduced power consumption, with enhancement of COP. These results are analysed experimentally by carrying out performance and exergy analysis in a Vapour Compression Refrigeration System (VCRS), using R600a as a refrigerant. The experimental results show that, there is an improvement of COP by 14.61% and exergy efficiency by 7.51%. Also, the efficiency defect in the major components of VCRS has been reduced effectively.

Key words*: Nanoparticles, COP, tribological properties, exergy, VCRS, efficiency defect.*

1. Introduction:

Halogenated refrigerants utilized in vapor compression based refrigeration, air conditioning and a heat pump system creates greenhouse gas emissions that in turn, contribute significantly to the global warming. Presently, the usage of natural refrigerants in refrigeration, heat pump and air-conditioning systems is becoming more attractive due to their environmentally being characteristics as compared to synthetic refrigerants [1, 2]. Among the natural refrigerants, hydrocarbons such as propane (R290) and isobutene (R600a) have been concerned and mainly used in small heat pump and refrigeration systems since they have excellent thermodynamic properties and applicability employed in the system equipment's [3-5]. More than 85% of refrigerator producers in China depend on R600a which is thoroughly commanding refrigerant in numerous countries. Globally, hydrocarbons are utilized as a part of around 36% of the domestic refrigerators and coolers, and this number is assessed to ascend to 75% by 2020 [6].

1.1. Background of study:

Various studies have already been carried out to evaluate the performance of the Vapour Compression Refrigeration System operated using different Nano refrigerants and Nanoadditive compressor oil. Nano refrigerant is one kind of nanofluid, in which the base fluid is a conventional refrigerant. Initially, some experimental studies showed that the Nano refrigerant has higher thermal conductivity than the conventional refrigerant.

Jiang et al., [7, 8] measured the thermal conductivities of CNT–R113 Nano refrigerants and found out that the measured thermal conductivities of CNT–R113 Nano refrigerants is enhanced on an average of 65% with the volume fraction of 0.1%. Wang et al., [9] have investigated the use of the nanoparticle in the heat transfer. Wang observed that addition of nanofluids would enhance thermal conductivity compared to conventional coolants. Xiao-Min et al., [10] investigated the pool boiling heat transfer of the R11 refrigerant containing TiO_2 nanoparticles, and the results indicated that the heat transfer increased by 20% with a particle loading of 0.01 g/L. Park and Jung [11] experimented with heat transfer enhancement of Nano carbon tubes for refrigerants. In this study, the authors have considered the R123 and R134a to investigate the heat transfer in carbon nanotubes. Peng et al., [12, 13] found out that the heat transfer coefficient of CuO–R113 was higher than that of pure refrigerant R113, and the maximum enhancement of heat transfer coefficient was 29.7%. Bi et al., [14] investigated the performance of a domestic refrigerator using TiO_2-R600a Nano refrigerant and reported that an improvement in the COP resulted along with the reduction in power consumption by 9.6%.

1.2. Performance of Nanoparticles:

Kumar and Elansezhian [15] investigated the performance of a VCRS operated using R152a refrigerant containing ZnO nanoparticles and stated that the system performance has improved with 21% less energy consumption with 0.5 vol% nano ZnO. It may also be noted that R152a has a lesser value of Ozone Depleting Potential (ODP) and Global Warming Potential (GWP) compared to the R134a. However, mixing of nanoparticles with the refrigerants is a tedious process with a lot of cost involvement. Also, incomplete dispersion leading to aggregation and sedimentation of nanoparticles in the Nano refrigerant may reduce the stability of Nano refrigerant and may result in blockages in the tubes, limiting the application of Nano refrigerant in the refrigeration system. Singh and Lal [16] conducted an experimental study on Alumina nanoparticles of 20 nm diameter dispersed in refrigerant R134a to improve its heat transfer performance. It has been found out that the performance of the system has been improved. The improvement in coefficient of performance (COP) was maximum (7.2 to 8.5%) with 0.5% Al_2O_3 (wt. %) nanoparticles. However, when the mass fraction of nanoparticles increased to 1% in refrigerant COP was found to be lower than even from pure R134a. In the expansion valve, with the increase of Al_2O_3 mass fraction by 1% had low down the pressure and temperature after the expansion of Nano refrigerant. In addition to this, the specific heat of refrigerant decreased. So these both factors would result in a decrease in the refrigeration effect and COP.

Alternatively, many studies have also been carried out by dispersing nanoparticles into the lubricant of the compressor. By dispersing nanoparticles into the compressor lubricant, the heat transfer properties and thermophysical properties of the lubricant is improved. Owing to the improved lubricating properties of the resultant suspension, the wear and friction between the moving parts of the compressor reduces. This results in decreased work input to the compressor there by improving the efficiency and reliability of the compressor.

Lee et al., [17] have experimented with the performance evaluation of mineral oil with 0.1 vol% fullerene nanoparticles. Lee has performed the study to friction rate and wear rate with the addition of the nanoparticles. Experimental observations showed that the friction coefficient decreased by 90% as compared to the raw lubricant. Jwo et al. [18] have investigated about the hydrocarbon refrigerant system performance with Nano lubricant. In this study authors have replaced polyester lubricant and R-134a with mineral oil lubricant and hydrocarbon refrigerant to evaluate the performance of the system. Authors have considered the Al_2O_3 nanoparticles in the mineral oil which had improved lubricant as well as the heat transfer performance. From their empirical experimentation with a combination of 60% of R134a with 0.1 wt. % Al_2O_3 nanoparticles has shown the better optimization and increase 4.4% of the coefficient of performance. An experimental study indicated that the freezing capacity was higher and the power consumption reduces by 25% when POE oil was replaced by a mixture of mineral oil and alumina nanoparticles for a refrigerator system operated using R134a refrigerant [19].

Kumar and Elansezhian [20] investigated an experimental work wherein Nano Al_2O_3-PAG oil was used as a lubricant in an R134a Vapor Compression Refrigeration System. The study on heat transfer performance of the Nano refrigerants is done to reduce the energy consumption. The refrigeration system with 0.2% V concentration of nanoparticles performs better than pure lubricant with R134a refrigerant and has 10.32% less energy consumption. Alawi et al. [21] in his study enhanced the properties of the heat transfer fluid with the addition of nanoparticles. Authors have described that COP and freezing speed in cooling systems are enhanced by the addition of nanoparticles to refrigerants. With the addition of nanoparticles, it will also increase the heat transfer rate and reduce pressure drop. The addition of the nanoparticles will increase the lubricant property which helps to improve the heat transfer rate. Subramani et al. [22] have investigated the usage of TiO_2 nanolubricant in replacement of SUNISO3GS with mineral oil as lubricant and R134a as a refrigerant in a Vapor Compression Refrigeration System. The experimental results show that a reduction in power consumption by 15.4% along with the increase in COP by 20%.

2. Contributions of the Present work:

The previous studies which have been carried out by dispersing nanoparticles in to the compressor lubricant have reported positive results in improvement of COP and reduction in power consumption of the refrigerator system. However, there are a few setbacks associated with the previous studies. In most of the earlier reviews, a relatively higher concentration of nanoparticles was used, which not only increased the preparation cost of nanofluids but also induced greater chances of loss of stability of the nanofluids due to particle aggregation resulting in blockages in the system. In addition to this, the thermophysical and heat transfer properties of the prepared nanolubricants were computed based on mathematical models, and there are a very few studies that have experimentally investigated them.

In the present study, a minimal concentration of nanoparticles was used for dispersion in the compressor lubricant, restricting to a maximum concentration of 0.05 vol%. This concentration will not only reduce the cost associated with the preparation process but also reduces the chances of coagulation. In addition to this, polyisopropanol was used as a surfactant with the aim of maintaining the stability of the prepared nanolubricant for a considerably long time along its service. Also, all the thermophysical properties of the prepared nanolubricant were experimentally evaluated. Another novelty of the present work is that there are a very few works that have taken into consideration the exergy losses of the individual components when dealing with Nano refrigeration.

3. Materials and Methodology:

3.1. Nanoparticles and their Properties:

Due to many potential applications of nanoparticles in the areas of medication, dynamics, optics and electronics exists vast scientific research on these particles. In comparison with their more substantial form, these nanoparticles are incredibly reactive due to its very high surface area. This phenomenon is applied in generating materials processing distinctive characteristics for numerous applications. The nanoparticles selected for experimentation are Al_2O_3, TiO_2 and ZnO.

Al_2O_3 nanoparticles possess better heat transfer properties thereby enhancing the thermal conductivity of the system. TiO_2 nanoparticles possess good lubrication properties while ZnO nanoparticles also possess excellent lubrication properties. The molecular formula and various properties of nanoparticles are expressed in Tab.1.

Tab.1. Properties of Al_2O_3, TiO_2 and ZnO [23]

Properties	**Al_2O_3 nanoparticles**	**TiO_2 nanoparticles**	**ZnO nanoparticles**
Molecular Formula	Al_2O_3	TiO_2	ZnO
Melting point	2072 °C	1843 °C	1975 °C
Boiling point	2977 °C	2972 °C	2360 °C
Colour	Ivory/White	White	White
Density	0.26 g/cm^3	4.23 g/cm^3	5.6 g/cm^3
Molecular mass	101.96 g/mol	79.9378 g/mol	81.40 g/mol
Average particle size	50nm	50nm	50 nm
Unique properties	Insoluble in water, Odourless	Excellent Photocatalytic properties. Tendency to degrade contaminants and germs UV Filtering properties	Antibacterial, Anti-corrosive, Anti-fungal, UV Filtering properties

3.2. Preparation of Nano additive Compressor Oil:

Nano additive Compressor oil is a nanofluid containing nanoparticles as additives in the refrigerant oil. Two-step preparation process is used to prepare nano refrigerant oil. Four samples of Nano additive Compressor oil were prepared by dispersing different nanoparticles in various volume fractions and are expressed in Tab.2.

Tab.2. Nano additive compressor oil samples

Sample	Composition
Sample 1	0.02 vol % Al_2O_3 + 0.01 vol % TiO_2
Sample 2	0.01 vol % Al_2O_3 + 0.005 vol % TiO_2
Sample 3	0.05 vol % Al_2O_3
Sample 4	0.02 vol % Al_2O_3 + 0.02 vol % ZnO

After addition of nanoparticles to the refrigerant oil, the mixture was stirred using a magnetic stirrer for 1 hour and was agitated in an ultrasonic agitator for about 2 hours to form stable Nanoadditive Compressor oil. Due to the very small volume fraction of nanoparticles, the cost associated with the preparation process is reduced considerably.

3.3. Experimental Setup and Procedure:

The experimental setup for this study comprised of 2015, top-freezer mounted single door domestic refrigerator (GODREJ, RDEDGE 185 CHTM) with hermetically sealed reciprocating compressor with 175 W nominal input power at 230 V in 50 HZ, a wire mesh air-cooled condenser, a capillary strainer (filter), and a capillary tube with ball valves and a single evaporator. Here, the capillary tube which connects the condenser and calorimeter has a length of 2.6m and diameter of 0.31mm. Fig.1 depicts a domestic refrigerator test rig unit which is generally utilized for domestic usage.

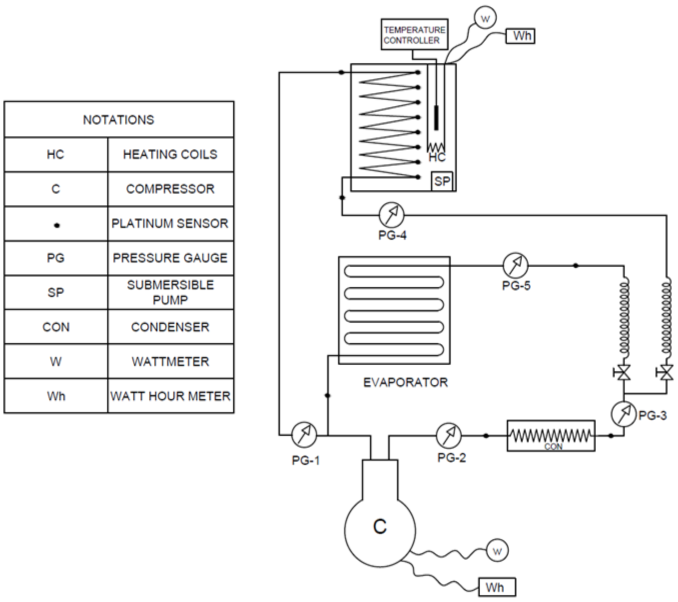


Fig.1. Setup of Domestic Refrigerator

In order to determine the actual COP and refrigeration capacity of a domestic refrigerator, the evaporator similar to the one used in the domestic refrigerator was tested under calorimeter filled with an equal proportion of Ethylene Glycol solution and water as the secondary refrigerant. This calorimeter was insulated with Poly Urethane Foam (PUF) insulation to reduce the ambient heat infiltration. In order to divert the refrigerant flow to either one of the refrigerators, i.e., the evaporator in refrigerator cabin or in the calorimeter, ball valves were attached in the circuit between the inlet of capillary tube and outlet of the condenser.

During the estimation process, six calibrated Resistance Temperature Detectors (PT100 RTD) with an accuracy of ± 0.1^{o}C were attached at positions of compressor outlet, condenser outlet and inlet and outlet of the evaporator (both in refrigerator unit and calorimeter). The temperature inside the calorimeter was measured using rod-type temperature sensor where as the power consumption of the compressor and heater was calibrated using a Watt meter with 1W accuracy (MULTISPAN

AVH13N). There are five pressure gauges have an accuracy of ±0.25% is mounted in the circuit for measuring pressure at various points in the system.

The calorimeter was employed in evaluating the cooling load in the system. The outer surface of calorimeter was surrounded by stainless steel plates and was insulated using PUF to minimize the ambient heat infiltration. The inner vessel of calorimeter comprises of heater coil (500W), i.e., electrical resistance-type heater Nichrome coil and the evaporator is wound inside the shell. It is provided with a drain pipe which helps in draining the fluid efficiently whenever it needs replacement and a lid at the top to view the state of the system. A submersible pump is placed inside the calorimeter to maintain a uniform temperature inside the calorimeter.

Firstly, to eliminate impurities, moisture and other foreign materials inside the test rig, nitrogen gas was flushed inside the rig and was thoroughly checked. The evacuation was established through vacuum pump whereas the refrigerant was charged into the system by using a charging unit. 72 grams of R600a was charged into the refrigerator through the charging unit and all the experimental observations were made after attaining steady-state conditions. In order to curb uncertainties in experimental outcomes, the experiments were repeated for three times and average values were determined with a limiting variation of up to ± 5 %. These measured values were utilized in assessing the performance characteristics of the refrigerator.

Based on the constraints regarding the availability of resources and cost of equipment, two tests were conducted to assess the refrigerator performance. These experiments were conducted using the eco-friendly R600a for the same set of the ambient temperature of 32°C and working conditions [24].

3.3.1 Exergy test:

This exergy test was conducted on calorimeter after attaining a steady state condition which was recognized by no change in temperature of calorimeter for 30 minutes. The initial readings of the heater, compressor, temperature detectors and pressure gauges were observed and recorded. During testing, the mains for the test rig are switched on followed by a compressor, heater and submersible pump. Also, the temperaturewas set on Digital Thermostat attached to the test rig.

The results were noted at various set temperatures in periods of 5°C from 25°C to -15°C and the final KWh value of heater was noted after completion of 5 minutes from digital energy meter. At the same time, the pressure gauge value at the high and low side was noted along with temperature at various channels. From Digital Watt meter, the Power of compressor in KWh was noted.

4. Results and Discussion:

4.1. Evaluation of Thermophysical Properties:

This section offers the evaluation of thermophysical properties of the Nanoadditive compressor oil such as thermal conductivity, kinematic viscosity, tribological properties and zeta potential that were calculated through various tests over four samples.

Since the changing of oil in the compressor has many complications; the best of four samples were selected and refilled in the compressor.

4.1.1 *Thermal Conductivity:*

The thermal conductivity of a fluid is its ability to conduct heat. A digital instrument called KD2 PRO was used to measure the thermal conductivities of the prepared Nanoadditive oil and plain mineral oil. In general, the thermal conductivity of a solution is increased by the addition of any solute to a solvent due to various factors like Brownian movement, thermophoresis and diffusiophoresis. Brownian movement, a zigzag, irregular motion exhibited by minute particles suspended in a fluid is a key mechanism governing the thermal behavior of nanoparticle-fluid suspensions at the molecular and nanoscale level [25]. Also, when nanoparticles are dispersed in the solvent, the unique surface properties of nanoparticles accelerate Brownian movement in the dispersion resulting in excellent heat transfer properties of the distribution.

Thermophoresis occurs as a consequence of Brownian motion amid the particles. When there is a temperature gradient in the particulate system, small particles tend to disperse faster in hotter regions and slower in a colderregion. The apparent migration from hotter to colder regions corresponds as a result of differential dispersion. Fig.2 denotes the Brownian movement of particles.

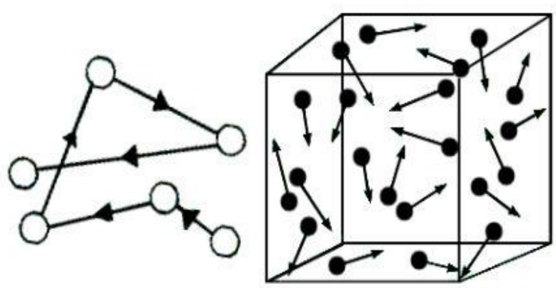


Fig.2. Brownian movement of particles (zigzag motion)

The various material compositions and their average thermal conductivity along with enhancement percentage are expressed in Tab.3. From the Tab.3. It can be witnessed that, the mineral oil containing 0.05% of nano-alumina powder produces a maximum enhancement in thermal conductivity of lubricant and mineral oil comprising a mixture of 0.01 volume % Al_2O_3 and 0.005 volume % of TiO_2, produced the least increase in thermal conductivity of lubricant.

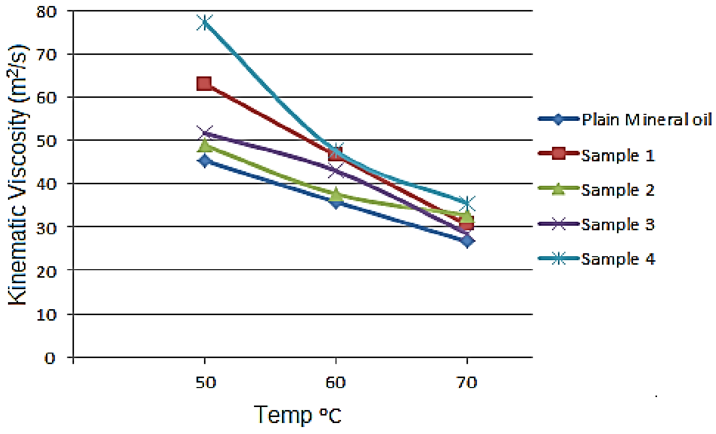
Tab.3. Enhancement of Thermal Conductivity by addition of nanoparticles

Sample No	Composition	Average Thermal Conductivity (W/mK)	Enhancement (%)
	Mineral Oil	0.169	-
1	Mineral oil + 0.02 vol% Al_2O_3 + 0.01 vol% TiO_2	0.215	27.22
2	Mineral oil + 0.01 vol% Al_2O_3 + 0.005 vol% TiO_2	0.189	11.83
3	Mineral oil + 0.05 vol% Al_2O_3	0.246	45.56
4	Mineral oil + 0.02 vol% Al_2O_3 + 0.02 vol% ZnO	0.221	30.77

This enhancement in thermal conductivity due to sample 3 might be attributed through the excellent heat transfer properties of aluminum oxide nanoparticles. Besides thermal conductivity, the heat stored in the bulk of fluid decreases thereby reducing the chances of formation of oil sludge and blocks inside the compressor. This, in turn, enhances the ability in retaining its effect of lubricating for a relatively extended period.

4.1.2 *Kinematic Viscosity:*

It is required that the lubricant should retain its viscosity without much loss throughout its operating period and with increasing temperature. The viscosity of the lubricant must be in an optimum range because usage of a high viscosity lubricant leads to power loss and high operating temperature and usage of a low viscosity lubricant reduces the lubricating effect of the lubricant causing excessive wear between the moving parts. The viscosity of the mineral oil and samples are measured using Redwood viscometer.



From the Fig.3 it can be observed that sample 1 exhibited the highest value of Kinematic viscosity than the other three samples. Conversely, sample 3 and 4 are to be chosen as the samples with better results by considering that variation in the value of Kinematic viscosity is not so high between 50°C and 70°C and both the samples can effectively retain the enhancement values with increase in temperature as well.

Fig.3. Kinematic Viscosity vs. Temperature for different samples of lubricants

4.1.3 Anti-wear and Friction Properties:

The tribological properties comprise of wear, friction and lubrication characteristics of any material. Pin on Disc Tribometer was utilized in determining the tribological properties where all the testing sections were rinsed thoroughly with plain compressor oil. This Pin on Disc Tribometer comprises of a stationary pin under applied load which is in contact with a rotating disc with required lubrication. The parameters of Pin and Disc can be explained in Tab.4.

Tab.4. Description of Pin and Disc

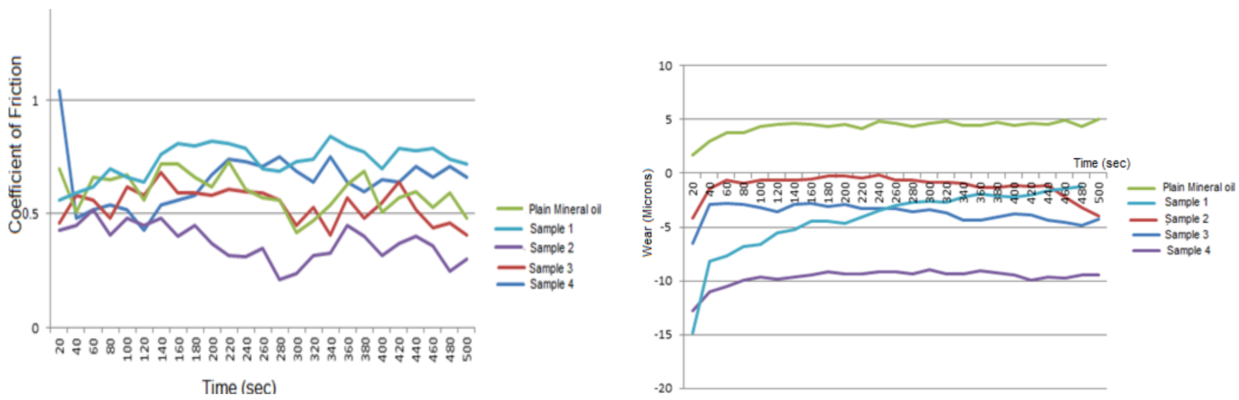
S.No	Element	Material	Hardness (HRc)
1	Pin	D2 Steel	55
2	Disc	EN34 Case Hardened Steel	60

Different mechanisms aid in improving the lubricating properties on a base lubricant by dispersing nanoparticles onto it. In most of the cases, nanoparticles behave as a bearing between the contact surfaces [26]. In the Pin on Disc Tribometer, the various sample oils and plain oil were tested under experimental conditions. The different results obtained from experiments were expressed in Tab.5.

Tab.5. Comparison of wear on a pin by plain oil and Nano lubricant oil

Lubricating Sample	The initial weight of the pin (g)	Final Weight of the pin (g)	Loss of weight due to wear (g)
Plain Mineral oil	15.318	15.28	0.038
Sample 1	15.458	15.43	0.028
Sample 2	15.259	15.23	0.029
Sample 3	16.305	16.28	0.025
Sample 4	14.813	14.79	0.023

From the above results shown in Tab.5, it can be observed that the wear produced on the pin by application of Nanoadditive oil samples was lesser than the wear produced on the pin by application of plain mineral oil. Also, it can be noted that Sample 4 exhibited the highest wear reduction properties while Sample 2 showed the lowest wear reduction process. The variation of wear concerning time for all the plain mineral oil and sample oils can be presented in Fig.4. (a).



(a) **(b)**

Fig.4. (a) Wear vs. Time (b) Co-efficient of friction vs. Time

In case of frictional properties of the lubricants, the same test equipment was utilized in determining the coefficient of friction. The results obtained through this experiment are depicted in Fig.4. (b). Based on the figure, it can be noted that the coefficient of friction of sample 3 and 4 was higher than the coefficient of friction of plain mineral oil which is due to the net effect of friction between the pin and the suspended nanoparticles in the lubricants. The absence of suspended particles in the case of plain mineral oil makes it produce a lower coefficient of friction at the contact surface. The coefficient of friction generated in this case is only due to the friction between the pin and the disc. However, sample 1 and sample 2 generates a lesser coefficient of friction than that produced by application of plain mineral oil. This may be due to the deposition of stable triboflim in these cases. The former case is more effective than the latter in the current application.

4.1.4 Zeta Potential:

The measure of zeta potential is the potential difference existing between the surface of a solid particle immersed in a conducting liquid and the bulk of the liquid. Here, all the Nano lubricant samples exhibited the absolute zeta potential value of greater than 30 mV because of the addition of the surfactant polyisopropanol. Out of all the samples, mineral oil containing a mixture of 0.02 vol% Al_2O_3 and 0.02 vol % ZnO exhibited the highest absolute value of zeta potential and Mineral oil comprising a mixture of 0.02 vol % Al_2O_3 and 0.01 vol % TiO_2 showed the least absolute value of zeta potential. This poses the chances of coagulation and flocculation in the refrigerant fluids. The samples with Zeta potential value more than +30mV and lesser than -30mV are considered to be more stable [27]. The zeta potential values of various Nano lubricant samples can be shown in Tab.6.

Tab.6. Zeta potential values of Nano lubricant samples

Nanofluid Sample	Composition	Zeta Potential (mV)
Sample 1	Mineral oil + 0.02 vol% Al_2O_3 + 0.01 vol% TiO_2	-31
Sample 2	Mineral oil + 0.01 vol% Al_2O_3 + 0.005 vol% TiO_2	-47
Sample 3	Mineral oil + 0.05 vol% Al_2O_3	38
Sample 4	Mineral oil + 0.02 vol% Al_2O_3 + 0.02 vol% ZnO	-54

Since changing the lubricating oil of the compressor process which required charging and discharging of the refrigerant from the entire system, sample possessing the most optimum thermophysical properties was to be selected for direct testing in the setup. Hence, Sample 4 exhibiting the highest stability, highest value of wear reduction, good viscosity index and excellent heat transfer properties were chosen.

4.2. Results of Performance and Exergy Analysis

The results obtained from the exergy test readings are discussed below.

4.2.1 Exergy test:

The various parameters like COP, exergy efficiency and efficiency defects of various components are found by measuring the experimental values of temperature, pressure and power consumption obtained during the test [28-32].

Fig. 5 represents the variation of COP against the set temperature of the calorimeter; the ambient was constant at 32°C. COP gradually increases as we go closer to ambient temperature. As this trend is thermodynamically proven, it's easier to bring a small temperature drop in a closed body for the refrigeration system. The results obtained showed that the COP of nano additive oil is higher than that of plain mineral oil. COP improvement is about 14.61% on an average through all temperatures tested. System working with nano additive compressor oil exhibited significantly higher COP which reduces the power consumption. This indirectly reduces the environmental pollution and effect of global warming.

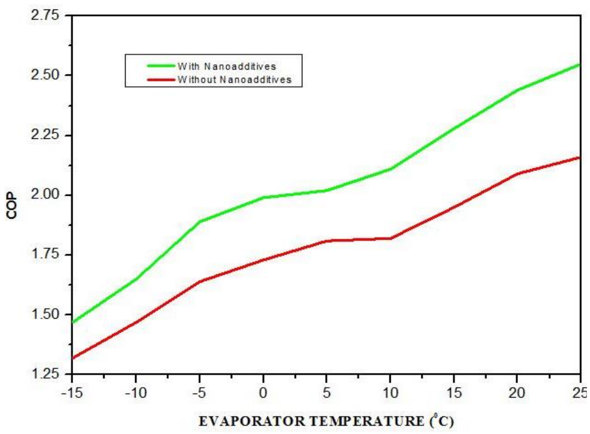


Fig.5. Evaporator temperature Vs. COP

Fig. 6 represents the variation of exergy efficiency against evaporator temperature. Exergy efficiency decreases with an increase in evaporator temperature. Exergy efficiency is related to the performance evaluation of the second law of thermodynamics. As the evaporator temperature increases, the irreversibility of the components increases which reduces the exergy efficiency [33]. Exergy efficiency is improved up to 7.51% on an average among all temperatures.

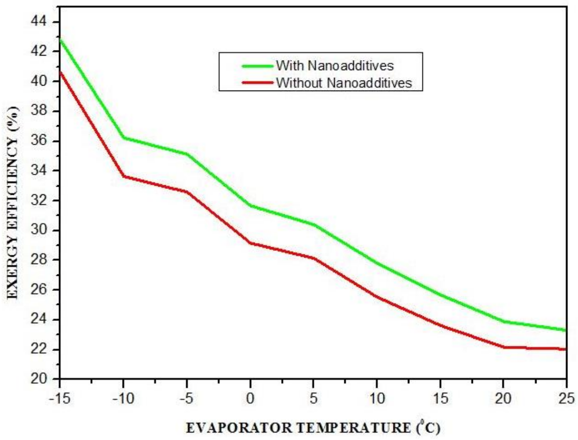


Fig.6. Evaporator temperature Vs. Exergy efficiency

In this Fig.7, the efficiency defect in compressor along with the variation in temperature of the evaporator is measured. It can be observed from the below figure that, the efficiency defect in compressor decreases with a decrease in evaporator temperature. This is because the cooler the compressor runs, the more efficient it is and also as the temperature difference increases exergy utilization will be high [34]. The result obtained showed that the defect in efficiency percentage of plain fluid and Nanoadditive fluid varies in the range of 7% to 2% concerning an increase in evaporator temperature. At higher evaporator temperatures the difference in the efficiency defect becomes closer.

Fig. 8 represents the efficiency defect in the condenser with the varying evaporator temperature. The graph shows that the efficiency defect decreases with a decrease in evaporator temperature. This is because exergy utilization becomes higher at lower temperatures. The addition of nanoparticles reduces the efficiency defect by 3% in the condenser.

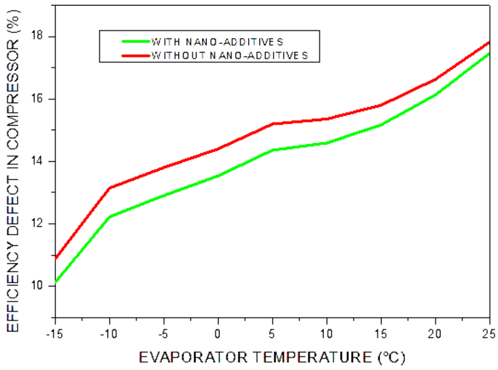


Fig.7. Evaporator temperature Vs. Exergy defect in Compressor

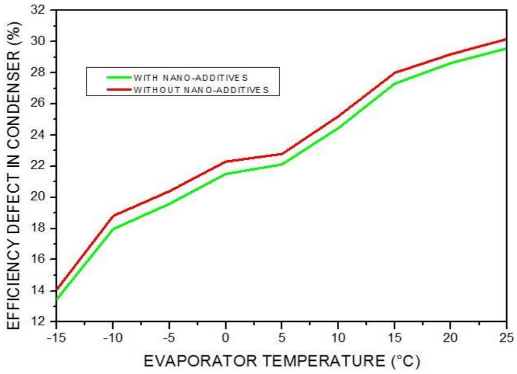


Fig.8. Evaporator temperature Vs. Efficiency defect in Condenser

Fig. 9 shows the variation of efficiency defect in a capillary tube with the variation in evaporator temperature. From the figure, it can be observed that the efficiency defect decreases with an increase in evaporator temperature. In the capillary tube, the expansion of refrigerant from high pressure to low pressure is done at constant enthalpy process causing a temperature drop. As the evaporator temperature decreases, the temperature difference becomes higher resulting in higher utilization of exergy available. The result obtained shows that efficiency defect in the capillary tube is 1.96% lower for Nanoadditive oil than plain mineral oil.

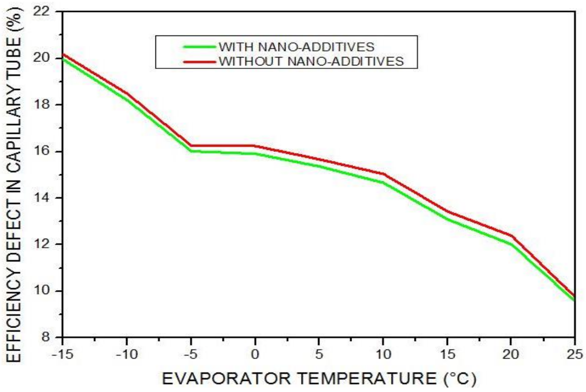


Fig.9. Evaporator temperature Vs. Efficiency defect in the Capillary tube

Fig. 10 shows the variation of efficiency defect in the evaporator with evaporator temperature for plain fluid and Nanoadditive fluid. The figure shows that the efficiency defect in the evaporator increases with an increase in evaporator temperature. As the evaporator temperature increases, the heat transfer between the refrigerant entered into the evaporator tubes and the medium being also cooled increases which ultimately increase the refrigerating effect, thus the exergy loss decreases. The defect in efficiency of the evaporator for plain fluid was in the range 17.89% and for the Nanoadditive fluid, it was observed as 17.46%.

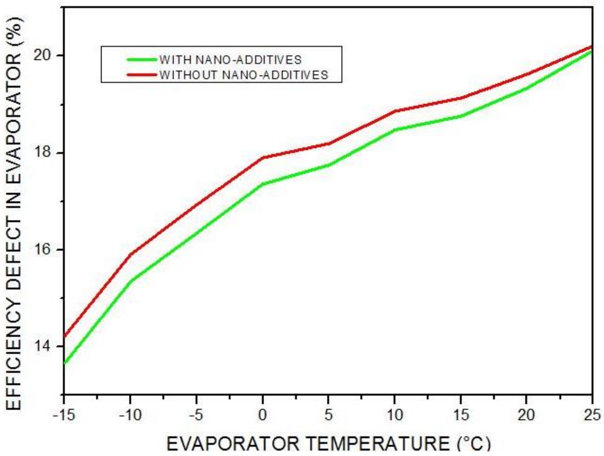


Fig.10. Evaporator temperature Vs. Efficiency defect in Evaporator

Fig. 11. a, b represents the variation of pressure levels of evaporator and condenser concerning the evaporator temperature. A slight increase in discharge pressure indicates the piston is sliding smoothly due to Nanoadditive compressor oil. Reduced friction allows the piston-cylinder assemblage to do more useful work of compressing the refrigerant. The evaporator pressure is notably reduced which results in improved pressure drop in the capillary tube. This improves the performance of the capillary.

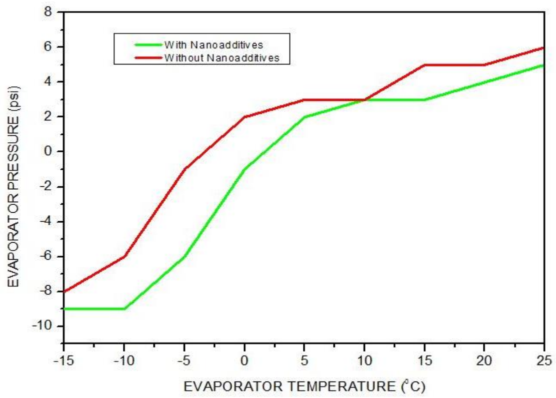


Fig.11. a Variation of Evaporator Pressure vs. Evaporator temperature

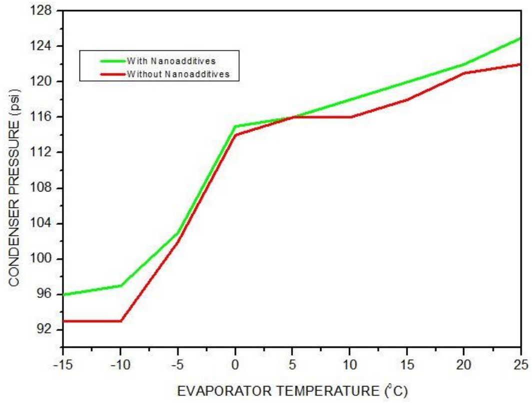


Fig.11. b Variation of Condenser Pressure vs. Evaporator temperature

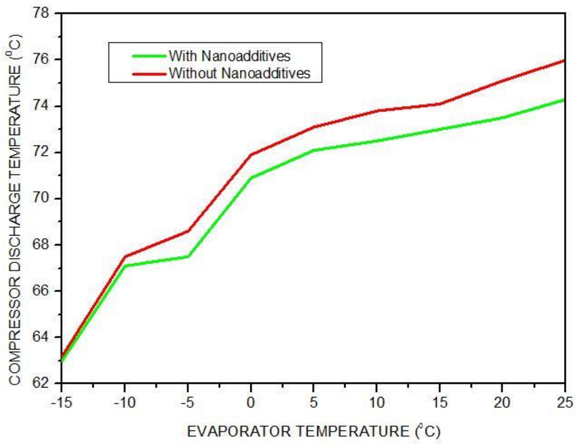


Fig. 12 displays the variation in discharge temperature of the compressor based on the change in evaporator temperature. For a maximum temperature limit of 25°C, the discharge temperature of the compressor in case of plain fluid and Nanoadditive fluid were 76°C and 74.3°C. Discharge temperature at compressor reduces, due to the high thermal conductivity of the Nanoadditive compressor oil which disperses heat effectively, but the condensing temperature is effectively increased due to higher discharge pressure.

Fig.12. Evaporation temperature Vs. Compression discharge temperature

5. Conclusion:

In this study, out of four samples considered for the analysis of tribological properties; the sample 4 exhibiting the highest stability, highest value of wear reduction, good viscosity index and excellent heat transfer properties.

The sample 4 was taken for experimental analysis in a VCRS operated using R600a as a refrigerant and the following conclusions were obtained.

- Enhancement of compressor discharge pressure by a small margin of 2-3 psi, causing the rise in condensing temperature and reducing the latent heat of condensation.
- The refrigerant discharge temperature was also reduced.
- Improvement in exergy efficiency by 7.51% because of lower evaporator temperature operation and reduced frictional losses in compressor.

- The efficiency defect in all the components of VCRS operating with nanoadditive compressor oil is consistently better compared with plain mineral oil.
- On the whole, the COP was improved by 14.61%.

References:

1. Bolaji, B. O., & Huan, Z., Ozone depletion and global warming: Case for the use of natural refrigerant–a review. *Renewable and Sustainable Energy Reviews*, (2013) 18, 49-54.
2. Bhatkar, V. W., *et al.,* Alternative refrigerants in vapour compression refrigeration cycle for sustainable environment: a review of recent research. *International Journal of Environmental Science and Technology,* (2013), 10(4), 871-880.
3. Palm, B., Hydrocarbons as refrigerants in small heat pump and refrigeration systems–a review. *International journal of refrigeration*, (2008), 31(4), 552-563.
4. Corberan, J. M., *et al.,* Review of standards for the use of hydrocarbon refrigerants in A/C, heat pump and refrigeration equipment. *International Journal of refrigeration*, (2008), 31(4), 748-756.
5. Miyara, A., *et al.,* Ways of next generation refrigerants and heat pump/refrigeration systems. *International Journal of refrigeration,* (2010), 18(1), 1-5.
6. Shecco, Natural refrigerants market growth for Europe, 2012.
7. Jiang, W., *et al.,* Measurement and model on thermal conductivities of carbon nanotube nanorefrigerants. *International Journal of Thermal Sciences*, (2009), 48(6), 1108-1115.
8. Jiang, W., *et al.,* Experimental and model research on nanorefrigerant thermal conductivity. *HVAC&R Research*, (2009), 15(3), 651-669.
9. Wang, K. J., *et al.,* Nano-scale thermal transporting and its use in engineering. In *Proceedings of the 4th Symposium on Refrigeration and Air Conditioning Southeast University Press, Nanjing, China,* (2006), pp. 66-75.
10. Xiao-Min, W. U., *et al.,* Investigation of pool boiling heat transfer of R11 with TiO2 nanoparticle. *Journal of EngineeringThermophysics, 28* (2008), 124-126.
11. Park, K. J., & Jung, D., Boiling heat transfer enhancement with carbon nanotubes for refrigerants used in building air-conditioning. *Energy and Buildings,* (2007), 39(9), 1061-1064.
12. Peng, H., *et al.,* Heat transfer characteristics of refrigerant-based nanofluid flow boiling inside a horizontal smooth tube. *International Journal of Refrigeration,* (2009), 32(6), 1259-1270.
13. Peng, H., *et al.,* Measurement and correlation of frictional pressure drop of refrigerant-based nanofluid flow boiling inside a horizontal smooth tube. *International Journal of Refrigeration*, (2009), 32(7), 1756-1764.
14. Bi, S., *et al.,* Performance of a domestic refrigerator using TiO_2-R600a nano-refrigerant as working fluid. *Energy Conversion and Management*, (2011), 52(1), 733-737.
15. Kumar, D. S., &Elansezhian, R., ZnOnanorefrigerant in R152a refrigeration system for energy conservation and green environment. *Frontiers of Mechanical Engineering,* (2014), 9(1), 75-80.
16. Singh, K., &Lal, K., An investigation into the performance of a nanorefrigerant (R134a+ Al_2O_3) based refrigeration system. *IJRMET*, (2014), 4(2), 158-162.
17. Lee, K., *et al.,* Performance evaluation of nano-lubricants of fullerene nanoparticles in refrigeration mineral oil. *Current Applied Physics,* (2009), *9*(2), e128-e131.
18. Jwo, C. S., *et al.,* Effects of nanolubricant on performance of hydrocarbon refrigerant system. *Journal of Vacuum Science & Technology B: Microelectronics and Nanometer Structures Processing, Measurement, and Phenomena*, (2009), 27(3), 1473-1477.

19. Subramani, N., & Prakash, M. J., Experimental studies on a vapour compression system using nanorefrigerants. *International Journal of Engineering, Science and Technology,* (2011), 3(9), 95-102.
20. Kumar, D. S., & Elansezhian, R., Experimental study on Al_2O_3-R134a nanorefrigerant in refrigeration system. *International Journal of Modern Engineering Research,* (2012), 2(5), 3927-3929.
21. Omer A.Alawi.,*et al.,*Applications of nanorefrigerant and nanolubricants in refrigeration, air-conditioning and heat pump systems: A review. *International Communications in Heat and Mass Transfer,* (2015) 68, 91-97.
22. Subramani, N., *et al.,* Performance studies on a vapour compression refrigeration system using nano-lubricant. *Int. J. Innov. Res. Sci. Eng. Technol*, (2013), 2(1), 522-530.
23. Hayness WM (2015). CRC Handbook of chemistry and physics (96thed). Boca Raton, FL CRC Press. ISBN 978-1-4822-6096-0.
24. IS 1476 (part-1) Schedule-5 Direct cool Refrigerator, Bureau of Energy Efficiency.
25. SeokPilJanga and Stephen U.S.Choib., *Role of Brownian motion in the enhanced thermal conductivity of nanofluids.* Applied Physics Letters volume 84, NUMBER 21, 24 May 2004.
26. Li Chang and Klaus Friedrich., *Enhancement effect of nanoparticles on the sliding wear of short fiber-reinforced polymer composites,* (2010), 43, 2355-2364.
27. Giri Prasad, M.J., *et al.,*Investigation of Stability of Water Based Mwcnts Nanofluids and Size Distribution of MWCNTS Functionalised by Different Chemical Treatment Processes. Applied Mechanics and Materials, (2015), 852, 712-718.
28. RecepYumrutus., *et al.,*Exergy analysis of vapour compression refrigeration systems. *Exergy, an International Journal,* (2002) 2, 266-272.
29. Jatinder Gill., *et al.*, Energetic and Exergetic Analysis of a Domestic Refrigerator System with LPG as a replacement for R134a refrigerant, using POE lubricant and Mineral oil based TiO_2-, SiO_2- and Al_2O_3-lubricants. *International journal of refrigeration,* (2018), doi: 10.1016/j.ijrefrig.2018.05.010.
30. Jatinder Gill., *et al.,* Exergy analysis of vapor compression refrigeration system using R450A as a replacement of R134a. *Journal of Thermal Analysis and Calorimetry,* (2018), htts://doi.org/10.1007/s10973-018-7675-z.
31. R. Saravana Kumar and V. Selladurai., Exergy analysis of a domestic refrigerator using eco-friendly R290/R600a refrigerant mixture as an alternative to R134a. *Journal of Thermal Analysis and Calorimetry,* (2014), 115(1), 933-940.
32. Fang WANG., *et al.,* Energy and Exergy analysis of heat pump using R744/R32 refrigerant mixture. *Thermal Science,* (2014), 18(5), 1649-1654.
33. Gill, J., & Singh, J., Energetic and exergetic performance analysis of the vapour compression refrigeration system using adaptive neuro-fuzzy inference system approach. *Exp Thermal Fluid Sci,* (2017), 88, 246-260.
34. Jatinder Gill., et al., Component – wise exergy analysis using adaptive neuro – fuzzy inference system in vapour compression refrigeration system. *Journal of Thermal Analysis and calorimetry,* (2018), htts://doi.org/10.1007/s10973-018-7857-8.