

EXPERIMENTAL INVESTIGATION ON PERFORMANCE ENHANCEMENT OF DOMESTIC REFRIGERATOR USING COPPER BASED NANOFLUIDS

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Abstract: -A household refrigerator is a necessary piece of equipment for humans. Almost no house exists without a refrigerator. Air conditioning and refrigeration account for between 30 and 35 percent of total energy use. The researchers are always trying to build an energy-efficient cooling system and increase cooling capacity. Nano technological goods, methods, and applications contribute to environmental and climate conservation by conserving raw materials, energy, and water, as well as lowering greenhouse gas emissions and hazardous waste. The use of nanoparticles in small amount in vapor compression refrigeration system aided in improving system performance and reduced energy consumption. This paper presents the energy consumption & thermal performance of domestic refrigerator using CuO/POE Oil and Cu/POE oil nanofluids with 0.1%, 0.2 to 0.3% wt. concentration in hermetically sealed compressor of the system used in a residential refrigerator. From the results it is found that compression works get reduced, cooling capacity & COPs of the systems get increased.

Keywords:- Vapor Compression Cycle, Performance Enhance of VCC, Energy Consumption Nanoparticles, Nanofluids,

1. Introduction- Refrigeration is essential in our busy lives, allowing us to buy perishable items in bulk and store them safely. Refrigerators have become indispensable for keeping food fresh, operating on a vapor compression cycle. Domestic refrigerators typically use hermetically sealed compressors, which combine the compressor and motor in a single, sealed unit. The compressor shell, made of steel, is welded to prevent refrigerant leaks, while the bottom houses oil for lubrication, cooling, and sealing. Many researchers have sought to improve domestic refrigeration systems through various methods. One approach involves adding nanoparticles to the lubricant in vapor compression refrigeration systems, creating a nano-lubricant. This mixture can enhance performance by: 1. improving the lubricant's tribological characteristics, which benefits compressor efficiency. 2. Enhancing the thermo physical properties and heat transfer of refrigerants, leading to better cooling. 3. Increasing the solubility between lubricant and refrigerant, allowing more oil to return to the compressor.

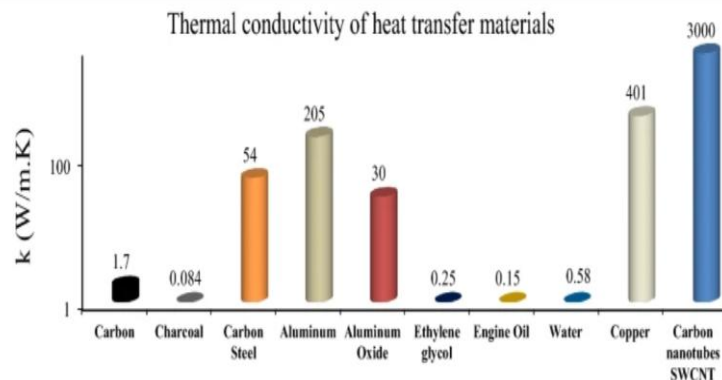


Fig1. Thermal Conductivity of Different Types of Materials
(Abdul Kaggwa, 2019)

Choi and Eastman (1995) first suggested using nanoparticles to boost fluid thermal conductivity, mitigating clogging issues. Research into nanofluids for convective heat transfer has since expanded, finding applications in electronics and refrigeration. Based on the application nanoparticles are currently made out of a very wide variety of materials, the most common of the new generation of nanoparticles being ceramics, which are best split into metal oxide ceramics, such as titanium, zinc, aluminum, copper and iron oxides, to name a prominent few and silicate nanoparticles, generally in the form of Nano scale flakes of clay. Nanoparticles can be used in refrigeration systems because of its remarkable improvement in thermo physical and heat transfer capabilities to enhance the performance of refrigeration systems.

2. Literature review: Start with a review of existing literature on refrigeration, domestic refrigerator technology, nanofluids, and their applications to understand the field's current state and identify research gaps. Most refrigeration systems use the vapor compression cycle, where expansion occurs through an irreversible expansion valve, leading to reduced cooling capacity and increased work compared to the Carnot cycle. Researchers have explored various methods to enhance vapor compression system performance, including: 1. Different compressor types, flash chambers, and refrigerants. 2. Sub cooling methods, such as using liquid line suction heat exchangers or external cooling sources. 3. Multistage compression. Nanofluids, specifically nano refrigerants and lubricants, are a recent trend. This literature focuses on their role in enhancing vapor compression system performance. Studies suggest nanofluids improve efficiency in HVAC&R applications by enhancing thermal dissipation and lubrication when used as additives in conventional refrigerants and oils. Nano lubricants, which are dispersions of nanometer-scale particles in conventional lubricants, have gained attention for improving energy efficiency and durability in refrigeration systems (Marcucci Pico et al., 2023). Key operational factors such as nanoparticle concentration, temperature, and particle characteristics influence the performance of these nano-fluids (Zafar Said et al., 2023). Enhanced thermal conductivity and viscosity are associated with these nanofluids, impacting heat transfer performance. The use of nanolubricant in vapor compression systems has demonstrated potential for improved thermal performance (T.O. Babarinde, D.M. Madyira,

2023). Baskaran N. et al. (2022) found that the performance of nano refrigerant R134a-ZrO₂ at a concentration of 0.2 g/l resulted in reduced downtime and energy consumption. Similarly, Mustafa W. Hamdallah et al. (2021) reported notable increases in density ratio, COP, and viscosity with CuO nanoparticles, alongside a significant reduction in electrical consumption. Past studies have shown that the addition of nanoparticles (e.g., diamond, CuO, TiO₂) can enhance the coefficient of performance (COP) and refrigeration capacity while lowering power consumption in various refrigeration systems (Marcucci Pico et al., 2020; Anish et al., 2020; Adelekan et al., 2019). Zawawi et al. (2017) also indicated that the incorporation of specific nanoparticles can improve the viscosity and thermal conductivity of lubricants. Overall, nanofluids present a promising avenue for optimizing refrigeration system performance (W.H. Azmia et al., 2017; Krishnan et al., 2017). Baskar and Karikalan (2017) studied the cooling performance of a VCRVCR system using ZrO₂ nanoparticles in compressor oil at concentrations of 0.1%, 0.2%, and 0.3%. They found an increase in the coefficient of performance (COP) by 7.61%, 14.05%, and 11.90%, respectively. Singh and Ansari (2017) experimented with the nanorefrigerant R600a/R290, finding a performance improvement of 3.18%-11.57% using CuO particles. Murshed et al. (2017) and Babarinde et al. (2020b) highlighted that uniform dispersion of nanoparticles in compressor oil is crucial for performance. Kushwaha et al. (2016) noted that using nano-Al₂O₃ with R134a improved COP. Veera et al. (2016) found increased heat transfer coefficients with Al₂O₃ and TiO₂ nanorefrigerants. M.E. Haque et al. (2016) reported reduced energy consumption and increased freezer capacity using AL₂O₃ nanolubricant in household refrigerators. Kumar et al. (2016) observed that ZrO₂ nanoparticles at 0.01%-0.06% concentration improved performance in VCRS. Mahbulul et al. (2013, 2015) found that 5% Al₂O₃ nanoparticles increased COP by 15% in an R134a refrigerator. Desai and Patil & Subramanian et al. (2015) investigated SiO₂ nano-oil as a lubricant. M.D. Suziyana et al. (2015) observed a 2.1% reduction in energy consumption and improved COP with 0.2% Al₂O₃ in POE oil. V. M. Jamadar and A. M. Patil (2014) focused on compressor cooling to enhance COP. R. Reji Kumar et al. (2014) reported higher freezing capacity and 11.5% reduced power consumption with a nanorefrigerant. T. Coumaressin and K. Palaniradja (2014) analyzed the performance of CuO-R134a nanofluids in vapor compression systems, finding that the evaporator heat transfer coefficient improved with nano CuO use. Laura et al. (2014) tested nanofluids as lubricants in heat pump compressors but found no significant benefits compared to commercial oils. Krishna Kant Dwivedi & R.C. Gupta (2014) reported a 20–25% energy savings in household refrigerators by cooling the compressor. FatouTouTieNdoye et al. (2014) found that using various nanoparticles improved heat transfer coefficients but also increased pumping power. Sendil et al. (2013) observed a COP of 3.5 and a 10.32% reduction in power consumption with Al₂O₃ in PAG oil for R134a refrigerators. Sreejith (2013) noted a 12–19% energy reduction using CuO in different compressor oils. Jubin V Jose et al. (2013) and Gobinath Natarajan (2012) found that TiO₂ nanoparticles as additives reduced power consumption compared to mineral oils. R. Reji Kumar et al. (2013) reported higher freezing capacity and reduced power use with Al₂O₃ nano lubricants. Subramani et al. (2013) found that using TiO₂ nanolubricant improved performance, decreasing power consumption by 15.4%. Rashmi G. Walvekar et al. (2013) optimized CNT concentration, improving COP by 4.2%. Javadi et al. (2013) noted a 25% energy saving using TiO₂ in R134a systems. Kumar and Elansezhian (2012) found better cooling performance and 10.32% energy reduction with Al₂O₃-PAG oil. Subramani

and Prakash (2011) reported a 25% power reduction using Al₂O₃ in mineral oil. Ahamed et al. (2011) highlighted lower energy losses with nanofluids as lubricants. M.S. Hossain et al. (2010) confirmed the safe operation of a domestic refrigerator with TiO₂ nanoparticles in HFC134a.

3. METHODOLOGY

3.1 Experimental Set up: The experimental setup used for the present study consists following technical Specifications.

1. Refrigerator Capacity 165 lit. Approx.-a). Compressor Hermetic (0 to 1000 W), b). Condenser Air cooled, Natural Convection Type., c). Expansion Device Capillary Tube (with different length and diameter) d), Evaporator Air cooled Plate type.e). Refrigerant R - 134a (NON-CFC). f) Thermostat Built-in

2. Energy meter- for compressor and heater energy measurement, one each

3. Temperature Indicator: - Digital, Multi-Channel, Range - 0°C to +100°C with K type thermocouple.

4 Dimmer stat: - 230 Volts, Sun grace make for heater controller

5. Pressure Gauges-Wikamake, 0-300 PSI (g), 1No. & -30" of Hg 0-150 PSI (g), 1No

Safety Controls

6). Over load Protector- To switch off the compressor if getting overheated and stops the working.

7) Thermostat - To switch off the compressor if the refrigerator temperature decreases below the set limit.

8) Service Required

230 Volts Single phase A.C. stabilized power supply.

3.2 Refrigerant, Lubricant, and Nanoparticles Selection and Preparation of Nanofluid:

Selection of the Nanoparticles-taken place based on factors like thermal conductivity and the based upon gap in literature CuO & Cu have better thermal conductivity (refer fig 1.1)

Selection of Refrigerant- refrigerant used as R134a which is most commonly used now days have better ODP and GWP

Selection of lubricant: Lubricants perform several functions in a compressor system. Of course, they must be able to lubricate the machine. In some systems, the lubricant is required to act as a cooling fluid as well as a sealant. This is why it's important to select the proper lubricant for compressor.

The refrigeration oil should be chemically and thermally stable and not react with the refrigerant. Also very important is how the refrigeration oil interacts with the refrigerant (e.g. solubility properties) and how the mixture performs in the compressor. Lubricant related problems can occur in a refrigeration compressor when the lubricant viscosity becomes too low or when there is absence of oil.

Here we have used same lubricant ie POE oil that is being used currently in domestic refrigerator

Table1. Properties of R134a refrigerant

Sr. No.	Properties	R-134a
1	Boiling Point	-14.90F or -26.10F
2	Auto-Ignition Temperature	14180F or 7700F
3	Ozone Depletion Potential	0
4	Solubility in Water	0.11% by weight at 77 ⁰ F or 25 ⁰ F
5	Critical Temperature	252 ⁰ F or 122 ⁰ F
6	Cylinder color code	Light Blue
7	Global Warming Potential (GWP)	1200

Table2.Properties of CuO & Cu Nanoparticles

Properties	Copper Oxide	Pure Copper
Chemical Formula	CuO	CU
Color	Blackish	Brown Black Powder
Morphology	Spherical	Spherical
Density	6.31 g/cm ³	8.940 g/cm ³
Phase	Alpha phase	Alpha phase
Average particle Size	Less than 100 nm	Less than 100 nm
Surface area	10-30 m ² /gm	15-20 m ² /gm

Preparation of Nanofluids

The preparation of Nano fluids is that the first key step in experimental studies with Nano fluids. Ensure that the nanoparticles are uniformly distributed to prevent blockages and damage to the compressor. There are two methods for the preparation of Nano fluid that is single step and two step method. for our project work the Nanoparticles of Copper & Copper oxide are purchased directly from Nano shell-Tech. the Copper & Copper oxide Nano powder with 0.1, 0.2, & 0.3 wt% was added in to the pure POE oil act as base fluids then, composition dispersed by magnetic stirring followed by sonication and total solution homogenized by Homogenizer. No surfactant was used in nanolubricant.

Determination of amount of nanoparticles added in base fluid[7]

(Sample calculation)

Following formula gives the amount of nanoparticles added in base fluid.

$$\phi = \left[\frac{\left(\frac{W_{Al2O3}}{\rho_{Al2O3}} \right)}{\left(\frac{W_{Al2O3}}{\rho_{Al2O3}} + \frac{W_{bf}}{\rho_{bf}} \right)} \right] \times 100$$

If we want to prepare 300 ml of nanofluids, say CuO with base fluid as ZEDOPLUS oil. We know that the density of CuO is 8940 kg/m³ and density of ZEDOPLUS oil is 865 kg/m³.

For 0.05% of concentration $W_{CuO} = 0.6731$ gms

Similarly,

For 0.1% of concentration $W_{CuO} = 1.3462$ gms and so on.

In these study two step methods is employed for preparation of nanofluids. The Nanoparticles of Copper metal & Copper Oxide nanoparticles are purchased directly from Nano shell-Tech. the Cu metal & Copper Oxide nanopowder with 0.01 to 0.03wt% was added in to the POE oil act as base fluids then, composition dispersed by magnetic stirring followed by sonication. In these study two step methods is employed for preparation of nanofluids.

BASE OIL +NANOPARTICLES = NANOFLUID
POE oil (300ml) +CuO (0.6731gm)= Nanolubricant



Fig2. Weighing of Nanoparticles



Fig3. Magnetic stirring of nanolubricant



Fig4. Ultra sonication of nanolubricant



Fig5. Charging of Domestic Refrigerator

3.3 Experimentation and Calculations

As per the guidelines given by ASHRAE handbook, 2022, the energy consumption test and no-load pull-down test were conducted with the following system parameters.

Freezer compartment: -18°C to -15°C

Food compartment: 3°C to 5°C

Steady ambient temperature: 25°C to 32°C

Furthermore, certain randomized experiments were conducted to establish the reproducibility of the data. When the system was left to function, measurements were taken of the temperatures; pressure, energy consumed, and the amount of refrigerant flow were collected once in every ten seconds till the steady-state operating conditions were reached. The observed temperatures, pressures, mass flow rate, electric power, and energy were utilized to calculate the operation characteristics of the refrigeration system.

Experimentation is carried firstly with POEOil as lubricant with R134a refrigerant. The readings are taken with POE oil 10-12 times, from the readings it is found that the instrument was better precise. Then the experimentation is also carried out with POEOil + copper&POEOil + Copper oxidenanolubricant with 0.1, 0.2 & 0.3 wt% concentrations.

Experimental Procedure: Controlled experiments conducted by varying the concentration of nanofluids, and other relevant parameters, maintaining consistent and accurate data recording throughout. Put the main switch 'ON'

The refrigerator will start its functioning.

Observe the drop in temperature referring to the temperature indicator.

Wait for some time (30 Minutes)

Noted down the different readings as per given in the observation table.

Varying Heat Load.....

After 10 min heater switch started the heater input adjusted with the help of heater control switch at 0% (No Load), 25% Load and 50% resp., and readings are recorded after steady state reached (30 min) for each concentration. Noted the changes in temperature, pressures & heat energy input.

The following equations are used to determine the performance parameters and results obtained are presented in table 3

1) Theoretical COP

$$\text{COP}_{th} = \frac{\text{Refrigeration effect}}{\text{Actual Compression Work}} = \frac{h_1 - h_4}{h_2 - h_1}$$

2) Actual COP

$$\text{COPact} = \frac{\text{Actual Refrigeration Effect}}{\text{Actual Compressor Work Done.}}$$

Where

Refrigeration Effect = Amount of Heat absorbed during the specific time interval (Kw)
= mass of air x Cpa x Temperature drop

Compressor work done. = $N_c \times 3600 / T_c \times \text{EMCc}$ Kw.

$$\% \text{ increase of COP} = \frac{\text{COP2} - \text{COP1}}{\text{COP2}} \times 100$$

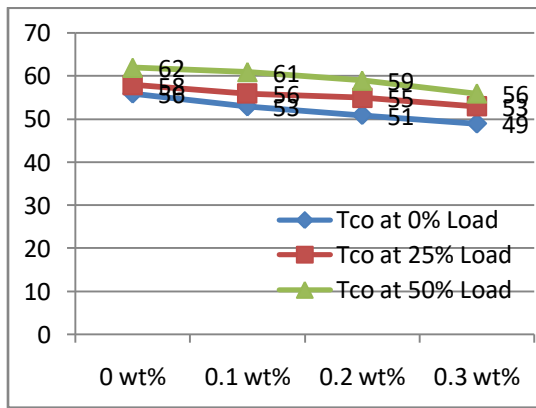
Table3. Experimental Results Summary

Coolant Type	Wt% of NPs	Tdis			TC			Wact			COPact		
		0% Load	25% Load	50% Load	0% Load	25% Load	50% Load	0% Load	25% Load	50% Load	0% Load	25% Load	50% Load
Conventional Oil	0%	56	58	62	42	40	37	0.268	0.281	0.304	0.789	0.757	0.695
CuO/POE Oil	0.1%	53	56	61	44	42	40	0.256	0.268	0.281	0.826	0.747	0.847
	0.2%	51	55	59	45	44	41	0.250	0.256	0.274	0.845	0.782	0.848
	0.3%	49	53	56	47	46	44	0.239	0.245	0.256	0.883	0.818	0.910
Cu/POE Oil	0.1%	52	55	58	46	44	42	0.245	0.256	0.268	0.864	0.782	0.868
	0.2%	49	53	54	48	47	46	0.234	0.239	0.245	0.902	0.836	0.951
	0.3%	47	49	50	52	50	48	0.216	0.225	0.234	0.977	0.889	0.992

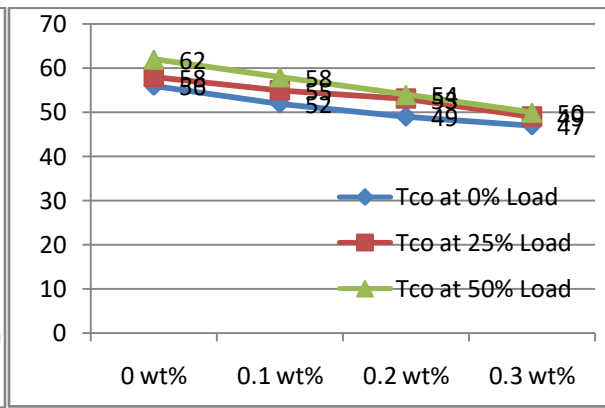
Coolant Type	Wt% of NPs	TCO			Wact			COP Act			% Decrease in Wact			% Increase in COP act		
		0% Load	25% Load	50% Load	0% Load	25% Load	50% Load	0% Load	25% Load	50% Load	0% Load	25% Load	50% Load	0% Load	25% Load	50% Load
POE Oil	0 wt%	56	58	62	0.27	0.281	0.304	0.79	0.757	0.695	0	0	0	0	0	0
Cu+POE Oil	0.1 wt%	53	56	61	0.26	0.268	0.281	0.83	0.747	0.847	10.4	7.4	10	6	6.3	6.2
	0.2 wt%	51	55	59	0.25	0.256	0.274	0.85	0.782	0.848	22.2	17.9	16.7	10.3	9.5	11.8
	0.3 wt%	49	53	56	0.24	0.245	0.256	0.88	0.818	0.91	29.6	28.6	23.3	12.3	12.6	12.8

Cu+ POE Oil	0.1 wt%	52	55	58	0.24	0.256	0.268	0.86	0.782	0.868	18.5	14.8	13.3	8.2	8.4	7.4
	0.2 wt%	49	53	54	0.23	0.239	0.245	0.9	0.836	0.951	25.9	21.4	20	12.3	13.6	13.8
	0.3 wt%	47	49	50	0.22	0.225	0.234	0.98	0.889	0.992	37	28.6	26.7	15.2	15.5	19.3

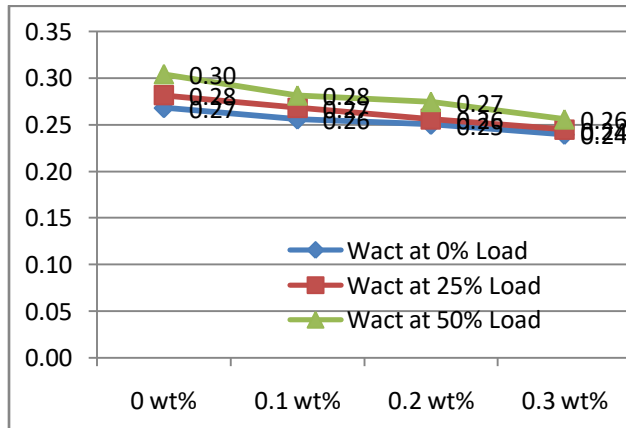
4. RESULTS AND DISCUSSIONS: Average Results obtained are plotted as shown below.



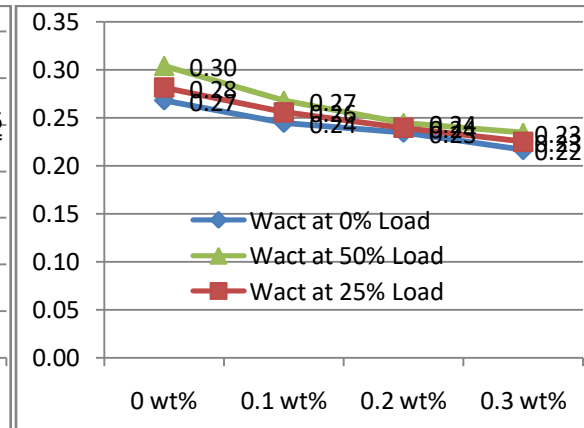
Graph1. CuO NPs Conc. Vs Tdis.



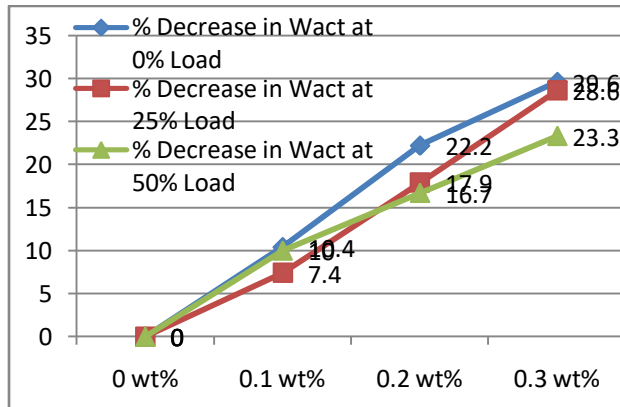
Graph2. Cu NPs Conc. Vs Tdis.



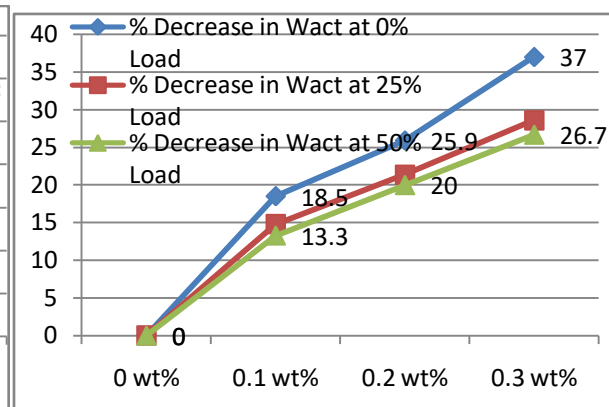
Graph3. CuO NPs Conc. vs. Wact



Graph4. Cu NPs Conc. vs. Wact



Graph5. CuONPs Conc. vs. % Wact



Graph5. CuONPs Conc. vs. % Wact

The result shows that with increase in concentration of nanoparticles performance of household refrigerator increases and copper metal particles shows higher improvement in performance comparatively copper oxide particles.

5. CONCLUSION

1. Coefficient of performance increases with increase in the Concentration of nanoparticles increased from of 0 % to 0.3%,
2. The power consumption of Vapor Compression refrigeration system decreased as the Concentration of nanoparticles increases from of 0.1% to 0.3%.
3. The use of nanofluids as cooling medium will be the best method for enhancing the performance of refrigeration system
4. Using this method there is no need to modify the current system or to add the extra components in the system
5. Maintaining the uniform suspension of nanoparticles in a lubricant is the big Challenge.

6. FUTURE SCOPE AND CHALLENGES

Experimentation is carried out to access the effect of CuO & Cunanoparticles in lubricant or coolant in hermetically sealed compressor and result are found positive. There is scope to investigate the effect of addition of nanoparticles in the lubricant on reliability of compressor or refrigeration system therolly with long term observation and investigations, and more studies on tribological behavior of addition of nanoparticles in different types of coolant lubricant used in compressor of refrigeration Air conditioning system.

Preparation and maintaining the uniform/Homogenous suspension of nanoparticles in base fluid is the big challenge because it is found that nanoparticles get settle down at the bottom of base fluid after some time.

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