An experimental investigation of VCRS using R134a/ POE oil /mineral oil/nano-SiO2 as working fluid

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Abstract*—This paper investigates the reliability and performance of Vapour Compression Refrigeration System using Silica (SiO2) Nano powder mixed with Polyolester (POE) oil / Mineral oil (MO) as Nano lubricant and R-134a refrigerants. The aim of this work is to find which type of lubricant oil works better with SiO2 nanoparticles in the field of refrigeration. POE Oil / Mineral Oil are mixed with Silica (SiO2) Nano powder by ultrasonic sonication and stirring process to prepare the Nano lubricants. These Nano lubricants were used in the compressor of refrigeration system instead of Polyolester (POE) oil/Mineral oil. An investigation was done on the compatibility of POE/Mineral oil mixed with Silica (SiO2) Nano powder (at a concentration of 0.5%, 1% and 1.5% by mass fraction) as Nano lubricant. The refrigeration system performance with the Nano lubricant was investigated by using energy consumption and refrigeration effect test. The replacement of Polyol-ester lubricant by the mineral lubricant mixed with SiO2 reduces power consumption. It gives better results at mass fraction of 0.5% for all combinations of Nano-oils. It is found that the freezing capacity is higher and the power consumption reduces by 13.89% when POE oil is replaced by a mixture of mineral oil and 0.5% of Silica nanoparticles. It has been observed that C.O.P. is increased by 12.16% when POE is replaced by a Nano lubricant (mineral oil + 0.5% of SiO2).Thus the above Nano lubricants can be used in refrigeration system to considerably reduce energy consumption and better Coefficient of Performance (COP).

Keywords*—Vapour Compression Refrigeration system; Silica (SiO2) Nano powder; Nano lubricant; COP; Mineral oil; POE oil; R134a refrigerant;

1. INTRODUCTION

In a vapor compression refrigeration (VCR) system, the refrigerant undergoes phase change from liquid to vapor at the evaporator and then from vapor to liquid at the condenser in a closed cycle absorbing the heat in the evaporator and rejecting it at the condenser. The coefficient of performance (COP), which is the ratio of refrigeration effect obtained at the evaporator to the power input to the compressor, can be increased either by increasing the heat removal rate or by decreasing the compressor work. [1].

Oil is necessary for a correct working of the compressor in the refrigeration and air-conditioning vapour compression systems. Its main role is to ensure the existence of a thin oil film allowing the lubrication of the mechanical moving elements, in order to protect them against wear. The lubricant also plays several secondary roles as a tightness element, reducing the noise, or helping the evacuation of chemical deposits or impurities that may be present in the system. Nano-particles as additives are also considered to improve the lubrication properties of lubricant oil for the compressor of vapor compression refrigeration systems. Recently, different types of Nano-oils have attracted special attention because it has ability to reduce the friction and wear in compressor, which, in turn, improve the efficiency of the compressors and also reduce energy consumption. Thus, the use of Nano-oils is more beneficial to compressor performance. [2]

Various methods have been tried out for improving the COP of the vapor compression refrigeration system, as reported in the literature.

Nilesh Desai et al. [3] has carried out an experimental investigation of a vapor compression refrigeration system using R134a/SiO_2/polyester Nano refrigerant as working fluid. In the experiment the Nano-oil with specific concentrations of 1%, 2% and 2.5 % (by mass fraction) were added in the compressor oil. They found that as the nanoparticles concentration in POE oil increases, there is decrease in compressor work and it is optimum at 2%. It has been observed that energy saving can be achieved from a minimum value of 7.03% to a maximum value of 12.30% using Nano lubricant compared to traditional refrigerants. The result shows the COP of system were improved by 7.61%, 14.05% & 11.90%, respectively, when the Nano-oil was used instead of pure oil.

Bi et al. [4] found that there is remarkable reduction in the power consumption and significant improvement in freezing capacity. It has been observed that the compressor using mineral oil consumes 16.67% less energy than POE oil. It has been found that energy saving can be achieved to a maximum value of 21.2 % using Nano lubricant compared to traditional refrigerants. The oil return ratio of mineral oil was only 84% compared to 92% for the Nano lubricant.

Subramani et al. [5] has carried out an experimental investigation of a vapor compression refrigeration system. In experimental study, three cases have been considered. The hermetic compressor filled with i) pure POE oil ii) SUNISO 3GS oil (mineral oil) and iii) SUNISO 3GS+ Al2O3 Nano-particles as lubricant. The mass fraction of the Nano-particles in the Nano-lubricant is 0.06%. The reduction in power consumption is 18% if the SUSISO 3GS is used instead of POE Oil and a reduction of 25% is observed when SUNISO 3GS is mixed Nano-particles and SUNISO 3GS + Al2O3 Nano-particle mixture has the highest COP when compared with the other cases. The advantages of adding Nano-particle to the lubricant is that it reduces the power consumption of the compressor and there is sub cooling of the Nano-refrigerant in the condenser which in turn increases the COP.

This research paper focuses on the energy consumption reduction by using SiO_2 as a Nano-lubricant. However, there is very less research work on the SiO_2 as Nano-particles as additives with oils used in refrigeration system. It is revealed that this research work will be useful to overcome the challenges of Nano-lubricant.

2. MATERIALS AND METHODS

This section provides a description of the materials and methodology used for conduction experimental work on a VCR test rig.

2.1. Materials:

In this section materials required, properties of materials and specification of experimental setup has been discussed.

2.1.1 Refrigerant

The working fluid used in the refrigeration system is termed as refrigerant. HFC134a is the most widely used alternative refrigerant in refrigeration equipment such as domestic refrigerators, chillers and automobile air conditioners. HFC134a has been accepted as long term alternative refrigerant in many countries.

Table1 Properties of R-134a (CF_3CH_2F) [6]

Critical Temperature (°C)	101.06
Critical Pressure (M Pa)	4.05
Ozone Depletion Potential	0
Global Warming Potential	1200
Latent Heat of Vaporization (KJ/Kg)	215.9
Boiling Point (°C)	-26.1
Liquid Melting Point (°C)	-101
Molar Mass (g/mol)	102.03

2.1.2. Lubricating Oils

The lubricant oil, a type commonly used in refrigeration and air-conditioning systems are Polyol Ester (RL68H) and Mineral oil (VG32, SUNISO 3GS). These oils are selected owing to its common usage and superior quality.

Fig. 1 Polyol-ester oil (RL68H)

Fig. 2 Mineral Oil (VG32, SUNISO 3GS)

2.1.3 Nanoparticles

It is insoluble in water, odorless, Stable under normal, temperature and pressures.

Table 2 Properties of SiO_2 Nanoparticles [7]

Melting Point (°C)	1713
Boiling Point (°C)	2950
Density (Kg/m^3)	2220
Specific heat (J/Kg K)	745
Thermal Conductivity (W/m K)	1.4
Molecular Mass (g/mol)	60.08
Specific Surface Area (SSA)(m^2/g)	250
Average Particle Size (APS)(nm)	10-20

Fig. 3 SiO_2 Nanoparticles

Fig. 4 SiO_2 Nano in powdered Form

2.2. Methods:

In this section techniques and procedures adopted during experiments has been discussed.

2.2.1. Preparation of Nano lubricant

Preparation of Nano-oil for the lubrication is the first step in the experimental studies. The Nano fluids can be prepared using single step or two step methods [8]. In the present study two step procedures is used. The Nanoparticles are added to the refrigeration system by adding them first into the compressor lubricant to make a Nano-lubricant mixture then the mixture has put into the refrigeration test rig compressor as lubricant.

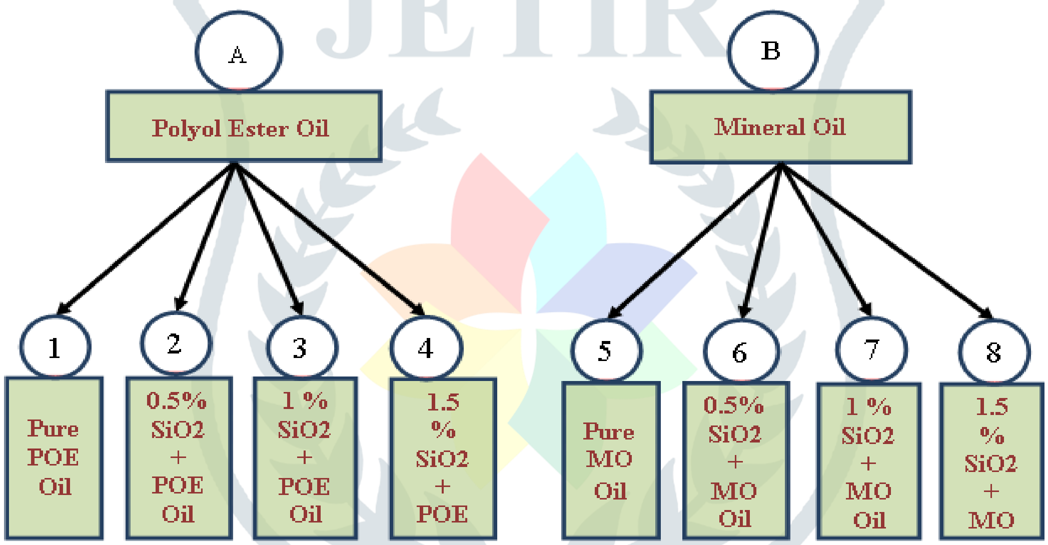

Fig. 5 Different blends of Nano Lubricant

Commercially available Nanoparticles of silicon dioxide having average size in the range of 10-20 nm and purity of 99.9% were supplied by Nano wings private limited India. The required weight of the SiO_2 Nanoparticles was accurately measured by high precision electronic balance having a measurement range of 10 mg to 210 g and maximum error of 0.1 mg. Nano lubricant blends of POE-SiO_2 and MO-SiO_2 with different mass fractions were prepared as Shown in figure 5 and then the Nano oil mixture has kept on the magnetic stirrer to fully separate the Nanoparticles for 1 hr.

Fig.6 Nano lubricant on magnetic stirrer

Fig. 7 Nano lubricant on Ultrasonic vibrator

For getting the uniform dispersion of particles in the MO and POE oil a standard ultrasonic agitator is used for the period of 180 min. Experimental observation shows that the stable dispersion of SiO_2 Nanoparticles can be kept for more than 3 days without deposition or coagulation. No surfactant is added in this work because there may be any influence in diminution of thermal conductivity and performance [9]

3. EXPERIMENTAL SETUP AND TESTING

A. Experimental Set up.

The experimental refrigeration setup was fabricated with following components. A hermetically sealed reciprocating compressor for R-134a refrigerant, a forced type air cooled condenser, a capillary tube as an expansion valve and a Shell and coil type evaporator containing water. Five thermocouples, two pressure gauges and one energy meter are provided at respective locations to measure the temperatures at required locations, the inlet and outlet pressure of compressor and the power consumption respectively.

Fig. 8 Experimental set up.

B. Performance test on Vapour compression refrigeration system

The refrigeration system performance test includes energy consumption tests and freezing capacity tests. The type of evaporator used in this system is a water tank having a capacity of 14.5 liters. To measure the energy consumed during refrigeration system operation, time taken for 10 pulses is noted. The test is carried out for 30 min for each mixture of Nano fluid by noting down the average drop in temperature of water from its initial temperature. The freezing capacity is determined by the mass of water stored in the evaporator.

C. Experimental Procedure

The refrigeration system experiment was carried out at various stages for different concentrations of Silica Nano powder with POE oil (RL68H) and Mineral oil (VG32) in VCRS using R-134a as refrigerant. First performance test was carried by using R-134a and pure POE oil for base data. In this operation, Evaporator tank is filled with water and initial temperature of water was measured at various points. Now, the system was run for 30 min, and for every 5 min., all the pressure, temperature and energy readings are noted down. After the completion of test with POE oil, lubricant oil was completely drained out from compressor and system was completely evacuated by connecting the vacuum pump to the charging line of compressor (service port) for 10 minutes. Again the compressor was charged with prepared Nano lubricant and R-134a refrigerant and complete performance test was carried out and the same procedure was repeated for each concentration of Nano lubricants. Same procedure was repeated for Mineral oil and its respective blends.

4. RESULTS AND DISCUSSION

a) Effect Nano lubricants on Freezing capacity

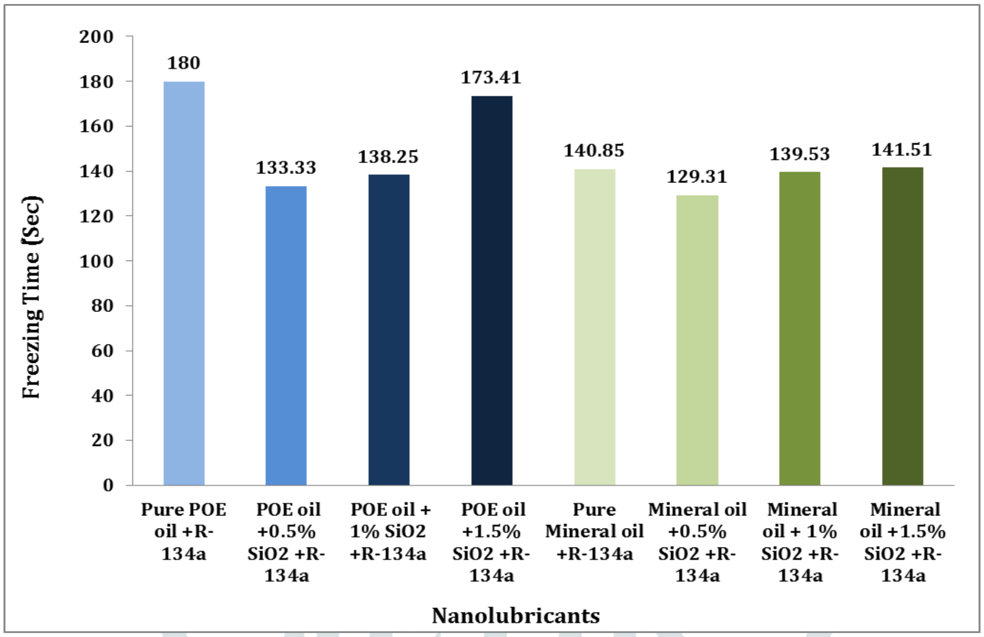

Fig.9 Effect of Nanoparticles on the freezing Capacity

From the figure 9 it is clear that, in both the cases the time required for reducing the cooling load temperature through 1^0C is less at mass fraction of 0.5% of SiO_2 in mineral oil. The time taken to reduce the temperature of water through 1^0C with POE oil is 180 seconds and it is reduced by 28.16 % when MO+ 0.5 % of SiO_2 is used because the Nanoparticles present in the refrigerant improves the heat transfer rate in evaporator.

b) Effect of Nano lubricants on Energy Consumption

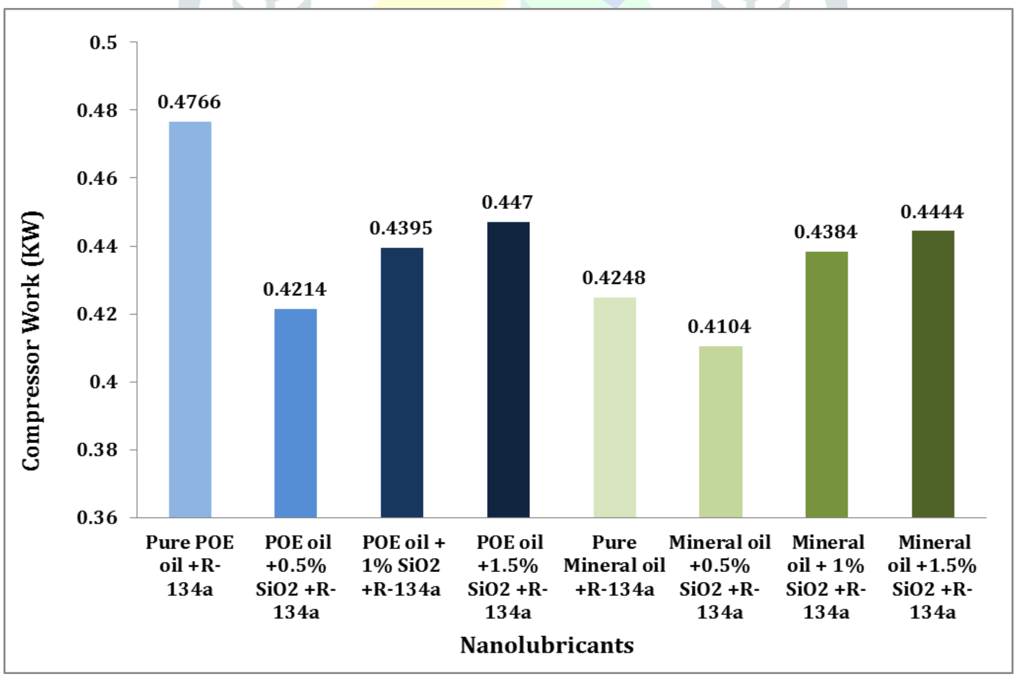

Fig. 10 Effect of Nano lubricants on the Power Consumption

The reduction in power consumption is 10.86 % when the Mineral oil (SUNISO 3GS) is used instead of POE oil (RL68H) and reduction of 13.89 % is observed when MO is mixed with 0.5% of SiO_2.

c) **Effect of Nano lubricants on Coefficient Of Performance**

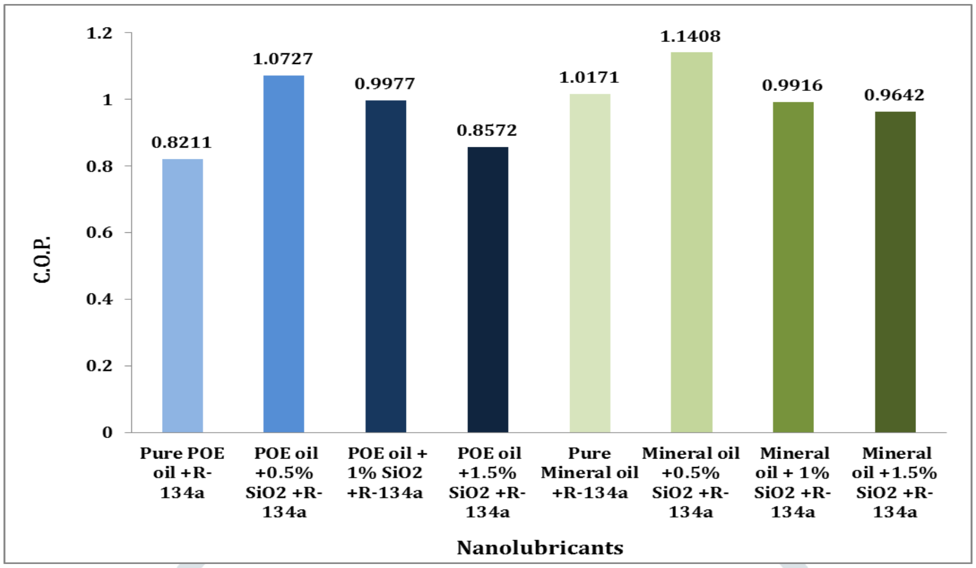

Fig. 11 Effect of Nano lubricants on the C.O.P

Figure 11 shows the effect of Nanoparticles concentration on the coefficient of performance. The actual COP is calculated using the refrigeration effect and energy input to the compressor. The increase in COP is 4.39 % when POE oil is replaced with Mineral oil. It is found that the VCRS system using (Mineral oil+0.5% SiO_2) as lubricant has highest COP. When Nano lubricant (0.5% SiO_2 +Mineral oil) is used instead of pure mineral oil then COP is increased by 12.16%.

5. CONCLUSIONS

Based on the experimental results and discussion, the following findings can be made. The results showed that the addition of Nano SiO_2 improves the performance of the vapour compression refrigeration system significantly.

- In all cases freezing capacity is better at 0.5 % of SiO_2 and it is highest for system using Mineral oil mixed with 0.5% SiO_2 as lubricant.
- It has been observed that the compressor using mixture of mineral oil and 0.5% of silica consumes 13.89% less energy than POE oil.
- The VCR system has maximum COP of 1.1408 when 0.5% Silica is mixed with mineral oil.
- The results indicated that R-134a works better with Mineral Oil than POE Oil.

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