An experimental investigation of VCRS by addition of nano-SiO_2 as lubricant additives

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Abstract— The conventional refrigerants plays major role in global warming and ozone layer depletion, therefore there is need to use refrigerants having less global warming potential (GWP). Hydrocarbon refrigerants are found to be eco-friendly andmore energy efficient; hence it can be used as an alternative to replace R-134a in Vapour Compression Refrigeration System. The present work is developed to test the applicability of nanofluids as lubricant in the compressor of VCRS; with the purpose to detect the possible positive effects of SiO_2 Nanoparticles as lubricant additives. Nanolubricants were prepared by mixing nano silica in the POE oil and Mineral oil by different mass fraction 0.5%, 1% and 1.5% of SiO_2. The experiment has been conducted for the different nanolubricants on the refrigeration test rig using R-134a and R-600a as refrigerant. The performance parameters such as refrigeration effect, compressor work and C.O.P are measured for different combinations of nanolubricant.The results indicated thatthe VCR system works normally and safely with nanolubricant. It gives better results at mass fraction of 0.5% for combinations of nano-oils. The usage of R600a with zero ozone depleting potential (ODP) and very less global warming potential (GWP)provides a green and clean environment. The replacement of R-134a refrigerant and Polyol-ester lubricant by the hydrocarbon refrigerant and mineral lubricant mixed with SiO_2 reduces the power consumption. It is found that in VCR system using R-600a the C.O.P. is increased by 29.22% when POE is replaced by a mixture of POE and 0.5% ofSiO_2. Thus, use of silicon dioxide nanoparticles in refrigeration system is more effective.

Keywords: COP,Mineral oil, nanolubricant, POE oil,R-134a,R-600a, Vapour compression refrigeration system.

I. INTRODUCTION

Requirement of refrigeration and air conditioning is increasing day by dayto a great extent. Different refrigeration cycles are available for use but vapour compression refrigeration cycle is one of the mostly used refrigeration cycle. It is used in commercial and domestic refrigerators, industrial services, petrochemical and chemical processing plants,Oil refineries and natural gas processing plants.So improvement in the performance of system is too important forhigher refrigerating effect orreduced power consumption for the same refrigerating effect. Many efforts have done to improve the performance of VC refrigeration system [1].

The performance of VCRS is measured in term of COP which is the ratio of refrigeration effect to the net energy supplied tothe compressor. The COP of VCRS is increased either by (i) increasing the refrigeration effect or (ii) by decreasing theamount of energy supplied to the compressor.

Various methods have been used for improving the COP of the vapor compression refrigeration system. In the past few years, rapid advances in nanotechnology have lead to emerging of new generation of heat transfer fluids called ‘‘nanofluids’’. It shows the ability of material to transmit or conduct heat. Nanofluids have [2] i) Better dispersion stability iii) reduces particle clogging ii) higher heat transfer between the particles and fluids iv) reduced pumping power

In the refrigeration and air-conditioning vapour compression systems, oil is necessary for a correct working of the compressor. 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 [3][4].

In a VCRS the nanoparticles can be added to the lubricant of compressor oil. When the refrigerant is circulated through the system it carries traces ofnanolubricants(lubricant + nanoparticles mixture) so that the other parts of the system will have nanolubricant -refrigerant mixture [5]. Addition of Nanoparticles to the lubricant oil results in improving the thermal performance of VCRS. In current scenario, the application of hydrocarbon (Isobutane) as a refrigerant is increasing considerably in the view of replacing refrigerant R134a, as HC refrigerant is more energy efficient, have less global warming potential (GWP) and have no ozone depletion potential (ODP) [6].The conventional refrigerant R134a has a global warming potential (GWP) of 1300 whereas R600a has a significant reduced value of GWP of 3 only. The Kyoto Protocol of the United Nations suggested minimizing the usage of green house gases along with hydroflurocarbons (HFCs) to use as refrigerants in refrigeration system [7].

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The present work is based on the use of nanofluids as nanolubricants in compressor for VCRS using R-134a and R-600a as refrigerant. Nanolubricants were prepared by mixing nano SiO_2in the POE oil, Mineral oil by different mass fraction 0.5%, 1% and 1.5% of SiO_2. The system has been tested in order to detect possible positive effects of Silica nano on the performance of VCRS.

Nomenclature

COP	Coefficient Of Performance
GWP	Global Warming Potential
HC	Hydrocarbons
MO	Mineral Oil
ODP	Ozone Depletion Potential
POE	Polyol-ester
VCRS	Vapour-Compression Refrigeration System

II. OBJECTIVES OF RESEARCH WORK

The use of nano-additives in the lubricant to enhance the performance of the compressor and, at the same time, improve the performance of the evaporator andcondenser, represents a new type of energy saving technology. The concerned literature finds only particular class of use nonmaterial's i.e.TiO2, CuO, Al_2O_3etc in VCRS, still there are some other nonmaterial's, whose thermal conductivity enhancement is better. Such materials like SiO_2 applicability in VCRS can explore the new path. This work targets the same.

- To study the effect of addition of SiO2Nanoparticles mixed with polyol-ester oil (RL68H) on thermal performance of VCRS i.e. COP using R-134a and R-600a as refrigerant
- To study the effect of addition of SiO_2 Nanoparticles mixed with mineral oil (SUNISO 3GS) on thermal performance of VCRS i.e. COP using R-134a and R-600a as refrigerant.
- To find out the optimal concentration of SiO2 in the system using R-134a and R-600a as refrigerant.
- To find out the maximum COP enhancement of the system with POE oil or mineral oil.
- To find out the maximum COP enhancement of the system using R-134a and R-600a as refrigerant.

III. MATERIALS AND METHODS

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

3.1. Materials

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

3.1.1 Refrigerants

Table1 Properties of Refrigeran⌉ts

Properties	**Tetrafluro ethane (HFC)**[8]	**Isobutene (HC)**[5]
Numerical Designation	R-134a	R-600a
Chemical Formula	CF_3CH_2F	$(CH3)_3$ CH
Critical Temperature (°C)	101.06°C	135°C
Critical Pressure (M Pa)	4.05	3.65
Ozone Depletion Potential	0	0
Global Warming Potential	1200	3
Latent Heat of Vaporization	215.9 KJ/Kg	362.6KJ/Kg
Boiling Point (°C)	-26.1°C	-11.7°C
Liquid Melting Point (°C)	-101°C	-159.6°C
Molar Mass(g/mol)	102.03g/mol	58.12 g/mol

3.1.2. Nanoparticles

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

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Table 2 Properties of Nanoparticles [9]

Properties	**Nanoparticles**
Molecular Formula	SiO_2
Melting Point (°C)	1713
Boiling Point (°C)	2950
Color	White
Density (Kg/m^3)	2220
Specific heat(J/KgK)	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

3.1.3. Experimental Setup and Instrumentation

In this experiment we have concentrated our work to investigate the performance of the VCRS by using SiO_2 Nanoparticles as nanolubricant, so as to improve the performance of the system. The photographic view of the vapour compression refrigeration system is shown in figure 1.

The system consists of hermetically sealed compressor, forced air cooled condenser, capillary tube as expansion device, and shell and coil type evaporator. Bourdon Pressure gauges are placed at the inlet and outlet of the compressor to record the pressures of the refrigerant. A calibrated refrigerant flow meter (rotometer) is used to measure the mass flow rate of refrigerant.

Fig.1 Photographic view of Experimental setup

Table 3 Refrigeration System Specifications

Components	**Type**
Refrigerant	R-134a
Compressor	Hermetically sealed
Condenser	Forced convective air cooled
Fan motor (Condenser)	Induction type
Drier / filter	Dryall make
Expansion device	Capillary tube

The system is equipped with six temperature sensors to record temperatures. Before temperature measurement, the surfaces of the tubes are polished for removing the dust and then the thermocouples areplaced on the surface by wrapping the insulation tape around the tubes to avoid any heat losses to the surrounding. An energy meter is connected with compressor to measure the energy consumption. A service port is provided at the inlet of the compressor for charging and recovering the refrigerant. The evacuation can also bedone through this service port.

Table 4 Measurement Equipments

Refrigerant flow measurement	Rota meter

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Pressure indication	2Bourdon Pressure gauges are provided
Energy meter	3200 imp/kwh
Evaporator for refrigeration test rig	Direct expansion coil,Immersed tube type
Temperature indication	Digital led
Water tank Insulation	Puf
Supply	1 phase, 230 volts, 50 Hz, AC.

3.2. Methods

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

3.2.1. Preparation of nanolubricant

Preparation of nano-oil for the lubrication is the first step in the experimental studies. The Nanofluids can be prepared using single step or two step methods [10]. In the present study two step procedure is used. The Nanoparticles are added to the refrigeration system by adding themfirst into the compressor lubricant to make a Nano-lubricant mixture then the mixture has put into the refrigeration test rig compressor as lubricant.

Fig.2 Photograph of SiO_2 Nanoparticles on digital balance

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. Nanolubricant samples of POE-SiO_2 and MO-SiO_2 with different mass fractionswere prepared and then thenano oil mixture has kept on the magnetic stirrer to fully separate the Nanoparticles for 1 hr.

Fig.3 Nanolubricant on magnetic stirrer

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_2Nanoparticles can be kept for more than 3 days without deposition orcoagulation. No surfactant is added in this work because there may be any influence in diminution of thermal conductivity and performance[11]

Fig. 4 Photograph of Nanolubricant on Ultrasonic vibrator (Sonicater)

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3.2.2. Evacuation and charging of VCRS

Before charging of refrigerant, it is necessary to remove the air and moister from refrigeration unit. Thus evacuation is done by connecting the vacuum pump to the charging line of compressor (service port) for 10 minutes. It avoids the bad effect on the system such as pitting,clogging and deterioration of the lubricating oil.

The evacuation system consists of a vacuum pump, a pressure gauge and hoses. The hoses ofvacuum pump were connected with the service valveto remove the moisture from the refrigeration system. When the pump is turned on the internal pressure gauge shows pressure inside the refrigerator system.

Fig.5 Photograph of evacuation pump

During the charging of refrigerant a charging line is equipped with a pressure gauge which records the pressure. One end of the charging line is connected to the charging valve and another end to the refrigerant cylinder.When the sufficient quantity of the refrigerant is taken in to the systems the compressor is stopped and the refrigerant cylinder is disconnected from the system.Using this charging line refrigerants were charged into the system according to desired amount.

Fig. 6 Charging of the refrigeration system

3.2.3. Experimental Procedure

To perform the experimental work the following procedure is used.

- The refrigeration test rig is selected, working on vapour compression cycle.
- Flushing of system is done by pressurized nitrogen gas at a pressure of 5-7 bars and this pressure is maintained for 45 minutes.[12]
- The pure oil and Nanolubricant of different mass fractions arecharged in to the compressor one after another.
- Vacuum pump is used to evacuate the system which insures VCR system free from moisture and the test rig is charged with the help of charging system.
- Leakage tests are done by using soap solution.
- The temperatures and pressures at different locations are recorded at every five minute interval. In order to reduce the experimental uncertainties the experiments are repeated for six times and average values are considered. All the experimental observations are taken after attaining the steady state condition.

The experiment has been conducted on the refrigeration test rig by using Nanoparticles with 0.5%, 1% and 1.5% (by mass)[12] fraction of SiO_2 in the POE oil and Mineral oil and tested in the refrigeration test rig using R-134athen same procedure is followed for R-600a as refrigerant. The performance parameters such as refrigeration effect, compressor work and C.O.P are measured for above combinations.

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IV. RESULTS AND DISCUSSION

The major results from the experimental study are presented and discussed in this section.

4.1. Effect of Nanoparticles on the freezing Capacity

Table 5 Time required to drop the temperature of water by 1^{0}C (sec.)

Mass Fraction	POE+ R134a	MO+ R134a	POE+ R600a	MO+ R600a
Pure oil	180	140.85	200	178.57
0.5	133.33	129.31	146.34	152.28
1	138.25	139.53	191.082	196.078
1.5	173.41	141.51	181.81	197.37

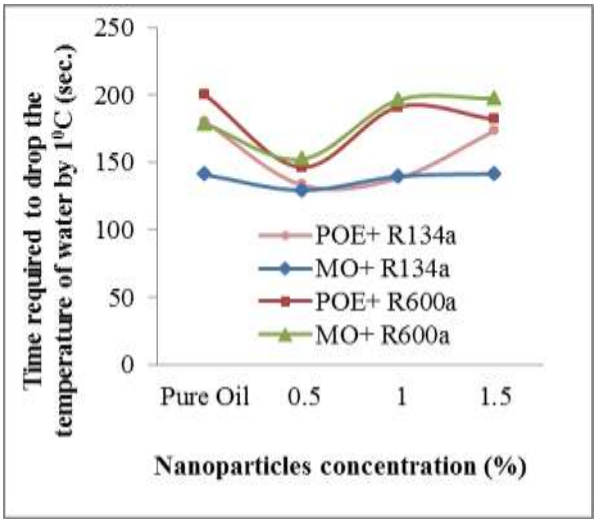

Fig.7 Effect of Nanoparticles on the freezing Capacity

From the figure 7 it is clear that, in all the four cases the time required for reducing the cooling load temperature through 1^{0}C is less at mass fraction of 0.5% of $SiO_2$and it is minimum for MO+R-134a combination. The time taken to reduce the temperature of water through 1^{0}C 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.

4.2. Effect of Nanoparticles on the Refrigeration Effect (R.E.)

Table 6 Refrigeration Effect (R.E.)

Mass Fraction	POE+ R134a	MO+ R134a	POE+ R600a	MO+ R600a
Pure oil	0.3914	0.4317	0.3036	0.3407
0.5	0.4553	0.4688	0.4149	0.398
1	0.4385	0.4351	0.317	0.3103
1.5	0.3508	0.4284	0.3339	0.3069

In all the four cases the refrigeration effect reaches its peak value at a mass fraction of 0.5% of SiO_2 and it is highest for MO+R-134a combination. The increase in refrigeration effect is 9.34 % when the Mineral oil (SUNISO 3GS) is used instead of POE oil (RL68H) and increase of 16.51 % is observed when MO+ 0.5 % of SiO_2 is usedin VCRS using R-134a as refrigerant because the Nanoparticles present in the refrigerant improves the heat transfer rate in evaporator.

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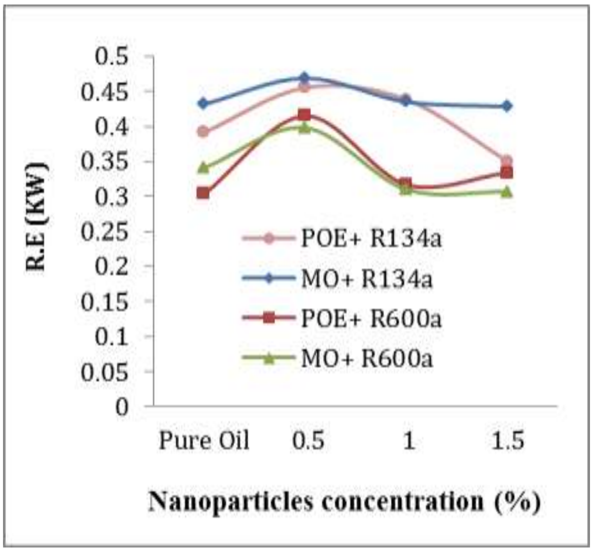

Fig. 8 Effect of Nanoparticles on the R.E

4.3. Effect of Nanoparticles on the Power Consumption

Table 7 Compressor Work

Mass Fraction	POE+ R134a	MO+ R134a	POE+ R600a	MO+ R600a
Pure oil	0.4766	0.4248	0.2728	0.2742
0.5	0.4214	0.4104	0.252	0.24
1	0.4395	0.4384	0.2679	0.2648
1.5	0.447	0.4444	0.2682	0.2654

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 in VCRS using R-134a. It is conclude that when we replace R-134a with R-600a the energy consumption is reduced considerably at mass fraction of 0.5% of Nanoparticles mixed with mineral oil.

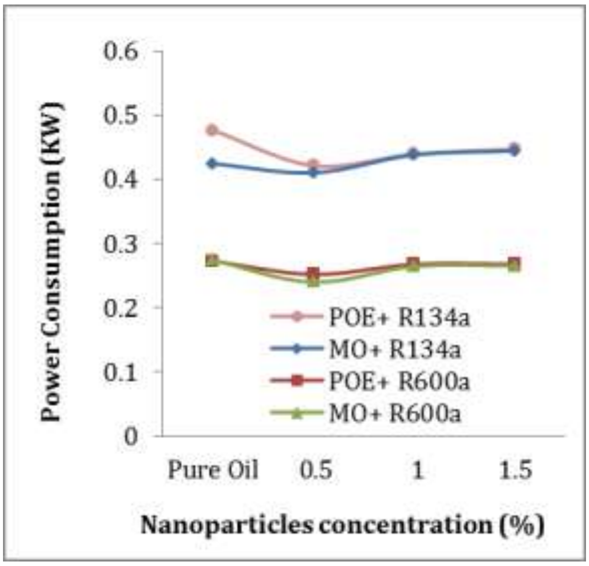

Fig. 9 Effect of Nanoparticles on the Power Consumption

4.4. Effect of Nanoparticles on the Coefficient of performance (C.O.P.)

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Table 8 Coefficient of performance (C.O.P.)

Mass Fraction	POE+ R134a	MO+ R134a	POE+ R600a	MO+ R600a
Pure oil	0.8211	1.0171	1.1123	1.2421
0.5	1.0727	1.1408	1.5714	1.4001
1	0.9977	0.9916	1.1901	1.1721
1.5	0.8572	0.9642	1.2449	1.1567

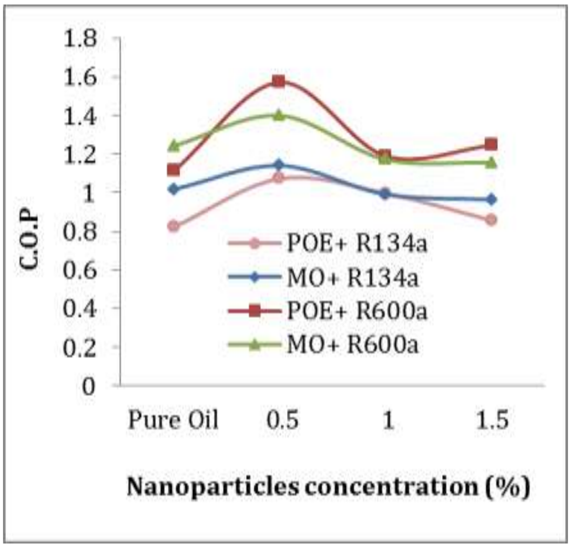

Fig. 10 Effect of Nanoparticles on the C.O.P

Figure 10 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. It is found that the VCRS system using R-600a as refrigerant has highest COP than the system using R-134a. The increase in COP is 29.21% when POE oil mixed with 0.5% SiO_2 is used as lubricant instead of POE oil in VCRS using R-600a as refrigerant.

V.CONCLUSIONS

Based on the experimental results and discussion, the following findings can be made. The results showed that the addition ofnano SiO_2improves the performance of the vapour compression refrigeration systemsignificantly.

- In all cases freezing capacity is better at 0.5 % of SiO_2 it is highest forsystem usingMineral oil mixed with 0.5% SiO_2 as lubricant and R-134a as a refrigerant.
- A VCR system using R-134a gives maximum refrigeration effect when 0.5% Silica is mixed with mineral oil.
- The replacement of R-134a with R-600a reduces power consumption effectively.
- The effect of R-600a is to reduce the compressor work where as R-134a leads to increase the refrigeration effect.
- The VCR system using R-600a as refrigerant has maximum COP when 0.5% Silica is mixed with POE oil.
- The results indicated that R-600a works better with POE Oil and R-134a with Mineral Oil.

VI. FUTURE SCOPE

There is lot of scope of using materials like SiO_2**,** ZrO_2-SiO_2 Nanoparticles as lubricant additives in a device working on vapour compression cycle such as domestic refrigerator,air conditioning systemand heat pump etc. and also in vapour absorption system.

Future research should focus on increasing the efficiency of condenser. The condenser efficiency decreases due to the bad effectsof high velocity refrigerant coming out of the compressor. High velocity refrigerant has serious affect on the VCRS such as pitting, erosion etc. There are potentials to explore research to determine thermal performance of the VCRS with diffuser at condenser inlet using R-600a as refrigerant and nano-SiO_2 as lubricant additive.

Further research is required to investigate the influence of the SiO_2 Nanoparticles size, shape and distribution on the thermal performance of the VCRS using R-600a as refrigerant.

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