An Experimental investigation on Vapour Compression Refrigeration system by using R290 with TiO_2 nano-lubricant.

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Abstract*: In this work, varied concentrations of nano-lubricant was used in Vapour Compression Refrigeration system for the experimental investigation. R290 refrigerant Gas enhanced with varied TiO_2 nanoparticle/PAG(poly alkalene Glycol) oil concentrations(0.2 g/L, 0.4 g/L and 0.6 g/L) nano-lubricants used in a compressor of a domestic Refrigerator. Performance tests such as power consumption, compressor power input, cooling capacity and coefficient of performance (COP) were conducted at steady state. Analysis is based on temperature, pressure, energy readings obtained from appropriate thermocouples, gauges and analogue energy meter respectively attached to the test rig. The highest COP was found to be 4.00 and obtained with pure PAG oil with 130W power consumption and the COP 3.71 was obtained with 0.6g/L nano-lubricant but the power consumption was a bit low i.e. 120W.

Keywords* : *Coefficient of performance, TiO_2 nanoparticle, Nano-lubricant

I. INTRODUCTION

Nowadays human society is facing major problems like global warming and the shortage of energy. In a vapour compression refrigeration system compressor takes the energy to do work. To solve the energy shortage problem reduction in work of compressor is an effective way. In terms of environmental protection, high ozone depletion, global warming impact refrigerants (CFCs and HFCs etc.) is being replaced by very low or zero ozone depletion, global warming impact refrigerants such as R290 and R600a.

Nano-lubricant was proposed on the basis of the concept of the nanofluids, which was prepared by mixing the nanoparticles and lubricant oil. There were three main advantages with the nanoparticle used in the refrigerator those are enhancement of the solubility between the lubricant and the refrigerant, reduction in friction coefficient and wear rate. For example, Jatinder Gill, Jagdev Singh [1], found that TiO_2 nanoparticles could be used as additives to enhance the solubility between LPG refrigerant and mineral oil. The refrigeration systems using the mixture of mineral oil and LPG added with nanoparticles TiO_2, appeared to give better performance Ruixiang WANG[2,3], $NiFe_2O_4$/OLFs, fullerenes (C70) and $NiFe_2O_4$ lubricating oil decrease the friction coefficient and improves the COP. Deepak Bondre[4], concluded that the coefficient of performance (COP) of vapour compression refrigeration system is found to be improved by maximum 17.2% using R134a with POE/Al_2O_3 (0.1% mass Fraction). Energy consumption by compressor was reduced by 32.48% in case of 0.1% Al_2O_3, 8.4% in case of 0.05% Al_2O_3, 22.41% in case of 0.2% Al_2O_3. R. Krishna Sabareesh [5], concluded that the addition of nanoparticles in the lubricating oil i.e. 0.01% mass fraction increased the average heat transfer rate by about 3.6%, and reduced the average compressor work by about 11%, which ultimately resulted in an increase of 17% in the COP. Venkataramana [6], experimentally studied the effect of using 0.1 g/L TiO_2 nanoparticle and mineral oil mixture as replacement for POE (polyol-ester) oil in a domestic refrigerator, charged with different refrigerants (R436A, R436B and R134a), and observed under varied ambient temperature conditions. The reported results showed improved energy efficiency and irreversibility indexes. Mahbubul [7], investigated the influence of particle concentration and temperature on the thermal conductivity and viscosity of the Al_2O_3/R141b nanorefrigerants. They determined that thermal conductivity increased with the rise of particle concentration and temperature. Shengshan Bi [8], conducted an experimental analysis of R600a-TiO_2 nano-refrigerant in domestic refrigerator. R600a-TiO_2 nano-refrigerant used as working fluid. The performance was better than pure R600a and 9.6 % energy consumption was reduced. Senthilkumar [9] found that the power consumption of R134a-cryo SiC refrigerant system was reduced by 18.41% and R134a-SiC refrigerant system was reduced by 17% compared to pure R134a system. The COP of the R134a-cryo SiC refrigerant system and R134a-SiC refrigerant system was increased when compared to pure R134a system. The increase in COP is due to aggregate heat transfer effect, Sendil Kumar [10], conducted a study on performance of PAG/ZnO with R152a refrigerant on a vapour compression refrigeration system. The results showed that, performance of the system was improved with increase in ZnO nanoparticles concentrations with the decrease in suction temperature and pressure ratio. Kumar and Elansezhian [11] conducted experimental studies on the effects of R134a/Al_2O_3/PAG oil blend on the energy consumption and the cooling capacity of the vapour compression refrigeration system. The results observed that 0.2 % concentration nano-refrigerant blend consumed 10.32 % less energy compared with pure R134a/PAG mixture. Subramanian and Prakash [12] studied the performance parameters of a vapour compression refrigeration system using Al_2O_3/MO lubricant with R134a refrigerant as working fluid. They used POE oil, SUSISO 3GS oil and SUSISO 3GS oil/ Al_2O_3 nanoparticle as lubricant. The experimental result showed that, the refrigeration system COP increased by 33% and compressor energy consumption decreased by 25% and by using SUSISO 3GS oil/Al_2O_3 nanoparticle instead of POE oil. The refrigeration system cooling capacity was also increased when using R134a/Al_2O_3 nano-refrigerant in the refrigerant system. T. Coumaressin and K. Palaniradja [13], conducted an experimental study on the performance of a domestic refrigerator using CuO-R134a nano-refrigerant as working fluid. The experimental studies indicate that the refrigeration system works normally with nano-refrigerant.

Nano particles CuO size from 10 to 70 nm in varied concentrations ranged from 0.05 to 1% were used. It is found that the evaporating heat transfer coefficient is maximum when CuO concentration up to 0.55% then decreases. Sanukrishna S. S. [14] found that the R134a-Cuo/PAG based nano-refrigerant operated normally and safely. The enhanced COP of the system was observed with nano-refrigerant. Moreover, the power consumption of the reciprocating compressor was reduced with the application of nano-lubricant compared to pure lubricant. Ravinder Kumar[15] studied the effect of zinc oxide nanoparticles with five weight concentrations (0.2–1.0) wt% in vapour compression refrigeration system using R290/R600a (50/50) as a working fluid.The compressor energy consumption was reduced by 7.48 % and COP enhanced 45% by using (0.2–1.0) wt% nanoparticles in the system. Aly M. A. Soliman, Ching-Song Jwo, A. Manoj Babu, Olayinka S. Ohunakin [16-19]were used R134a with Al_2O_3/MO,Tio_2, Al_2O_3/MO and TiO_2,Al_2O_3,SiO_2/MO respectively in VCR system. They found that power consumption reduces and COP improves with nano lubricant compares to pure MO oil. T.M. Yusof, Nilesh S. [20,21], were used R134a as a working fluid POE/Al_2O_3, POE/SiO_2 as a lubricants respectively. They found that power consumption reduction and better COP with nano lubricant compares to pure POE oil. MinSheng Liu [22], studied thermal conductivities of synthetic engine oil, water and ethylene glycol in the presence of copper (Cu), copper oxide (CuO), and multi-walled carbon nanotube (MWNT) are investigated. Test results showed that the COP of the water chiller is increased by 5.15% relative to that without nano-fluid. Lung-Yue Jeng [23] experimentally studied Al_2O_3/water nano-fluid and HC refrigerant as the working fluid and VCRS cooling for the CPU, he found that the hybrid cooling system can be used in other heat dissipation applications involving high-heat components to increase system performance and extend the lifetime of the apparatus or equipment. Damola S. Adelekan, Olayinka S[24] experimentally studied TiO_2 nano-lubricants with LPG in a domestic refrigerator. He concluded that TiO_2 nano-lubricant gives better COP with less power consumption than pure MO lubricant. Adriano Akel Vasconcelos [25] experimentally evaluated SWCNT-water nano-fluid as a secondary fluid in a refrigeration system. He found that thermal conductivity is more with the nano fluid compares to pure water.

Thus, the use of nanoparticles in vapour compression refrigeration system is a new and an innovative way to improve the efficiency of the system. The literature reveals that very little work has been done with the use of TiO_2 nanoparticles in vapour compression refrigeration system. The present study analyses the effect of TiO_2 nanopaticles on compressor power consumption, cooling capacity and COP of a VCR system. The hydrocarbon R290 as an alternative to refrigerant Hydrofluorocarbons-134a in a domestic vapour compression refrigeration system has been used. R290 is a popular eco-friendly refrigerant available in the Indian market. By using three concentrations (0.2,0.4,0.6)g/L of TiO_2(50-80nm) nanoparticles, the effect on COP and power consumption of the refrigeration system has been studied, which is found to be accomplished by a reduction in the compressor energy consumption and improvement in COP.

II. METHODOLOGY

A. *Experimental Setup*

The vapour compression refrigeration test rig shown in Fig. 1 having four main components which are compressor, condenser, expansion device (capillary tube), evaporator. K-type thermocouples (typical accuracy 2.2^0c) and Pressure gauges (bourdon type gauge) were used to measure temperature and static pressure respectively. A digital temperature indicator is connected to the thermocouples. The power input to the compressor was measured using an analogue energy meter with an accuracy of 3200 impulses/kWh. Specifications of experimental test setup are shown in Table-1

Table-1

Specification of experimental test setup

S.NO	Component	Units
1	Gross capacity	165 L
2	Compressor type	Reciprocating
3	Condenser type	Air cooled
4	Refrigerant	R290
5	Energy meter	Analogue
6	Pressure gauges	Bourdon type gauge

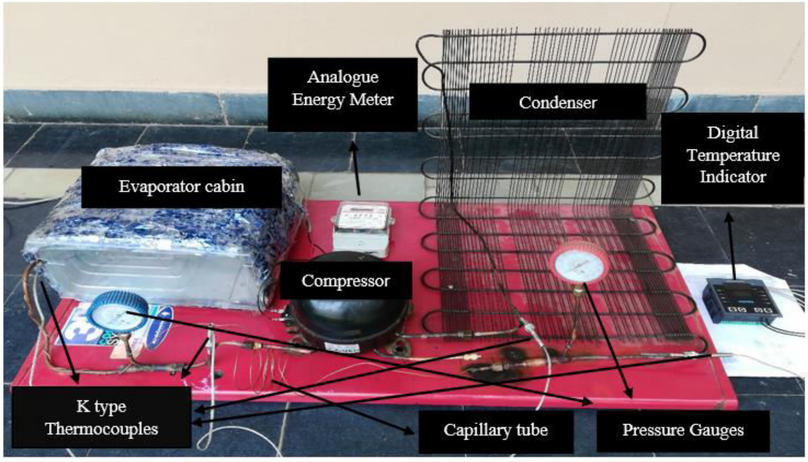

Fig. 1 *Vapour compression refrigeration system experimental test rig*

B. *Preparation of nano-lubricant*

TiO_2 nano particles of 50-80 nm were added to the poly alkylene glycol (PAG) oil of varied concentrations (0.2g/l, 0.4g/l, 0.6g/l) in the compressor of the system. The preparation and stability of this lubricant and nanoparticle mixture is very important. It was ensured that there was no chemical reaction change in the prepared nano-lubricant. The desirable properties of nano-lubricant were stable and durable suspension, less coagulation. The lubricant oil, alkylene glycol (PAG) commonly used in refrigeration and air-conditioning systems. Because of its superior quality PAG oil was selected. The nanoparticles of TiO_2 commercially available in 50-80 nm size was mixed with PAG oil to make nano-lubricant. The size distribution by intensity and TEM micrograph of nanoparticle are shown in Fig. 2 and Fig. 3. In this work preparation of nano-lubricant was followed by two step method. PAG oil and the nanoparticles of TiO_2 mixture were initially prepared with the aid of magnetic stirrer for 2 h shown in Fig. 4. The mixture was then further kept for vibration with an ultrasonicator for 30 mins to prevent any clustering of particles in the mixture to obtain proper homogenization and to fully separate the nanoparticles shown in Fig. 5. To ensure stability and uniform dispersion of the prepared nano-lubricant proper agitation in sonication process was done. The prepared nano TiO_2 lubricant was then charged into the compressor through the service port provided and varied concentrations (0.2g/l, 0.4g/l, 0.6g/l) TiO_2 nano-lubricant held in glass beaker is shown in Fig. 6, also characteristics of the lubricant oil shown in Table-2.

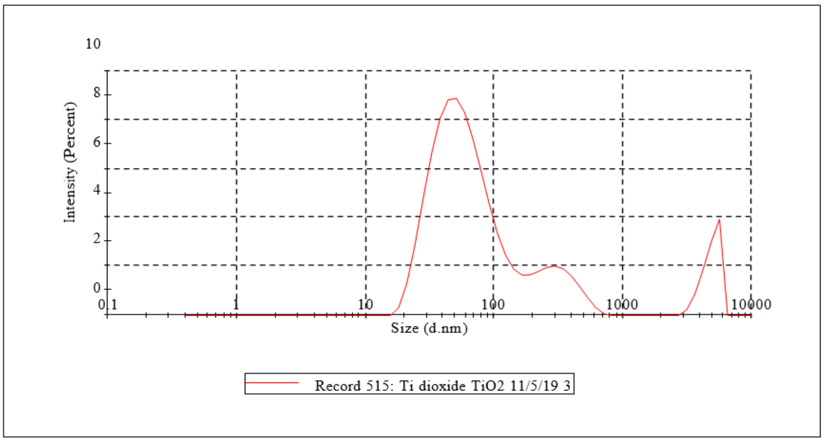

Fig. 2 *Size Distribution by Intensity*

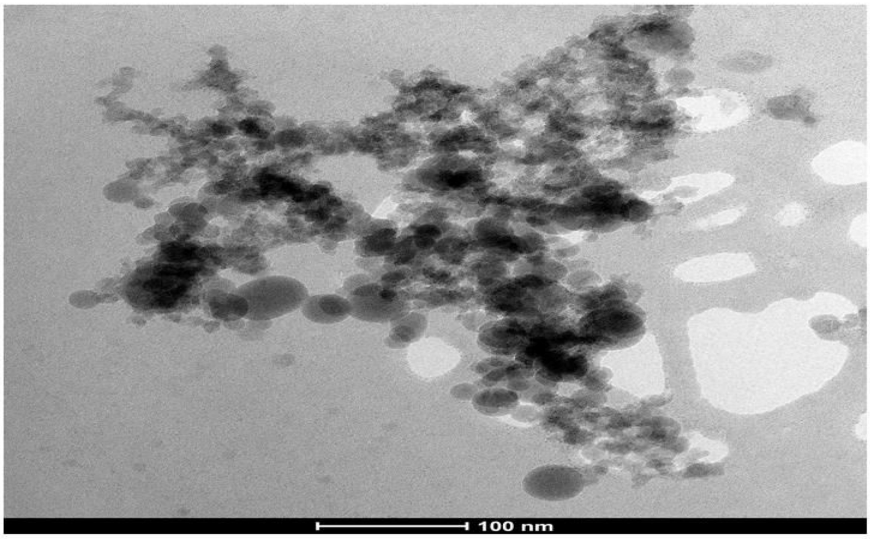

Fig. 3 *TEM Image Titanium Dioxide NPs*

Fig. 4 *Magnetic stirring*

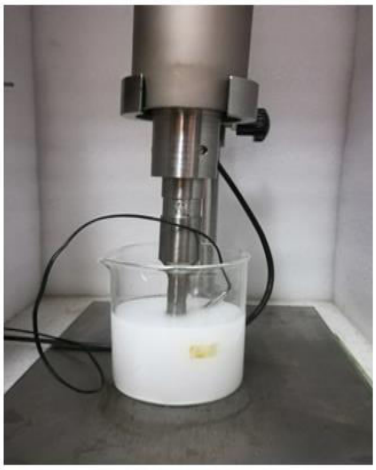

Fig. 5 *Ultrasonication*

Fig. 6 *Varied concentrations of TiO_2/PAG Oil*

Table-2
Characteristics of the Lubricant Oil

S.NO	Lubricating oil characteristics	Units
1	Oil type	Polyalkylene glycol (PAG)
2	Density at 28 °C kg/m^3	835.992
3	Kinematic viscosity (centistokes) at 28 °C	49.57

C. *Experimental Procedure*

The experiment was evaluated thoroughly for leaks and evacuated regularly prior to charging the system. The lubricant pure PAG oil was charged in the compressor. The setup was charged with 2.8kg/cm^2 of the working fluid R290 and the performance tests were conducted. Similar tests were conducted with 0.2g/l, 0.4g/l, 0.6g/l concentrations of TiO_2/PAG oil. The suction temperature (T1), discharge temperature (T2), condensing temperature (T3), Evaporator temperature (T4), suction (P1) and discharge (P2) pressures were noted. The analogue watt-hr meter was used to measure the power consumption. One litre of water was kept inside the evaporator chamber for one hour. Initial (T_i) and final (T_f) temperatures of water was noted. The refrigeration effect and compressor energy consumption was calculated using the following standard expressions:

$$Refrigeration\,effect\ per\,hour = \frac{m\,C_p\,(T_i - T_f)}{t}\,kW \qquad (1)$$

$$Energy\,input = \frac{n \times 3600}{t \times K}\,kW \qquad (2)$$

$$Coefficient\ of\ Performance\,(COP) = \frac{Refrigeration\,Effect}{Energy\,Input} \qquad (3)$$

where *m* is the mass of the cooling load(water) in *kg*, *Cp* is the specific heat in *kJ/kg K*, *Ti and Tf* are initial and final temperatures of the water in ^0c, *t* is the time in *s*, *n* is the number of impulses taken from the energy meter, and *K* is the energy meter constant *Imp/kWh*.

Table-3

Ranges and Condition of Experiment

S.NO	Parameter	Range
1	Nano Type	TiO2
2	Nano Size	Size50-80nm
3	Nano concentration (g/L)	0.2 g/L, 0.4 g/L, 0.6 g/L
4	Refrigerant type	HCs
5	Capillary Tube length (m)	2 m
6	Mass charged (kg/cm^2)	2.8 kg/cm^2
7	Ambient Temperature Range	29^0-32^0 C

Table-4

Temperature and pressure variations of R290 with varied concentration of nano-lubricant

oil	Refrigerant	T1 (^{0}C)	T2 (^{0}C)	T3 (^{0}C)	T4 (^{0}C)	P1 (Psi)	P2 (Psi)	Ti (^{0}C)	Tf (^{0}C)
Pure PAG	R290	17	54	33	0	8	180	28	14
0.2g/L of Tio_2 with PAG	R290	19	59	36	2	7	190	28	18
0.4g/L of Tio_2 with PAG	R290	14	58	33	2	8	190	25	13
0.6g/L of Tio_2 with PAG	R290	13	56	33	0	8	195	27	15

III. RESULTS AND DISCUSSION

A. *Power consumption*

Power consumption of the refrigerator system is shown in table-5. It can be observed from Fig. 7 that the lowest power consumption index of 120 W was obtained using R290 with 0.2 g/L, 0.6g/L concentrations of nano-lubricant. nano-lubricant had highest power consumption index of 130 W was obtained using R290 with pure and 0.4g/L concentration of oil. Compares to R290 with pure oil and 0.4g/L concentration, power consumption was reduced by 7.69% using R290 with 0.2g/L, 0.6g/L concentrations of nano lubricant. Power consumption for R290 with varied concentrations of nano-lubricant shown in Table-5.

Table-5

Power consumption of R290 with varied concentration of nano-lubricant

oil	Refrigerant	Power consumption(W)
Pure PAG	R290	130
0.2g/L of Tio_2 with PAG	R290	120
0.4g/L of Tio_2 with PAG	R290	130
0.6g/L of Tio_2 with PAG	R290	120

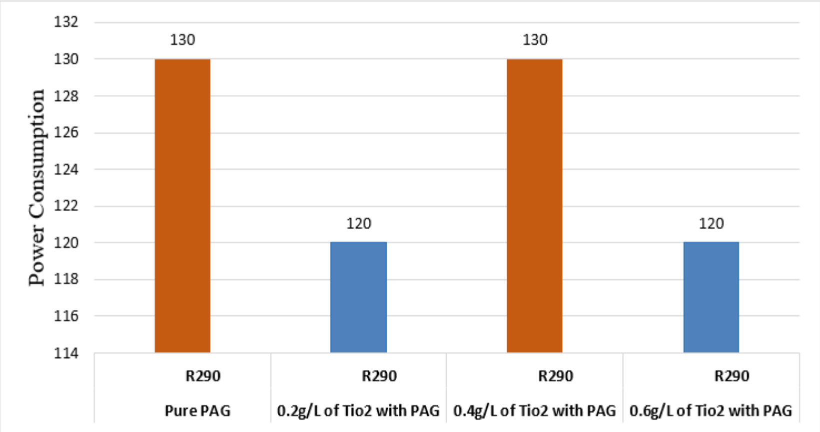

***Fig.** 7 Power consumption(W) of R290 with varied concentration of nano-lubricant*

A. *Energy input*

Energy input to the refrigeration system shown in Table-6. It can be observed from Fig. 8.The lowest compressor power input of 3.75 W was obtained with 0.2 g/L, 0.6g/L concentrations of nano-lubricant mixture. It is about 7.63% reduced compares to pure PAG oil mixture. The highest compressor power input of 4.37 W was obtained with 0.4g/L concentration of nano-lubricant. It is about 7.63% increased compares pure PAG oil mixture. Energy input for R290 with varied concentrations of nano-lubricant shown in Table-6.

Table-6

Energy input for R290 with varied concentration of nano-lubricant

Oil	Refrigerant	Compressor power input(W)
Pure PAG	R290	4.06
0.2g/L of Tio_2 with PAG	R290	3.75
0.4g/L of Tio_2 with PAG	R290	4.37
0.6g/L of Tio_2 with PAG	R290	3.75

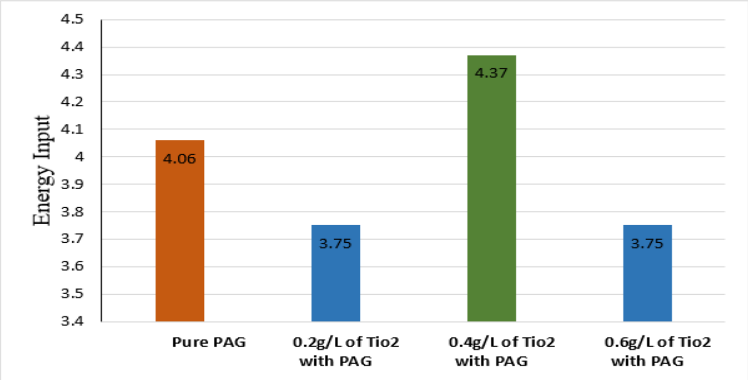

Fig. 8 *Energy input (W) for R290 with varied concentration of nano-lubricant*

B. *Cooling capacity*

Cooling capacity of the refrigeration system shown in Table-7. It can be observed from Fig. 9. The highest cooling capacity was obtained with pure lubricant. The highest cooling capacity at steady state of 16.25 W was achieved with pure PAG oil; Also, the lowest cooling capacity index of 11.61 W was obtained with 0.2g/L concentration of nano-lubricant, The cooling capacity at steady state of 13.93 W was achieved with 0.4,0.6g/L, this gave about 16.65% better performance than with pure PAG oil. Cooling capacity for R290 with varied concentrations of nano-lubricant shown in Table-7.

Table-7

Cooling capacity for R290 with varied concentration of nano-lubricant

Oil	Refrigerant	Cooling capacity(W)
Pure PAG	R290	16.25
0.2g/L of Tio_2 with PAG	R290	11.61
0.4g/L of Tio_2 with PAG	R290	13.93
0.6g/L of Tio_2 with PAG	R290	13.93

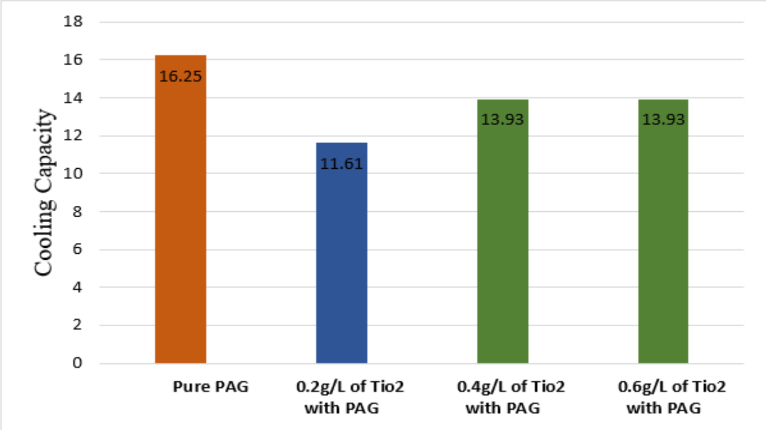

Fig. 9 *Cooling capacity(W) for R290 with varied concentration of nano-lubricant*

C. *Coefficient of performance*

It can be seen in Fig. 10. The highest COP of 4.00 was attained with pure PAG oil in the domestic refrigerator system, The lowest COP value of 3.09, was obtained with 0.2 g/L nanolubricant mixture. The COP value of 3.71, was obtained with 0.6 g/L nanolubricant mixture, this gave a 7.25% increase in values, when compared with the corresponding R290 refrigerant containing pure PAG oil mixture. COP for R290/R600a(50/50) with varied concentrations of nano-lubricant shown in Table-8.

Table-8

COP for R290 with varied concentration of nano-lubricant

Oil	Refrigerant	COP
Pure PAG	R290	4.00
0.2g/L of Tio_2 with PAG	R290	3.09
0.4g/L of Tio_2 with PAG	R290	3.18
0.6g/L of Tio_2 with PAG	R290	3.71

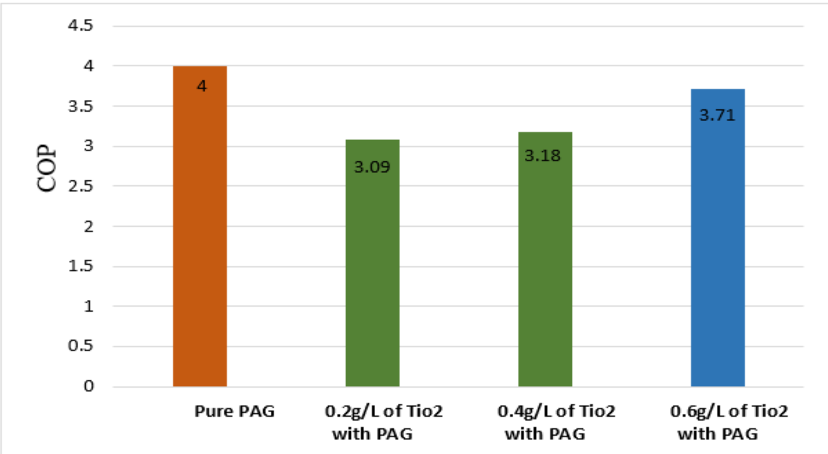

Fig. 10 *COP for R290 with varied concentration of nano-lubricant.*

Table-9

Comparison of cooling capacity, compressor power input, COP, Power consumption with varied concentration of nano-lubricant and R290 mixture

Oil	Refrigerant	Cooling capacity(W)	Compressor power input(W)	COP	Power consumption(W)
Pure PAG	R290	16.25	4.06	4.00	130
0.2g/L of Tio_2 with PAG	R290	11.61	3.75	3.09	120
0.4g/L of Tio_2 with PAG	R290	13.93	4.37	3.18	130
0.6g/L of Tio_2 with PAG	R290	13.93	3.75	3.71	120

IV. Conclusion

From the experimental investigation of varied concentrations of TiO2 nanoparticle/PAG oil nano- lubricant in R290 refrigerants, the following findings were concluded:

- All TiO_2 based nano-lubricants worked safely in the domestic refrigerator.
- Evaporator air temperature slightly lower with nano-lubricant when compared to pure lubricant for same charge of refrigerants.
- The lowest compressor power input was 3.75 W, and obtained with either of 0.2 g/L or 0.6 g/L nano-lubricants.
- The highest cooling capacity index of 16.25 W was obtained with pure PAG oil.
- The highest COP was found to be 4.00 and obtained with pure PAG oil with 130W power consumption and also the COP was 3.71 obtained with 0.6g/L nano-lubricant but the power consumption was a bit low i.e. 120W.

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