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Performance Enhancement of Vapor Compression Refrigeration System using CuO Nano Particles in CARE 30 Test Rig

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A B S T R A C T

The refrigeration system excution with the nano oil was explored to enhance the coefficient of performance (COP) of the vapor compression refrigeration system (VCRS) using CARE 30 which is a mixture of 50% refrigerant R200 and 50% refrigerant R600a in which 1 gram of Copper oxide (CuO) nano particles (NP) are used. Nano lubricant was used in the compressor of R-134a refrigeration system (compatible with CARE 30) mixed with polyolester (POE) oil. To execute this examination, a test setup was planned and fabricated in the workshop. The outcome demonstrates that CARE 30 and POE oil with CuO NP works typically and securely in the refrigeration system. The refrigeration system performance found is better than the customary CARE 30 and POE oil only refrigertion system. Therefore, the nano lubricant (POE compressor lubricant mixed with CuO NP) could be used as a vital piece of refrigeration system to lower the energy consumption and for the enhancement of COP of VCRS.

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NOMENCLATURE

COP	Coefficient of performance	ml	milli liter
VCRS	Vapour compression refrigeration system	rpm	Rotations per minute
NP	Nano particles	ODP	Ozone depletion potential
nm	Nano meter	GWP	Global warming potential
CuO	Copper oxide NP	EER	Energy Efficiency Ratio
POE	Polyolester	P_1	Compressor suction pressure in bar
PAG	Polyalkylene glycol	P_2	Compressor discharge pressure in bar
MO	Mineral oil	T_1	Temperature after evaporator in Celcius
AB	Alkyl benzene	T_2	Temperature after compressor in Celcius
HFC	Hydroflourocarbon	T_3	Temperature after condenser in Celcius
HC	Hydrocarbon	T_C	Cabin set point temperature in Celcius
kJ	kilo Joul	CARE 30	Refrigerant (50%, R290 and 50%, R600a)
kW	kilo Watt	WOL	Without load
g	gram	WL	With load

INTRODUCTION

Currently used best practices in HVACR industry include use of hydroflourocarbon (HFC) refrigerants as per Montreal protocol [1] which has zero ozone depletion potential (ODP). However, these HFC have higher global warming potential (GWP)[1] contributing to environment change and is one of the threat to human survival on earth. High power consumed by HVACR industry has huge carbon foot print. From the above, it is important and unavoidable to have HVACR systems used in the industry need less energy input as much as possible and the systems to deliver high output. Hence it is the requirement of the time to find the ways to enhance the performance of refrigeration systems and materials which reduces energy consumption and has less impact

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[1] https://www.ghgprotocol.org (global warming potential values)

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on the environment. The refrigerants selection should have zero ODP as well as least possible GWP. The refrigerants should have low boiling and freezing point. The selection of refrigerants should be mainly for the high latent heat of vaporization, they must be non-toxic, harmless, non-flammable, non-explosive, non-corrosive, high miscibility with lubricating oils. Refrigerants to give high COP for a selected working range of temperatures.

Figure 1 shows a schematic representation of the VCRS which has major components namely compressor, condenser, capillary tube and evaporator [2]. The system works at high pressure (compressor discharge line, condenser and inlet of the capillary tube) and low pressure (outlet of capillary tube, evaporator and compressor suction line). The refrigerant flows throughout the refrigeration circuit with a phase change happening due to the heat transfer at various refrigeration system components and the refrigerant. The heat is rejected at the condenser and the heat is absorbed in the evaporator.

PREVIOUS STUDIES

Following studies are carried out as part of literature survey for the project.

Studies related to various HC refrigerants

Yadav et al. [3] in his theoretical analysis for vapour compression refrigeration system he analysed the performance of various refrigerants at different mass fractions. The refrigerants performance analysed are R-134a, R290a, R600a and mixture of R290a and R600a in varying mass fractions like (25%-75%), (50%-50%), (75%-25%) respectively and also at varying outside conditions. The evaluation was made in terms of volumetric efficiency, pressure ratio, cooling capacity, condenser temperature, compressor discharge temperature and coefficient of performance. They tabulated the coefficient of performance of each of the refrigerant at different evaporator temperatures by keeping the compressor outlet and the condensing temperature fixed. Also, found out the COP by keeping the evaporator temperature fixed and varied the condenser temperature. For this analysis R-134a refrigerant results were compared with the performance of R290, R600a and mixtures of R290 and R600a. The COP of refrigerants R290, R600a and their mixtures are found to be higher than the refrigerant R-134a. The COP is found to be reduced for reduced evaporator temperatures from -5 to -30°C. The COP at -15°C obtained for refrigerant R-134a is 2.1 whereas the COP obtained for R290, R600a and mixture of R290/R600a at -15°C is 3.83, 2.47 and 2.12, respectively.

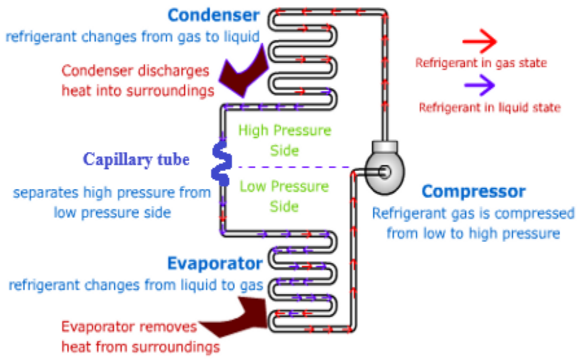

Figure 1. VCRS schematic diagram

Kaleemullah et al. [4] in their detailed review, they have presented a comparative study of various NP based lubricants for the performance enhancement of VCRS. Most used NP were Al_2O_3, TiO_2, CuO, ZnO and SiO_2 among few others. These NP are used in different mass % fraction by weight and by % volume by volume. Various types of compressor lubricants used in the VCRS are POE, PAG, AB and MO. Few lubricants works well with few refrigerants. The study covers the procedure for NP and lubricant mixing and the steps to be followed for the preparation of Nano based lubricants and concluded that Nano based lubricants and Nano based refrigerants mostly enhances the performance of the VCRS. Ravinder and Jagdev [5] has experimentally investigated that the Zinc oxide NP when appended with VCR system refrigerant R290/R600a (50/50) via the compressor lubricating oil resulted in reduction in power consumption of the compressor.

Studies related to R-134a refrigerant

Julie and Anthony [6] compiled the low pressure R-134a potential alternatives with their composition, their average molar mass, bubble point, dew point, critical temperature, GWP and classification of refrigerants per ASHRAE. The alternatives proposed are refrigerants R-513A, R-450A, R-515A, R1234yf, R1234ze (E) and R-600a. Fedele et al. [7] recommends addition of NP to the lubricant or R-134a refrigeration system without any dispersant. The optimal suspension performance was achieved at weight fractions 1.0 and 1.5 wt. %. NP Al_2O_3 should be added to lubricant to acquire an effective increase of thermal conductivity. The results showed that the thermal conductivities were respectively enhanced by 2.0%, 4.6%, and 2.5% when NP of Al_2O_3 at 1.0, 1.5, and 2.0 wt. % were added at 40°C. In the three weight fraction specimen, the optimal enhancement of the thermal conductivity is 1.5 wt. %. The thermal conductivities increase from 1.5% to 4.6% when the sample temperature are from 20 to 40°C at 1.5 wt.%, and the trend of growth rates of the thermal conductivity is proportional to temperature. NP Al_2O_3 has better growth rates of thermal conductivity at higher temperature, so nanofluids has better effects in the cases of higher temperature.

Studies related to various compressor lubricants

Mahesh et al. [8] stated that due to the enhanced properties and better performance, nanorefrigerants, nano lubricants have proven to be a promising option for enhancing the efficiency of the refrigeration system. Subramani et al. [9] extensive experimental and theoretical studies carried out to evaluate the performance parameters of a vapour compression system with pure SUNISO 3GS oil and with different Nanolubricants. The conclusions drawn from the study are, the freezing capacity is higher for TiO_2 nanolubricant compared with other three cases. The power consumption of the compressor is reduced by 15.4% TiO_2 nanolubricant is used instead of SUNISO 3GS oil. The reductions in power consumption are 11.9% and 8.4% respectively with Al_2O_3 nanolubricant and CuO nanolubricant. The coefficient of performance of the refrigeration system increases by 20% when TiO_2 nanolubricant is used instead of SUNISO 3GS oil. An increase in COP with Al_2O_3 nanolubricant and CuO nanolubricant are 16 and 11%, respectively. The energy enhancement factor in the evaporator with Al_2O_3, TiO_2 and CuO Nanolubricants are 1.5338, 1.5353 and 1.5449, respectively

Studies related to different nanoparticles

Veera and Govindha [10] compared performance of refrigeration system using POE lubricant and various Nano particles and found that the TiO_2 gives the highest energy saving of 26.1% for the same concentration and the second highest energy saving obtained by using CuO which is 24.5%. Suresh et al [11] explored that HFC refrigerant R-134a has GWP of 1300 whereas R152a has a significant reduced value of GWP of 140 only. The ZrO_2 nanoparticle concentration is an important factor considered for heat transfer enhancement in the refrigeration system. The concentration of Nano ZrO2 ranges between 0.01% and 0.06% volume concentration with particle size of 20nm with R-134a and R152a. The COP of the system was significantly improved with 33.45% when 0.06% volume concentration of ZrO_2 with R152a refrigerant was used. The discharge temperature of the R152a/ZrO_2 Nano refrigerant was nearly the same as that of R-134a. The usage of R152a with Zero ODP and very low GWP provides a green and clean environment. Sendil and Elansezhian [12] in their experimental analysis the VCRS performance using refrigerant R152a and PAG lubricating oil suspended with ZnO NP (0.1%, 0.3%, 0.5% concentration by volume) and observed that the power consumption is reduced by 21% for a 0.5% concentration by volume of NP compared to R-134a VCRS without NP.

Studies related to CuO nanoparticles

Mahesh et al. [8] in their experiment found that the density of CuO Nano lubricant decreased with increase in temperature. The added CuO Nano particles significantly influenced the nucleate boiling heat transfer coefficient of R600a refrigerant at higher heat flux values. In the experiment it is observed that the thermo-phoretic mobility of nanoparticles play a major role in nanofluids heat transport. Abdel-Hadi et al. [13] has conducted an experiment and evaluated the improvement in the evaporating heat transfer coefficient in VCRS by using CuO-R-134a. A horizontal tube in tube heat exchanger made of copper was used. The hot water was allowed to pass in an annular manner surrounding the inner tube and the refrigerant passed through the inner copper tube and heat flux measured for various concentrations of CuO NP ranging from 0.05% to 1% with a particles size varying from 15 to 70nm. The results showed that, at certain concentration of NP the evaporating heat transfer coefficient increased due to increase in heat flux or increase in mass flux. In the conclusion, it is revealed that there is an increase in evaporating heat transfer coefficient with increase in heat flux, increase in CuO NP concentration for a range of 0.1 to 0.55%, decreases for CuO NP size ranging from 15 to 25nm then decreased for all other heat flux values.

Fadhilah et al. [14] in their mathematical model conducted study on the thermo physical properties of Nanorefrigerant CuO-R-134a. They have designed a copper horizontal smooth tube of an evaporator using CAD software for calculating the properties of Nanorefrigerant. The thermal conductivity of the Nanorefrigerant is evaluated by taking into consideration the Refrigerant velocity (V) 1.2m/s, Diameter of NP (d_p) 40 nm, thermal conductivity of copper (K_{copper}) as 401 W/m-k, heat transfer coefficient of air (hair) 50 W/m^2 k, Inlet temperature (T_i) 26°C and Outlet temperature (T_o) -10°C, tube length (L) 1.4m, Inner tube diameter 0.00772m and outer tube diameter 0.00952m and found out the Reynolds number of Nanorefrigerant, viscosity and heat transfer rate by using various formulas and concluded that the thermal conductivity is directly proportional to the volume fraction of the NP. With each 1% CuO NP concentration addition to the refrigerant R-134a (0.0139 W/m-k), the thermal conductivity of the refrigerant is increased by 0.01 W/m-k. With 1% volume fraction the increase is thermal conductivity was found as 3121% that is 0.0139 W/m-k enhanced to 0.4477 W/m-k. The use of NP volume fraction up to 5% found to increase the thermal conductivity of the base refrigerant R-134a. The viscosity of the Nanorefrigerant is also enhanced about 44.45% as compared to the based refrigerant viscosity by addition of 1% of NP volume fraction. Also, the study states that it is important to have superior thermal properties of the Nano refrigerant which withstands the changes in the temperature, pressures and the NP would not cause the clogging, corrosion, or pressure drop in overall performance of VCRS.

Nano lubricant

Another word used to portray nanoparticle-based suspensions is Nano oils or Nano lubricants [15, 16]. These are prepared by using oils utilized for motor and machine lubrication. Up until now, a few materials including metals, oxides and allotropes of carbon have been utilized to define Nano ointments. The expansion of nanomaterial essentially upgrades the thermal conductivity which helps to enhance the heat transfer properties required for improving the VCRS performance.

Nano fluids are fundamentally utilized for their upgraded thermal properties as coolants in heat exchangers, for example, heat exchangers, electronic cooling system (such as flat plate) and radiators. Heat exchange over level plate has been dissected by numerous analysts. In many cases, they are likewise helpful for their controlled optical properties. Graphene based nanofluid has been found to improve Polymers chain response effectiveness. Nano fluids in sun powered systems are another application where nanofluids are utilized for their tuneable optical properties. Nanofluids could be used in the HVACR works, enhancing VCRS and life cycle of the compressors. It is to note that considerable tests and hypothetical work is utmost important to choose and rely on nanofluids for their applications [17]. The use of Nano lubricants or Nano refrigerants appears to be very attractive. However, their application is hindered by (to list a) few of the following factors:

- Choking hazard
- Poor long haul steadiness
- High pressure drop
- High pumping power
- Low specific heat
- Particle settling
- Fouling
- High production cost

MATERIAL AND METHOD

CuO nanoparticles details

The CuO Nanoparticles used in this project is procured from m/s ottokemi[1] and the product details are as under:

- Product code: CN
- Elemental NP: Copper Nano powder 99.8 % (metal basis, 0<10%)
- Particle size: 30-50 nm
- Particle morphology: Spherical
- Crystallographic structure: Cubic single crystal

Experimental test rig details

The test rig experimental setup was designed and developed with the parts as detailed below. Hermetically, the rig consisted of sealed compressor for R-134a refrigerant, an air cooled condenser, an expansion device i.e., a capillary tube and an evaporator cabin to place water in it. The system equiped with seven thermocouples, two pressure gauges and one digital energy meter. These thermocouples are fixed to read the temperatures at required areas. The suction and discharge pressure of compressor are read at pressure gauges and the digital energy meter provides the power utilized by the test rig especially for one refrigeration cycle to obtain the required cabin set point temperature and to cut off the compressor once the set point temperature is reached to the cabin temperature.

The above figure shows the experimental set up / test rig labelled with its major components and accessories used in this project. First of all, the setup was planned. The decision was made to choose a low capacity compressor and corresponding refrigeration system components due to high flammability of the hydrocarbon refrigerant. Then, the required refrigeration system components were procured and sent to the refrigeration system fabrication workshop. Secondly the mild steel base frame with wheels was made in the steel fabrication workshop and sent to the refrigeration system fabrication workshop.

Thirdly, the evaporator cabin was fabricated by specialist fabricator with glass door. The manufactured cabin box and the steel base frames were transported to the fabrication workshop. The evaporator cabin is fabricated by using stainless steel sheet on the external side or the cabin and the galvanized iron sheet at the inside of the cabin. In between the two layers polyurethane foam insulation in injected. The door of the cabin is made with 10mm thick heat resistant glass for visibility during the experiment. The evaporator which comprised of aluminium enclosure embedded with copper pipes around it was fixed within a GI sheets sandwich box having 2 inches thick PUF insulation which is a cubic box into which the evaporator was fixed. A different angle iron stand was fabricated on which the evaporator box was fixed at a comfortable height for clear visibility. A hermetically sealed compressor was chosen in which both compressor and motor are restricted in a sealed external welded steel shell. The motor and compressor are specifically coupled on the same shaft, with motor inside the refrigeration circuit. This compressor was screwed on the base side of the base casing. The condenser fan is installed between the compressor and the condenser. This installation of condenser fan is such that it serves dual purpose one to cool the refrigerant flowing through the condenser coils and also it cools the compressor to protect the compressor from overheating. The condenser utilized is air cooled type provided with a condenser fan to cool the hot refrigerant passing through the condenser coils. A compressor is fixed strategically so that the condenser fan

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[1] https://www.ottokemi.com/product

cools the compressor too. The condenser is made of steel pipes which is coated with copper. A capillary tube is utilized as the expansion device which is made of copper and has an inside diameter of 0.036 in (0.91mm). Because of its high protection from stream grating it limits flow stream of fluid refrigerant from the condenser to evaporator it is favoured more long and less in distance across because of which it makes more pressure difference. The planning to fix different refrigeration system components was executed according to the working standard of a basic VCRS as shown in Figure 2. The compressor having suction end is connected with the evaporator and the discharge end is connected with the condenser. From the condenser, the refrigerant pipe line goes to the filter drier, sight glass and then to the capillary tube. The capillary tube other end was connected to the evaporator coil inside the cabin. The pressure gauges are given at the suction and the discharge end of the compressor to quantify the pressures. Seven digital temperature-measuring devices (i.e.; thermocouples) fixed at different locations to measure the temperature at the following locations in the refrigeration circuit.

- Suction of the compressor which is vapor line from the evaporator
- Discharge of the compressor
- After the condenser coil
- After the capillary tube
- Ambient temperature and Cabin temperature
- Water temperature kept inside the cabin in a bowl.

Methodology

Following points below describes the methodology applied in this project.

- Literature survey for identifying suitable HC refrigerant.
- Literature survey for identifying suitable compressor lubricant.
- Literature survey for identifying suitable Nanoparticle.
- Planning and Fabrication of VCRS test rig to suit the proposed HC refrigerant and Nanoparticle.
- Experimentation, each 3 cycles readings noted for R-134a, CARE 30 and CARE 30 with CuO NP
- Tabulation of test readings, calculations and representation through suitable graphs and discussion.
- Conclusions and Future scope.

Preparation of nano lubricant

The following steps are followed during the preparation of the Nanolubricant. First step is Nano lubricant preparation and the second step is Nano lubricant injection into the compressor.

Nano lubricant preparation

- The Nano particles are put into a cup.

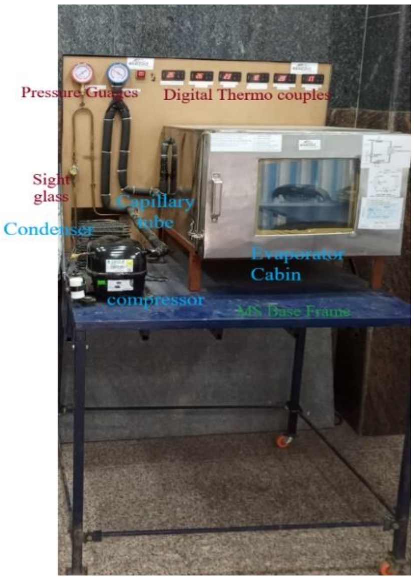

Figure 2. Test rig/Experimental set up

- 1 g. of CuO Nano particles are weighed on a digital weighing scale.
- 100ml of fresh POE oil is poured into a glass beaker.

Then the CuO Nano particles and the lubricant are mixed in a beaker.

The nano lubricant is prepared by mixing POE oil and NP at a ratio of 1 g in 100 ml. The oil mixed with Nano particles is kept at magnetic stirrer for about 12 hours at a speed of 1000 rpm to obtain a homogeneous mixture of oil and nano particles. The rpm is increased slowly so as not the get the lubricant spill out of the beaker. The mixing process is observed from time to time to make sure that the mixing is taking place properly and peddle is rotating.

Nano lubricant injection into the compressor

The compressor procured is factory pre charged with 300ml of lubricant. Then the final step is injecting the nano lubricant into the compressor of the refrigeration system as a lubricant

RESULTS AND DISCUSSION

The results of the experiments are listed in Tables 1 to 3. Figure 3 is a comparison for COP shown on y-axis and refrigerants R-134a, CARE 30 and CARE 30 with CuO NP on x-axis. The above figure shows the following:

- When R-134a test rig is charged with HC refrigerant CARE 30 its COP increased by 28%.
- When R-134a test rig is charged with CARE 30 added with 1 gram of CuO NP, the COP increased by 44%.
- The COP for the CARE 30 test rig is 2.615, when 1 gram of CuO NP added, the COP is increased to 2.944. Hence, there is an increase in COP by 12.6%.

TABLE 1. Test readings of R-134a with POE oil

Abbn.	Cycle-I		Cycle-II		Cycle-III	
	WOL	**WL**	**WOL**	**WL**	**WOL**	**WL**
P1	0.4	0.9	0.6	0.8	0.4	0.4
P2	7.8	7.8	7.8	8	8.8	9.6
T_1	-6	6	-8	-19	-9	-19
T_2	54	61	51	62	52	58
T_3	33	34	33	37	34	36
T_C	-7	-7	-7	-7	-7	-7

TABLE 2. Readings of CARE 30 HC Refrigerant with POE oil

Abbn.	Cycle-I		Cycle-II		Cycle-III	
	WOL	**WL**	**WOL**	**WL**	**WOL**	**WL**
P1	0.4	0.9	0.9	1	0.9	0.9
P2	7.8	7.8	7.8	7.8	8	8.4
T_1	-6	6	7	-2	-5	-5
T_2	54	61	58	59	55	62
T_3	33	34	34	34	33	34
T_C	-7	-7	-7	-7	-7	-7

TABLE 3. Test rig readings with CARE 30 refrigerant added with 1 gram of CuO NP

Abbn.	Cycle-I		Cycle-II		Cycle-III	
	WOL	**WL**	**WOL**	**WL**	**WOL**	**WL**
P1	0.5	0.8	0.6	0.7	0.4	0.4
P2	6.5	6.8	6	6.5	7	7.2
T_1	12	13	10	13	11	11
T_2	49	54	47	55	48	54
T_3	31	32	30	31	31	31
T_C	-7	-7	-7	-7	-7	-7

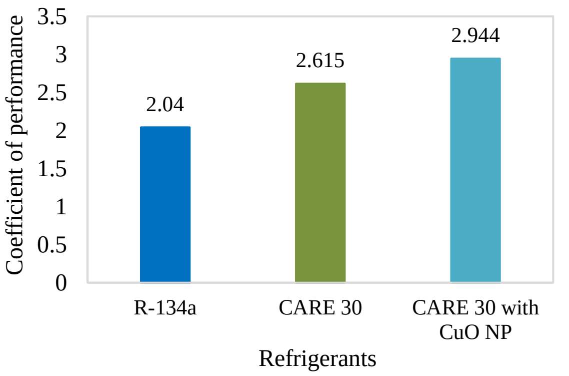

Figure 3. Variation in average COP for various refrigerants

Figure 4 is a comparison of average power consumption on y-axis and refrigerants R-134a, CARE 30 and CARE 30 with CuO NP on x-axis. The above figure shows the following:

- When R-134a test rig charged with HC refrigerant CARE 30 its Average power consumption decreased by 41%.
- When R-134a test rig is charged with CARE 30 added with 1 gram of CuO NP, the average power consumption decreased by 51%.
- The average power consumption for the CARE 30 test rig is 0.066 kWh, when 1 gram of CuO NP added; the average power consumption is decreased to 0.0484 kWh. Hence, there is a significant decrease in Average power consumption by 26.6%.

Figure 5 is a comparison of average refrigeration effect on y-axis and refrigerants R-134a, CARE 30 and CARE 30 with CuO NP on x-axis. The above figure shows the following:

- When R-134a test rig charged with HC refrigerant CARE 30 its average refrigeration effect decreased by 10%.

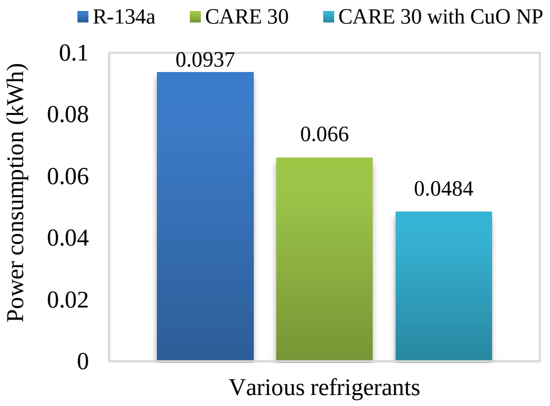

Figure 4. Variation of average power consumption for various refrigerants

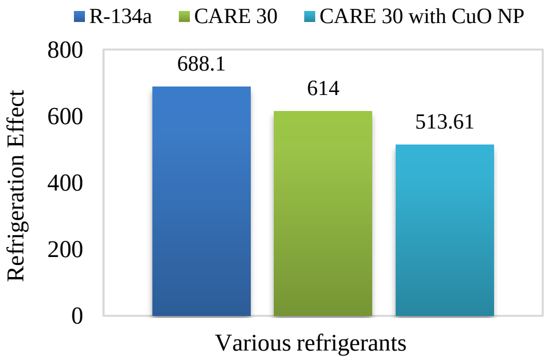

Figure 5. Average refrigeration effect for various refrigerants

- When R-134a test rig is charged with CARE 30 added with 1 gram of CuO NP, the average refrigeration effect decreased by 25.3%.
- The average Refrigeration Effect for the CARE 30 test rig is 614 kJ, when 1 gram of CuO NP added, the average R.E. is decreased to 513.61 kJ. Hence, there is a decrease in average refrigeration effect by 16.3%.

Figure 6 is a comparison of average compressor work input on y-axis and refrigerants R-134a, CARE 30 and CARE 30 with CuO NP on x-axis which shows the following:

- When R-134a test rig charged with HC refrigerant CARE 30 its average compressor work input decreased by 29.56%.
- When R-134a test rig is charged with CARE 30 added with 1 gram of CuO NP, the average compressor work input decreased by 48.3%.
- The average compressor work input for the CARE 30 test rig is 237.6 kJ, when 1 gram of CuO NP added; the average compressor work input is decreased to 174.12 kJ. Hence, there is a decrease in average compressor work input by 26.7%.

Figure 7 is a comparison of EER on y-axis for refrigerants R-134a, CARE 30 and CARE 30 with CuO NP on x-axis which shows the following results:

- When R-134a test rig charged with HC refrigerant CARE 30 its EER increased by 28%.
- When R-134a test rig is charged with CARE 30 added with 1 gram of CuO NP, the EER increased by 44%.

The EER for the CARE 30 test rig is 8.92, when 1 gram of CuO NP added, the EER is increased to 10.04. Hence, there is an increase in EER by 12.6%.

Similar studies carried out using HC refrigerants and their mixtures in various mass fractions when compared their performance with refrigerant R-134a in the same refrigeration equipment showed up an improvement in VCRS [1] performance. In addition, use of CuO NP along with refrigerants R-134a, R290, R600a also improved the VCRS refrigerant perforance [17].

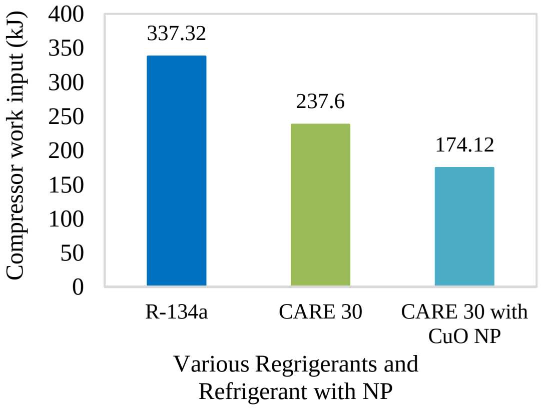

Figure 6. Average compressor work input for various refrigerants

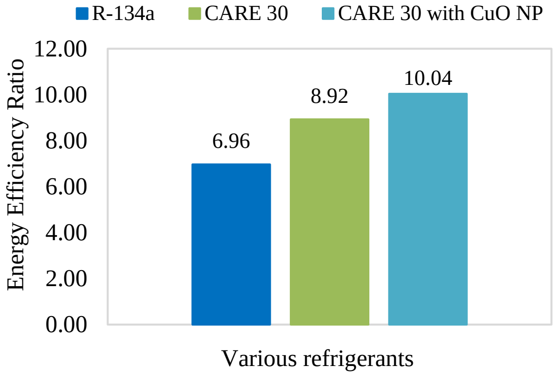

Figure 7. Changes in Energy Efficiency Ratio for various refrigerants

CONCLUSIONS

The experimental investigation was carried out using HC CARE 30 refrigerant in a CFC R134a refrigerant VCRS test rig and later copper oxide nano particles were mixed with compressor lubricant and it is concluded that the CARE 30 refrigerant worked safely and smoothly in a R134a VCRS test rig and the COP of the refrigeration system is improved when compared with the test rig with refrigerant R134a with POE oil. The COP was found to be 11.26% higher when 1 gram of *CuO mixed with 300 ml of compressor lubricant (POE).* Hence it is observed that the POE oil when mixed with CuO nano particles improves the COP of the system.

The COP for the CARE 30 test rig is 2.615, when 1 gram of CuO NP added, the COP is increased to 2.944. Hence, there is an increase in COP by 12.6%. For CARE 30 with CuO NP, the readings of three cycles when calculated for COP gives a difference of 0.265 i.e., 9.4% which is within the permissible limit. Also, for CARE 30 with CuO NP, the readings of three cycles when calculated for power consumption gives a difference of 0.0098 i.e., 22.4% which is within the permissible limit. The average power consumption for the CARE 30 test rig is 0.066 kWh, when 1 gram of CuO NP added, the average power consumption is decreased to 0.0484 kWh. Hence, there is a significant decrease in Average power consumption by 26.6%.

The average cycle time for the CARE 30 test rig is 1373 seconds, when 1 gram of CuO NP added, the average cycle time decreased 1366 seconds. Hence, there is a reduction in average cycle time by 0.005%. For CARE 30 with CuO NP, the readings of three cycles when observed for compressor discharge pressure gives a difference of 0.7 bar i.e., 10.7% which is within the permissible limit. For CARE 30 with CuO NP, the readings of three cycles when observed for compressor suction pressure gives a difference of 0.4 bar i.e., 50%.

For CARE 30 with CuO NP, the readings of three cycles when calculated for refrigeration effect gives a difference of 131.4 kJ i.e., 22.2%.The average refrigeration effect for the CARE 30 test rig is 614 kJ, when 1 gram of CuO NP added, the average R.E. is decreased to 513.61 kJ. Hence, there is a decrease in average refrigeration effect by 16.3%. The average compressor work input for the CARE 30 test rig is 237.6 kJ, when 1 gram of CuO NP added, the average compressor work input is decreased to 174.12 kJ. Hence, there is a decrease in average compressor work input by 26.7%.

The refrigerant charge quantity for the CARE 30 test rig is 105 grams, when 1 gram of CuO NP added, the quantity of refrigerant charged is decreased to 103 grams. Hence, there is a negligible decrease in quantity of refrigerant charged. The EER for the CARE 30 test rig is 8.92, when 1 gram of CuO NP added, the EER is increased to 10.04. Hence, there is an increase in EER by 12.6%.

FUTURE SCOPE OF WORK

1) More research to focus on eco-friendly HC refrigerants like Care Series (Care 30, Care 40 etc.) and HC mixtures along with various NP. Plethora of NP types, sizes and quantity of NP used in the VCRS are yet to be tested and used. More studies to be conducted for the confirmation of the reduced system life cycle cost while using NP in VCRS as nano refrigerants or nano lubricants.

2) The compressor lubricant mixed with nano particles (nano compressor oil or nano lubricant) with HC refrigerants is yet to be supplied in the market and need clear guidelines from local authorities for the same. The market is yet to start to supply the refrigerants mixed with NP ready for use by competent technical professionals.

3) International research and development organizations to issue the guidelines for future researches related to use of NP in VCRS along with various refrigerants and compressor oils especially for household and commercial products and to further reduce the gap in further research works to obtain results to change the market trends and to save energy and environment.

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Persian Abstract

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چکیده

برای افزایش ضریب عملکرد (COP) سیستم تبرید فشرده‌سازی بخار (VCRS) با استفاده از CARE 30 که مخلوطی از ۵۰ درصد مبرد R200 و ۵۰ درصد مبرد R600a است که در آن ۱ گرم از اکسید مس (CuO) نانو ذرات (NP) استفاده می‌شود. از روان‌کننده نانو در کمپرسور سیستم تبرید R-134a (سازگار با CARE 30) مخلوط با روغن پلی الاستر (POE) استفاده شد. برای اجرای این معاینه، یک آزمایش آزمایشی در کارگاه برنامه‌ریزی و ساخته شد. نتیجه نشان می‌دهد که روغن CARE 30 و POE با CuO NP به طور معمول و ایمن در سیستم تبرید کار می‌کند. عملکرد سیستم تبرید یافت شده از سیستم تبرید فقط روغن CARE 30 و POE بهتر است. بنابراین، روان‌کننده نانو روان‌کننده کمپرسور POE مخلوط با (CuO NP) می‌تواند به عنوان قطعه حیاتی سیستم تبرید برای کاهش مصرف انرژی و افزایش COP VCRS استفاده شود.