Experimental investigation of vapor compression refrigeration system performance using Nano-refrigerant

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ABSTRACT

Experimental investigation of vapor compression refrigeration system performance using Nano-refrigerant is presented in this work. Nano-refrigerant was prepared in current work by mixing 50 nanometers diameter of copper oxide CuO nanoparticles with Polyolester lubrication oil and added to the compressor of the refrigeration system to be mixed with pure refrigerant R-134a during its circulation through refrigeration system. Three concentrations (0.1%, 0.25%, and 0.4%) of CuO-R134 a Nano-refrigerant are used to study the performance of the refrigeration system test rig and to investigate the effect of using Nano-refrigerant as a working fluid compared with pure refrigerant R-134a. The results showed that, the increasing in concentration of CuO nanoparticles in the Nano-refrigerant will significantly enhance the performance of the refrigeration system, as adding nanoparticles will increase the thermal conductivity, heat transfer and improve the thermo-physical properties of Nano-refrigerant. Investigation of performance parameters for refrigeration system using Nano-refrigerant with 0.4% concentration compared with that for pure refrigerant R-134a shows that, Nano-refrigerant has reflect higher performance in range of 10% and 1.5% increase in COP and refrigeration effect respectively and 7% reduction in power consumption for refrigeration system. It can be concluded that, Nano-refrigerants can be efficiently and economically feasible to be used in the vapor compression refrigeration systems.

Keywords: Nano-refrigerant, Nano fluid, Nanoparticles, Coefficient of performance

استقصاء تجريبي لأداء منظومة تبريد انضغاطيه باستخدام وسيط تبريد نانوي

أحمد جاسم حمد

مدرس

الكلية التقنية-بغداد

الخلاصة

يقدم هذا البحث استقصاء تجريبي لأداء منظومة تبريد انضغاطيه باستخدام وسيط تبريد نانوي. تم تحضير وسيط التبريد النانوي خلال العمل الحالي بخلط جسيمات نانوية من اوكسيد النحاس(CuO) بقطر 50 نانومتر مع زيت التشحيم بوليليستر لمنظومة التبريد وأضيف الى ضاغط المنظومة حيث يخلط مع وسيط التبريد R-134a عندما 'يضغط خلال اجزاء منظومة التبريد. تم تحضير واستخدام وسيط تبريد نانوي بثلاثة تراكيز (0.1% , 0.25% , 0.4%) من CuO-R134a لدراسة اداء محطة فحص لمنظومة تبريد انضغاطيه ولاستقصاء تأثير استخدام وسيط تبريد نانوي كمائع عامل مقارنة مع وسيط التبريد R-134a . أظهرت النتائج ، أن زيادة تركيز الجسيمات النانوية لأوكسيد النحاس في وسيط التبريد النانوي سوف تحسن اداء منظومة التبريد الانضغاطية بشكل واضح لان اضافة هذه الجسيمات النانوية تؤدي الى زيادة الموصلية الحرارية وانتقال الحرارة وكذلك تحسن الميزات الفيزيائية – الحرارية لوسيط التبريد النانوي. استقصاء معلمات الاداء لمنظومة التبريد الانضغاطية باستخدام وسيط تبريد نانوي بتركيز (0.4%) مقارنة مع وسيط التبريد R-134a أظهر بأن وسيط التبريد النانوي قد أعطى اداء افضل من خلال زيادة قيم معامل الاداء وتأثير التبريد بحدود 10% و 1.5% على التوالي مع تخفيض 7% من استهلاك القدرة الكهربائية لمنظومة التبريد. يمكن الاستنتاج بان وسائط التبريد النانوية تعتبر مجدية اقتصاديا وكفؤة اذا ما استخدمت في منظومات التبريد الانضغاطية.

NOMENCLATURE

COP : Coefficient of performance (dimensionless)
H : Enthalpy (kJ/kg)
q_{ev} : Refrigeration effect (kJ/kg)
R_{con} : Nano-refrigerant concentration ratio (dimensionless)
T : Temperature (^oC)
T_{amb} : Ambient temperature (^oC)
T_{dis} : Compressor discharge temperature (^oC)
$T_{ev,in}$: Evaporator inlet temperature (^oC)
p_{dis} : Compressor discharge pressure (bar)
p_{suc} : Compressor suction pressure (bar)
PR : Pressure ratio (dimensionless)
W_{compr} : Work of compressor (kJ/kg)

Abbreviations

CuO : Copper oxide
HC : Hydrocarbons
HFC : Hydro-fluorocarbons
MO : Mineral oil
MNRO : Mineral-based Nano-refrigeration oil
POE : Polyolester lubrication oil
VCR : Vapor compression refrigeration

INTRODUCTION

Nano scale materials are materials with dimensions on the order of nanometers or at least one dimension is less than approximately 100 nanometers. These materials include nanoparticles, quantum dots, and carbon nanotubes which can act as carriers for liquid droplets or gases **[**1**]**. Nano-materials are being investigated for numerous applications due to their superior electrical, optical, mechanical, and chemical performance, among many other favorable properties. Researchers have found that the nanoparticles have a beneficial effects and heat transfer improvement when they are mixed in a common polyloester lubricant and added to a refrigerant. The mechanism behind the improved performance is not well understood yet, and performance benefits are sensitive to material selection and concentration. A partial explanation for how nanoparticles improve heat transfer is that highly thermally conductive nanoparticles increase the overall thermal conductivity of the fluid. This, however, accounts for only about 20% of the total increase in system performance. One theory holds that, when present in sufficient concentrations, highly thermally conductive nanoparticles further enhance heat transfer by encouraging more vigorous boiling. The nanoparticles may serve as nucleation sites for boiling translated to improved heat transfer in the system [2]. Rapid advances in nanotechnology have led to emerging of new generation of heat transfer fluids called (Nanofluids). Nanofluids are defined as suspension of nanoparticles in a base fluid. Some typical nanofluids are ethylene glycol based copper nanofluids, water based copper oxide nanofluids, etc. Nanofluids are dilute suspensions of functionalized nanoparticles composite materials developed about a decade ago with the specific aim of increasing the thermal conductivity of heat transfer fluids, which have now evolved into a promising nanotechnological area.[3] Many researchers have investigated the thermo-physical properties and heat transfer performance of the nanoparticles-fluid (or refrigerant) suspensions. Shawn et al [4], investigated the thermal diffusivity of fluid mixtures and suspensions of nanoparticles with a precision of better than 1% by testing the thermal conductivity of ethanol-water mixtures, in nearly pure ethanol, the increase in thermal conductivity with water concentration is a factor of 2 larger than predicted by effective medium theory. It is observed that, the largest increase in thermal conductivity was 1.3% ±0.8% for 4 nm diameter Au particles suspended in ethanol. Mark [5], studied the influence of copper oxide (CuO) nanoparticle concentration on the boiling performance of R134a /polyloester mixtures on a roughened, horizontal flat surface and investigated the two lubricant based nanofluids.

(Nano-lubricants) that made with a synthetic polyloester and 30 nm diameter CuO nanoparticles to a 4 % and a 2 % volume fraction, respectively. The study showed that, the mixtures with the 4 % volume fraction Nano- lubricant had boiling heat fluxes for a given superheat were on average 140 % larger than those for mixtures with the 2 % volume fraction Nano-lubricant. Ching et al [6], studied experimentally the improvement in thermal conductivity of Al_2O_3 nanofluids produced from mixing Al_2O_3 nanoparticles with lubricant of R-134a refrigeration system on the temperature (20-40 °C) under different weight fractions. The results showed that the thermal conductivities were respectively enhanced by 2.0%, 4.6%, and 2.5% when nanoparticles of Al_2O_3 at 1.0, 1.5, and 2.0 wt. % were added at 40 °C. Robert and Patrick [7], reviewed the nanofluids pool boiling heat transfer performance experimental studies and classified the iterators including the enhancement and degradation in heat transfer during nucleate boiling performance for different nanofluids. The findings in this study showed that, the changes in the surface play the most important role in determining whether enhancement is achieved, and it is observed that Nano-fluidic systems can be engineered to operate at conditions which would achieve heat transfer enhancement during nucleate boiling. Ruixiang et al [8], investigated experimentally a method that uses nanoparticles to enhance the energy efficiency of retrofitted residential air conditioners (RAC) employing HFCs as alternative refrigerants and investigated the reliability and performance of RAC with nanoparticles in the working fluid. A new mineral-based Nano-refrigeration oil, formed by blending some nanoparticles ($NiFe_2O_4$) into naphthenic based oil B32, was employed in the RAC using R410a as refrigerant. The results indicated that the mixture of R410a/MNRO works normally in the RAC works normally in the RAC and the cooling/heating energy efficiency ratio of the RAC increased about 6% by replacing the Polyol-Easter oil VG 32 lubricant with MNRO. Subramani and Prakash [9], conducted experimental study to investigate the improvement in the thermo-physical properties and heat transfer characteristics of the Nano-refrigerant prepared by adding nanoparticles to the lubricant in the refrigeration system. The experimental study indicated that the freezing capacity is higher and the power consumption reduces by 25 % when POE oil is replaced by a mixture of mineral oil and alumina nanoparticles. Sendil and Elansezhian [10], conducted experimental study on Al_2O_3-R134a Nano-refrigerant in refrigeration system. The results indicated that, the Nano refrigerant works normally and safely in the refrigeration system and system performance was better than pure lubricant with R134a working fluid with 10.32% less energy used with 0.2% concentration of nanoparticles in the refrigerant. Mahbubul et al [11], investigated the thermo-physical properties, pressure drop and heat transfer performance of Al2O3 nanoparticles suspended in refrigerant R-134a with concentrations of 1 to 5 vol. % in a horizontal smooth tube. The results indicated that, the thermal conductivity of Nano-refrigerant increased with the augmentation of particle concentration and the viscosity, pressure drop, and heat transfer coefficients of the Nano-refrigerant showed a significant increment with the increase of volume fractions In current work a Nano-refrigerant CuO-R-134a is prepared by mixing a nanoparticles of copper oxide CuO with polyloester lubricating oil at different mass fractions and added to the compressor of refrigeration system test rig to improve the refrigerant properties. The performance parameters of VCR system such as COP, refrigeration capacity and power consumption are investigated experimentally to show the effect of adding CuO nanoparticles to the refrigerant.

THEORETICAL ANALYSIS

The simple vapor compression refrigeration cycle for refrigeration system test rig used in present work is indicated on p-h diagram shown in figure (1). Process from point 1 to 2 represents the compression process in the compressor, process from point 2 to 3 represents heat rejection through the condenser, process from point 3 to 4 shows throttling effect through capillary tube and the process from point 4 to 1 represents refrigeration effect through the evaporator, [12].

The performance parameters of refrigeration system are determined using the following equations with aid of engineering equations solver (EES) software.

The refrigeration effect (q_{ev}) through the evaporator can be calculated by:

$$q_{ev} = (h_1 - h_4) \qquad (1)$$

The work of the compressor can be determined by:

$$W_{compr} = (h_2 - h_1) \qquad (2)$$

The coefficient of performance (COP) of the refrigeration system can be determined by:

$$\text{COP} = \frac{q_{ev}}{w_{compr}} = \frac{(h_1 - h_4)}{(h_2 - h_1)} \qquad (3)$$

And the pressure ratio (PR) of the refrigeration system is determined by:

$$\text{PR} = \frac{p_{dis}}{p_{suc}} \qquad (4)$$

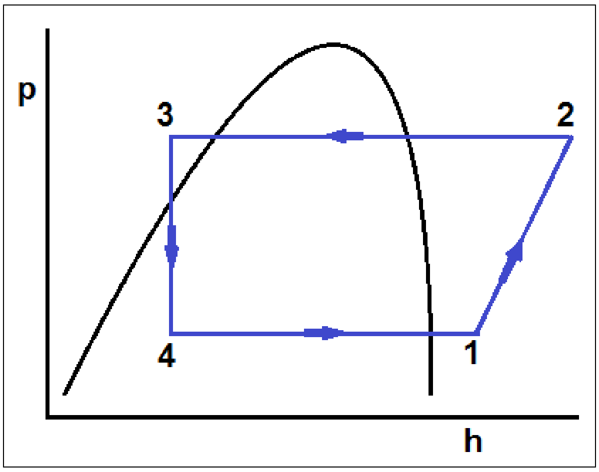

Figure (1) p-h diagram of VCR system [12]

EXPERIMENTAL WORK

The experimental work was conducted on VCR system test rig (340L capacity Lab. refrigerator) and the experimental tests are carried out to investigate the performance of the refrigeration system in two cases, at first a pure refrigerant R-134a was used as base line case and at a second case, CuO-R134a Nano-refrigerant was used for performance comparison. The refrigeration system test rig used in current work is consists of, reciprocating compressor, wire and tube air cooled condenser, capillary tube as expansion device , freezing compartment (evaporator) and other accessories as shown in figures (2) and (3). Pressure gauges and thermocouples with readers are at first calibrated and then placed at various locations in the test rig system to measure the pressure and temperature of the refrigerant throughout operation period. The test rig system is at first air evacuated and charged with 200g of refrigerant R-134a and the experimental results including, temperatures, pressures, refrigerant mass flow rate and electrical power consumption are established with measurement time interval during 2 hours test period to be a foundation for system performance comparison. The refrigerant R-134a was then recovered from the test rig system and the system charged with 200g of Nano-refrigerant by adding CuO-lubrication oil suspension to the compressor of the refrigeration system and the tests were conducted under the same operating conditions with three concentrations of Nano-refrigerant, 0.1%, 0.25%, and 0.4% of nanoparticles-R134a.

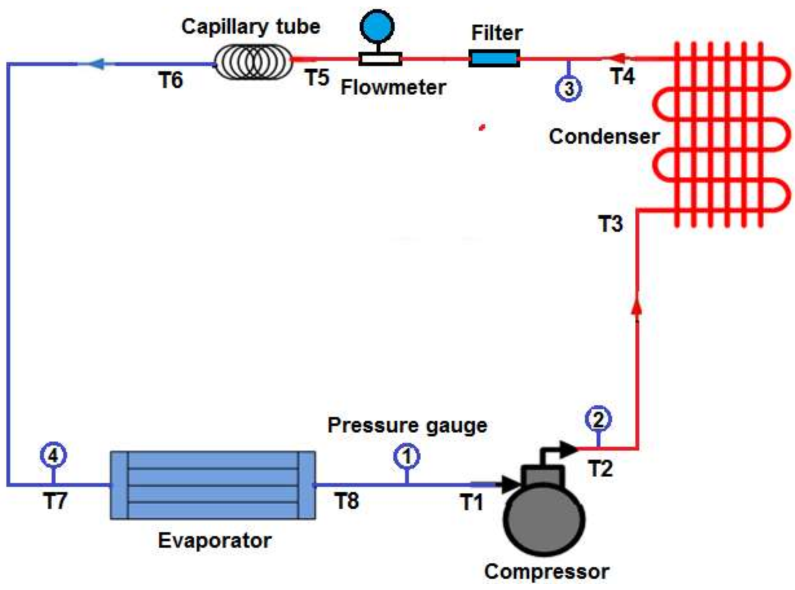

Figure (2) Schematic diagram of VCR system test rig

Figure (3) Refrigeration system test rig

PREPARATION OF NANOPARTICLES–LUB.OIL SUSPENSION

To achieve uniform dispersion of nanoparticles with working fluid, a 50 nm diameter of copper oxide CuO nanoparticles (brought from laboratory materials suppliers) was mixed with Polyolester lubrication oil which is compatible with refrigerant R-134a at three mass fractions and added to the system compressor to be mixed with refrigerant R-134a during its circulation through refrigeration system due to the difficulty of preparing Nano-refrigerant CuO-R134a directly .The nanoparticles-lubrication oil suspension was prepared with three concentrations using, 4 digits electronic balance, magnetic stirrer and ultrasonic vibrator (shaker) in the engineering materials Lab as shown in figure (4). The nanoparticles-oil suspension was at first kept vibrated on magnetic stirrer for 2 hours to obtain proper homogenization and then kept vibrated in the ultrasonic vibrator for 1hour to maintain the suspension with uniform dispersion and to prevent nanoparticles sediments. The nanoparticles-lubrication oil suspension was then added to compressor to form Nano-refrigerant CuO-R134a with three concentrations 0.1%, 0.25%, and 0.4% when circulated through components of the refrigeration system.

The different concentrations of Nano-refrigerant are determined using the following relation:

$$R_{con} = \frac{m_n}{m_n + m_r} \qquad (4)$$

Where: R_{con}: Nano-refrigerant concentration ratio.

m_n : Mass of nanoparticles (g). m_r : Mass of refrigerant (g).

a- Four digits electronic balance before

b- Nanoparticles-oil suspension dispersion (on magnetic stirrer)

Figure (4) Lab. devices used for preparation of nanoparticles-lubrication oil suspension

RESULTS AND DISCUSSION

The performance of the refrigeration system test rig is studied experimentally to investigate the effect of using Nano-refrigerant (CuO- R-134a) as a working fluid comparing with pure refrigerant R-134a at thermal load 600 kJ in the freezing compartment. The effect of nanoparticles-R134a concentrations on system coefficient of performance is indicated in the figure (5) which shows a higher value of COP for Nano-refrigerant with 0.4% concentration relative to other concentrations 0.1% and 0.25%. This effect of Nano-refrigerant concentration percentage on COP is shown as well in figure (6) at steady state of system operation (after 120 minutes). It can be seen from these figures that, the value of COP increases directly with increasing in concentrations of Nano-refrigerant, and for 0.1% concentration the value of COP is approximately close to that for 0.25%, while for Nano-refrigerant with 0.4% concentration the value of COP is obviously higher due to the enhancement in Nano-refrigerant properties caused by CuO nanoparticles. Adding CuO nanoparticles to R-134a refrigerant will increase the thermal conductivity and then enhance heat transfer of the refrigerant and also improve the other thermo-physical properties due to the effect of thermal conductivity of CuO nanoparticles which is significantly higher than that for pure R-134a. The effect of adding nanoparticles is also shown in figure (7) which indicates the variation of evaporator inlet temperature with time for different nanoparticles-refrigerant concentrations at ambient temperature 35°C, it can be seen from the figure that, the lower value of temperature is for Nano-refrigerant with 0.4% concentration throughout system operating period. Comparison of refrigeration system performance using Nano-refrigerant with 0.4% concentration with that using pure R-134a is indicated in figures (8), (9) and (10), which show a higher values of, COP (in range of 10%), refrigeration effect (in range of 1.5%) and lower value of evaporator inlet temperature for Nano-refrigerant compared with R-134a due to the enhancement in system performance produced by using Nano-refrigerant as a working fluid.

Figures (11) and (12) show the comparison of system discharge temperature and pressure as a function of time between refrigerant R-134a and Nano-refrigerant with 0.4% concentration, it can be seen from these figures a significant decrease in discharge temperature and pressure values in range of 4% for Nano-refrigerant specifically after 60 minutes of system operation. Variation of system pressure ratio with time is indicated in figure (13) which show a relatively lower pressure ratio for Nano-refrigerant throughout operating period which mean an energy efficient operation for system using Nano-refrigerant compared with pure refrigerant R-134a. Figures (14) and (15) show the variations of compressor work and power consumption with time respectively for refrigerant R-134a and Nano-refrigerant, it can be seen from these figures a slight increase in value of compressor work and power consumption at first 70 minutes of system operation due to effect of the thermal load in the freezing compartment and then become steady for the rest of operating period with significant reduction in power consumption for Nano-refrigerant in range of 7%. The reduction in system power consumption make using Nano-refrigerants as working fluid in refrigeration systems are economically and efficiently feasible.

CONCLUSION

Three concentrations of CuO-R134a Nano-refrigerant are used to study the performance of the refrigeration system test rig and to investigate the effect of using Nano-refrigerant as a working fluid compared with pure refrigerant R-134a. Concentration percentage (0.4%) of the Nano-refrigerant has reflected higher performance for the refrigeration system compared with other concentrations (0.1% and 0.25%). It can be concluded from the results, that the increasing in concentration of CuO nanoparticles in the Nano-refrigerant will significantly enhance the performance of the refrigeration system, as adding nanoparticles will increase the thermal conductivity, heat transfer and improve the thermo-physical properties of Nano-refrigerant. Investigation of performance parameters for refrigeration system using Nano-refrigerant compared with that for pure refrigerant R-134a showed that, Nano-refrigerant was reflected higher performance in range of 10% increase in COP and 1.5% increase in value of refrigeration effect and 7% reduction in power consumption for refrigeration system, so it can be used efficiently and feasibly in the refrigeration systems.

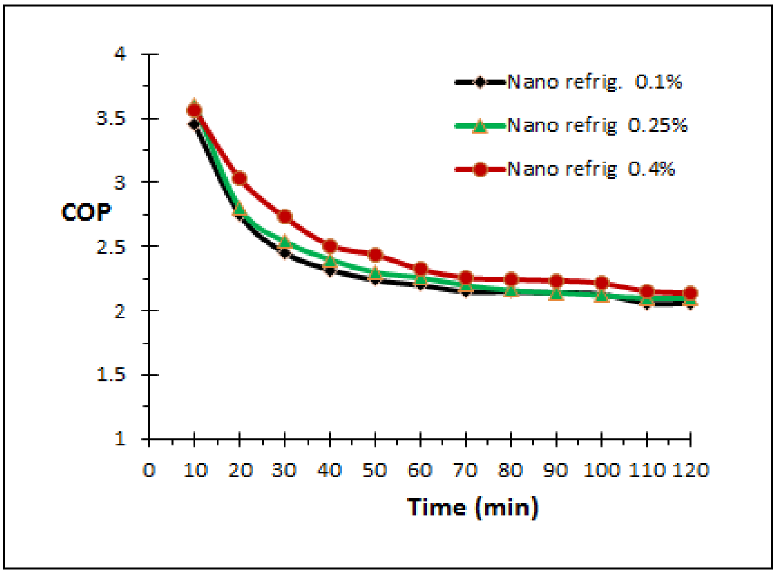

Figure (5) Comparison of COP for refrigeration system as a function of time at different nanoparticles-refrigerant concentrations and T_{amb} = 35°C

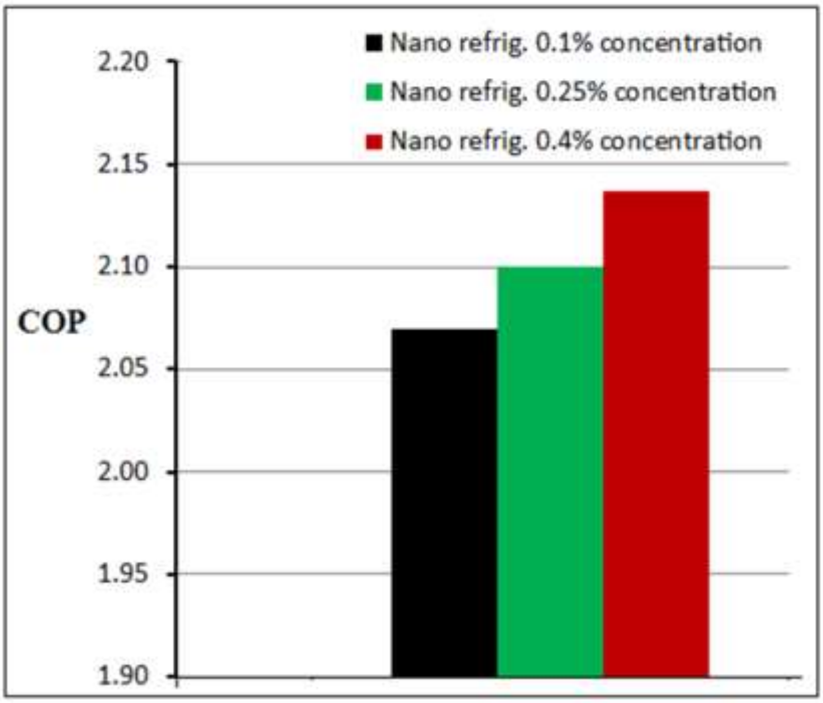

Figure (6) Variation of COP with concentration percentage of Nano-refrigerant at steady state of system operation and T_{amb} = 35°C

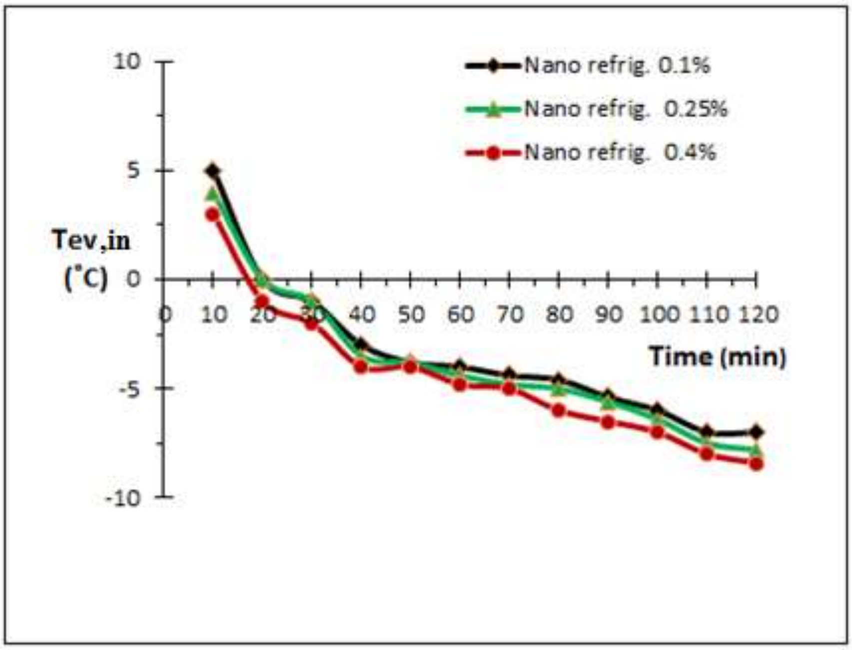

Figure (7) Variation of evaporator inlet temperature with time for different Nanoparticles-refrigerant concentrations and T_{amb} = 35°C

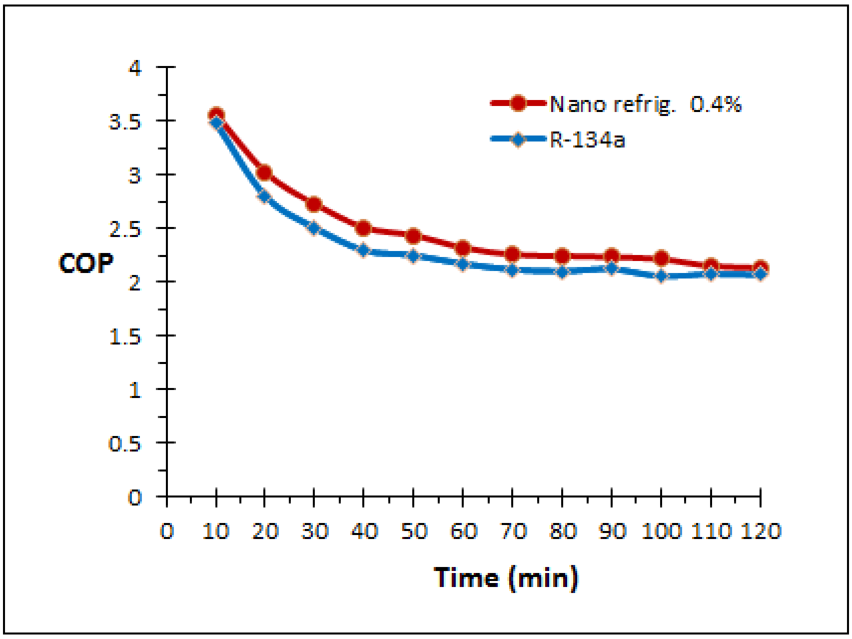

Figure (8) Comparison of COP as a function of time between refrigerant R-134a and Nano-refrigerant with 0.4% concentration at T_{amb} = 35°C

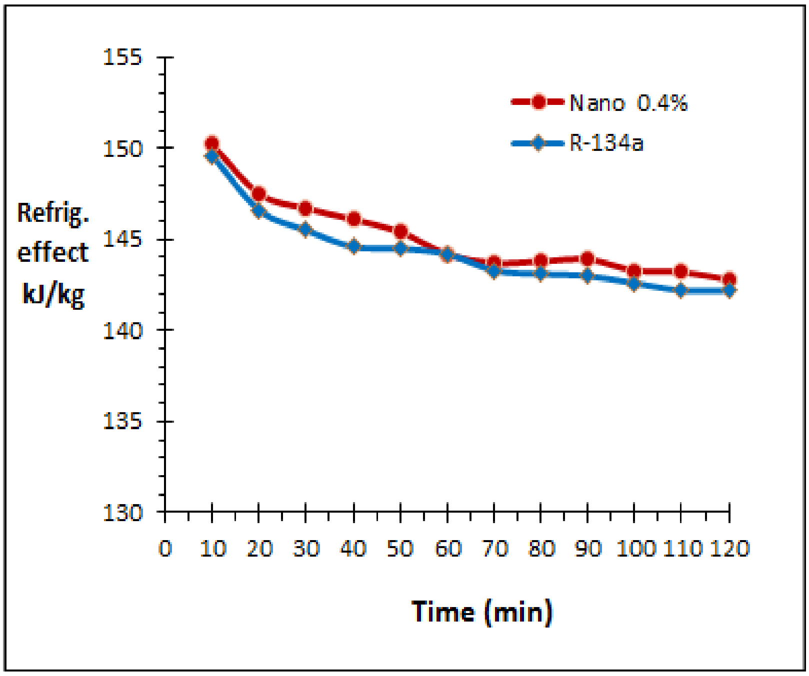

Figure (9) Comparison of refrigeration effect as a function of time between refrigerant R-134a and Nano-refrigerant with 0.4% concentration at T_{amb} = 35°C

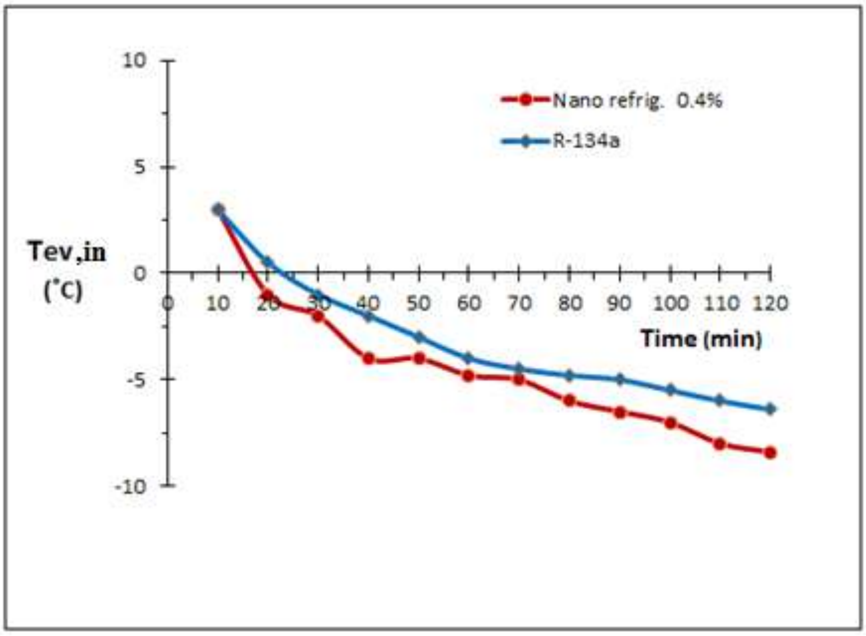

Figure (10) Comparison of evaporator inlet temperature as a function of time between refrigerant R-134a and Nano-refrigerant with 0.4% concentration at T_{amb} = 35°C

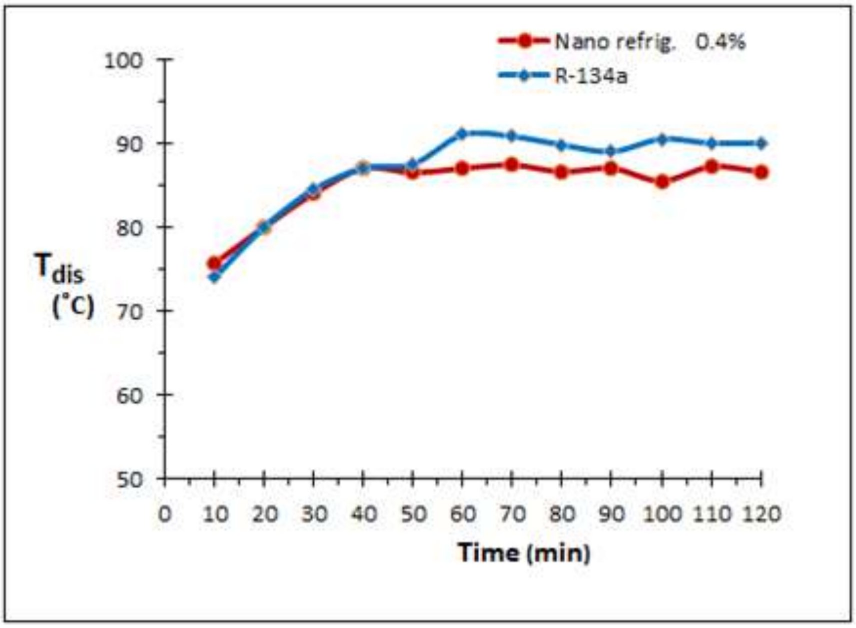

Figure (11) Comparison of system discharge temperature as a function of time between refrigerant R-134a and Nano-refrigerant with 0.4% concentration at T_{amb} = 35°C

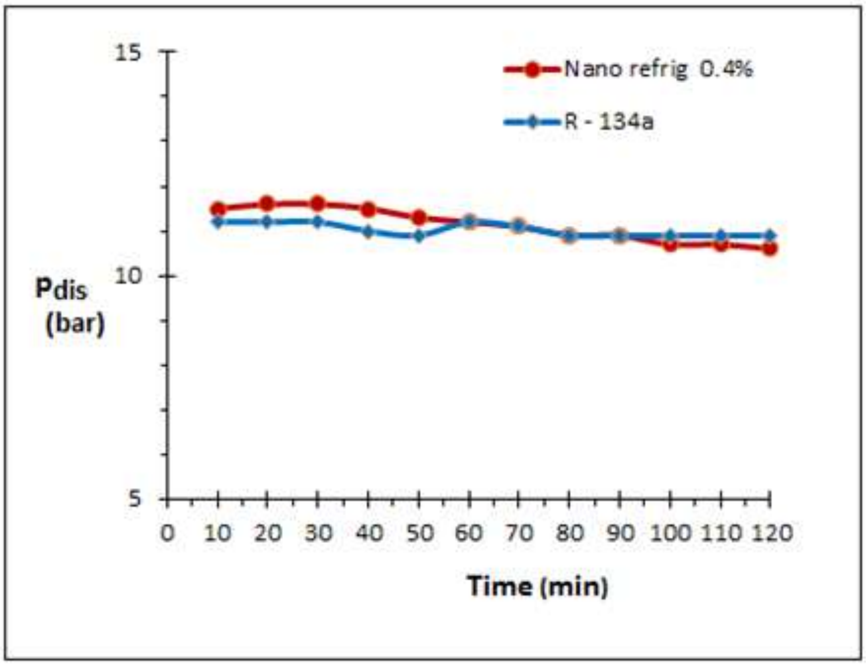

Figure (12) Comparison of system discharge pressure as a function of time between refrigerant R-134a and Nano-refrigerant with 0.4% concentration at T_{amb} = 35°C

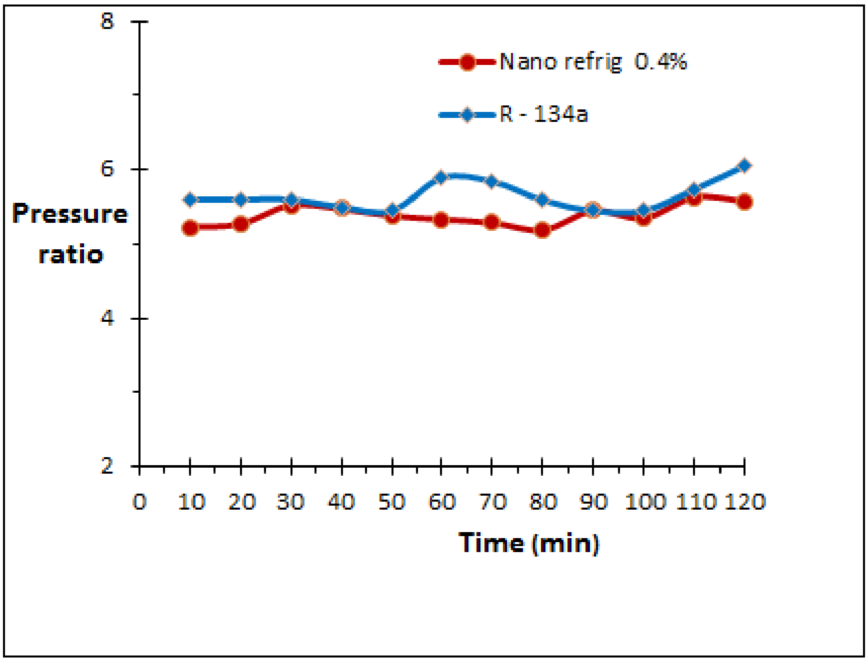

Figure (13) Variation of pressure ratio with time for refrigerant R-134a and Nano-refrigerant with 0.4% concentration at T_{amb} = 35°C

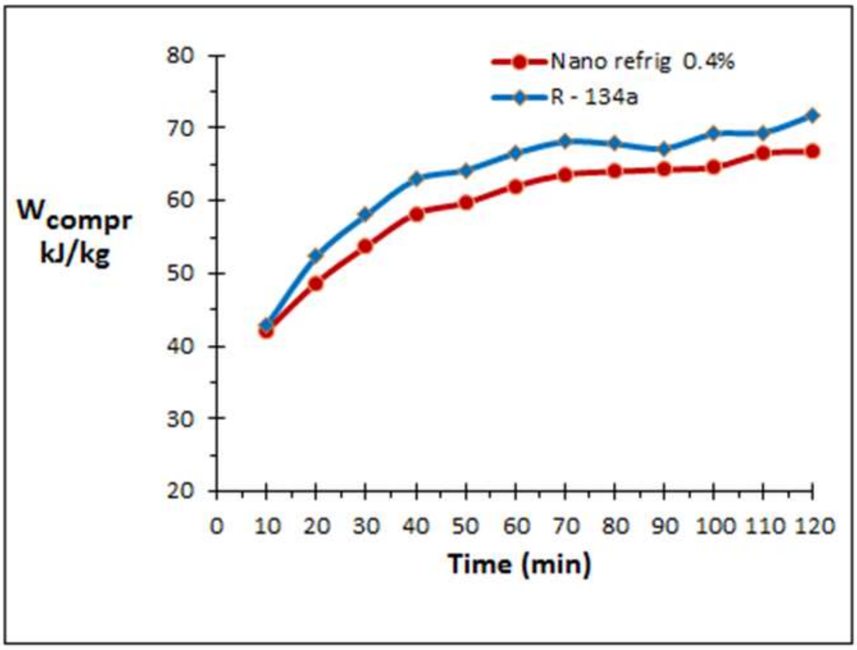

Figure (14) Variation of compressor work with time for refrigerant R-134a and Nano-refrigerant with 0.4% concentration at T_{amb} = 35°C

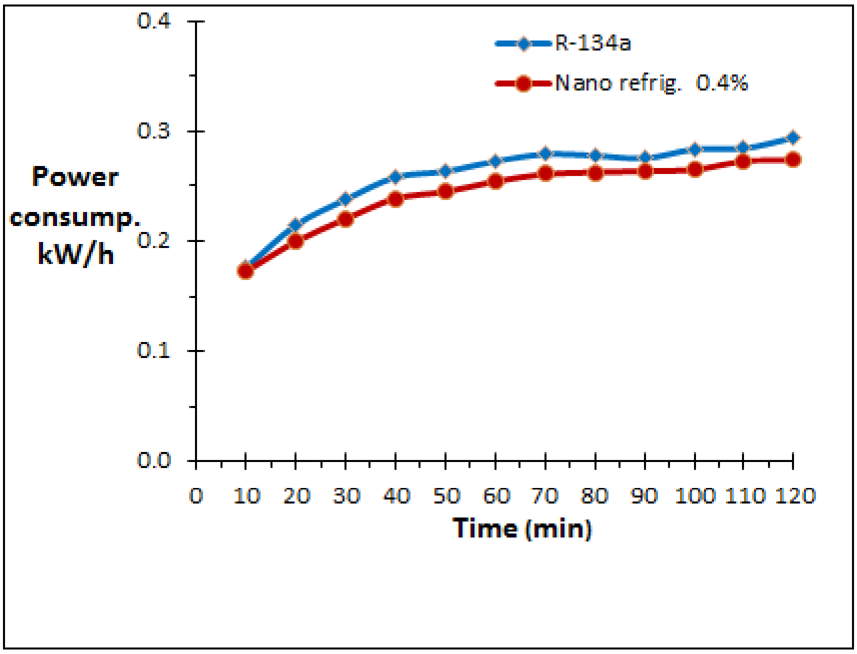

Figure (15) Comparison of power consumption as a function of time between refrigerant R-134a and Nano-refrigerant with 0.4% concentration at T_{amb} = 35°C

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