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A performance study of Vapour compression refrigeration system using ZrO2 Nano particle with R134a and R152a

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Abstract- In this paper the performance of a vapour compression refrigeration system with ZrO2 nanoparticles in the working fluid was studied. Nano refrigerant was synthesized on the basis of the concept of the nanofluids, which was prepared by mixing ZrO2 nanoparticles with R152a refrigerant. The conventional refrigerant R134a has a global warming potential (GWP) of 1300 whereas R152a has a significant reduced value of GWP of 140 only. ZrO2nanoparticles with R152a refrigerant were used in R134a refrigeration system. The system performance with nanoparticles was then investigated. The results indicated that ZrO2 nano refrigerant works normally and safely in the system. The ZrO2 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 20 nm with R134a and R152a was studied. The coefficient of performance of the system was significantly improved with 33.45% when 0.06%volume concentration of ZrO2 with R152a refrigerant was used. The discharge temperature of the R152a/ZrO2 Nano refrigerant was nearly same as that of R134a. The usage of R152a with zero ozone depleting potential and very low Global Warming Potential provides a green and clean environment.

Key words - R134a, R152a, Nano Refrigerant, ZrO2, COP

I. INTRODUCTION

Nanofluids are promise to significantly enhance tribological, rheological and thermal properties of fluids. They are acquired by diffusing solid nanoparticles (diameter 1 nm to 100 nm) made by metallic oxides, metals, carbon nanotubes etc. In common fluids such as water, glycol, oils and refrigerants are also at relatively low concentrations of nanoparticles, it is possible to get strong enhancements of heat exchange coefficients and thermal conductivity, through a conforming enhancement of energy efficiency of plants and components employing such fluids. Other parameters prompting the performance of nanofluids are material, size and shape of nanoparticles, pH and Zeta potential of the colloidal solution, type and concentration of dispersants. Voluminous potential applications for nanofluids in HVAC&R. As nanolubricants, they can improve anti-wear, thermal dissipation and extreme pressure properties of compressors lubricants. The dispersion of nanoparticles directly in the refrigerant can increase the thermodynamic performance of HVAC&R machines.

Choi et al. [1] first suggested coining the term ‘‘nanofluids” by depressing particles in base fluids. These nanofluids have been exposed to have additional heat transfer capabilities and have become a current research topic in heat transfer research. Many efforts have been made to study the effective high thermal conductivity, convective heat transfer, and the phase change heat transfer of nanofluids. However, inconsistent results have shown that the nanoparticles can both enhance and reduce the phase change heat transfer.

Shengshan Bi et al. [2] have investigated the basic characteristics of the TiO2-R134a nano-refrigerants, reliability, the dispersion behavior, thermal conductivity and flow boiling heat transfer [3,4]. The performance of a domestic refrigerator with nanoparticles added was also investigated. The results indicated performance was better than the R134a and POE oil system, with 26.1% less energy consumption used with 0.1% mass fraction TiO2 nanoparticles compared to the R134a and POE oil system. The same tests with Al2O3 nanoparticles showed that the different nanoparticles properties have little effect on the refrigerator performance. Thus, nanoparticles can be used in domestic refrigerators to considerably reduce energy consumption. In the former experiment, the nanoparticles were added into the refrigeration system in two different ways. In one way the nanoparticles were added to the refrigeration system by first adding them into the lubricant to make a nanoparticle lubricant mixture. Then, the mixtures were put into the compressor as the lubricant [5]. In the other way nanoparticles and traditional refrigerant were mixed directly to make nano-refrigerant [6]. The results of both of the ways had showed the better performance of the refrigerator with nanoparticles added.

Bi et al. [7] has investigated the nano refrigerant TiO2/R600a on a domestic refrigerator and conducting an energy consumption test and freezing capacity test in that domestic refrigerator. The results indicate that the refrigerator with nano refrigerant consumed 9.6% less energy with 0.5 g/L TiO2/R600a nano refrigerant as compared to one with base refrigerant. A nano refrigerant-based refrigerator showed reduced compressor suction and discharge pressure, and the largest reduction was observed for a concentration of 0.5 g/L. The test was conducted multiple times to ensure repeatability.

Sendil Kumar et al [8] have investigated on nano refrigerant. Nano Al2O3/PAG oil was used as nano-refrigerant in R134a vapour compression refrigeration system. The system performance was investigated using energy consumption test and freeze capacity test. The results indicate that Al2O3 nano refrigerant works normally and safely in the refrigeration system. The refrigeration system performance was better than pure lubricant with R134a working fluid with 10.32% less energy used with 0.2%Vol of the concentration used. And also heat transfer coefficient increases with the usage of nano Al2O3.

R. Reji Kumar [9] have investigated heat transfer enhancement was numerically on the surface of a refrigerator by using Al2O3 nano-refrigerants, where nanofluids could be a significant factor in maintaining the surface temperature within a required range. In the addition of nanoparticles to the refrigerant results in improvements in the thermo physical properties and heat transfer characteristics of the refrigerant, thereby improving the performance of the refrigeration system. The experimental studies indicate that the refrigeration system with nano-refrigerant works normally. It is found that the freezing capacity is higher and the power consumption reduces by 11.5 % when POE oil is replaced by a mixture of mineral oil and Aluminium oxide nanoparticles.

Subramani and Prakash [10] studied the R134a/ Al2O3 nano refrigerant and found that there is an enhancement in COP while nanoparticles were added to the system. They also determined the system's COP theoretically for both R134a and R134a/ Al2O3. They found that the COP of that use R134a increases by 10.11% while the R134a/ Al2O3 mixture used in the actual refrigeration cycle and enhancement ratio was 9.74% when COP determined theoretically. Saidur [11] studied the use of nanorefrigerants in domestic refrigerators to reduce the energy consumption and emissions of greenhouse gasses. They used TiO2-mineral oil- R134a and Al2O3 -mineral oil-R134a with mass fractions of 0.06% and 0.1% as nanorefrigerants. The nanorefrigerants containing TiO2nanoparticles of 0.1 wt. % displayed the highest energy savings up to 25%.

Baskaran, A. et al [12] analysed the performance of a vapour compression refrigeration system with various eco-friendly refrigerants of HFC152a, HFC32, HC290, HC1270, HC600a and RE170 and their results were compared with R134a as possible alternative replacement. The results showed that the refrigerant R152a have higher COP of 4.65% than that of R134a.

Baskaran, A. et al [13] analyzed the performance of a vapour compression refrigeration system with various refrigerants mixture of HFC152a, HC290, HC600a and RE170 and their results were compared with R134a as possible alternative replacement. The results showed that the refrigerant blend R152a / R600a (76/24 by wt. %) was found to be replacement for R134a and also the COP of this blend is 2.3% higher than that of R134a.

A.Baskaran et al [14] analyzed the energy and exergy performance of a vapour compression refrigeration system with various eco-friendly refrigerants of HFC152a, and RE170 and their results were compared with R134a as possible alternative replacement. The results showed that the refrigerant R152a have higher average COP of 4.65% than that of R134a. The exergetic efficiency of the system using R152a is 5.02% higher than that of R134a at -10°C evaporating temperature. The average exergy loss for R152a is 8.2% lower than that of R134a.

Melih Aktas et al [15] have studied five different nanorefrigerants with Al2O3 nanoparticles and their pure fluids: R12, R134a, R430a, R436a, and R600a. The coefficient of performance (COP) and compressor work for various evaporation and condensation temperatures are investigated. The enthalpy of nanorefrigerants is obtained through the density. The results indicate that COP is enhanced by adding nanoparticles to the pure refrigerant and maximum values obtained using the R600a/ Al2O3 mixture.

Even though the nanorefrigerants have been extensively studied over the years, there quiet remains scope to discuss specifically application of nano refrigerants in HVAC&R system. This paper presents the effect of nanoparticles on the thermodynamic performance of a refrigeration system. The aim of the current study is to examine the COP and the compressor work of 0.06% volume concentrations of ZrO2 nanoparticles with R134a and R152a. The performance of the nanorefrigerants in a VCR cycle is evaluated [11, 15]. The performance parameters of the refrigeration cycle, such as the COP, compressor work, Refrigerating Effect and condenser duty were investigated for various evaporation and condensation temperatures.

II. THEORETICAL MODEL

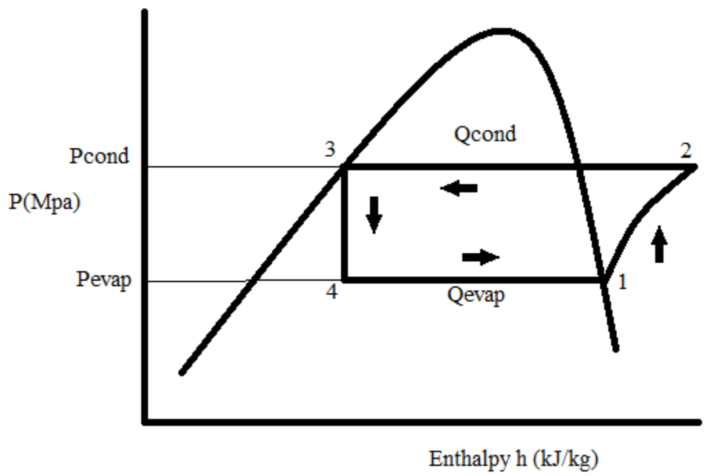

Figure 1. P-h diagram of vapor compression refrigeration cycle

Generally, the vapor compression refrigeration system consists of a condenser, an expansion valve, an evaporator, and a compressor. The vapor compression refrigeration cycle consists of four processes:

(1-2) compressing refrigerant in compressor isentropically,

(2-3) condensation at constant pressure,

(3-4) adiabatic expansion in the expansion valve,

(4-1) evaporation at constant pressure.

The pressure enthalpy diagram of was given in Figure 1. The evaporation of the refrigerant occurs at a constant pressure during process (4-1) in the evaporator. The refrigerant at the inlet of the evaporator is vaporized by removing heat from the area desired to cool. Saturated vapor at point 1 goes into the compressor at low pressure and is exposed to a reversible adiabatic compression during the process from 1 to 2 in Figure 1. During process (2-3), while the heat is rejected in the condenser at a constant pressure, the working fluid changes to a saturated liquid when exiting the condenser. Refrigerant at point 1 in Figure.1 is saturated vapor at the evaporator temperature and at point 3 is saturated liquid at the condenser temperature. The working fluid at the exit of the expansion valve enters the evaporator, and the cycle is completed. Completely vaporized refrigerant enters the compressor, and its pressure and temperature increase during the compressing process. Calculations of the comparison of pure and blended refrigerants during various refrigeration cycles can be seen in previous studies [16, 17].

The refrigeration effect (RE), also called the heat transfer rate of the evaporator (qe) is calculated as follows:

$$q_e = h_1 - h_4 \quad (1)$$

The condenser duty, also called the heat transfer rate of the condenser (qc) is calculated as follows:

$$q_c = h_2 - h_3 \quad (2)$$

The isentropic compression work of the compressor (W_{comp}) is expressed as follows:

$$W_{comp} = h_2 - h_1 \quad (3)$$

The isentropic efficiency of the compressor is calculated as follows:

η_{isen} = Isentropic compressor work / Actual compressor work

$$\eta_{isen} = h2s-h1/h2a-h1 \quad (4)$$

The performance of refrigerators is determined in terms of the COP. COP is defined as follows:

$$COP = qe / Wcomp = h1-h4 / h2-h1 \quad (5)$$

The density of a mixture of nanoparticles (ρ_{NR}) and the base fluid (ρ_{PR}) can be determined based on Xuan and Roetzel [18];

$$\rho_{NR} = \omega \rho_{NP} + (1 - \omega)\, \rho_{PR} \quad (6)$$

III. NANO PARTICLE CHARACTERIZATION

ZrO2 nanoparticles synthesized by either the sol–gel method (solution method) or the hydrothermal method. As the solution method presents a low cost and environmentally friendly synthetic route, most of the literature for ZrO2 nanoparticles is based on the solution method. In addition, synthesis of ZrO2 nanoparticles in the solution requires a well-defined shape and size of ZrO2 nanoparticles. Further it was characterized by X-ray diffraction (XRD) and, scanning electron microscopy (SEM).

X-RAY DIFFRACTION (XRD) PATTERN

Crystallinity, crystallite phase and size of all the samples were obtained by X-ray diffract meter using Cuk α radiation (λ=0.1540598 nm). Scanning range was between 10 and 80° and scan rate was 0.05°/s. In order to determine the crystallite size of each sample, Debye–Scherer formula (D=K λ/β·cos)was applied, in which K (=0.94) stands for shape factor, λ (=0.1540598 nm) represents the wavelength of α radiation, β is the half width of each diffraction peak, and stands for the half angle of each diffraction peak.

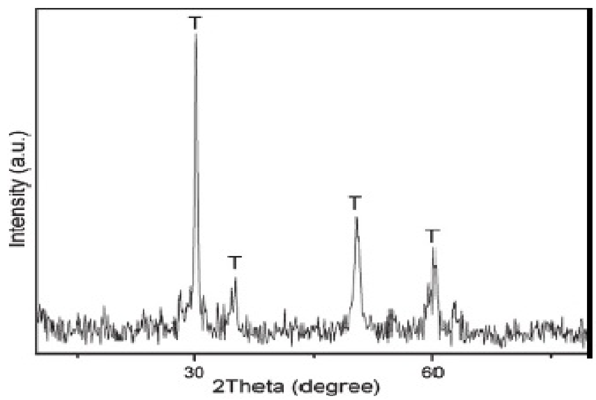

Fig: 3.1 Bulk Zirconia

Fig 3.1 shows the XRD pattern of bulk zirconia .The distinguishing characteristic peak for tetragonal occurs at 2θ =30.5° for the (111) reflection, and the respective peaks for monoclinic occur at 2 =28.4° and 2θ =31.6° for the (111) reflection. The XRD pattern of the sample is shown in Fig. 1, indicating the effect of organic additives on the crystallinity of zirconia nanoparticles. As it can be seen, three characteristic peaks at 2θ =30.22, 50.31 and 60.12 are included which are corresponding to tetragonal phase.

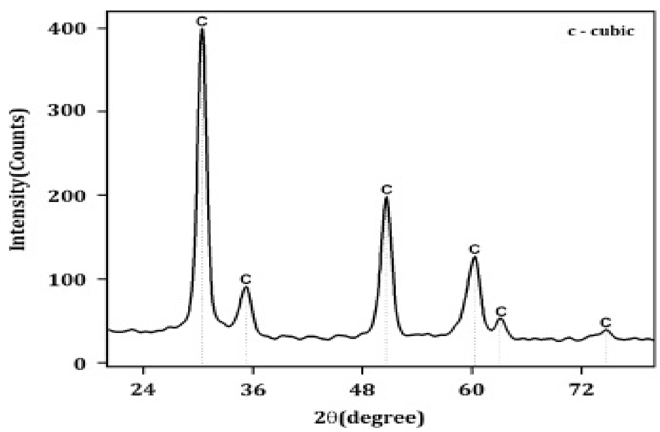

Fig: 3.2 Nano Zirconia

Fig 3.2 shows the XRD pattern of nano zirconia. The zirconia was sintered 500°C the phase transitions of the particle size is reduced and change the structure from tetragonal to cubic structure. The characteristic peaks at 2θ =28.33, 35.80, 51.33, 60.12 and 74.33 are included which are corresponding to cubic phase.

SCANNING ELECTRON MICROSCOPY (SEM) IMAGE

Aggregated and non-aggregated zirconia could be well distinguished from the SEM results. The SEM findings not only justify the aggregation of the particles but also show the particle morphology.

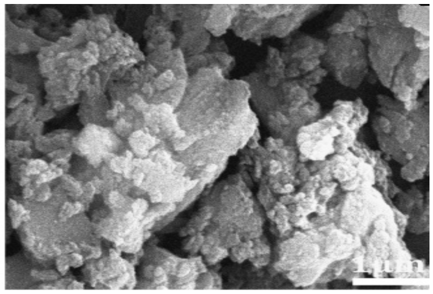

Figure 3.3 Bulk Zirconia – Cubic Morphology

Fig 3.3 shows the SEM image of bulk zirconia, that the synthesized cubic zirconia has an aggregated surface with higher particles size, compared to spherical morphology. Aggromalated surfaces are found in cubic morphology of bulk Zirconia.

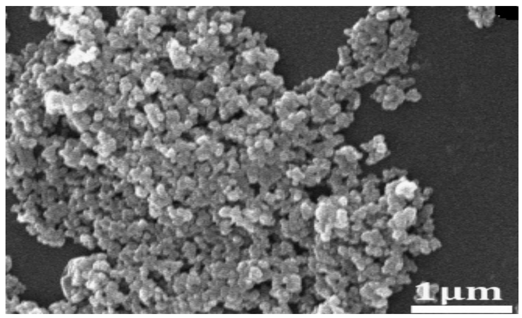

Figure 3.4 Nano Zirconia – Spherical Morphology

Fig 3.4 shows the SEM image of nano zirconia, that the disaggregated particles with almost spherical morphology.

IV. RESULT AND DISCUSSION

COEFFICIENT OF PERFORMANCE

Figure 4.1 shows the variation of coefficient of performance with evaporating temperature varies from -20°C to 10°C at 45°C condensation temperature. It was seen from the figure, the coefficient of performance of the system increases when the evaporating temperature increases. The performance of the system with ZrO2+R152a Nano refrigerant is higher than that of R134a and R152a. This same trend is observed in 50°C and 55°C condensation temperatures as shown in figures 4.2 and 4.3.

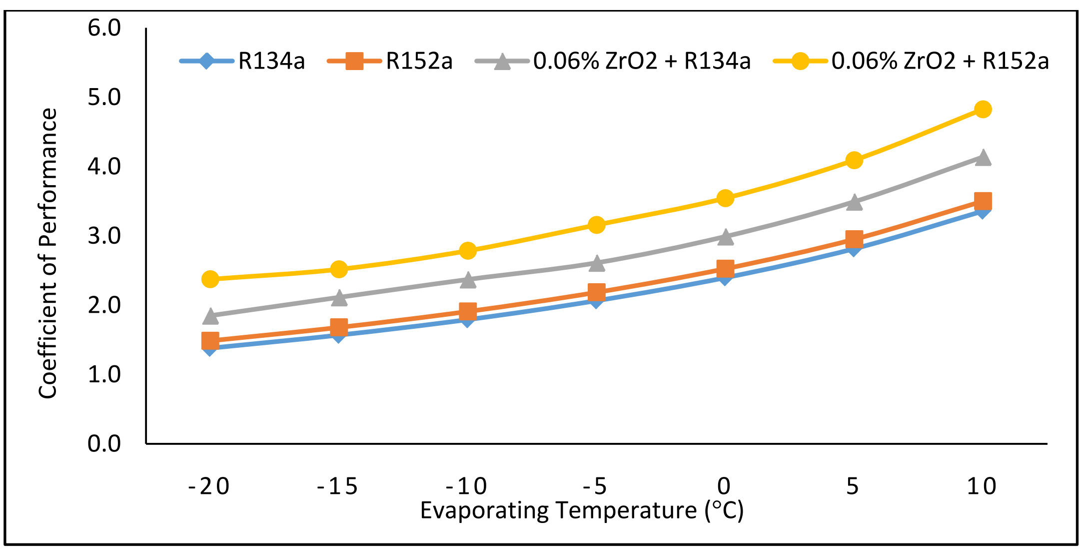

Figure 4.1 Variation of COP with evaporating temperature at condensing temperature of 45°C

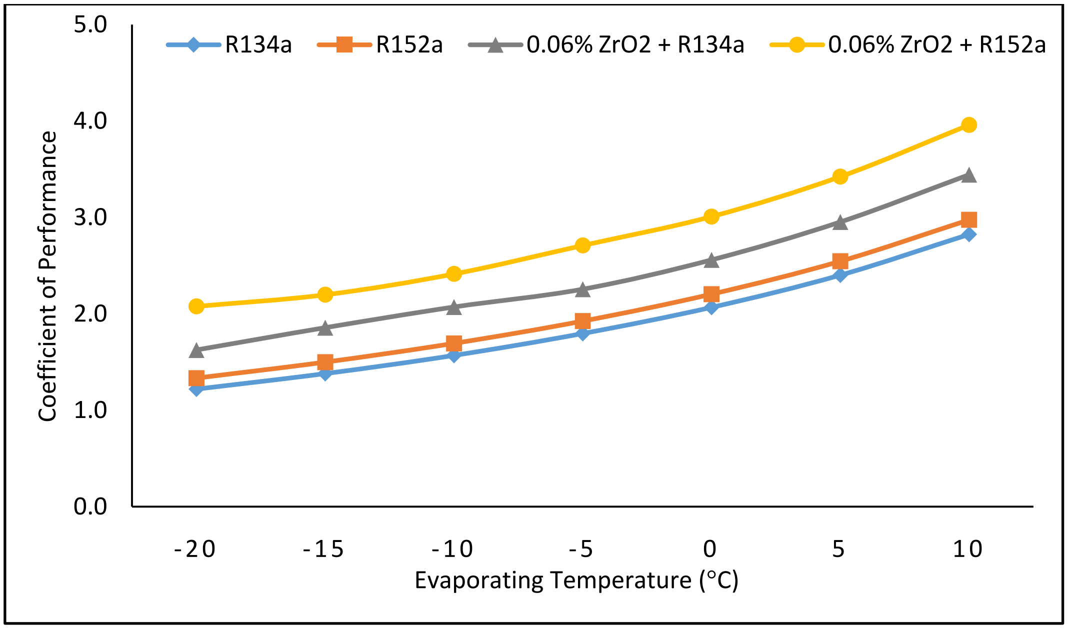

Figure 4.2 Variation of COP with evaporating temperature at condensing temperature of 50°C

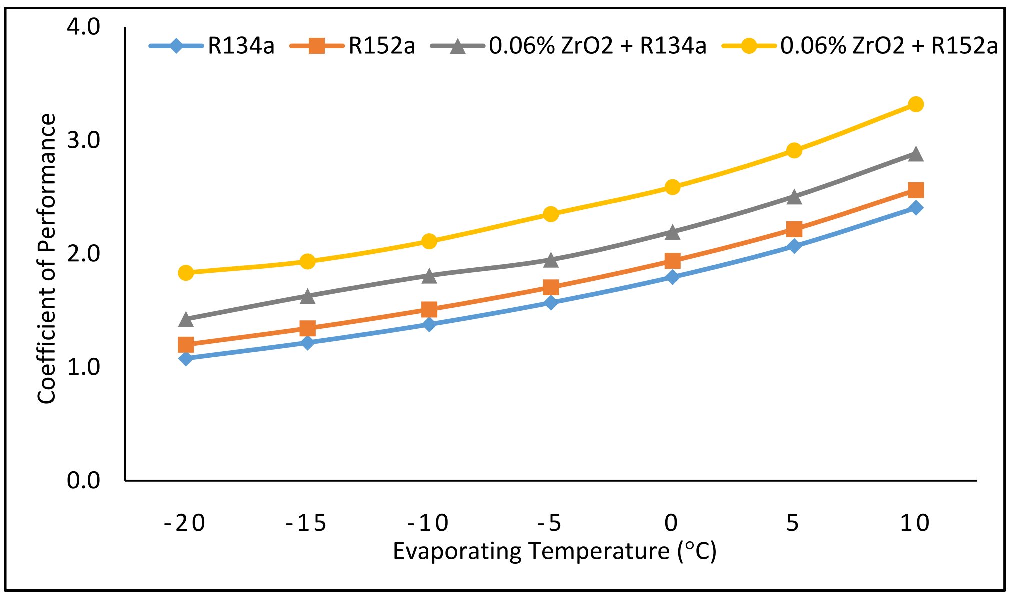

Figure 4.3 Variation of COP with evaporating temperature at condensing temperature of 55°C

COMPRESSOR WORK

Figure 4.4 shows the variation of compressor work with evaporating temperature varies from -20°C to 10°C at 45°C condensation temperature. It was seen from the figure, the compressor work of the system decreases when the evaporating temperature increases. The compressor work of the system with ZrO_2+R152a Nano refrigerant is lower than that of R152a and higher than that of R134a. This same trend is observed in 50°C and 55°C condensation temperatures as shown in figures 4.5 and 4.6.

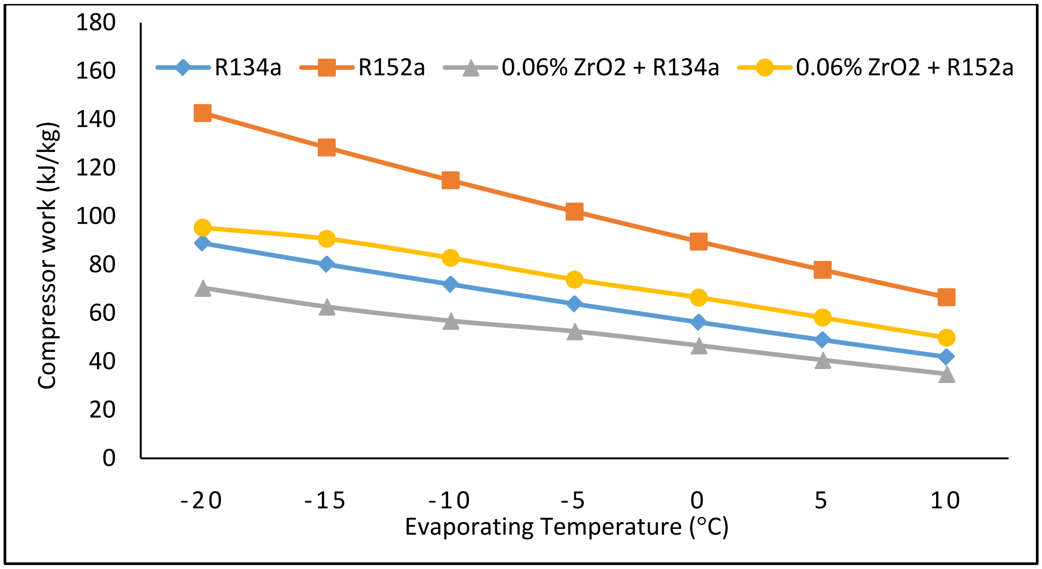

Figure 4.4 Variation of Compressor work with evaporating temperature at condensing temperature of 45°C

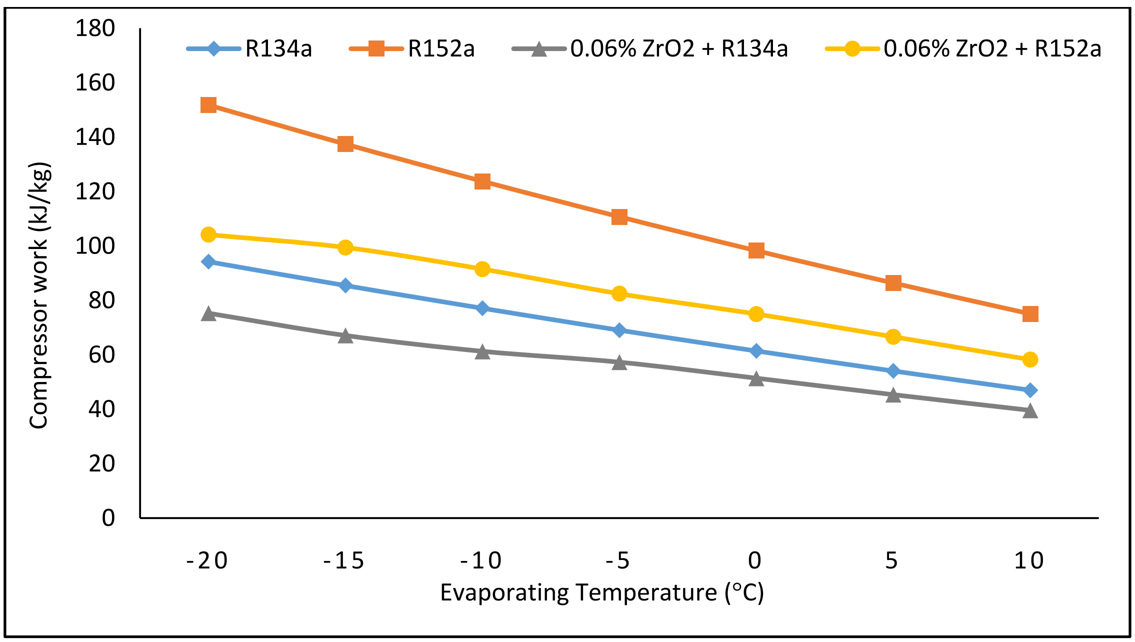

Figure 4.5 Variation of Compressor work with evaporating temperature at condensing temperature of 50°C

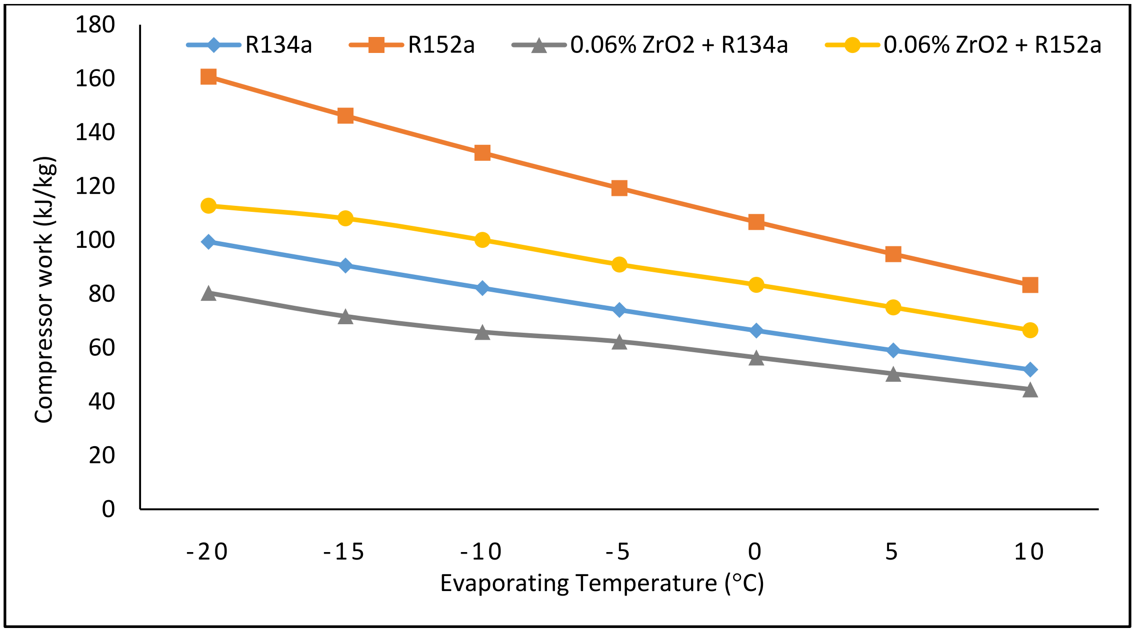

Figure 4.6 Variation of Compressor work with evaporating temperature at condensing temperature of 55°C

Refrigerating Effect (RE)

Figure 4.7 shows the variation of refrigerating effect with evaporating temperature varies from -20°C to 10°C at 45°C condensation temperature. It was seen from the figure, the refrigerating effect of the system increases when the evaporating temperature increases. The refrigerating effect of the system with ZrO2+R152a Nano refrigerant is higher than that of R152a and R134a. This same trend is observed in 50°C and 55°C condensation temperatures as shown in figures 4.8 and 4.9.

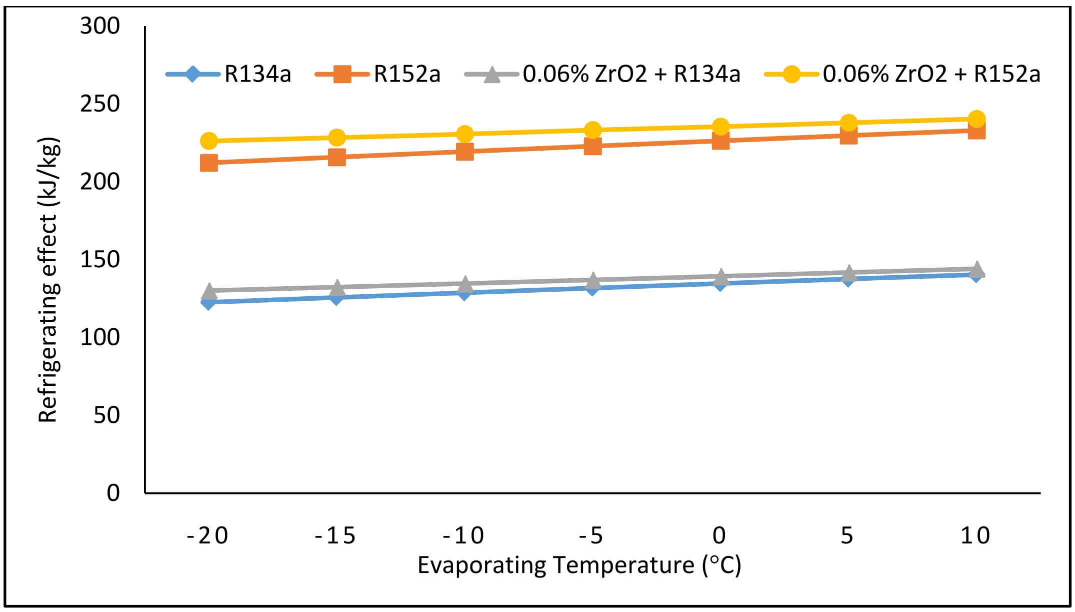

Figure 4.7 Variation of Refrigerating effect with evaporating temperature at condensing temperature of 45°C

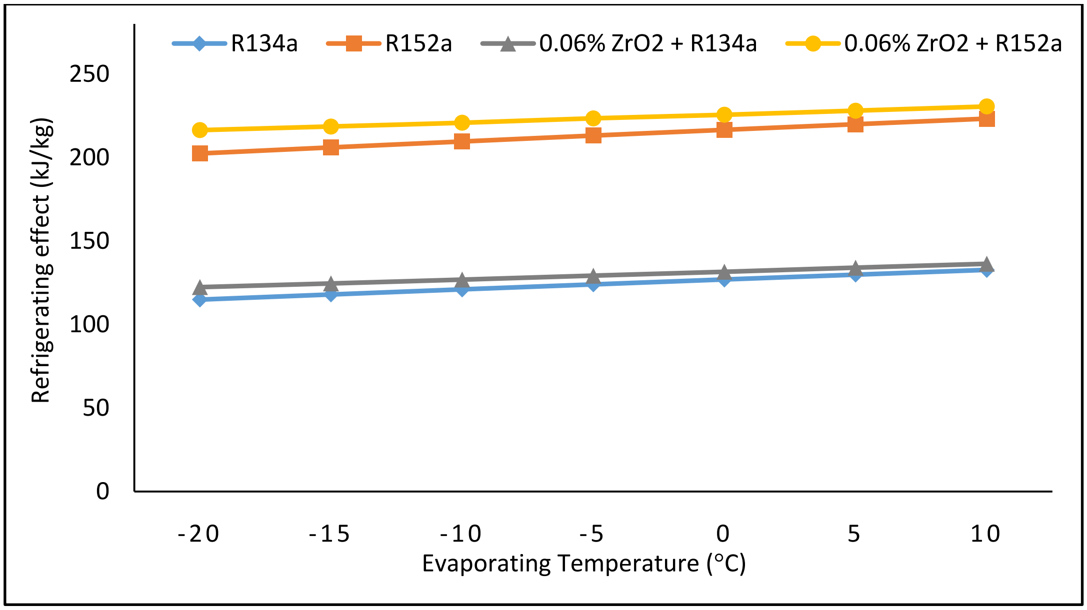

Figure 4.8 Variation of Refrigerating effect with evaporating temperature at condensing temperature of 50°C

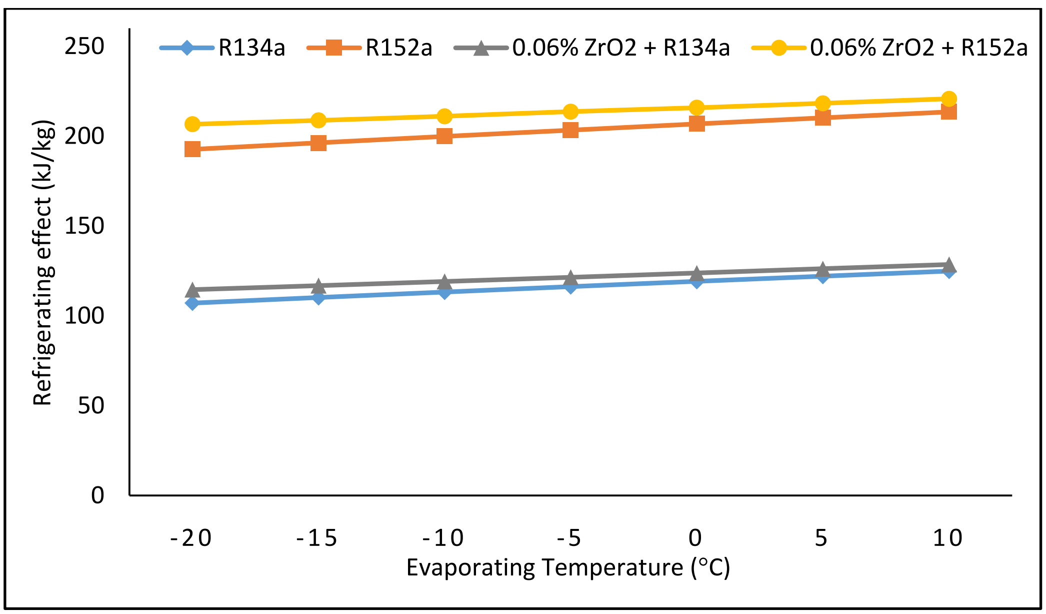

Figure 4.9 Variation of Refrigerating effect with evaporating temperature at condensing temperature of 55°C

CONDENSER DUTY (q_C)

Figure 4.10 shows the variation of condenser duty with evaporating temperature varies from -20°C to 10°C at 45°C condensation temperature. It was seen from the figure, the condenser duty of the system decreases when the evaporating temperature increases. The condenser duty of the system with ZrO2+R152a Nano refrigerant is lower than that of R152a and higher than that of R134a. This same trend is observed in 50°C and 55°C condensation temperatures as shown in figures 4.11 and 4.12.

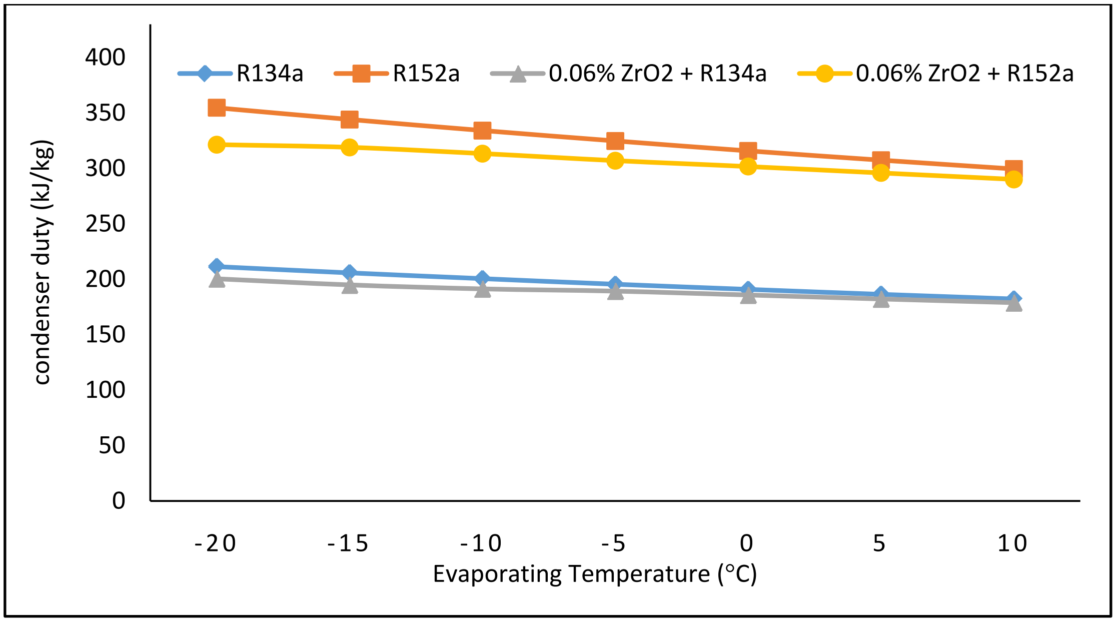

Figure 4.10 Variation of condenser duty with evaporating temperature at condensing temperature of 45°C

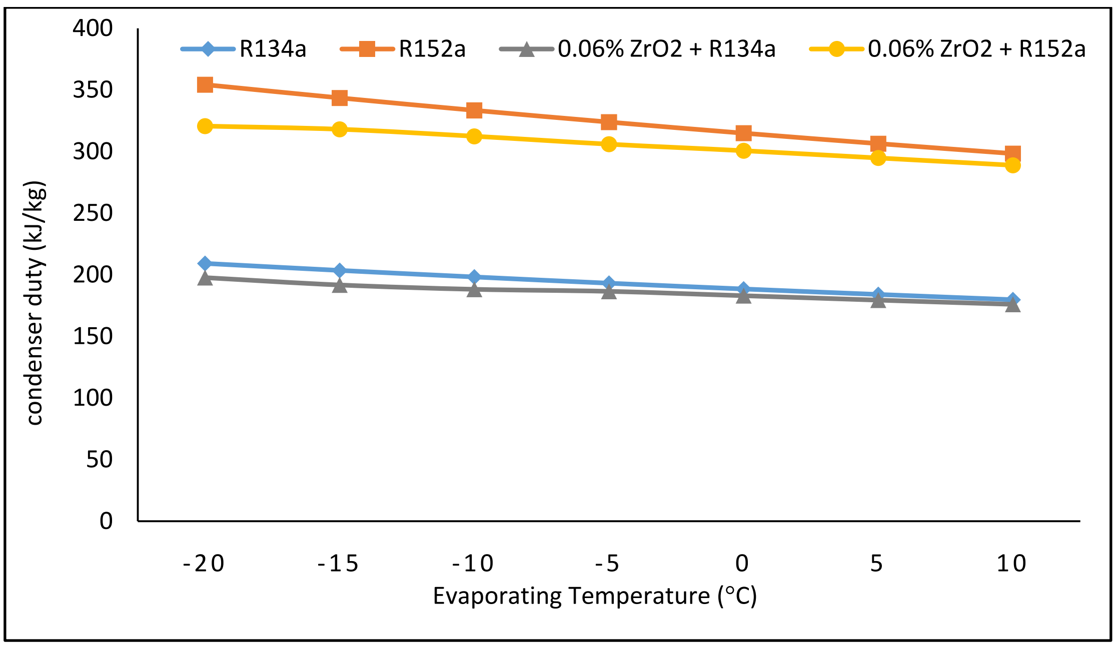

Figure 4.11 Variation of condenser duty with evaporating temperature at condensing temperature of 50°C

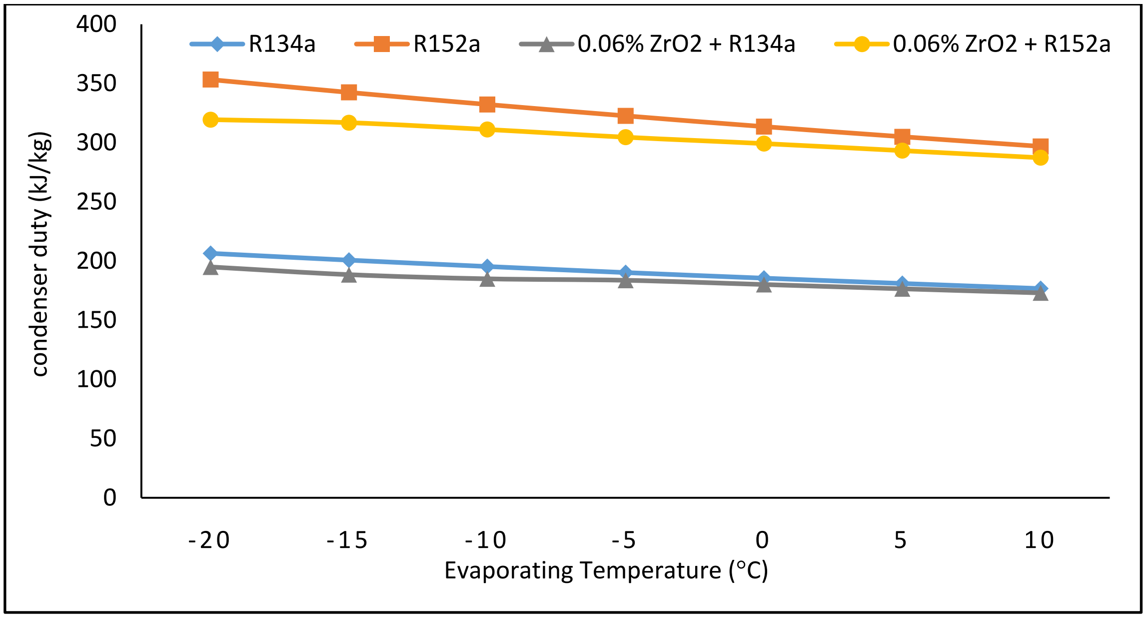

Figure 4.12 Variation of condenser duty with evaporating temperature at condensing temperature of 55°C

Some results study for the validation process of the current study can be seen in the table 1.

Table 1. The results from comparative study for the validation process of the current results.

Author's Name	Refrigerant	Study of System	T1 (°C)	Density of Nano Particle (ρ) (kg/m3)	P1 (bar)	T2 (°C)	T3 (°C)	P3 (bar)	COP	Increase (%)
Melih Aktas et. al [15]	R134a	Theoretical	−7	—	2.25	81.21	45	11.60	1.96	—
Present Study	R152a	Theoretical	−7	—	2.038	97.79	45	10.37	2.087	6.85
Melih Aktas et. al [15]	R134a/ Al2O3	Theoretical	−2.03	3690	2.72	76.23	45	11.49	2.29	14.41
	R134a/ Al2O3	Theoretical	−3.96	2200	2.53	78.26	44.85	10.09	2.15	9.69
Present Study	R134a / ZrO2	Theoretical	0.6	5890	2.99	71.8	44.4	11.42	2.47	20.64
Present Study	R152a / ZrO2	Theoretical	5.87	5890	3.24	80.93	43.95	10.09	3.136	33.45

V. Conclusion

In this study, the effect of adding the ZrO2 Nano particle to R134a and R152a was investigated by means of refrigeration effect, compressor work, condenser duty and COP comparisons. The prediction method based on nano refrigerant density was taken in to consideration in the calculations to define nano refrigerant enthalpies in the refrigeration cycle. R152a and R152a - ZrO2 nano refrigerants had the highest COP under all conditions considered in this study. Although R134a showed the lowest compressor work, cannot be used in the applications anymore because of its GWP value. Results obtained using theoretical analysis were compared with the results available in the literature. The performance improvement of the refrigeration cycle by applying a nanoparticle is mainly due to heat transfer enhancement in heat exchangers and reduction of power consumption of the compressor by improvement of lubrication. These effects are included in the theoretical analysis as well.

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