Thermal Performance Improvements of Vapour Compression Refrigeration System Using Eco Friendly Based Nanorefrigerants in Primary Circuit

R. S. Mishra, Rahul Kumar Jaiswal
Department of Mechanical Engineering, Delhi Technological University, Delhi, India

Article Info

Article history:
Received 12 July 2015
Received in revised form
20 July 2015
Accepted 28 August 2015
Available online 15 September 2015

Keywords
First law Efficiency Improvement,
Energy-Exergy Analysis,
Nano refrigerants,
Ecofriendly Refrigerant,
Vapour Compression Refrigeration System,
Second Law (Exergetic Efficiency) Improvement

Abstract

Now a days nano refrigerants are being considered as a most efficient heat transfer fluids having superior heat transfer properties than conventional refrigerants in various thermal applications. Refrigerant based nano fluid termed as "Nanorefrigerant" have the great potential for improve thing first law thermal performance in terms of coefficient of performance in the refrigeration and air conditioning system. The thermo physical properties by addition of different nanoparticle mixed with eco friendly refrigerant are analyzed and their effects on the coefficient of performance (C.O.P.) have been reported in this paper. The thermal modeling have been done for the same cooling load and same geometry parameter for all nanoparticles and refrigerant combination mixture in the vapour compression refrigeration based chiller system having two concentric tube type heat exchanger as evaporator and condenser. The experimental results are indicating the thermal conductivity, dynamic viscosity and density of nanorefrigerant (different nanoparticle i.e. Cu, Al_2O_3,CuO and TiO_2 with eco friendly refrigerant R134a,R407c and R404A) increased about 15 to 94 %, 20% and 12 to 34 % respectively compared to base refrigerant on the other hand specific heat of nanorefrigerant is slightly lower that the base refrigerant. Moreover Al_2O_3/R134a nanorefrigerant shows highest C.O.P. of 35%. R404A and R407 with different nanoparticle show enhancement in C.O.P. about 3 to 14 % and 3 to 12 % respectively. Therefore application of nanorefrigerant in refrigeration and air conditioning system is most required to improve the performance of the system.

Nomenclature

COP	Coefficient of performance
COPt	Global coefficient of performance
Cp	Specific heat (J/kg K)
D	Diameter (m)
h	Specific enthalpy (J/kg)
k	Thermal conductivity (W/m K)
L	Length (m)
M	Mass flow rate (kg/s)
N	compressor speed (r.p.m.)
P	Power consumption (W)
p	Pressure (Pa)
Q	Volumetric rate of flow (m3/s)
q	Heat transfer rate (W)
q"	Heat Flux (W/m2)
r	Radius (m)
S	Area (m2)
T	Temperature (K)
t	Time (s)
U	Overall heat transfer coefficient (W/m2 K)
VG	Geometric compressor volume (m3)
v	Velocity (m/s)
x	Refrigerant quality
X n,o	nanoparticle/oil suspension concentration

Suffixes

air	Environment
avg	Brine/nanofluid
C	Compressor
e	Evaporation
i	Inner
in	Input
k	Condensation
l	Liquid
M	Metal
o	Outer
out	Output
r	Refrigerant
sat	Saturated
V	Vapor
w	Water
nf	Nanofluid
m	Base fluid
p	Nanoparticle
ϕ	volume fraction
n	nanoparticle
o	Lubricating oil
f	Saturated liquid
G	Saturated vapour
nb	Nucleate boiling
wn	Nanoparticle concentration in nanoparticle oil suspension

Greek symbols

α	Heat transfer coefficient (W/m^2 K)
λ	Phase change latent heat (J/kg)
μ	Dynamic viscosity (Pa s)
η_v	Compressor volumetric efficiency

Corresponding Author,
E-mail address: professor_rsmishra@yahoo.co.in

η_{is} Compressor isentropic efficiency
η_G Global electromechanical compressor efficiency
ρ Density (kg/m^3)
σ Surface tension (N/m)

1. Introduction

Now a days refrigeration and air conditioning system are more important for industrial and domestic appliances. These systems consume more electricity than the other. Lots of research have been done till now to reduce the power consumption of refrigeration and air conditioning system. Nanofluid is a new kind of heat transfer medium, containing nanoparticles (1–100 nm) which are uniformly and stably distributed in a base fluid. These distributed nanoparticles, generally a metal or metal oxide greatly enhance the thermal conductivity of the nanofluid, increases conduction and convection coefficients, allowing for more heat transfer. Nanofluids have been considered for applications as advanced heat transfer fluids for almost two decades. However, due to the wide variety and the complexity of the nanofluid systems, no agreement has been achieved on the magnitude of potential benefits of using nanofluids for heat transfer applications. Compared to conventional solid–liquid suspensions for heat transfer intensifications, nanofluids having properly dispersed nanoparticles possess the following advantages:

- High heat transger surface area between particle and fluid.
- High dispersion stability with Brownian motion of particles.
- Reduced pumping power as compared to pure liquid to achieve equivalent heat transfer intensification.
- High specific surface area and therefore more heat Reduced particle clogging as compared to conventional slurries, thus promoting system miniaturization.
- Adjustable properties including thermal conductivity and surface wettability by varying particle concentrations to suit different applications.

The first test with nanofluids gave more encouraging features than they were thought to possess. The four unique features observed are listed below.

- Abnormal enhancement of thermal conductivity. The most important feature observed in nanofluids was an abnormal rise in thermal conductivity, far beyond expectations and much higher than any theory could predict.
- Stability**.** Nanofluids have been reported to be stable over months using a stabilizing agent.
- Small concentration and Newtonian behavior. Large enhancement of conductivity was achieved with a very small concentration of particles that completely maintained the Newtonian behavior of the fluid. The rise in viscosity was nominal; hence, pressure drop was increased only marginally.
- Particles size dependence. Unlike the situation with microslurries, the enhancement of conductivity was found to depend not only on particle concentration but also on particle size. In general, with decreasing particle size, an increase in enhancement was observed.

The above potentials provided the thrust necessary to begin research in nanofluids, with the expectation that these fluids will play an important role in developing the next generation of cooling technology. The result can be a highly conducting and stable nanofluid with exciting newer applications in the future.

1.1. Nanofluids and its Thermo Physical Property

Thermo physical properties of the nanofluids are quite essential to predict their heat transfer behavior. It is extremely important in the control for the industrial and energy saving perspectives. There is great industrial interest in nanofluids. Nanoparticles have great potential to improve the thermal transport properties compared to conventional particles fluids suspension, millimetre and micrometer sized particles. In the last decade, nanofluids have gained significant attention due to its enhanced thermal properties. Experimental studies show that thermal conductivity of nanofluids depends on many factors such as particle volume fraction, particle material, particle size, particle shape, base fluid material, and temperature. Amount and types of additives and the acidity of the nanofluid were also shown to be effective in the thermal conductivity enhancement. The transport properties of nanofluid: dynamic thermal conductivity and viscosity are not only dependent on volume fraction of nanoparticle, also highly dependent on other parameters such as particle shape, size, mixture combinations and slip mechanisms, surfactant, etc. Studies showed that the thermal conductivity as well as viscosity both increases by use of nanofluid compared to base fluid. So far, various theoretical and experimental studies have been conducted and various correlations have been proposed for thermal conductivity and dynamic viscosity of nanofluids. However, no general correlations have been established due to lack of common understanding on mechanism of nanofluid. As compared with the experimental studies on thermal conductivity of nanofluids, there are limited rheological studies reported in the literature for viscosity. Different models of viscosity have been used by researchers to model the effective viscosity of nanofluid as a function of volume fraction.

1.2. Applications of Nanofluids

The novel and advanced concepts of nanofluids offer fascinating heat transfer characteristics compared to conventional heat transfer fluids. There are considerable researches on the superior heat transfer properties of nanofluids especially on thermal conductivity and convective heat transfer. Applications of nanofluids in industries such as heat exchanging devices appear promising with these characteristics. Kostic reported that nanofluids can be used in following specific areas:

- Heat-transfer nanofluids.
- Tribological nanofluids.
- Surfactant and coating nanofluids.
- Chemical nanofluids.
- Process/extraction nanofluids.
- Environmental (pollution cleaning) nanofluids.
- Bio- and pharmaceutical-nanofluids.
- Medical nanofluids (drug delivery and functional tissue–cell interaction).

- *Design of nanofluid*

In light of all the mentioned nanofluid property trends, development of a heat transfer nanofluid requires a complex approach that accounts for changes in all important thermophysical properties caused by introduction of nanomaterials to the fluid. Understanding the correlations between nanofluid composition and thermo-physical Properties is the key for engineering nanofluids with desired properties. The complexity of correlations between Nanofluid parameters and properties described in the previous section indicates that manipulation of the system performance requires prioritizing and identification of critical parameters and properties of nanofluids. Systems engineering is an interdisciplinary field widely used for designing and managing complex engineering projects, where the properties of a system as a whole, may greatly differ from the sum of the parts' properties. Therefore systems engineering can be used to prioritize nanofluid parameters and their contributions to the cooling performance.

The decision matrix is one of the systems engineering approaches, used here as a semi quantitative technique that Allows ranking multi-dimensional nanofluid engineering options .It also offers an alternative way to look at the Inner workings of a nanofluid system and allows for design choices addressing the heat transfer demands of a given Industrial application.

2. Literature Review

Buzelin & Amico [1] developed an intelligent refrigeration system to reduce energy consumption in industrial refrigeration systems is proposed and introduced. A typical industrial refrigeration system was conceived, built and modified in the laboratory, receiving a novel power law control system, which utilizes a frequency inverter. The operation and energy consumption of the system operating either with the new control system or with the traditional on-off control were compared to realistically quantify the obtained gains. In this manner, the measured temperature data acquired from several points of both systems and the energy consumption in kW h during a 24 h experimental run period are compared. Jwo et al. [2] conducted studies on a refrigeration system replacing R-134a refrigerant and polyester lubricant with a hydrocarbon refrigerant and mineral lubricant. The mineral lubricant included added Al_2O_3 nanoparticles to improve the lubrication and heat-transfer performance. Their studies show that the 60% R-134a and 0.1 wt % Al_2O_3 nanoparticles were optimal. Under these conditions, the power consumption was reduced by about 2.4%, and the coefficient of performance was increased by 4.4%. Peng et al. [3] conducted experimental on the nucleate pool boiling heat transfer characteristics of refrigerant/oil mixture with diamond nano particles. The refrigerant used was R113 and the oil was VG68. They found out that the nucleate pool boiling heat transfer coefficient of R113/oil mixture with diamond nanoparticles is larger than the R113/oil mixture. They also proposed a general correlation for predicting the nucleate pool boiling heat transfer coefficient of refrigerant/oil mixture with nanoparticles, which well satisfies their experimental results. Henderson et al. [4] conducted an experimental analysis on the flow boiling heat transfer of R134a based nanofluids in a horizontal tube. They found excellent dispersion of CuO nanoparticle with R134a and POE oil and the heat transfer coefficient increases more than 100% over baseline R134a/POE oil results. Bobbo et al. [5] conducted a study on the influence of dispersion of single wall carbon nanohorns (SWCNH) and Ti2O3 on the tribological properties of POE oil together with the effects on the solubility of R134a at different temperatures. They showed that the tribological behaviour of the base lubricant can be either improved or worsen by adding nanoparticles. On the other hand the nanoparticle dispersion did not affect significantly the solubility. Bi et al. [6] conducted an experimental study on the performance of a domestic refrigerator using Ti2O3 -R600a nanorefrigerant as working fluid. They showed that the Ti2O3-R600a system worked normally and efficiently in the refrigerator and an energy saving of 9.6%. They too cited that the freezing velocity of nano refrigerating system was more than that with pure R600a system. The purpose of this article is to report the results obtained from the experimental studies on a vapour compression system. Lee et al. [7] investigated the friction coefficient of the mineral oil mixed with 0.1 vol.% fullerene nanoparticles, and the results indicated that the friction coefficient decreased by 90% in comparison with rawlubricant, which lead us to the conclusion that nanoparticles can improve the efficiency and reliability of the compressor. Wang and Xie [8] found that Ti2O3 nanoparticles could be used as additives to enhance the solubility between mineral oil and hydrofluorocarbon (HFC) refrigerant. The refrigeration systems using the mixture of R134a and mineral oil appended with nanoparticles Ti2O3, appeared to give better performance by returning more lubricant oil back to the compressor, and had the similar performance compared to the systems using polyol-ester (POE) and R134a. In the present study the refrigerant selected is R600a and the nanoparticle is alumina. Isobutane (R600a) is more widely adopted in domestic refrigerator because of its better environmental and energy performances. In this paper, a new refrigerator test system was built up according to the National Standard of India. A domestic R600a refrigerator was selected. Al2O3-R600a nano-refrigerant was prepared and used as working fluid. The energy consumption test and freeze capacity test were conducted to compare the performance of the refrigerator with nano-refrigerant and pure refrigerant so as to provide the basic data for the application of the nanoparticles in the refrigeration system. Heris et al.,[9] investigated laminar flow convective heat transfer through circular tube with constant wall temperature boundary condition for nanofluids containing CuO and Al2O3 oxide nanoparticles in water as base fluid. The experimental apparatus consisting of a test chamber constructed of 1 m annular tube with 6 mm diameter inner copper tube and with 0.5 mm thickness and 32 mm diameter outer stainless steel tube. Nanofluid flows inside the inner tube while saturated steam enters annular section, which creates constant wall temperature boundary condition. The fluid after passing through the test section enters heat exchanger in which water was used as cooling fluid. The experimental results emphasized that the single phase correlation with nanofluids properties (Homogeneous Model) was not able to predict heat transfer coefficient enhancement of nanofluids. The comparison between experimental results obtained for CuO/ water and Al2O3 / water nanofluids indicated that heat transfer coefficient ratios for nanofluid to homogeneous model in low concentration were close to each other but by increasing the volume fraction, higher heat transfer enhancement for Al2O3/water was observed. They concluded that heat transfer enhancement by nanofluid depends on several factors including increment of thermal conductivity, nanoparticles chaotic movements, fluctuations and interactions. Hwang et al., [10] investigated the convective heat transfer coefficient of Al_2O_3 /water based nanofluid. In their experiment nanofluid considered flowing through circular tube having 1.812 mm inside diameter and maintaining constant heat flux for fully developed laminar regime. Al_2O_3 /water based nanofluids with various volume % concentration 0.01% to 0.3% are manufactured with two-step method. They have also obtained the thermo physical property of nanofluid such as density, viscosity, heat capacity and thermal conductivity. They have concluded that the convective heat transfer coefficient enhancement occurs with 0.01 and 0.3 vol % concentration of nanoparticle in fully developed laminar regime and heat transfer enhancement about 8 % obtained under the same Reynolds number of base fluid. They also concluded that enhancement in heat transfer coefficient were much higher that the thermal conductivity enhancement at the same vol % concentration of nanoparticle. Sharma et al.,[11] investigated to evaluate friction factor and heat transfer coefficient with a inserted twisted tape in the flow region of tube with Al_2O_3 nanofluid they have consider a test section of L/D ration 160 and 1.5m length. For uniform heating test section were wrapped with 1 KW .The aluminum strip having 0.018mm width and 1mm thick are used. Test section is subjected to 180° twist holding both end of test section in lathe machine obtaining 5, 10 and 15 twist ratio. Their result show enhancement in heat transfer coefficient with Al_2O_3 nanoparticle into the base fluid compare to the base water. The heat transfer coefficient was 23.7 % higher that the water at Reynolds number 9000.Yu et al., [12] investigated the heat transfer coefficient of silicon carbide nanoparticle having diameter 170nm and 3.7 vol % suspended into the pure water and found that an increment in heat transfer coefficient about 50-60 % compared to host fluid. Their test section was stainless steel tube with 4.76 mm outside diameter and 2.27 inside diameter. Their test rigs have heat exchanger flow meter horizontal tube, pre heater as a closed loop system. They concluded that enhancement is 14-32 % higher that the predicted value for single phase turbulent correlation of heat transfer. Also they found that the pressure loss is little lower than the Al_2O_3 water nanofluid. Torii and Yang [13] investigated the heat transfer coefficient of suspended diamond nanoparticle into the host fluid by maintaining constant heat flux. Their test section contains a flow loop, a digital flow meter, a pump, a reservoir and a tank. The test is prepared stainless steel tube having 4.3 mm outer diameter 4.0 mm inner diameter and 1000 mm length. The whole is heated with a dc electrode heater considering joule heating. They reported that (i) the heat transfer performance of nanofluid increases with the suspension of diamond nano particle into the water compared to pure water. (ii) Reynols number variation influence the enhancement occurs in heat transfer coefficient. Rea et al., [14] investigated the heat transfer coefficient and viscous pressure loss for Al_2O_3 /water and zirconia-water nanoparticle based nanofluid flowing loop. The stainless steel vertical heated test section considered having outer diameter of 6.4 mm, an inner diameter of 4.5 mm and 1.01 m length. The test section 8 T type thermocouples sheathed and insulated electrically and soldered onto the outside wall of the tube along axial direction 5, 16, 30,44, 58, 89 and 100 cm from heated inlet section of the test facility. to measure the fluid temperatures Two same T-type thermocouples were inserted into the flowing passage of the channel after and before of the test section. They observed that the heat transfer coefficients increased 17% and 27%, in fully developed region compare to base water. The heat transfer of zirconia–water nanofluid increases by approx 2% at 1.32 vol. % in the inlet region and 3% at 1.32 vol % in the fully developed region. The observed pressure loss for nanofluids was higher than the base water having good agreement with predicted model for laminar flow. Murshed et al.[15] carried out experiments with spherical and rod-shaped TiO_2nanoparticles. The spherical particles were 15 nm in diameter and the rod-shaped particles were 10 nm in diameter and 40 nm in length. The base fluid was deionized water. The measurement method was transient hot wire. It should be mentioned here that they used oleic acid and cetyltrimethyl ammonium bromide (CTAB) surfactants (0.01 to 0.02 vol %). They maintained a nearly neutral (pH 6.2 to 6.8) suspension. For the first time, a nonlinear correlation between the volume fraction and conductivity enhancement was observed here at lower concentrations. This is interesting with respect to the temperature effect and pure metallic particles. They found that the conductivity enhancement was higher for rod-shaped particles than for spherical particles. Enhancement up to 29.7% was found with 5% spherical particles and up to 32.8% with rod-shaped particles. They attributed this to the higher shape factor (n =6) of the rods than of the spheres (n =3) in the Hamilton–Crosser [16] model. Xuan and Li [17] were first to show a significant increase in the turbulent heat transfer coefficient. They found that at fixed velocities, the heat transfer coefficient of nanofluids containing Cu nanoparticles at 2.0 vol% was improved by as high as 40% compared to the host water. The Dittus–Boelter correlation failed to obtain the improved experimented heat transfer behavior of nanofluids. Recent unpublished work shows that the effect of particle size and shape and dispersion becomes predominant in enhancing heat transfer in nanofluids. Even greater heat transfer effects are expected for nanofluids produced by the one-step process. Therefore, there is great potential to "engineer" ultra-energy-efficient heat transfer fluids by choosing the nanoparticle material as well as by controlling particle size, shape, and dispersion.

3. Performance Improvement Methodology

To increase thermal performance of vapour compression refrigeration system (VCRS) by improving 1st law efficiency in terms of coefficient of performance because the heat absorption is depending on many factors in terms of geometric parameters of the heat exchanger's thermo physical properties of the absorbing fluid, heat transfer rate, thermal conductivity of fluid, specific heat,density and viscosity etc. all these property can be enhance by the suspension of nanoparticle (100 nm - 10µm) in the base fluid (i.e. nanofluid) and nanoparticle suspended in the refrigerant called nanorefrigerent. Applications of nanorefrigerent in the VCRS instead of conventional refrigerant can inhances the thermal property of the system. Thus 1st law efficiency (i.e. C.O.P) can be increased and the power consumption for the same load can be reduced also cost saving achieved.

4. Vapour Compression Refrigeration System Modeling

In this paper to evaluate the performance parameter of VCRS using nanorefrigerent following model and formulation for each component of VCRS is used as shown in following Fig.-1

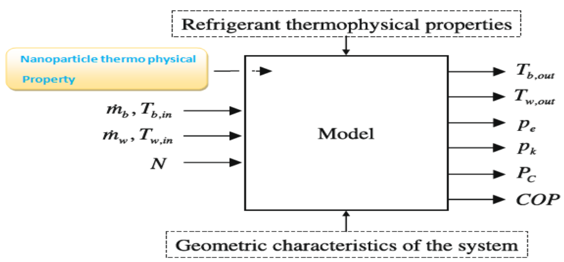

Fig: 1. Vapour Compression Refrigeration System Model

In this model we have taken only five variable and nanoparticle physical property with geometric parameter of the complete system (assumed) as input variable for the VCRS. These variables, together with the thermo physical properties of the refrigerant, nanoparticle and geometric characteristics of the VCRS (vapour compression refrigeration system) are used to obtain the evaporation and condensing pressure and brine, water outlet temp. Power consumption, energy efficiency and exergy efficiency of VCRS. Thus we will be able to evaluate the performance of VCRS by changing the operating parameter on the system performance so that we can optimize the performance of the VCRS.The schematic structure of the model proposed for this investigation is presented in Fig. 1 where it can be seen that the model input variable are brine inlet temperature in the evaporator, water inlet temperature in the condenser, compressor speed, types of refrigerant, mass flow rate of brine, water and geometric parameter of the heat exchanger (Evaporator and Condenser) and used to evaluate the performance of VCRS without nanofluid. When we go to compute the performance of VCRS using nano fluid an additional input parameter is required i.e. type of nanoparticle, diameter of nanoparticle, thermo physical property of nanofluid/nanoparticle (thermal conductivity, specific heat, density). The proposed model is basically a VCRS based chiller machine in which two concentric tube (copper) heat exchanger is used for evaporating and condensing operation. In this model refrigerant is supposed to flow in inner side of the evaporator tube and brine in annuli side as shown in fig-2. And water flow in inner side of the condenser tube and refrigerant in the annuli side as shown in fig-.2. The input parameter taken initially to compute the performance of VCRS using nanofluid and without nanofluid is given below.

Input variable	
Type of Refrigerant	R$=R404A
RPM of compressor	N=2900 {rpm}
Brine inlet Temperature	Tb_in =25+273.15 {K}
Water inlet Temperature	Tw_in=25+273.15 {K}
Mass flow rate of brine	m_b=0.006 {kg/s}
Mass flow rate of water	m_w=0.006 {kg/s}
Air Temperature	T_air=30+273.15 {K}
Inlet pressure of brine	Pb_in=2{bar}
Inlet pressure of water	Pw_in=2{bar}
Air Pressure	P_air=1.01325 {bar}
Acceleration due to gravity	g=9.81{m/s2}
Ambient Temperature	T_ambient=298{K}
Inside dia. of brine tube in evaporator	D_bie=0.013875 {m}
Inside dia. of refrigerant tube in evaporator	D_rie=0.007525 {m}
Outside dia. of refrigerant tube in evaporator	D_roe=0.009525 {m}
Geometric Parameter	
Inside dia. of brine tube in evaporator	D_bie=0.013875 {m}
Inside dia. of refrigerant tube in evaporator	D_rie=0.007525 {m}
Outside dia. of refrigerant tube in evaporator	D_roe=0.009525 {m}
Length of tube in evaporator	L_e=0.76 {m}
Surface area of evaporator	S_e=3.14*(D_roe)*L_e {m2}
Geometric compressor volume	V_g =5.79E-06 {m3}
Inside dia. of refrigerant tube in condenser 3-4	D_rik=0.013875 {m}
Inside radius of refrigerant tube in condenser 3-4	r_rik=D_rik/2 {m}
Inside dia. of water tube in condenser 3-4	D_wik=0.007525 {m}
outside dia. of water tube in condenser 3-4	{D_wok=0.009525 {m}}
outside radius of water tube in condenser 3-4	r_wok=D_wok/2 {m}
Length of tube in condenser 3-4	L_k=1.05 {m}
outside dia. of water tube in condenser 3-4	D_wok=0.00508 {m}
Surface area of condenser 3-4	S_k=3.14*(D_wok)*L_k {m2}
Inside dia. of refrigerant tube in condenser 2-3	D_ri23=0.007525 {m}
Inside radius of refrigerant tube in condenser 2-3	r_ri23=D_ri23/2 {m}
Outside dia. of	D_ro23=0.009525 {m}

refrigerant tube in condenser 2-3	
Outside radius of refrigerant tube in condenser 2-3	r_ro23=D_ro23/2 {m}
Length of tube in condenser 2-3	L_23=0.6 {m}
Surface area of condenser 2-3	S_23=3.14*D_ro23*L_23 {m2}
Inside dia. of Capillary Tube	D_cap=0.0006 {m}
Fouling in the tubes	R_TFO=0.000086 {m2 K/W}

Using these inputs and the main characteristics of the compressor and heat exchangers, the model compute the operating pressures (without considering pressure drops), secondary fluids output variables and the energy performance. The property of nanorefrigerant/refrigerant and the thermo-physical properties of secondary fluids are evaluated by using software

4.1. Vapor Compression System Modeling

The model contain of a set of below equations based on physical laws showing the main parts of the system, as shown Properly (Schematically) in Fig.(2).

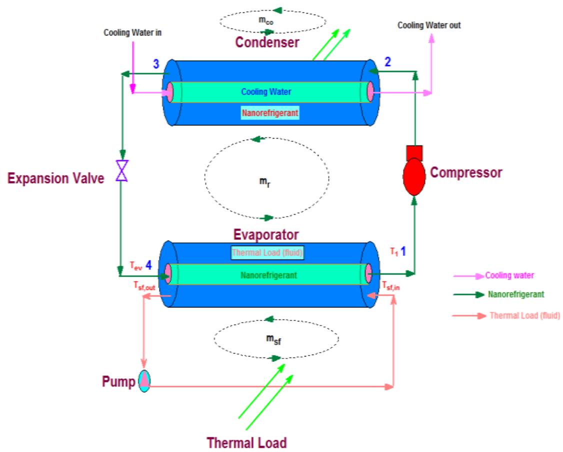

Fig: 2. Schematic Diagram of Vapour Compression Refrigeration System Model

The nanorefrigerant/refrigerant states are numbered in Fig. 3. To compute nanorefrigerant/refrigerant mass flow rate *(m_r)* Eq. (1) is used, where the compressor volumetric efficiency (η_v) is shown as a function of operating pressure and compressor speed (*N*) as shown in Eq. (2). For simplicity, *(ρ_1)* is the nanorefrigerant/refrigerant density taken is the one corresponding to the saturated condition.

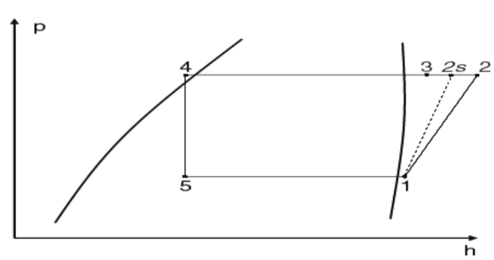

Fig: 3. Vapor Compression Cycle

Vapor at the evaporating pressure and V_g is the geometric compressor volume.

$$m_r = \eta_v \cdot \rho_1 \cdot V_g \cdot N \quad (1)$$

$$\eta_v = 1 + C - C \cdot \left[\frac{P_k}{P_e}\right]^{\left[\frac{1}{n_1}\right]} \quad (2)$$

$$C = \frac{V_{suction}}{V_{discharge}}$$

Where,

P_k & P_e is the condenser pressure and evaporator pressure. $V_{Suction}$ & $V_{Discharge}$ is the suction volume and discharge volume of compressor. n_1 is the index of expansion.

Based upon energy balance quation for condenser, evaporator, compressor and expainsion device a linear/non linear equation based simulation programm is prepared and solved. For nanofluid property calculations following equations are used.

4.2. Nanofluid/Nanorefrigerant Property Calculation

Direct suspension of nanoparticle into base refrigerant through appropriate method and procedure and then calculate the thermo physical property of nanorefrigerant with the help of following equation and that property is used to compute the performance of vapour compression refrigeration system (VCRS). To compute the performance of VCRS with nanoparticle based nanorefrigerant we use thermo physical property of nanorefrigerant instead of pure refrigerant as below.

Thermal conductivity of nanorefrigerant

Thermal conductivity of nanorefrigerant is computed by using Sitprasert correlation [18] this relation consider the effect of temperature dependence interfacial layer of nanofluid as below,

$$K_{r,n} = \frac{(K_p - k_l)\cdot\phi\cdot k_l\cdot(2\cdot\beta_1^3 - \beta^3 + 1) + (K_p + 2\cdot k_l)\cdot\beta_1^3\cdot(\phi\cdot\beta^3\cdot(k_l - K_r) + K_r)}{\beta_1^3\cdot(K_p + 2\cdot k_l) - ((K_p - k_l)\cdot\phi\cdot(\beta_1^3 + \beta^3 - 1))} \quad (3)$$

K r,n is the thermal conductivity of nanorefrigerant. ϕ is the volume % suspension of nanoparticle into the pure refrigerant.

Kp is the thermal conductivity of nanoparticle.

Kl is the interfacial thermal conductivity can be obtained using eq. (4)

$$\beta = 1 + \frac{t}{r_p}$$

$$\beta_1 = 1 + \frac{t}{2 \cdot r_p}$$

$$t = 0.01 \cdot (T_e - 273) \cdot r_p^{0.35}$$

$$k_l = C \cdot K_r \cdot \frac{t}{r_p} \quad (4)$$

Where t is the interfacial layer thickness. Kr is the thermal conductivity of pure refrigerant at liquid face. rp is the radius of nanoparticle in nanometer

C is constant its value 30 for Al2O3, CuO and 10 for TiO2, 100 for Cu.

Viscosity of nanorefrigerant

The viscosity of nanorefrigerant is computed using Brinkman correlation [19]

$$\mu_{r,n} = \mu_r \cdot \frac{1}{(1-\phi)^{2.5}}$$

Where μ r,n is the viscosity of nanorefrigerant. μ r is the viscosity of liquid pure refrigerant

Density of nanorefrigerant

The density of nanorefrigerant is calculated using Pak and Cho [20]

$$\rho_{n,r} = \phi \cdot \rho_p + (1-\phi) \cdot \rho_r$$

Where

$\rho_{n,r}$ is the density of nanorefrigerant

ρ_p is the nanoparticle density.

ρ_r is the density of liquid refrigerant

Specific heat of nanorefrigerant

Specific heat of nano refrigerant is computed using Pak and Cho[20]

$$Cp_{r,n} = (1-\phi) \cdot Cp_{r,l} + \phi \cdot Cp_p$$

Where Cp r,n is the specific heat of nanorefrigerant. Cp r,l id the specific heat of liquid pure refrigerant. Cp p is the nano particle specific heat. And other parameter/property of nanorefrigerant is calculated using following equation.

$$Re_{r,n} = G_n \cdot \frac{D_i}{\mu_{r,n}}$$

$$Re_r = G_r \cdot \frac{D_i}{\mu_r}$$

$$Pr_{r,n} = Cp_{r,n} \cdot \frac{\mu_{r,n}}{K_{r,n}}$$

$$Pr_r = Cp_{r,l} \cdot \frac{\mu_r}{K_r}$$

$$\alpha_{conv,r,n} = N_{u,r,n} \cdot \frac{K_{r,n}}{D_i}$$

$$\alpha_{conv,r} = N_{u,r} \cdot \frac{K_r}{D_i}$$

$$\alpha_{LV,nr} = F_n \cdot \alpha_{conv,r,n} + S_n \cdot \alpha_{nb,r,n}$$

$$\alpha_{nb,r,n} = 207 \cdot \frac{K_{r,n}}{BD_n} \cdot \left[\frac{q'' \cdot BD_n}{K_{r,n} \cdot T_e}\right]^{0.674} \cdot \left[\frac{\rho_{G,n}}{\rho_{l,r,n}}\right]^{0.581} \cdot Pr_{r,n}^{0.533}$$

$$BD_n = 0.51 \cdot \left[\frac{2 \cdot \sigma}{g_g \cdot (\rho_{l,r,n} - \rho_{G,n})}\right]^{0.5}$$

$$F_n = 53.64 \cdot \left[\frac{q''}{G_n \cdot h_{fg}}\right]^{0.314} \cdot X_{tt,n}^{-0.839}$$

$$G_n = \rho_{n,r} \cdot V_r$$

$$X_{tt,n} = \left[\frac{1-x}{x}\right]^{0.9} \cdot \left[\frac{\rho_{G,n}}{\rho_{l,r,n}}\right]^{0.5} \cdot \left[\frac{\mu_{r,n}}{\mu_{G,n}}\right]^{0.1}$$

$$S_n = 0.927 \cdot \left[\left(\frac{1-x}{x}\right)^{0.8} \cdot \left(\frac{\rho_{G,n}}{\rho_{l,r,n}}\right)^{0.5}\right]^{0.319}$$

Where Re r,n is the Reynold number of nanorefrigerant. Pr,n Prandle number of nanorefrigerant. Gr is the mass flux of nanorefrigerant Xtt,n is the martinelli parameter of nanorefrigerant.

X is the vapour quality of nanorefrigerant. BDn is the bubble diameter of nanorefrigerant. Sn is suppression factor of of nanorefrigerant. q" is the heat flux received by the nanorefrigerant in the evaporator.

Vr is the velocity of nanorefrigerant in the evaporator

All these property are used to compute the performance of VCRS using nanorefrigerant in the above equation from (1) to (28). Thus we can find out the performance of VCRS using nanorefrigerant in primary circuit. In this research direct suspension of nanoparticle into the base refrigerant is proposed and effect of various input parameter of the proposed model on the performance of VCRS is computed using nanofluid (nanorefrigerant) and without nanofluid are shown in result and discussion chapter.

5. Results and Discussion

A computational program has been developed to solve non linear system equations of vapour compression refrigeration cycle by considering nano-refrigerant flowing in the primary circuit of the enaporater and water into the secondary circuit of the evaporator. Theoretical analysis has been done using EES software for nanorefrigerant flowing in primary circuit and R718 (water) flowing in secondary circuit of VCRS and results are given below.

5.1. Thermo Physical Property of Nanorefrigerant

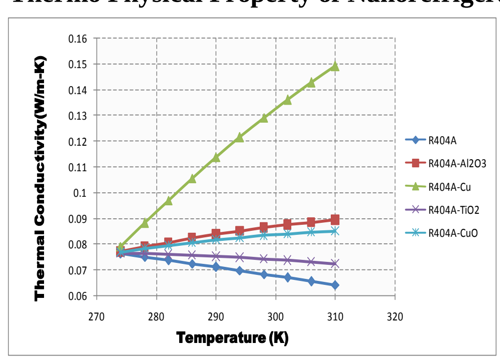

Fig: 4. Variation of Thermal conductivity with Temperature of R404A using different nanoparticles

Thermo physical property of base refrigerant using nanoparticle suspended into base refrigerant at 5 Vol % are shown below.

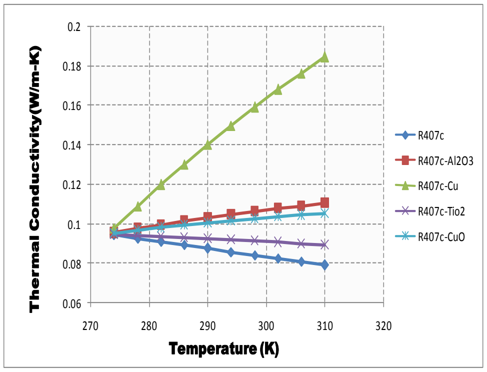

Fig: 5. Variation of Thermal conductivity with Temperature of R407c using different nanoparticles

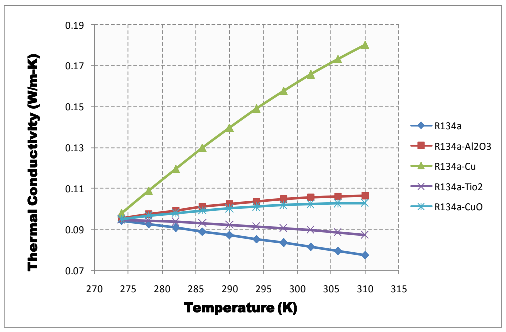

Fig: 6. Variation of Thermal conductivity with Temperature of R134a using different nanoparticles

Fig: 4, Fig: 5 and Fig: 6 show the enhancement in thermal conductivity of nanorefrigerant when different kind of nanoparticle is suspended into the host refrigerant. The enhancement factor varies from 0.06 to 2 for different nanoparticle.from the Fig we can see that cu nanoparticle have more EF at higher temperature which value is approx 2.

5.1.1. Effect of volume fraction on Thermo physical property of nanorefrigerant with different nanoparticle (at 280K temperature)

Thermal conductivity shown in Fig 5.4 is defined as the ratio of thermal conductivity of nanorefrigerant (pure refrigerant mixed with nanoparticle) to the thermal conductivity of pure refrigerant.

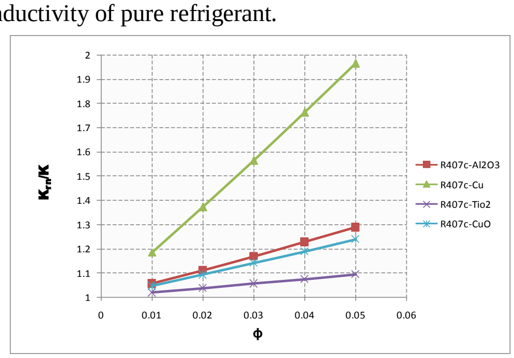

Fig: 7. Variation of Thermal conductivity Ratio with volume fraction (ϕ) of R134a using different nanoparticles

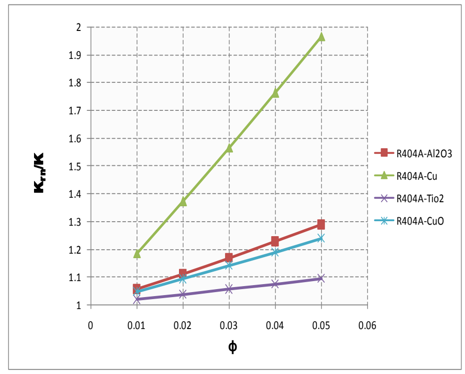

Fig: 8. Variation of Thermal conductivity Ratio with volume fraction (ϕ) of R404A using different nanoparticles

Fig (4) to Fig.(.)6 Shows that conductivity ratio of pure refrigerant to nanorefrigerant increases with increasing concentration of nanoparticle into the host refrigerant. From the fig we can see that Cu nanoparticle based nanorefrigerant have higher cond. Ratio than other nanoparticle and have approx two times higher than base refrigerant at 5 vol % concentration.

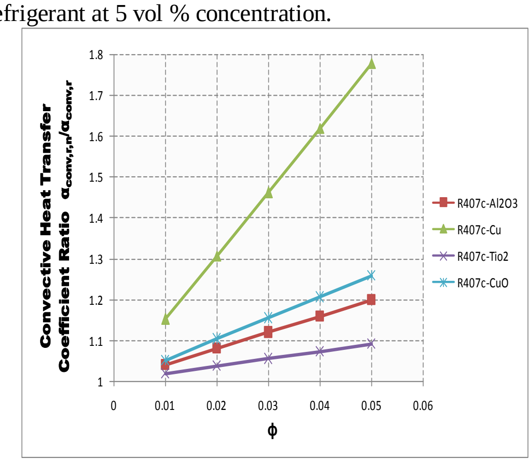

Fig: 9. Variation of Convective heat transfer coefficient ratio with volume fraction (ϕ) of R407c using different nanoparticles

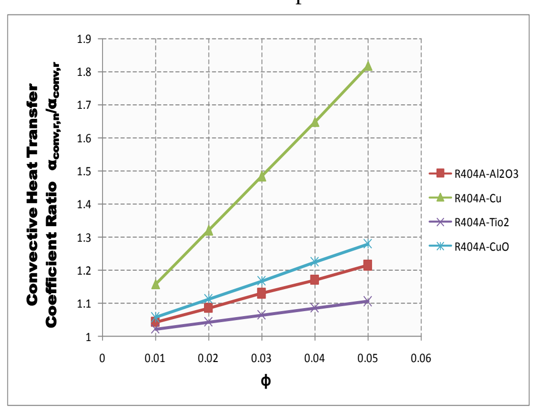

Fig: 10. Variation of Convective heat transfer coefficient ratio with volume fraction (ϕ) of R134a using different nanoparticles

Convective heat transfer coefficient ratio shown in Fig (7), Fig. (8) and Fig. (9) is defined as the ratio of

Convective heat transfer coefficient of nanorefrigerant (nanoparticle mixed with pure refrigerant) to the Convective heat transfer coefficient of pure refrigerant. The heat transfer Enhancement Factor shown in Figs (10), Fig. (11) and Fig.(12) is defined as the ratio of heat transfer coefficient of nano-refrigerant (nanoparticle mixed with pure refrigerant) to the heat transfer coefficient of pure refrigerant.

Fig (7) to Fig. (9) shows the convective heat transfer coefficient Ratio increases by increasing the concentration of nanoparticle. and copper nanoparticle based nanorefrigerant have highest convective heat transfer coefficient ratio than other particle its value ranges from 1 to 1.7.

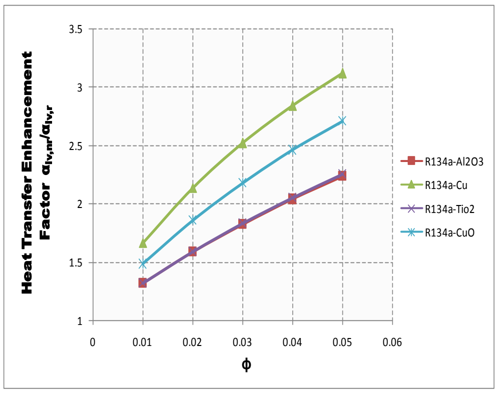

Fig: 11. Variation of Heat transfer Enhancement Factor with volume fraction (ϕ) of R134a using different nanoparticles

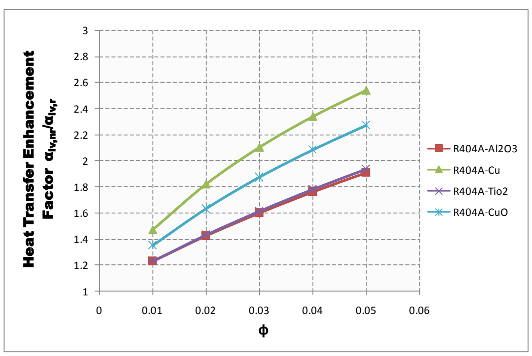

Fig: 12. Variation of Heat transfer Enhancement Factor with volume fraction (ϕ) of R404A using different nanoparticles

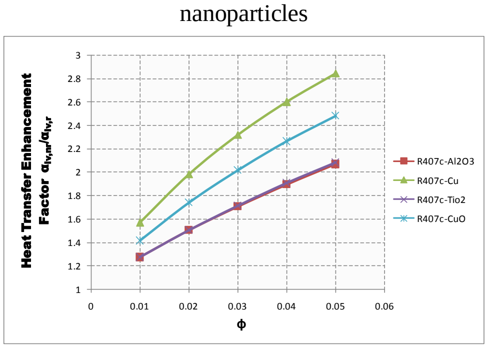

Fig: 13. Variation of Heat transfer Enhancement Factor with volume fraction (ϕ) of R407c using different nanoparticles

5.2. Effect of nanoparticle volume fraction (ϕ) on the 1st law of thermodynamics (C.O.P.) of VCRS

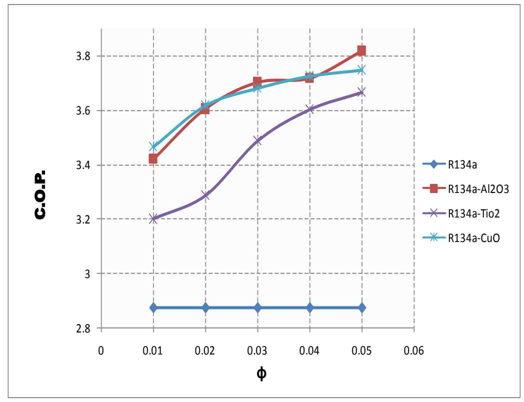

Fig: 14. Variation of C.O.P with volume fraction (ϕ) of VCRS with R134a using different nanoparticles

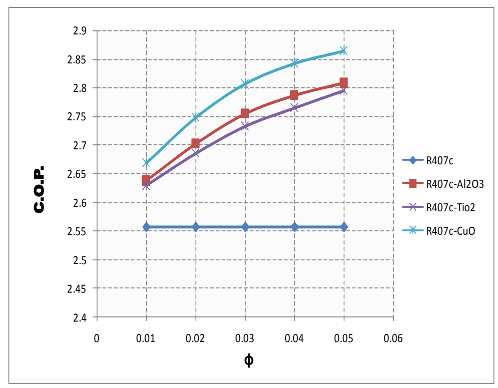

Fig: 15. Variation of C.O.P with volume fraction (ϕ) of VCRS with R407c using different nanoparticles

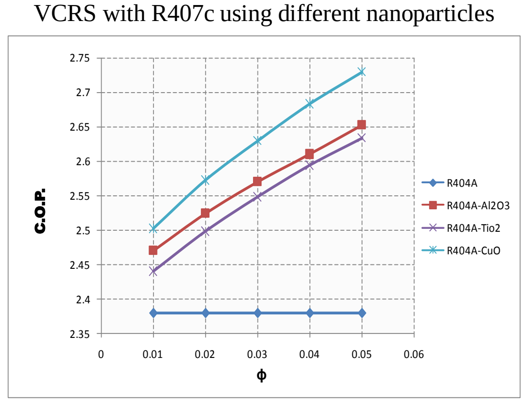

Fig: 16. Variation of C.O.P with volume fraction (ϕ) of VCRS with R404A using different nanoparticles

Fig (13) to Fig.(15) shows that C.O.P. enhancement of VCRS is achieved by using nanorefrigerant as a working fluid in VCRS. Fig-19 show that the maximum second law performance enhancement theoretically achieved about 35 % with combination of R134a with copper and 32% using R134a and Al2O3 nanoparticles at 5 vol % based nanorefrigerant. C.O.P. enhancements of VCRS with different combination of nanorefrigerant are given in tables 5.1(a)-5.1(c) as given below.

Table: 1(a). Enhancement in C.O.P using R-134a nanorefrigerant of VCRS

Refrigerant		**R134a**	
Nanoparticle	**Volume Fraction (ϕ)**	**C.O.P.**	**% Enhancement**
	0	2.82	-
Al_2O_3	0.01	3.421	21.3%
	0.02	3.604	27.8%
	0.03	3.701	31.2%
	0.04	3.717	31.8%
	0.05	3.817	35.4%
TiO_2	0.01	3.287	16.6%
	0.02	3.488	23.7%
	0.03	3.603	27.8%
	0.04	3.666	30.0%
	0.05	3.691	30.9%
CuO	0.01	3.464	22.8%
	0.02	3.616	28.2%
	0.03	3.681	30.5%
	0.04	3.725	32.1%
	0.05	3.748	32.9%

Table: 1(b). Enhancement in C.O.P using R407c nanorefrigerant of VCRS

Refrigerant		**R407c**	
Nanoparticle	**Volume Fraction (ϕ)**	**C.O.P.**	**% Enhancement**
	0	2.556	-
Al_2O_3	0.01	2.637	3.2%
	0.02	2.702	5.7%
	0.03	2.755	7.8%
	0.04	2.787	9.0%
	0.05	2.808	9.9%
TiO_2	0.01	2.629	2.9%
	0.02	2.685	5.0%
	0.03	2.733	6.9%
	0.04	2.765	8.2%
	0.05	2.795	9.4%
CuO	0.01	2.669	4.4%
	0.02	2.748	7.5%
	0.03	2.806	9.8%
	0.04	2.842	11.2%
	0.05	2.864	12.1%

Table: 1(c). Enhancement in C.O.P using R404a + nanorefrigerant of VCRS

Refrigerant		**R404A**	
Nanoparticle	**Volume Fraction (ϕ)**	**C.O.P.**	**% Enhancement**
	0	2.379	-
Al_2O_3	0.01	2.47	3.8%
	0.02	2.524	6.1%
	0.03	2.536	6.6%
	0.04	2.558	7.5%
	0.05	2.653	11.5%
TiO_2	0.01	2.44	2.6%
	0.02	2.498	5.0%
	0.03	2.548	7.1%
	0.04	2.594	9.0%
	0.05	2.634	10.7%
CuO	0.01	2.502	5.2%
	0.02	2.572	8.1%
	0.03	2.63	10.6%
	0.04	2.683	12.8%
	0.05	2.73	14.8%

5.3. Effect of nanoparticle volume fraction (ϕ) on the Exergy destruction ratio of VCRS

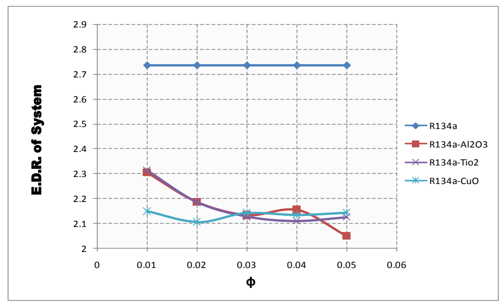

Fig: 17. Variation of Exergy destruction ratio with volume fraction (ϕ) of VCRS with R134a using different nanoparticles

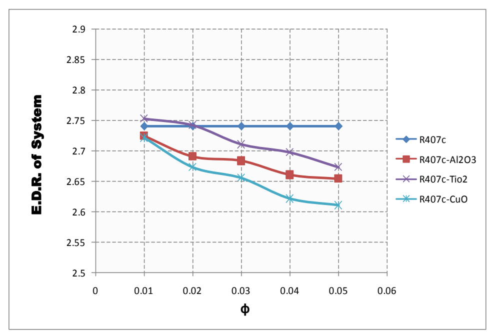

Fig: 18. Variation of Exergy Destruction ratio with volume fraction (ϕ) of VCRS with R407c using different nanoparticles

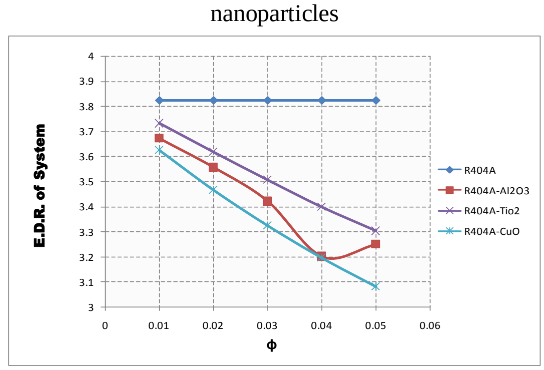

Fig: 19. Variation of Exergy destruction ratio with volume fraction (ϕ) of VCRS with R404a using different nanoparticles

Fig (17) to Fig (19) shows that the Eexergy.Destruction Ratio of VCRS is reduced by using nanofluid (nanoparticle based nanorefrigerant)

5.4. Effect of nanoparticle volume fraction (ϕ) on the 2nd law efficiency of VCRS

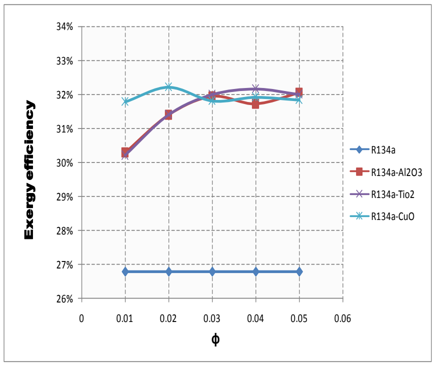

Fig: 20. Variation of Exergy Efficiency with volume fraction (ϕ) of VCRS with R134a using different nanoparticles

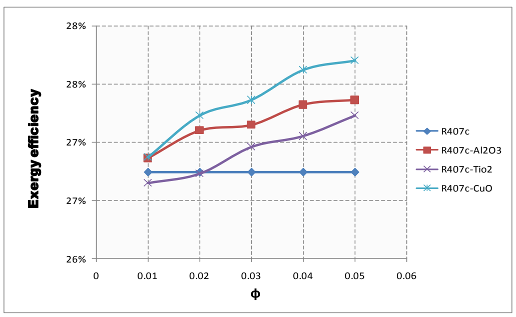

Fig: 21. Variation of Exergy Efficiency with volume fraction (ϕ) of VCRS with R407c using different nanoparticles

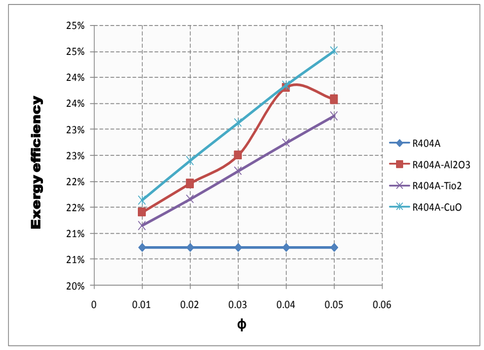

Fig: 22. Variation of Exergy Efficiency with volume fraction (ϕ) of VCRS with R404A using different nanoparticles

Fig (20) to Fig (22) shows that exergetic efficiency (i.e. 2nd Law efficiency) is increased by using nanorefrigerant and the exergetic effiency (i.e. 2nd law efficiency) of vapour compression refrigeration system using nanorefrigerant R134a/CuO is much higher than the other nanorefrigerant having value approx 35%.

6. Conclusions & Recommendations

It has been observed that the use of nano-refrigerants instead of pure refrigerant in vapour compression refrigeration cycle the thermal performances of nanorefrigerant enhances significantly as well as the performance of refrigeration system. The following conclusion have been drawn from present investigations

1. Use of nanoparticles enhances thermal performance of vapour compression refrigeration system from 8% to 35 % using nanorefrigerant in primary circuit.
2. Use of nanoparticles enhances the thermal performance of vapour compression refrigeration system from 7 to 21 % using nanofluid in secondary circuit.
3. Maximum enhancement in the performance was observed using R134a/ Cu nano-refrigerant in primary circuit and water in secondary circuit of VCRS.
4. Lowest enhancement in performance was observed using R404A/TiO_2 nanorefrigerant in primary circuit and water in secondary circuit of VCRS.

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