Thermodynamic Model Analysis of VCR System with Al2O3-Ethylene Glycol-Water Mixture Based Nanofluid as Secondary Fluid and R1234yf as Primary Refrigerant

Submitted in the partial fulfilment of the requirements

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MASTER OF TECHNOLOGY

In

Thermal Engineering

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DECLARATION

I, Mohd Anwer, Roll No. 2K20/THE/13 student of M. Tech (Thermal Engineering), hereby declare that the project dissertation titled "**Thermodynamic Model Analysis of VCR System with Al2O3-Ethylene Glycol-Water Mixture Based Nanofluid as Secondary Fluid and R1234yf as Primary Refrigerant**.**"** which is submitted by me to the Department of Mechanical Engineering, Delhi Technological University, Delhi in the partial fulfilment of the requirements for the award of degree of Master of Technology is original and not copied from any source without proper citation. This work is not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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I hereby certify that the Project Dissertation titled "Thermodynamic Model Analysis of VCR System with Al2O3-Ethylene Glycol-Water Mixture Based Nanofluid as Secondary Fluid and R1234yf as Primary Refrigerant" Which is submitted by Mohd Anwer Roll No. 2K13/THE/13 Department of Mechanical, Thermal Engineering, Delhi Technological University, Delhi in the partial fulfilment of the requirements for the award of degree of Master of Technology, is a record of the project work carried out by the students under my supervision. To the best of my knowledge this work has not been submitted in part or full for the award of any Degree or Diploma in this University or elsewhere.

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ABSTRACT

In this study, theoretical analysis of thermodynamic model incorporating nanofluid in the secondary loop refrigeration as secondary fluid is studied. In secondary loop refrigeration system, there are two loops which are interconnected by an intermediate heat exchanger. The thermodynamic model of vapour compression refrigeration system with Al2O3 nano particle (13nm) mixed in ethylene glycol-water mixture (50:50) in secondary loop and R1234yf refrigerant in the primary loop is used for theoretical analysis. The evaporator of the model is a double tube counter flow heat exchanger in which refrigerant circulate inside the inner tube and secondary fluid in the outer tube. The effect of nano particle aggregation, nano fluid mass flow rate and variation of temperature of evaporator and condenser on the of the system is studied. The results have shown that the Al2O3 nano particle (13nm) mixed in ethylene glycol water mixture (50:50) as the secondary refrigerant in the system operating at 274.5 K evaporator temperature can improve the COP of the system by 11.94 %, 15.45 %, and 25.16 % for 321 K, 323 K, and 328 K condenser temperature respectively. From obtained results it can be concluded that as the evaporator temperature or pressure increases the COP of the system with and without nano fluid increases but the improvement of COP of system with the secondary fluid is greatly enhance at lower evaporator temperature.

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Abbreviations used

ρ	density, kg/m^3
Cp	specific heat J/kgK
k	thermal conductivity, W/mK
μ	dynamic viscosity, Ns/m^2
m	mass flow rate
Q	heat transfer rate W
W_c	compressor work W
φ	volume fraction of particles
A_e	surface area of evaporator, m^2
U_e	overall heat transfer Coeff. of evaporator, W/m^{2}K
D	hydraulic diameter, m
EG	ethylene glycol
α	heat transfer coefficient, W/m^{2}K
r_0 & r_i	outer and inner diameter of tube, m
Pr	Prandtl number
Re	Reynolds number

Subscripts

b	brine
f	fluid (base fluid)
p	particles
nf	nanofluid

CHAPTER 1

INTRODUCTION

Over the last few decades, the temperature of the globe drove up rapidly and intensified hot weather and result into extreme heat now access to the cooling is not a luxury it became necessity. It is very essential to find innovative and advanced technological solution for the cooling system because the present mechanical cooling system which we are using causing drastic damage to the global health as they not only consume more energy powered by fossil fuel also cause harmful emissions that contribute to more global heating. Cooling already consumes considerable amount of the global electricity demand and we need to do research in this particular field to develop more efficient cooling system. Majority of refrigeration and air condition applications work on the vapour compression refrigeration system in which CFCs, HCFCs and HFCs are used as refrigerant. The chlorinated hydrocarbon refrigerant now obsoletes because of their Ozone Depletion Potential and replaced by HFCs. But hydrofluorocarbons also cause damage to environment due to their high global warming potential. Under the international agreement, India have to phase down use of HFCs from 2028 and reduce it to 15 % of the 2024-2026 level till 2047.

The aforementioned reason increase interest to research environment friendly refrigerant and also alternative approaches to the traditional vapour compression refrigeration system. Some environment friendly refrigerant includes ammonia, carbon dioxide and R1234yf it is new kind of refrigerant come under hydrofluoroolefins (HFOs) it has 0 ODP and less than 1 GWP, but these refrigerant have some issues. We need to modify VCR system to use them safely, one of the alternative approaches to use them is a secondary loop refrigeration system. It is an indirect refrigeration system in which two different refrigerants are used to provide refrigeration It consist two circuit primary circuit and secondary circuit. Primary circuit is the conventional direct expansion design that use a refrigerant which generally absorb latent heat and change it phase and circulated by a compressor. While in the secondary circuit, fluid mostly absorb sensible heat and flow with the help of pump. Ndoye et al. [4] conduct a numerical investigation for the performance of nanofluids in secondary loop and showed that nano fluid has great potential to reduce emissions, global worming impact and energy consumption by improving cold chain efficiency. Wang et al [9] Examine secondary loop refrigeration systems, which include risk evaluation of refrigerant in the various applications and suggested that the secondary loop refrigeration system may be a viable option for balancing environmental demands and system costs. Delvetura et al [14] evaluated secondary loop refrigeration system in supermarket and compared it with the conventional direct expansion type refrigeration system, Table 1 shows the comparison results. They concluded that the amount of refrigerant that can leak into the environment can be reduced by up to 90%.

Another alternative is the nanofluid, nanofluids are novel types of fluids created by dispersing nano meter sized particle of material in base fluid which greatly improving thermal properties such as, convective heat transfer coefficient, thermal -diffusivity and conductivity. Nano particles increases thermal performance of the base fluid due to their higher thermal conductivity and further thermal enhancement is achieved due to larger surface area in contact. Many researchers investigate thermal conductivity of numerous nanofluids to use them in various applications. In recent years numerous research has proven that nanofluid are superior than conventional heat transfer fluid due to their improved thermophysical properties. Chiam et al [3] performed experimental analysis to measure thermal conductivity and dynamic viscosity of Al_2O_3 nano particle in three different ratios of water and ethylene glycol mixture and observed thermal conductivity enhancement of Al2O3 from 2.6 to 12.85 % and concluded that with increase in temperature thermal conductivity increases but viscosity decreases exponentially.

Xu et al [8] investigate the relationship between the nanofluid properties and thermal conductivity of Al2O3 nano particle in different base fluid and concluded that the viscosity of base fluid and surface charge of particle, influence Al2O3 nano particle aggregation. Popa et al [2] measure specific heat of CuO water based and Al2O3 water, ethylene glycol based nanofluid experimentally and compared them the four empirical model and also proposed a new model which give more accurate specific heat for the particular nanofluid. Ehsan et al [6] conducted investigation of the application of different nano particle in the heat exchanger with water as base fluid and concluded that coefficient of heat transfer enhances with nano particle aggregation as well as with the Reynold number for all three nanofluid.

Akhtari et al investigate system performance with nanofluid in different heat exchanger and concluded that heat transfer performance is improved upto 13.2 % with particle concentration.

Table 1 -Comparison between Secondary loop system and traditional DX system. [14]

Refrigerant Charge	Less than 500 lbs	Up to 5000 lbs
Location of Refrigerant	Machine room only	At case and machine room
Leak Impact	Low - due to low system charge	High - due to large system charge
Refrigerant Emissions	Less than 5 %	Up to 30 %
Box Temperature	More stable box temperature	Greater temperature fluctuation

Elias et al. [12] examine the thermophysical properties of Aluminium oxide nanoparticles prepared in a double-step method in a car radiator coolant and concluded that the thermal performance of the system improved with nano fluid. They also compared their experimental results with the already proposed model and suggest the appropriate model for particular property of nanofluid.

Subramani and Prakash [13] study use of nano lubricant in a VCR cycle and found that the compressor power consumption is reduced by 25 % with the nano lubricant as compared to conventional POE oil.

Nair et al [19] perform the analysis of VCR cycle with nano lubricant and observed that the performance of the with nano lubricant is higher than the system without nano lubricant and their result showed 6.5 % improvement with nanofluid.

Kumar and Mishra [17] conducted experimental analysis for enhancement of vapour compression refrigeration system using silver oxide nano fluid on condenser side of the system and concluded that heating capacity of the considered cycle enhanced by 26-82 % by using 0.06 % volume concentration of silver nano particle. Mahbulbul et al [7] studied mathematical model to evaluate thermal properties of Al2O3 nano particle in R134a refrigerant in vapour compression system and concluded that optimum nano particle aggregation is essential to be considered in nano refrigerant production which can improve the refrigeration system outcome. Mahbulbul et al [6] perform experimental study to find the effect of nano particle parameter suspended in R141b and observed 179 times higher viscosity at 2 % particle concentration and concluded that the for same particle volume concentration, the viscosity increment rate was found to be greater than the thermal conductivity enhancement therefore optimal nano particles concentrations need to be dispersed in the refrigerants to have a better heat transfer performance. R. S. Mishra [15] evaluates a vapour compression refrigeration cycle that uses an environment friendly refrigerant as the primary refrigerant and a water-based nano fluid as the secondary fluid and concluded that nanofluid in the secondary circuit greatly affect its COP. Parsad et al [18] carried out thermal analysis of VCR cycle with R13a as primary refrigerant and EG-water mixture mixed with nano particle as a secondary fluid with the help engineering equation solver and show that the overall heat transfer coefficient of the cycle increases with nano fluid. R. S. Mishra [16] conducted a detailed analysis of a VCR cycle with water based nanofluid in secondary loop of the evaporator and environment friendly refrigerant in the primary circuit and their results showed that performance of system is improved by 11.84 % to 19 % as compared to without nano fluid.

Vascancelos et al [1] carried out experimental investigation of SWCNT nano particles in water in a VCR cycle and concluded the nanofluid performed better with improved refrigeration capacity and COP when compared to the base fluid. Faizan Ahmed [3] investigated nanofluid in a VCR cycle as secondary fluid and found the highest COP of 6.5 at a higher secondary fluid flow rate. with 15 % particle concentration at 40^0 C inlet temperature of nanofluid and concluded that nanofluid can be used without difficulty. He also did economic analysis and found annual cost saving of 2145 USD

CHAPTER 2

SYSTEM DESCRIPTION AND MODELING

2.1 SYTEM DESCRIPTION

It is observed from the literature review that secondary loop refrigeration system is a potential alternative approach which enable us to use refrigerants having some issues, for example R1234yf it is a new class of refrigerant came under hydrofluoroolefins (HFOs) widely used in the automobile air condition system by replacing previously used R134a refrigerant it is having 0 ODP and less than 1 GWP but it is a mid-flammable refrigerant. Secondary loop refrigeration system is the one of the practical ways to use this type of refrigerant. Secondary loop refrigeration systems use two different refrigerants, one in the primary circuit and one in the secondary circuit to provide refrigeration. Primary circuit is the conventional direct expansion design that use a refrigerant which generally absorb latent heat and change its phase and circulated by a compressor while in the secondary circuit, fluid mostly absorb sensible heat and flow with the help of pump figure 1 shows the schematic of secondary loop refrigeration system. The evaporator of the primary circuit act as the condenser for secondary circuit in which primary refrigerant absorb heat from secondary fluid and then secondary fluid used for the cooling at the desire location. Basically, secondary fluid act as a catalyst which increase the rate of heat transfer between evaporator and the medium which we want to cool.

There are two kind of secondary fluid which are used in secondary loop refrigeration system namely single-phase fluid which mostly circulate in the liquid phase and having some kind of antifreeze in it, another is two phase fluid and have advantage of latent heat. Existing vapour compression refrigeration system can be converted into secondary loop refrigeration system with little modification. It also provides other benefits such as reduced refrigerant charging, prevent refrigerant leaks in the desire location as it does not come in contact with the medium to be cooled. In this regard, incorporating nano technology into these systems may prove to be a promising option for enhancing system performance.

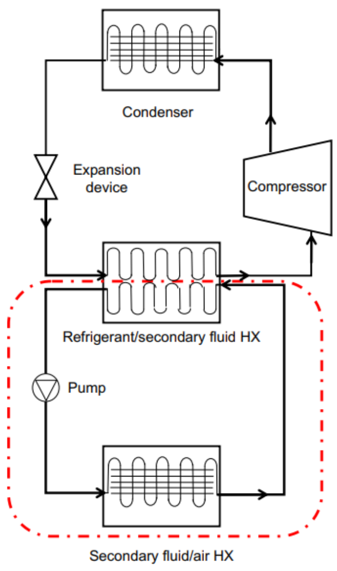

Fig: 1. secondary loop refrigeration system.

The nanofluids are novel kind of fluids developed by mixing nano meter sized particles of a material in a base fluid that greatly improve the thermophysical properties. But the nano particle should be uniformly and stably distributed in the base fluid and it is remaining a significant task to achieve desire stability of nanofluids. Nanofluids are formed generally by two known processes single step method and double step methods. In single step method nano particles are uniformly and stably distributed in base fluid with little to no aggregation of particle but it is a costly method.

Nano refrigerant is nothing but combination of nano particle and refrigerant. In recent years numerous research has proven that nanofluid are superior than conventional heat transfer fluid due to their improved thermophysical properties. But it is still a big challenge to use them in the refrigeration and air conditioning system due to their low stability in the conventional refrigerant. An alternative approach to incorporate them into secondary loop refrigeration system as secondary fluid is a significant solution to above stated problem. In extensive research it has proven that nano particles are stable for long period of time in the base fluid such as water, water-glycol mixture as compared to conventional refrigerant.

It is observed from the literature review that no one evaluate the performance of Aluminium oxide (Al2O3) Nano particle in base fluid of EG– water mixture (50:50) in the secondary circuit of vapour compression refrigeration system.

In this study a thermodynamic model of vapour compression refrigeration cycle with Al2O3 nano particle (13nm) mixed in ethylene glycol-water mixture (50:50) in secondary loop and R1234yf refrigerant in the primary loop is used for theoretical study. The primary loop of the system comprises of conventional system component, but in evaporator heat transfer take place between primary refrigerant and the secondary fluid and a secondary loop comprises of a double tube counter flow heat exchanger (geometry is given in table 2) in which refrigerant circulate inside the inner tube and secondary fluid in the outer tube and a pump the general structure of the system is represented in figure 2. The thermodynamic model is working with a constant mass flow of refrigerant and constant rpm of compressor and the model inputs are the mass flow rate of secondary fluid, secondary fluid inlet temperature, for simplicity of the system, superheating at evaporator and subcooling at condenser outlet is neglected.

The models using set of equations based on energy balance and physical laws. Using input, operating parameter and heat exchanger geometry, model predict the secondary fluid output parameter and performance of the system using engineering equation solver.

Table 2. Geometry of heat exchanger.

Sr. No.	**Description**	**Value**
1	Inner dia. of outer tube (Do)	15 mm
2	Outer dia. of inner tube	9.25 mm
3	Inner dia. of inner tube	10 mm
4	Length of the tube	2 m

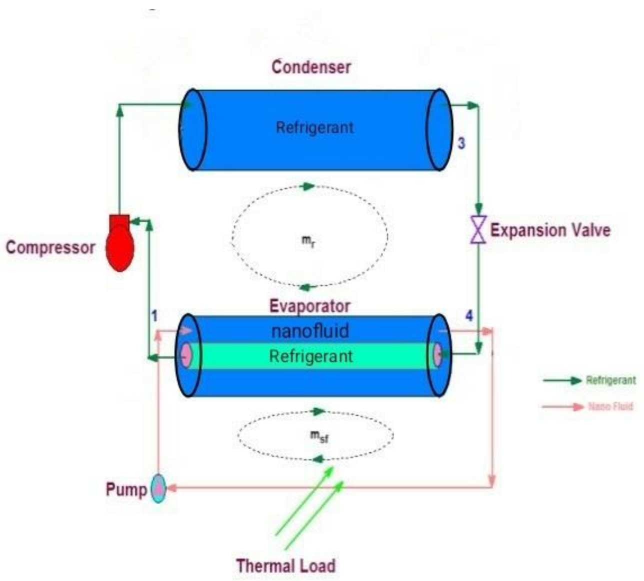

Fig. 2 Schematic of the model.

2.2 THERMODYNMIC MODELING

The model consist a vapour compression system incorporated with secondary loop by means of a double tube heat exchanger. Input date for the thermal modelling included nanoparticle size and volume fraction, the geometry of evaporator (inner and outer diameters), Secondary fluid inlet temperatures, condenser temperature and evaporator temperatures, excluding evaporator superheating and condenser subcooling which are available in table 3.

Table-3 Input conditions

Sr. No.	Description	Value
1	flow rate of Refrigerant	14.4 kg/hr
2	flow rate of secondary fluid	24.2 kg/hr
3	Inlet temperature of sec. fluid in the evaporator	300 K
4	Volume fraction of nano particle	0.5 %
5	Nano particle size	13nm
6	Compressor isentropic efficiency	75 %

2.2.1 Performance parameter of VCR system

Heat transfer rate in evaporator

Evaporator modelled using heat exchanger energy balance, and by using global heat transfer coefficient and LMTD.

$$Q_e = m_r(h_1 - h_4) \quad \text{W}$$

$$Q_e = m_b C_{pb}(T_{bin} - T_{bout}) \quad \text{W}$$

$$m_r(h_1 - h_4) = U_e A_e LMTD \quad \text{W}$$

$$A_e = \pi d_o l_e \ \text{m}^2$$

$$LMTD = \left[\frac{(\Delta T_i) - (\Delta T_e)}{\ln\left(\frac{\Delta T_i}{\Delta T_e}\right)}\right]$$

$$LMTD = \left[\frac{(T_{bin} - T_e) - (T_{bout} - T_e)}{\ln\left(\frac{T_{bin} - T_e}{T_{bout} - T_e}\right)}\right]$$

Where

U_e is the overall heat transfer coefficient of evaporator

Ae is the surface area of heat exchanger

LMTD is the logarithmic mean temperature difference

the overall heat transfer coefficient used in equation is computed as

$$1/U_e = \frac{1}{\alpha_{nf}} + \frac{\ln\left({}^{r_0}/_{r_i}\right)}{K_m} + \frac{r_0}{\alpha_r r_i} \quad \text{m}^2\text{K/W}$$

Zukauskas' correlation is used to compute heat transfer coefficient for the nano fluid.

$$\alpha_{nf} = \frac{K_{nf}}{d_0} C_1 . Re_{nf}^{m1} . Pr_{nf}^{0.36} \quad \text{W/m}^2\text{K}$$

d_0 is outer diameter of the tube

k_{nf} thermal conductivity of nanofluid

Re_{nf} Reynolds number of nanofluid

Pr_{nf} Prandtl number of nanofluid

C_1 and m_1 are coefficient of correlation and depend on the Reynolds number

C_1, m_1 = 0.9, 0.4	Re ≤ 100
C_1, m_1 = 0.683, 0.466	100 < Re ≤ 10000
C_1, m_1 = 0.4, 0.	10000 < Re ≤ 200000

Reynolds number of refrigerant is calculated by

$$R_{nf} = \frac{\rho_{nf} V_{nf} (D_o - d_o)}{\mu_{nf}}$$

Mass flow of nanofluid

$$m_{nf} = \rho_{nf} V_{nf} A \text{ kg/s}$$

$$A = \frac{\pi(D_o^2 - d_o^2)}{4} \text{ m}^2$$

Prandlt number of nanofluid

$$Pr_{nf} = \frac{\mu_{nf} C_{pnf}}{k_{nf}}$$

Heat transfer coefficient of refrigerant is computed by the Chens' correlation

$$\alpha_r = s.f\alpha_{nb} + F\alpha_{conv} \text{ W/m}^2\text{k}$$

Where,

α_{nb} is the nucleated boiling component of heat transfer coefficient.

α_{conv} - convective component of heat transfer coefficient

s.f - suppression factor and F is the Reynolds factor.

$$\alpha_{nb} = [\frac{0.00122.k_{le}^{0.79}.C_{ple}^{0.45}.\rho_{le}^{0.45}T_{sat}^{0.24}P_{sat}^{0.75}}{\sigma^{0.5}\mu_{le}^{0.29}\lambda_e^{0.24}\rho_{ve}^{0.24}}]$$

Where.

σ surface tension of the refrigerant

k_{le} thermal conductivity of refrigerant in the liquid phase in heat exchanger

C_{ple} specific heat of the refrigerant in the liquid phase in heat exchanger

ρ_{le} and ρ_{ve} are the density of refrigerant in the liquid phase and vapour phase in heat exchanger respectively.

λ_e enthalpy of vaporisation of refrigerant in heat exchanger

μ_{ve} viscosity of refrigerant in the vapour phase in heat exchanger

Convective component of heat transfer coefficient is computed by

$$\alpha_{conv} = 0.023. Re_r^{m1} . Pr_r^{0.36} . \frac{K_{le}}{d_i}$$

Reynold number of refrigerant

$$R_r = \frac{\rho_r V_r d_i}{\mu_r}$$

$$m_r = \rho_r V_r Ai$$

$$Ai = \frac{\pi d_i^2}{4} \quad \text{m}^2$$

Prandlt number of nanofluid

$$Pr_r = \frac{\mu_r C_{pr}}{k_r}$$

Suppression factor and Reynold number factor are computed by the following equations

$$sf = \frac{1}{1.00000253. (F^{1.15} Re_r)^{1.17}}$$

$$F = 1 \qquad \text{if } 1/\text{xtt} < 0.1$$

$$F = 2.35(1/\text{xtt} + 0.213)^{0.736} \quad \text{if } 1/\text{xtt} > 0.1$$

xtt is the Martinelli's Parameter.

$$xtt = \left(\frac{1 - xv}{xv}\right)^{0.9}\left(\frac{\rho_{ve}}{\rho_{le}}\right)^{0.5}\left(\frac{\mu_{le}}{\mu_{ve}}\right)^{0.1}$$

xv is the quality of refrigerant.

Compressor work

$$W_c = \frac{m_r(h_2 - h_1)}{\eta_{isc}} \quad \text{W}$$

Coefficient of Performance of the is calculated as

$$COP = \frac{Q_e}{W_c}$$

2.2.2 Nanofluid Properties

1. Density of nanofluid

The density of nanofluids is calculated on bases of mass conservation principle

$$\rho_{nf} = (1 - \varphi)\rho_f + \varphi\rho_p \qquad \text{kg/m}^3$$

2. Specific heat of nanofluid

Specific heat of nanofluid is determined by the correlation developed by Xuan and Roetzel.

$$C_{pnf} = \frac{(1-\varphi)\rho_f C_{pf} + \varphi\rho_p C_{pp}}{\rho_{nf}} \qquad \text{J/kgK}$$

3. Thermal conductivity

Thermal conductivity of nanofluid is computed by empirical correlation proposed by maxwell

$$k_{nf} = \frac{k_p + 2k_f + 2(k_p - k_f)\varphi}{k_p + 2k_f - 2(k_p - k_f)\varphi} k_f \quad \text{W/mK}$$

4. Viscosity

The viscosity of the nanofluid is calculated by given model.

$$\frac{\mu_{nf}}{\mu_f} = 123\,\varphi^2 + 7.3\,\varphi + 1 \quad \text{kg/msec}$$

CHAPTER 3

RESULTS, DISCUSSION AND CONCLUTION

3.1 RESULTS AND DISCUTION

3.1.1 Effect of nano particle volume concentration

The properties of nano particle, base fluid and nano fluid at 27^{o} C, with 0.5 % volume concentration of Al2O3 nano particle are shown in table 4. The thermal conductivity of the nanofluid against the nano particle concentration is represented in figure 3. The variation of viscosity of nano fluid with the nano particle volume concentration is shown in figure 4. The variation of heat transfer coefficient of nano fluid with nano particle concentration is represented in figure 5.

Table 4 properties of nano particle, base fluid and nano fluid at 27^{o} C, with 0.5 % volume concentration of Al2O3 nano particle.

Sr. No.	Properties	Al2O3 nano particle(13nm)	EG-water mixture (50:50)	Nano fluid - Al2O3+EG-W
1	Density (kg/m$^{3)}$	4000	1061	1075.695
2	Specific Heat (J/kg-K)	773	3348	3300.124
3	Thermal conductivity (W/mK)	40	0.3993	0.39916
4	Dynamic viscosity (kg/msec)		2.987 x 10^{-3}	3.1 x 10^{-3}

3.1.2 Effect of secondary fluid parameter

The variation of COP of system with the secondary fluid mass flow rate at condenser temperature of 321 K, 323 K, and 328 K are represented in table 5. The deviation of global heat transfer coefficient and refrigeration capacity with nano fluid mass flow rate is shown in table 6.

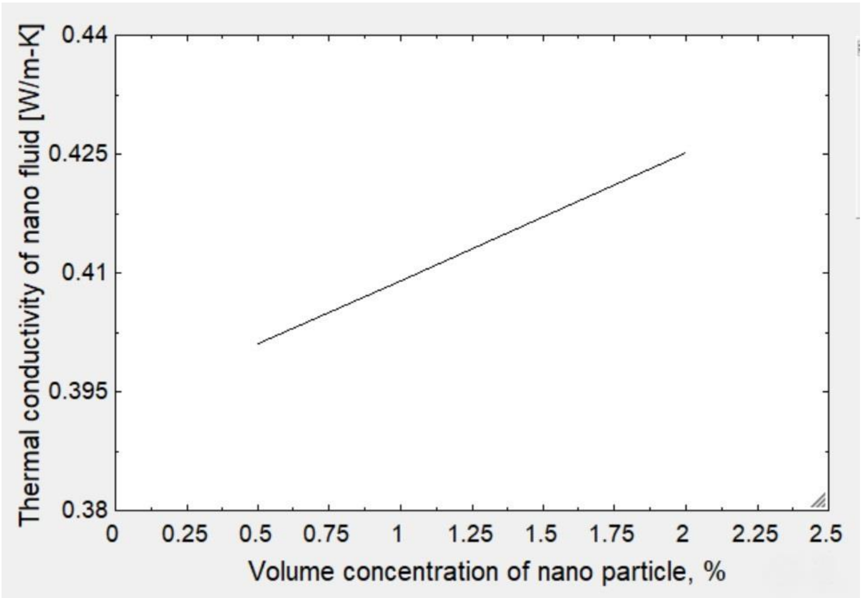

Fig. 3 Variation thermal conductivity of nano fluid with nano particle concentration

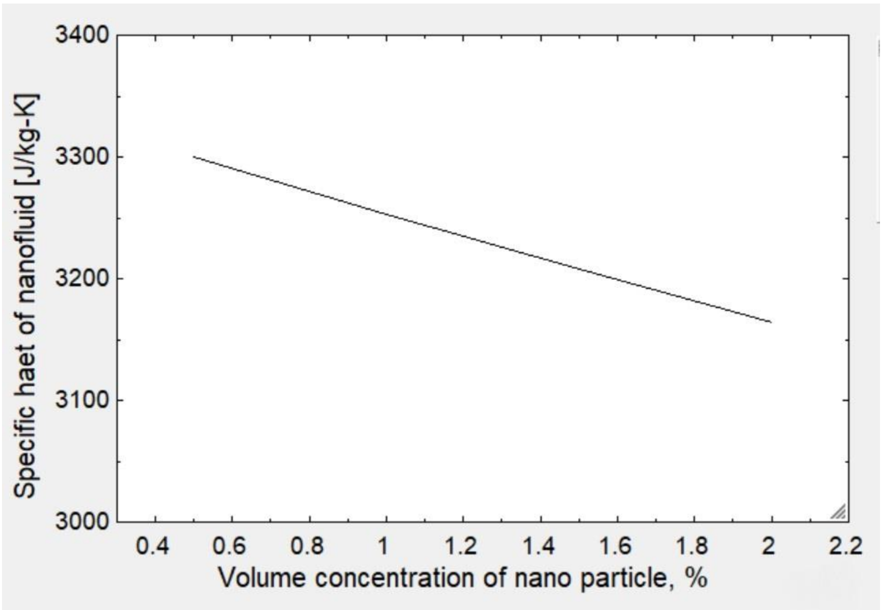

Fig. 4 Variation specific heat of nano fluid with nano particle concentration

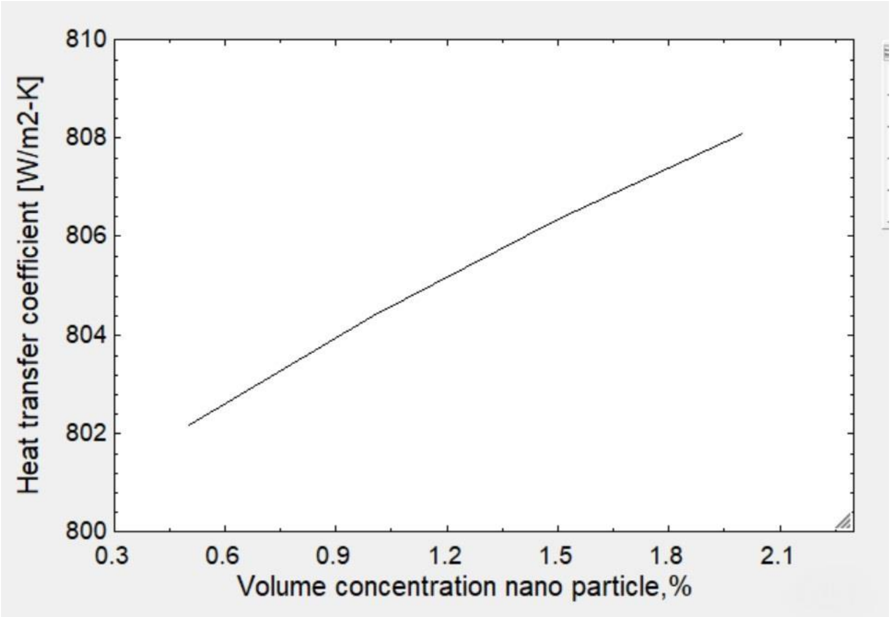

Fig. 5 Variation heat transfer coefficient of nano fluid with nano particle concentration

Table 5 Variation of COP with mass flow rate of nano fluid at different condenser temperature.

Mass flow rate of nanofluid fluid	**COP at 321 K cond. Temp.**	**COP at 323 K cond. Temp.**	**COP at 328 K cond. Temp.**
0.007 kg/s	3.383	3.265	3.017
0.008 kg/s	3.692	3.563	3.292
0.009kg/s	3.974	3.835	3.544

Table 6 deviation of global heat transfer coefficient and Refrigeration capacity with nano fluid mass flow rate.

Mass flow rate of nanofluid fluid	**Global heat transfer coefficient. (U_e)**	**Refrigeration capacity (Q_e)**
0.007 kg/s	501.2	394.3
0.008 kg/s	521.1	430.2
0.009kg/s	538.6	463.2

3.1.3 Effect of Condenser temperature.

The deviation of COP of the model with and without secondary loop corresponding to condenser temperature and at 274.5 K evaporator temperature is represented in table7.

Table 7 COP of the system with and without secondary loop corresponding to condenser temperature and at 274.5 K evaporator temperature.

Sr. No	**Condenser Temp.[K]**	**COP without Sec. Fluid**	**COP with Sec. Fluid**
1	321	3.158	3.535
2	323	2.962	3.420
3	328	2.537	3.175

3.2 CONCLUSION

Over the last few decades, the environmental impact of refrigeration and air conditioning applications has been studied and found that they are causing great damage to the environment due to their harmful emissions such as CFCs, HCFCs, and HFCs. This led the researchers to find alternative refrigerants which can replace these refrigerants in the existing system. But some of the new eco-friendly refrigerants have some issues like higher flammability and toxicity than the conventional refrigerants.

Secondary loop refrigeration system is a potential solution to the above stated problem, this system allows us to use these refrigerants by reducing the refrigerant charge and by reducing their leakage chances. It also serves some other benefits such as enhanced system performance.

In this study, some light also spread on nanotechnology. In recent years, enormous studies have been done on nanofluids in different applications with various nano-particle and base fluid combinations. The incorporation of nanofluid in the secondary loop refrigeration system can be the remarkable solution to the upcoming requirement.

The performance of the proposed model is studied with the results obtained by using EES (Engineering Equation Solver). The thermodynamic model results have shown that the Al_2O_3 nano particle (13nm) mixed in ethylene glycol water mixture (50:50) as the secondary refrigerant in the system operating at 274.5 K evaporator temperature can improve the COP of the system by 11.94 %, 15.45 %, and 25.16 % for 321 K, 323 K, and 328 K condenser temperature respectively.

From obtained results it can be concluded that as the evaporator temperature or pressure increases the coefficient of performance of the system with and without nano fluid increases. But the improvement of COP of system with the secondary loop is greatly enhance at lower evaporator temperature. It is also observed that as the condenser temperature or pressure increases the coefficient of performance of the system with and without nano fluid decreases but system with secondary fluid at higher condenser temperature gives better performance than the system without nano fluid.

3.2.1 Scope of future work

Even though the secondary loop refrigeration system has several advantages such as reduced refrigerant charge, minor chances of leakage and improved performance parameter than the conventional system there are some challenges including additional pump and intermediate heat exchanger which introduce more irreversibility in the system and reduced the performance of the system. Apart from the above challenges the initial cost of the system also increases due to inclusion of a pump and intermediate heat exchanger. Before considering secondary loop refrigeration system as substitute to conventional VCR system further research need to done in secondary loop refrigeration system.

From literature it is also observed that limited research Is available on application of secondary loop refrigeration system in the mobile air conditioning.

APPINDIX 1

Engineering Equation Solver (EES) programme.

```
"Input Parameter"
Pe=360000
Pc=1455000
Te=T_sat(R1234yf,P=Pe)
Tc=T_sat(R1234yf,P=Pc)
P1=Pe
P2=Pc
h1=Enthalpy(R1234yf,P=Pe, x=1)
s1=Entropy(R1234yf,P=P1,x=1)
s2=s1
h2=Enthalpy(R1234yf,P=P2,s=s2)
h3=Enthalpy(R1234yf,P=P2,x=0)
h4=h3
q=h1-h4
wc=(h2-h1)/0.75
Wc_dot=mr_dot*wc
cop1=q/wc
v1=Volume(R1234yf,P=P1,x=1)
kle=Conductivity(R1234yf,P=Pe,x=0)
cple=Cp(R1234yf,P=Pe,x=0)
```

```
rhole=Density(R1234yf,P=Pe,x=0)
sigmae=SurfaceTension(R1234yf,T=Te)
mule=Viscosity(R1234yf,P=Pe,x=0)
muve=Viscosity(R1234yf,P=Pe,x=1)
hle=Enthalpy(R1234yf,P=Pe,x=0)
hve=Enthalpy(R1234yf,P=Pe,x=1)
rhove=Density(R1234yf,P=Pe,x=1)
"Brine Properties"
Tb=300
Tbi=300
Cb=50 [%]
rhob=Density(EG,T=Tb,C=Cb)
Cpb=Cp(EG,T=Tb,C=Cb)
kb=Conductivity(EG,T=Tb,C=Cb)
mub=Viscosity(EG,T=300,C=Cb)
mnf_dot=0.007 [kg/s]
mr_dot=0.004
Qe1_dot=mr_dot*q
di=0.00925 [m]
do=0.01 [m]
ro=do/2
ri=di/2
doo=0.015 [m]
roo=doo/2
le=2 [m]
se=(22/7)*do*le
km=385 [W/m-K]
"Nano Particle Properties"
```

fyp=0.005

rhop=4000 [kg/m3]

Cpp=773 [J/kg-K]

kp=40 [W/m-K]

"Nanofluid Properties"

rhonf=(rhop*fyp+rhob*(1-fyp))

Cpnf=(rhop*Cpp*fyp+(1-fyp)*rhob*Cpb)/rhonf

knf=(kp+2*kb+2*(kp-kb)*fyp)*kb/(kp+2*kb-2*(kp-kb)*fyp)

munf=(123*fyp^2+7.3*fyp+1)*mub

"Evaporator Properties"

Hnf=knf*0.683*Renf^0.466*Prnf^0.36/do

D=doo-do

mnf_dot=rhonf*A*Vnf

A=pi*(roo^2-ro^2)

Renf=(rhonf*Vnf*D)/munf

Prnf=munf*Cpnf/knf

Hnb=0.00122*kle^0.79*cple^0.45*rhole^0.49*Te^0.24*Pe^0.75/(sigmae^0.5*mule ^0.29*(hve-hle)^0.24*rhove^0.24)

Hconv=0.023*Rer^0.8*Prr^0.4*kle/di

mr_dot=rhole*Ai*Vr

Ai=pi*ri^2

Rer=(rhole*Vr*di)/mule

Prr=mule*cple/kle

xv=0.5

xtt=(rhove/rhole)^0.5*(mule/muve)^0.1*((1-xv)/xv)^0.9

F=2.35*(1/xtt+0.213)^0.736

sf=1/(Rer*F^1.15)^1.17*1.00000253

Hr=sf*Hnb+F*Hconv

1/Ue=(1/Hnf+ro*ln(ro/ri)/km+ro/(ri*Hr))

Qe_dot=mnf_dot*Cpnf*(Tbi-Tbo)

```
Qe_dot=Ue*se*(Tbi-Tbo)/L
L=ln(x)
x=(Tbi-Te)/(Tbo-Te)
cop=Qe_dot/Wc_dot
lmtd=(Tbi-Tbo)/L
Improvement=((cop/cop1)-1)*100 [%]
```

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