Experimental Analysis of Vapour Compression Refrigeration System using Al_2O_3/CuO-R134a Nano Fluid as Refrigerant

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Abstract **–The objective of this paper is to investigate the influence of Al_2O_3/CuO nano particles on the heat transfer characteristics and performance of refrigerant based nanofluid flow through the vapour compression refrigeration system. As a replacement to CFC's and HFC's, R134a refrigerant is being widely used in current refrigeration and air-conditioning systems. But they consume more power and has high global warming potential. By addition of the 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. An experimental apparatus was build according to the national standards of India. Aluminium oxide and copper oxide nano fluids are used with R134a refrigerant in vapour compression refrigeration system and the heat transfer coefficient and performance of the system were evaluated by using TK Solver, using nano concentration 0 to 1%.The experimental results shows that the heat transfer coefficient of refrigerant based nanofluid is higher than that of pure refrigerant and also coefficient of performance is higher than the existing.**

Index terms - Aluminium oxide, COP, Copper oxide, heat transfer coefficient, nano refrigerant, R134a, TK solver.

1 INTRODUCTION

Vapour compression refrigeration system is predominantly used for refrigeration and air-conditioning systems nowadays. R134a refrigerant has replaced the CFC's and HFC's as they were said to have high ozone depleting potential. R134a has its own negatives like global warming potential, high power consumption and so on. In order to overcome current power scarcity, energy efficient refrigeration system with high heat transfer coefficient has to be developed. Nanofluids are thermal fluids prepared by suspending nano sized particles in conventional base fluids (water, ethylene glycol, refrigerant). Nanofluids are said to have higher thermal conductivity when compared to the base fluids and hence are said to improve the heat transfer characteristics of the base fluids. These thermo physical properties of nano fluids make it possible to be used in refrigeration systems. Eed Abdel Hafez et al [1] had performed heat transfer analysis of vapour compression refrigeration system using CuO – R134a and found that heat transfer co-efficient of refrigerant increases with 0.1 to 0.55% of CuO and 15 to 25 nm size of CuO Nano particles. D.Senthilkumar and Dr.R.Elansezhian[4] done investigation of R152a/R134a mixture in refrigeration system using hydrocarbon mixtures of R152a and R134a and concluded that the system worked safely and the maximum cop value 5.26 has obtained. HaoPeng et al [5] studied heat transfer characteristics of refrigerant based nano fluid flow boiling inside a horizontal smooth tube using CuO + R113 and observed that heat transfer coefficient R113 + CuO mixture is larger than that of pure refrigerant and 29.7 % of maximum heat transfer coefficient. T.Coumaressin et al [7] had conducted performance analysis of a refrigeration system using Nano fluid and concluded that evaporator heat transfer co-efficient increases with usage of Nano CuO-R134a. Juan carlos et al [9] studied applications of nano fluid in refrigeration system and found greater reduction of evaporator area with usage of Cu+H2O nano fluid. D.Senthilkumar and Dr.R.Elansezhian [10] conducted experimental study on Al_2O_3-R134a nano refrigerant in refrigeration system with 0.2% nano concentration and obtained increase of COP as 3.5 for capillary length of 10.5m. N.Subramani and M.J.Prakash [11] conducted an experimental study on vapour compression refrigeration system using nano refrigerants with Al_2O_3 and found increase of Co-efficient of heat transfer by 58%, reduction of power consumption by 18% and increase in COP by 33%.

The main objectives of the paper are (i) To improve the heat transfer characteristics in refrigerator system by adding Al_2O_3/CuO nano particles to the R134a refrigerant. (ii) To perform the heat transfer analysis and performance analysis in a vapour compression refrigeration system using a nanofluid as refrigerant. (iii) To develop a mathematical model for such a system. (iv) To perform heat transfer and performance analysis using TK Solver software. (v) To evaluate the heat transfer coefficients and Coefficient of performance for different concentrations of Al_2O_3/CuO nano particles and to come up with an optimized Al_2O_3/CuO concentration to maximize the heat transfer coefficient, Coefficient of performance and refrigeration effect.

2 EXPERIMENTAL SETUP

Evaporator, Reciprocating Compressor, Condenser, Expansion valve – solenoid Valve, Refrigerant – R134a
Evaporator vessel diameter, D = 295mm =0.295m
Energy meter constant, E = 750 rev/kWh

2.1 Working

The vapour – compression uses a circulating liquid refrigerant as a medium which absorbs and removes heat from the space to be cooled and subsequently rejects that heat elsewhere. Figure 1 depicts the typical, single – stage vapour – compression system. All such systems have 4 components: A compressor, a condenser, a thermal expansion valve and an evaporator. Circulating refrigerant enters the compressor in the thermodynamic state known as a saturated vapour and is compressed to a higher pressure, resulting in a higher temperature as well. The hot vapour is routed through a condenser where it is cooled and condensed into a liquid by flowing through a coil or tubes with cool air flowing across the coil or tubes.

The condensed liquid refrigerant, in the thermodynamic state known as a saturated liquid, is next routed through an expansion valve where it undergoes an abrupt reduction in pressure. That pressure reduction results in the adiabatic flash evaporation of a part of the liquid refrigerant. The cold mixture is then routed through the coil or tubes in the evaporator. A fan circulates the warm air in the enclosed space across the coil or tubes carrying the cold refrigerant liquid and vapour mixture. That warm air evaporates the liquid part of the cold refrigerant mixtures. At the same time, the circulating air is cooled and thus lowers the temperature of enclosed space to the desired temperature.

Experiment was conducted using the above setup using R134a pure refrigerant and the actual and theoretical COP of solenoid valve and expansion valve expansion are calculated and the following results are obtained.


Figure 1. VCRS experimental setup

Table 1. Observations from the refrigeration test rig

Observation	Solenoid Valve	Expansion Valve
Initial temp of water (ºC)	28	28.6
Final temp of water (ºC)	24.6	22.4
Pressure at comp. Inlet (bar)	1.1768	1.9613
Pressure at comp. Outlet (bar)	9.8459	11.0226
Pressure before throttling (bar)	9.7282	10.9246
Pressure after throttling (bar)	1.1866	2.2261
Temp. at compressor inlet (ºC)	31.8	30.08
Temp. at compressor outlet(ºC)	69.8	76.2
Temp. before throttling (ºC)	41.2	44
Temp. after throttling (ºC)	6	12
Mass of water (kg)	16.395	16.395

Table2. Performance of VCRS using pure R134a.

Sl.No	COP	Solenoid Valve	Expansion Valve
1	COP actual	0.7847	1.1127
2	COP theoretical	2.9747	3.8951
3	Refrigeration effect(kJ/Kg)	0.2586	0.4734

2.2 Conclusions

The conclusions from the experiment were:

Expansion valve can be preferred over solenoid valve as an expansion device. Refrigeration effect can be enhanced in the evaporator. To enhance the refrigeration effect, we should use a better refrigerant. Nano particles-Al_2O_3/CuO can be used as refrigerant. We can improve the heat transfer coefficient, Coefficient of performance in a designed evaporator section.

3 MATHEMATICAL MODELLING

Refrigerant to be used	:	R134a
Nanofluid	:	Al_2O_3, CuO

3.1 Thermophysical properties of Nano refrigerant

The thermal conductivity of refrigerant based nanofluid is calculated by Hamilton – Crosser equation [16]

$$K_{rn} = K_r\left(\frac{K_n+2K_r-2\varphi(K_r-K_n)}{K_n+2K_r+\varphi(K_r-K_n)}\right)$$

(1)

Where,
Krn– Thermal conductivity of nano refrigerant
Kr - Thermal conductivity of pure refrigerant (R134a)
Kn - Thermal conductivity of nano particle
φ - Particle volume fraction of nano particle

The dynamic viscosity of nano refrigerant is calculated by Brinkman equation [18]. The Dynamic viscosity of nano refrigerant is as given below,

$$\mu_{rn} = \mu_r \frac{1}{(1-\varphi)^{2.5}}$$

(2)

Where,
μr– Viscosity of pure refrigerant
φ – Particle volume fraction

The specific heat capacity of nano refrigerant is calculated by Pak-cho equation (Pak and Cho, 1998). The specific heat of nano refrigerant is as given below.

$$C_{p-rn} = (1 - \varphi)C_{p-r} + \varphi C_{p-n} \quad (3)$$

Where,
φ – Particle volume fraction
Cp-r – Specific heat of refrigerant
Cp-n – Specific heat of nano particle

The Reynolds's number of nano refrigerant can be calculated from the equation given below [16]

$$Rern = \frac{G \times D_i}{\mu_{rn}} \quad (4)$$

Where,
G - mass flux = 100 Kg/m2s
Di - Inner diameter of tube
µrn - Viscosity of nano refrigerant

The Prandtl number of nano refrigerant can be calculated from the equation given below [16]

$$Prrn = \frac{C_{p-rn} \times \mu_{rn}}{K_{rn}} \quad (5)$$

The Nusselt number of nano refrigerant can be calculated from the equation given below [16]

Nu = 0.023Rern0.8Prrn0.4
(6)

The volume fraction of nano particles used in the above given equations can be obtained using the below relation [5]

$$\phi = \frac{\omega \rho_r}{\omega \rho_r + (1-\omega)\rho_n} \quad (7)$$

Where,
ω - Mass fraction of nano particle
ρ_r - Density of pure refrigerant R134a
ρ_n - Density of nano particle

The relation for mass fraction of nano particle is given - below [5]

$$\omega = \frac{M_n}{M_n + M_r} \quad (8)$$

Where,
M_n – Mass of nano particles
M_n – Mass of pure refrigerant (R134a)

Convective heat transfer coefficient of nano refrigerant is given by the following relation [16]

$$h_{c-rn} = 0.023\left[\frac{G^4 \times C_{p-rn}{}^2 \times k_{rn}{}^3}{D_i \times \mu_{rn}{}^2}\right]^{\frac{1}{5}} \quad (9)$$

3.2 Formula for Experimental calculation

Mass of water in the evaporator vessel
m = Density of water × Volume of water

$$m = \rho \times \frac{\pi}{4} \times D^2 \times h \quad \text{Kg/sec} \quad (10)$$

Where,
ρ - Density of water
D – Diameter of vessel = 295 mm 0.295 m
h – Height of water in vessel

Heat absorbed from evaporator water,

$$\text{Refrigeration effect} = \frac{mc_p(T_i - T_f)}{dT} \text{ J/sec} \quad (11)$$

Where,
Ti – initial temperature of water
Tf – Final temperature of water
Cp – Specific heat of water = 4.186 KJ/Kg K
dT – Duration of experiment in sec

Work done by the compressor

$$\text{Work done} = \frac{3600}{E} \times \frac{10}{t} \text{ KW} \quad (12)$$

Where,
E – Energy meter constant = 750 rev/ kWh
T – Time taken for 10 revolution of the energy meter disc

3.3 Coefficient of performance

Actual COP of a vapour compression refrigeration system is given by

$$COP_{Act} = \frac{hA\Delta T}{V \times I} \quad (13)$$

Coefficient of performance of the refrigeration (COP)actual

$$COP_{actual} = \frac{\text{Refrigerationeffect}}{\text{Workdone}} \quad (14)$$

Theoretical COP of a vapour compression refrigeration system is given by

$$COP_{Theo} = \frac{H_2 - H_1}{H_4 - H_2} \quad (15)$$

Where,
H1 – Enthalpy of refrigerant at the inlet of evaporator.
H2 – Enthalpy of refrigerant at the outlet of evaporator.
H4 – Enthalpy of refrigerant at the outlet of compressor.

Table 3. Properties of Nano fluids and R134a.

Fluid	Specific heat (J/kgK)	Thermal conductivity (W/mK	Density (kg/m3)
R134a	1432	0.0803	1199.7
Al_2O_3	729	40	3880
CuO	535.6	20	6500

4 RESULTS AND DISCUSSION

4.1 Analysis and comparison of thermo physical properties of nano refrigerants

The thermo physical properties such as heat transfer coefficient, thermal conductivity, specific heat capacity and dynamic viscosity of Al_2O_3/CuO – R134a nano refrigerant are calculated using TK Solver and their properties for optimized nano concentration are tabulated below.

Table 4. Thermo physical properties of Al_2O_3-R134a nano refrigerant

ω	h_{rn}	K_{rn}	Cp_{rn}	μ_{rn}
0.55	0.6502	0.1706	1239.1921	2280.0395

Table 5. Thermo physical properties of CuO-R134a nano refrigerant

ω	h_{rn}	K_{rn}	Cp_{rn}	μ_{rn}
0.6	.6387	.1460	1237.6381	1884.6961

*Where ω = Mass fraction of nano particles, hrn = Heat transfer coefficient of nano refrigerant, Krn = Thermal conductivity of nano refrigerant, Cprn = Specific heat capacity of nano refrigerant, and μ_{rn} = Dynamic viscosity of nano refrigerant respectively.

Heat transfer coefficient of Al_2O_3 and CuO nano refrigerants are compared below. The curve rises gradually and then decreases as shown in the below figure. The peak value is achieved at 0.55% concentration of Al_2O_3 and at 0.6% concentration of CuO nano refrigerant.

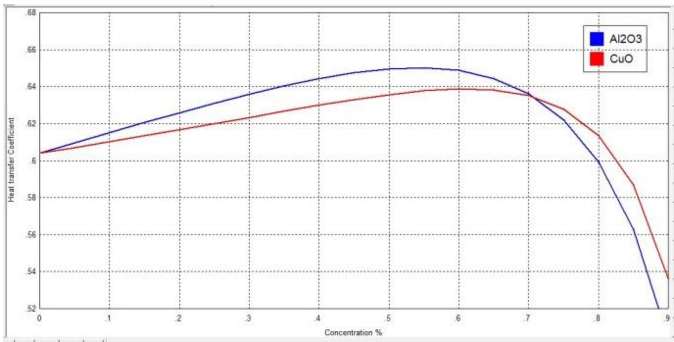

Figure 2. Heat transfer coefficient of Al_2O_3 and CuO

The curves of thermal conductivity of Al_2O_3 and CuO nano refrigerants are compared in the below figure. The curve seems to rise gradually as shown below.

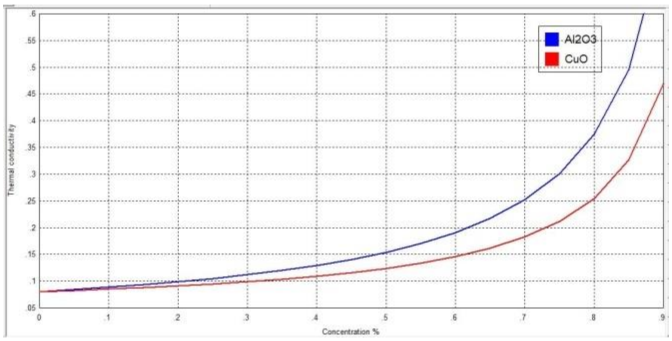

Figure 3. Thermal conductivity of Al_2O_3 and CuO

The characteristics curve for specific heat capacity of Al_2O_3 and CuO nano refrigerant decreases gradually as shown below.

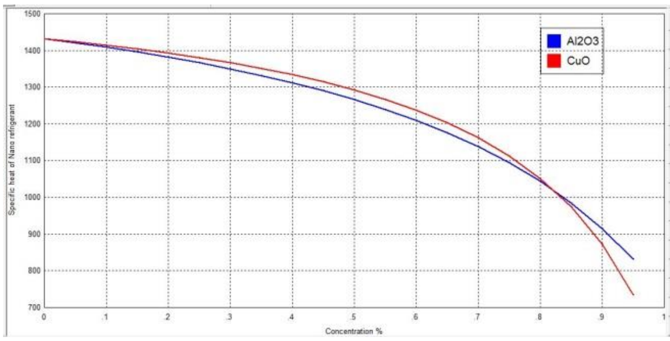

Figure 4. Specific heat capacity of Al_2O_3 and CuO

The curve for dynamic viscosity of Al_2O_3 and CuO nano refrigerants are compared below and seem to be increasing gradually.

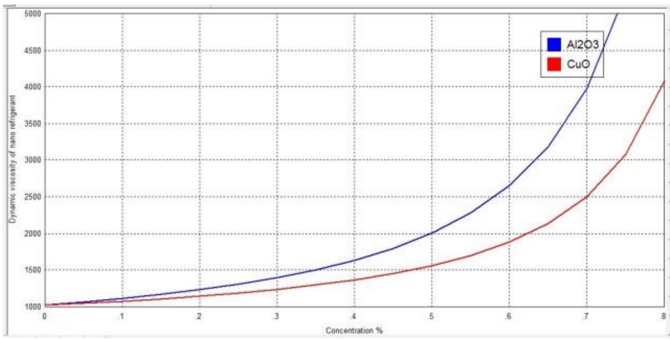

Figure 5. Dynamic viscosity of Al_2O_3 and CuO

4.2 Comparison of performance of Al_2O_3&CuO

The parameters obtained from the experiment conducted on vapour compression refrigeration system using pure R134a refrigerant are used to calculate the performance of the system with nano refrigerant of various composition and the coefficient of performance for different nano refrigerant combinations with solenoid as well expansion valve are calculated using TK solver and are tabulated below.

Table 6. Performance of Nano R134a refrigerant in VCRS

Coefficient Of Performance			
Al_2O_3		CuO	
Solenoid Valve	Expansion Valve	Solenoid valve	Expansion Valve
2.6911	3.7699	2.643	3.703

The performance of vapour compression refrigeration system (solenoid valve) using Al_2O_3 and CuO nano refrigerants are calculated and compared below. The peak COP is obtained at 0.55% concentration of Al_2O_3 (COP=2.6911) and 0.6% concentration of CuO nano refrigerant (COP=2.643)

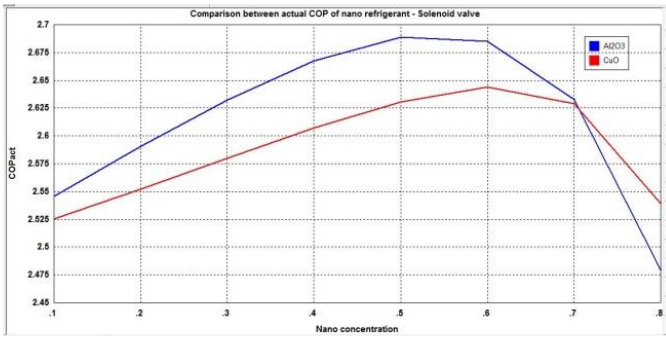

Figure 6. COP of Al_2O_3 and CuO –R134a nano refrigerants using solenoid valve

The performance of vapour compression refrigeration system (expansion valve) using Al_2O_3 and CuO nano refrigerants are calculated and compared below. The peak COP is obtained at 0.55% concentration of Al_2O_3 (COP=3.7699) and 0.6% concentration of CuO nano refrigerant (COP=3.703)

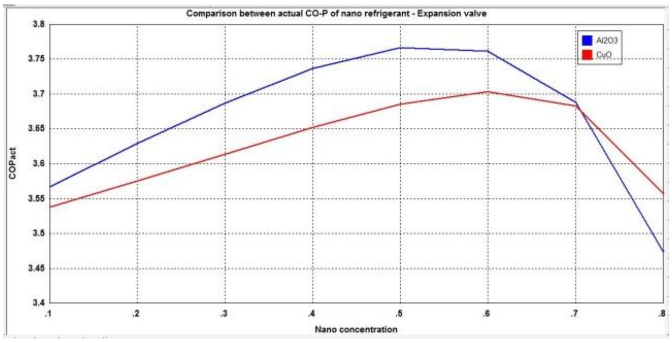

Figure 7. COP of Al_2O_3 and CuO –R134a nano refrigerants using expansion valve

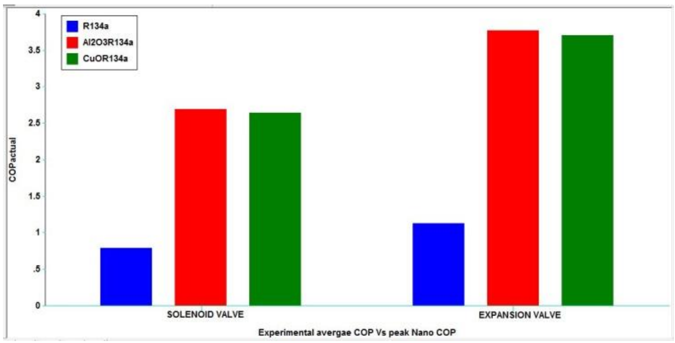

Figure 8. Comparison of experimental average COP and peak nano COP

The above figure shows the comparison between the experimental average actual COP of vapour compression refrigeration system using R134a and the peak actual COP of nano refrigerant at optimized nano concentrations. It is inferred from the above graph, that the COP of vapour compression refrigeration system increases with optimized mixing of nanofluids and Al_2O_3 is found to produce high COP when compared to other three nano refrigerants taken into account.

5 CONCLUSION

Al_2O_3/CuO nano particles with R134a refrigerant can be used as an excellent refrigerant to improve the heat transfer characteristics and performance in a refrigeration system. A successful model has been designed and the basic theoretical heat transfer analysis and performance analysis of the refrigeration system has been done. Heat transfer and performance analysis for the designed section has been successfully performed using TK Solver software. The obtained evaporating heat transfer coefficient and coefficient of performance result have been optimized at its maximum value for the best Al_2O_3/CuO nano particles concentration in R134a refrigerant. From the analysis it can be concluded that the heat transfer and performance characteristics of the system is higher with the usage of Al_2O_3 nano particles with R134a refrigerant compared to CuO nano particles.

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