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Performance Analysis of a Refrigeration System Using Nano Fluid

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Abstract

Evaporating heat transfer is very important in the refrigeration and air-conditioning systems. HFC 134a is the mostly widely used alternative refrigerant in refrigeration equipment such as domestic refrigerators and air conditioners. Though the global warming up potential of HFC134a is relatively high, it is affirmed that it is a long term alternative refrigerants in lots of countries. By addition of nanoparticles to the refrigerant results in improvements in the thermophysical properties and heat transfer characteristics of the refrigerant, thereby improving the performance of the refrigeration system. In this experiments the effect of using CuO-R134a in the vapour compression system on the evaporating heat transfer coefficient was investigated by CFD heat transfer analysis using the FLUENT software. An experimental apparatus was build according to the national standards of India. The experimental studies indicate that the refrigeration system with nanorefrigerant works normally. Heat transfer coefficients were evaluated using FLUENT for heat flux ranged from 10 to 40 kW/m^2, using nano CuO concentrations ranged from 0.05 to 1% and particle size from 10 to 70 nm. The results indicate that evaporator heat transfer coefficient increases with the usage of nanoCuO.

Keywords: Nanorefrigerant, CuO nanoparticles, Heat transfer coefficient, CFD.

1. Introduction

The rapid industrialization has led to unprecedented growth, development and technological advancement across the globe. Today global warming and ozone layer depletion on the one hand and spiraling oil prices on the other hand have become main challenges. Excessive use of fossil fuels is leading to their sharp diminution and nuclear energy is not out of harm's way. In the face of imminent energy resource crunch there is need for developing thermal systems which are energy efficient. Thermal systems like refrigerators and air conditioners consume large amount of electric power. It is essential to developing energy efficient refrigeration and air conditioning systems with nature friendly refrigerants. The rapid advances in nanotechnology have lead to emerging of new generation heat transfer fluids called nanofluids.

Nanofluids are prepared by suspending nano sized particles (1-100nm) in conventional fluids and have higher thermal conductivity than the base fluids. Nanofluids have the following characteristics compared to the normal solid liquid suspensions. i) higher heat transfer between the particles and fluids due to the high surface area of the particles ii) better dispersion stability with predominant Brownian motion iii)reduces particle clogging iv) reduced pumping power as compared to base fluid to obtain equivalent heat transfer. Based on the applications, nanoparticles are currently made out of a very wide variety of materials, the most common of the new generation of nanoparticles being ceramics, which are best split into metal oxide ceramics, such as titanium, zinc, aluminium and iron oxides, to name a prominent few and silicate nanoparticles, generally in the form of nanoscale flakes of clay. By addition of nanoparticles to the refrigerant results in improvements in the thermophysical properties and heat transfer characteristics of the refrigerant, thereby improving the performance of the refrigeration system. In a vapour compression refrigeration system the nanoparticles can be added to the lubricant .

HFC 134a is the mostly widely used alternative refrigerant in refrigeration equipment such as domestic refrigerators and air conditioners. Though the global warming up potential of HFC134a is relatively high, it is affirmed that it is a long term alternative refrigerants in lots of countries. An experiment on vapour compression refrigeration test rig has been conducted to calculate the refrigeration effect and coefficient of performance of the test rig to determine the potential places to enhance the refrigeration effect. Mathematical modeling is done on the test section of an evaporator tube using partial differential equations. Theoretical analysis has been done on the evaporator test section. Using the GAMBIT software the mesh of the evaporator test section is designed and using the FLUENT software the heat transfer analysis is done for various concentrations of the CuO nano particles.

2. Literature Survey

Many investigators have conducted studies on vapour compression refrigeration systems and to study the effect of nanoparticle in the refrigerant as well as lubricant on its performance. Pawel et al. (2005) conducted studies on nanofluids and found that there is the significant increase in the thermal conductivity of nanofluid when compared to the base fluid and also found that addition of nanoparticles results in significant increase in the critical heat flux. Bi et al. (2007) conducted studies on a domestic refrigerator using nanorefrigerants. In their studies R134a was used the refrigerant, and a mixture of mineral oil TiO_2 was used as the lubricant. They found that the refrigeration system with the nanorefrigerant worked normally and efficiently and the energy consumption reduces by 21.2%. When compared with R134a/POE oil system. After that Bi et al. (2008) found that there is remarkable reduction in the power consumption and significant improvement in freezing capacity. They pointed out the improvement in the system performance is due to better thermo physical properties of mineral oil and the presence of nanoparticles in the refrigerant. Jwo et al. (2009) 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 Al2O3 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%. Henderson et al. (2010) 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.

Bi et al. (2011) conducted an experimental study on the performance of a domestic refrigerator using TiO_2-R600a nanorefrigerant as working fluid. They showed that the TiO_2-R600a system worked normally and efficiently in the refrigerator and an energy saving of 9.6%. Senthilkumar and Elansezhian (2012) conducted an experimental study on the performance of a domestic refrigerator using Al_2O_3-R134a nanorefrigerant as working fluid. They found that the Al_2O_3-R134a system performance was better than pure lubricant with R134a working fluid with 10.30% less energy used with 0.2%V of the concentration used and also heat transfer coefficient increases with the usage of nano Al_2O_3. Krishna sabareesh et al(2012) conducted an experimental study on the performance of a domestic refrigerator using TiO_2 - R12 nanorefrigerant as working fluid. They found that the freezing capacity increased and heat transfer coefficient increases by 3.6 %, compression work reduced by 11% and also coefficient of performance increases by 17% due to the addition of nanoparticles in the lubricating oil. Reji kumar and Sridhar (2013) conducted an experimental study on the performance of a domestic refrigerator using TiO_2 – R600a nanorefrigerant as working fluid. They found that the energy consumption reduced by 11% and coefficient of performance increases by 19.6%.

In the present study the refrigerant selected is R134a and the nanoparticle is Cuo. R134a 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 R134a refrigerator was selected. CuO-R134a nano-refrigerant was prepared and used as working fluid. To evaluate the heat transfer coefficients for different concentrations of Cuonano particles.

3. Basic Experimental Observation of a Refrigeration Process

3.1 Equipment Used

Evaporator, Reciprocating Compressor, Condenser, Expansion valve – Capillary Tube, solenoid Valve, Refrigerant – R134a

3.2 Working

The vapour – compression uses a circulating liquid refrigerant as the medium which absorbs and removes heat from the space to be cooled and subsequently rejects that heat elsewhere. Fig. 1 depicts a typical, single – stage vapour – compression system. All such systems have four 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 vapor 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.

Fig. 1: Experimental Setup of the refrigeration test rig

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 mixture. At the same time, the circulating air is cooled and thus lowers the temperature of the enclosed space to the desired temperature.

3.3 Observations

Table 1: Observations from the refrigeration test rig.

Observation	Capillary tube	Solenoid Valve
Initial temp of water (˚C)	31	31
Final temp. of water (˚C)	10	11
Initial energy meter reading (kWh)	696.8	697
Final energy meter reading (kWh)	697	697.2
Pressure at comp. inlet (lb/in2)	45	35
Pressure at comp. Outlet (lb/in2)	190	190
Pressure before throttling(lb/in2)	190	190
Pressure after throttling(lb/in2)	45	35
Temp. at compressor inlet (˚C)	7	10
Temp. at compressor outlet(˚C)	55	65
Temp. before throttling (˚C)	46	41
Temp. after throttling (˚C)	9	5
Mass of water (kg)	12	12

3.4 Results

Table 2: Results from the refrigeration test rig.

COP	Capillary Tube	Solenoid Valve
COPcarnot	5.73	4.89
COPtheoretical	4.04	3.2
COPactual	1.463	1.39
Refrigeration Effect (kJ)	1053.36	1003.2

3.5 Conclusions

Capillary tube 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. We can use nano particles – Cuo. We can improve the heat transfer coefficient in a designed evaporator section.

4. Analysis of Evaporator Test Section

The evaporator test section considering here is a double pipe heat exchanger. The test section, evaporator is a straight horizontal tube in tube heat exchanger as shown in Fig. 2 which has a length of 1400 mm with inner tube made of copper having an outer diameter of 9.52 mm and inner diameter 7.72 mm. The refrigerant flows through the inner tube and the hot water used to evaporate the refrigerant flows through the annulus. The outer tube is made of copper having an outer diameter of 19.05 mm and inner diameter of 17 mm. the hot water flows around the refrigerant tube in counter direction and represents the load on the evaporator.

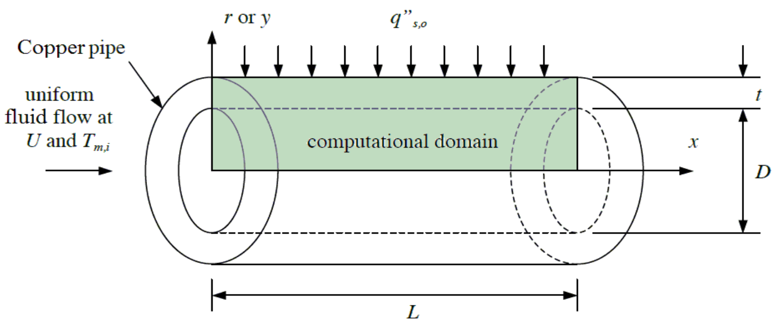

Fig. 2: Evaporator test section.

One can obtain an analytical solution to the governing equations in the fully developed region

$$u(r) = 2U\left[1 - \left(\frac{r}{R}\right)^2\right] \tag{1}$$

Where, R is the pipe radius. The length of the development region for laminar flow can be estimated using the following correlation (experimentally developed equation).

$$\frac{Xfd,h}{D} = 0.05\,\mathrm{Re}_D = 20 \tag{2}$$

For thermally fully – developed flow with a constant surface heat flux there is no longer any variation in the shape of the temperature profile in the axial x – direction. Again, one obtain an analytical solution to the governing equations in the fully – developed region as follows

$$T(r,x) = Ts(x) - \frac{2pUR2q}{kmL}\left[\frac{3}{16} + \frac{1}{16}\left(\frac{r}{R}\right)^4 - \frac{1}{4}\left(\frac{r}{R}\right)^2\right] \tag{3}$$

Where p is the density, k is the thermal conductivity, m is the mass flow rate, and T_s is the surface temperature on the inside of the pipe wall.

The length of the development region for laminar flow can be estimated using the following correlation

$$\frac{Xfd,t}{D} = 0.05\,\mathrm{Re}_D\,\mathrm{Pr} = 15 \tag{4}$$

Based on an overall energy balance for the pile, the mean temperature distribution for a uniform surface heat flux in the developing and fully – developed region can be calculated from the following (which is valid for both laminar and turbulent flow):

$$T_m(x) = Tm,t + \left(\frac{q}{mc_p}\right)\frac{x}{L} \tag{5}$$

Where, Cp is the specific heat and the mean temperature is defined based on a mass – weighted average.

Finally, the heat transfer coefficient for out pipe flow is defined as:

$$h(x) = \frac{q}{\pi DL\ [Ts\ (x) - T_m\ (x)]} \tag{6}$$

Thorough analysis of the problem was done and it was found out that the nature of heat transfer is Forced convection with CONSTANT HEAT FLUX. Heat flux is kept constant for varying concentrations of CuO so that different heat transfer coefficient values can be obtained.

5. Design Using Gambit Software

5.1 Gambit Introduction

GAMBIT is geometry and mesh generation software, usually used with Fluent. GAMBIT's single interface for geometry creation and meshing brings together most of Fluent's preprocessing technologies in one environment. GAMBITs combination of CAD interoperability, geometry cleanup, decomposition and meshing tools results in one of the easiest, fastest, and most straightforward preprocessing paths from CAD to quality CFD meshes. Different CFD problems require different mesh types, and GAMBIT gives you all the options you need in a single package.

5.2 Modeling of Evaporator Test Section Using Gambit Software

First the evaporator test section has been modeled using CATIA as shown below straight horizontal tube with diameters:

- Internal diameter of inner tube: 8 mm
- External diameter of inner tube: 10 mm
- Length of test section: 144 mm

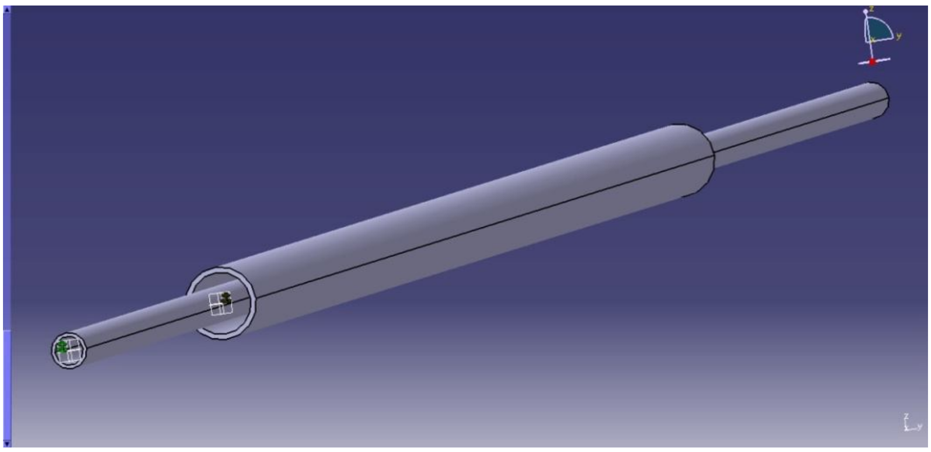

Fig. 3: Evaporator test section.

6. Mathematical Modeling

6.1. Heat transfer coefficient

The formulae for the heat transfer coefficient is given below

$$\frac{1}{h} = \frac{\pi d_i L\left(T_{av,ref} - T_{wall}\right)}{Q} - \frac{d_i}{2k}\ln\left(\frac{d_o}{d_i}\right) \tag{7}$$

$$Q = m_w C_w \left(T_{mo} - T_{wi}\right) \tag{8}$$

m_w = Cooling water mass flow rate,
T_{wi} = Inlet temperature of water, K
T_{wo} = outlet temperature of water, K
$T_{av,ref}$ = Average temperature of refrigerant, K
T_{wall} = average temperature of tube wall, K
D_i = inner diameter of refrigerant tube, m
D_o = outer diameter of refrigerant tube, m
L = evaporator length. m
C_w = Specific heat of water. kJ/kg K
K = evaporator tube thermal conductivity, Kw/m K

6.2 Evaluation of the properties of the nano fluid

The important parameters which influence the heat transfer characteristics of nanofluids are its properties which include thermal conductivity, viscosity, specific heat and density. These properties of nano fluids are pre requisites for estimation of heat transfer coefficient using the FLUENT software

6.2.1 Density of nano fluid

The base fluid is R134a refrigerant. The density of the nano fluid (R134a – Cuonano particles) for different concentrations of Cuo particles is developed by Pak and cho.
It is given by

$$P_{nf} = \phi P_p + \left(1-\phi\right) P_{bf} \tag{9}$$

6.2.2 Isobaric specific heat of nano fluid

Specific heat is the amount of heat required to raise the temperature of one gram of nano fluids by one degree centigrade.

$$C_{pnf} = \phi C_p + \left(1-\phi\right) C_{bf} \tag{10}$$

6.2.3 Thermal conductivity of nano fluid

The equation for calculating thermal conductivity is given below; it is developed by Maxwell – Eucken.

$$knf = kbf\{\frac{\left[(1+2\phi)(1-(kbf/kcuo))/(2(kbf/kcuo)+1)\right]}{\left[(1-\phi(1-(Kbf/kcuo))/((Kbf/kcuo+1)\right]}\} \tag{11}$$

6.2.4 Viscosity of nano fluid

The equation for calculating the Viscosity of the nano fluid given by Einstein is given below

$$\mu_{nf} = \mu_{bf}\left(1+2.5\phi\right) \tag{12}$$

Where ϕ Volume concentration of Cuo Nano particles, Kg/m^3

7. Results and Discussion

The results that were obtained after the FLUENT analysis are graphed below: Heat flux [q] and concentration were two parameters, which were changed during the process The values obtained for different heat fluxes, q = 10, 20, 30, 40 kW were plotted on a graph.

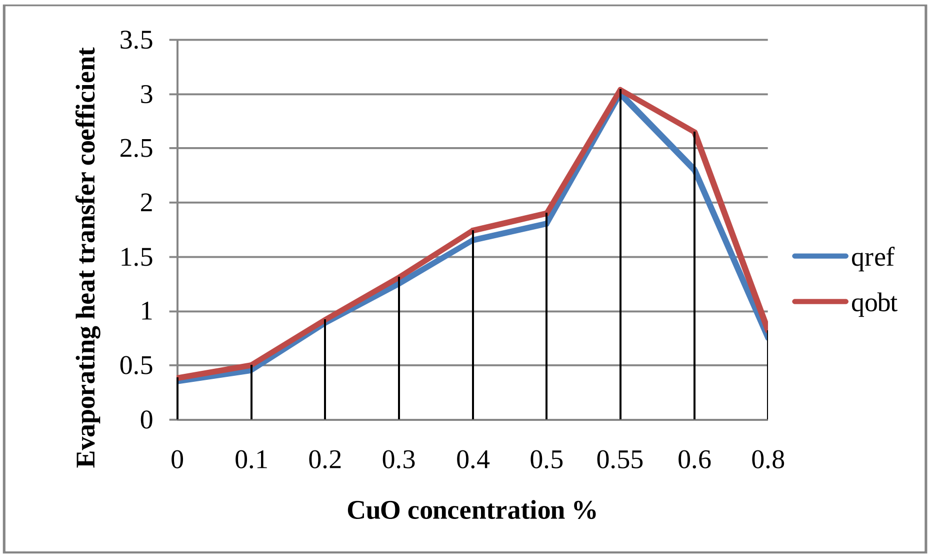

Fig. 4 *Plot for q = 10 kW, Conc. = 0.55%, h = 3.04 kW/m^2-K*

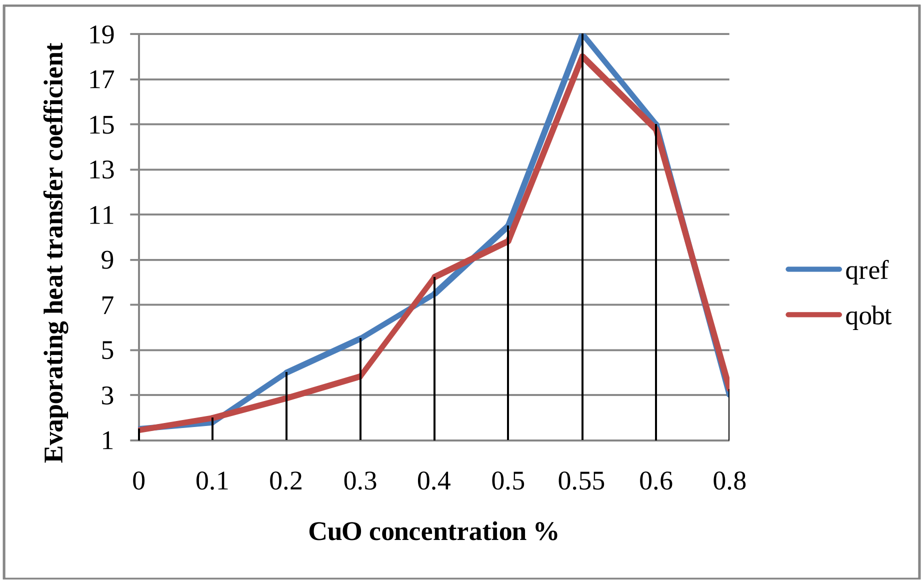

Fig. 5: Plot for q = 20 kW, Conc. = 0.55%, h = 18.03 kW/m^2-K.

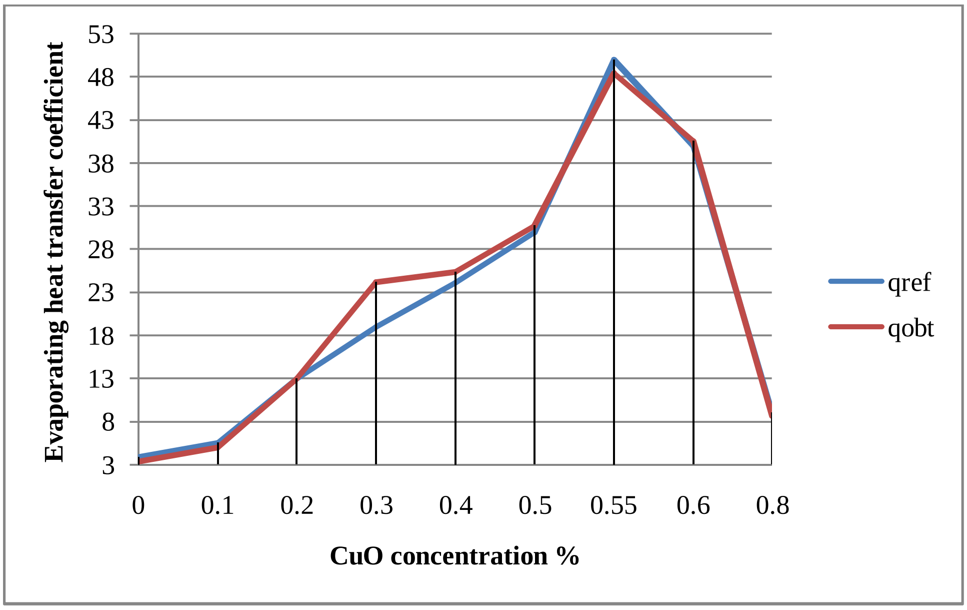

Fig. 6: Plot for q = 30 kW, Conc. = 0.55%, h = 48.45kW/m^2-K.

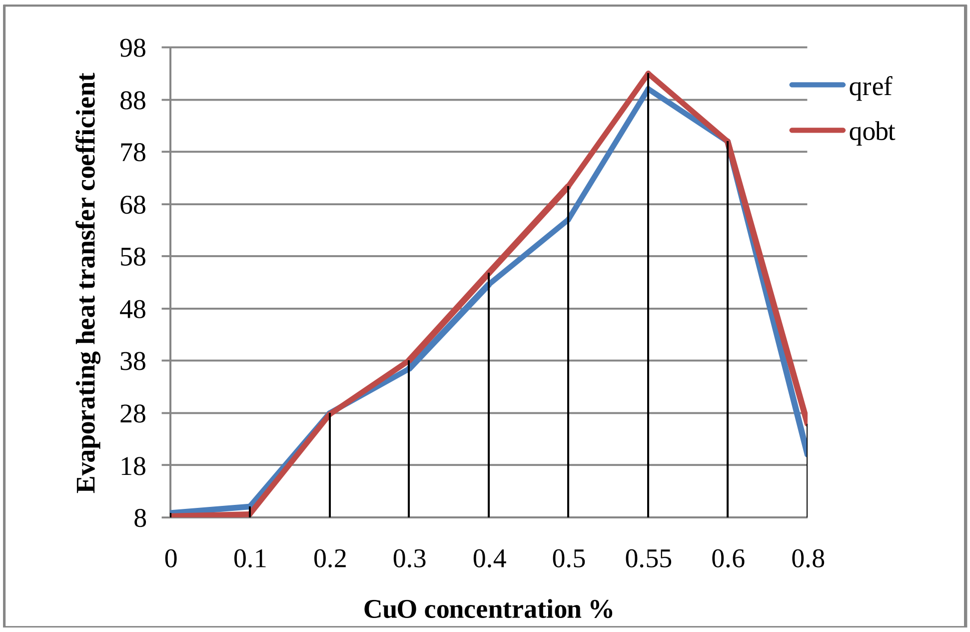

Fig. 7: Plot for q = 40 kW, Cone. = 0.55%, h = 93.02 kW/m^3-K.

From the above Figures shows the variation of the evaporating heat transfer coefficient with the CuO nanoparticles concentrations for the different values of heat flux. It is found that the evaporating heat transfer coefficient with the increase of CuO concentration upto 0.55% then decreases. At 0.55% concentration the evaporating heat transfer coefficient has its highest value for all values of heat flux.

8. Conclusion

Cuo nanoparticle with R134a refrigerant can be used as an excellent refrigerant to improve the heat transfer characteristics in a refrigeration system. A successful model has been designed and the basic theoretical heat transfer analysis of the refrigeration system has been done. Successful mesh has been designed for the designed test section using GAMBIT software. Computational Fluid Dynamics (CFD) Heat Transfer analysis for the designed test Section has been successfully performed using FLUENT software. The obtained evaporating heat transfer coefficient result with increases with the usage of nanoCuo.

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