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Evaluation of a Refrigeration System's Performance using Nano Fluid

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Research Article

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Abstract

In air conditioning and refrigeration systems, evaporating heat transfer is crucial. The most popular substitute refrigerant in refrigeration devices, including air conditioners and home refrigerators, is HFC 134a. Despite HFC134a's relatively significant potential for global warming, several nations have confirmed that it is a long-term substitute refrigerant. The performance of the refrigeration system is enhanced by the addition of nanoparticles to the refrigerant, which improves the thermophysical and heat transport characteristics of the refrigerant. In this experiment, CFD heat transfer analysis utilizing the FLUENT program was used to examine the impact of CuO-R134a in the vapour compression system on the evaporating heat transfer coefficient. In accordance with Indian national norms, an experimental equipment was constructed. According to the experimental research, the nanorefrigerant refrigeration system operates as intended. Using nano CuO concentrations ranging from 0.05 to 1% and particle sizes ranging from 10 to 70 nm, heat transfer coefficients were assessed using FLUENT for heat flux ranging from 10 to 40 kW/m2. The findings show that using nanoCuO enhances the evaporator heat transfer coefficient.

Keywords: CuO nanoparticles, CFD, heat transfer coefficient, and nanorefrigerant.

Introduction

Globally, incredible growth, progress, and technical innovation have resulted from the quick industrialization. Ozone layer depletion and global warming, on the one hand, and skyrocketing oil costs, on the other, have emerged as major issues. Fossil fuels are rapidly running short due to overuse, while nuclear energy is still in danger. The development of energy-efficient thermal systems is necessary in light of the impending shortage of energy resources. Air conditioners and refrigerators are examples of thermal systems that use a lot of electricity. Using environmentally friendly refrigerants is crucial for creating energy-efficient air conditioning and refrigeration systems. Nanofluids, a novel class of heat transfer fluids, have emerged as a result of the rapid development of nanotechnology. Nanofluids, which have a greater thermal conductivity than base fluids, are made by suspending nanoscale particles (1–100 nm) in ordinary fluids. When compared to typical solid liquid suspensions, nanofluids have the following properties. i) improved dispersion stability with predominant Brownian motion ii) increased heat transfer between the particles and fluids because of the particles' large surface area iii) lessens particle clogging iv) uses less pumping force than base fluid to achieve the same level of heat transmission. The most prevalent of the new generation of nanoparticles are ceramics, which are best divided into metal oxide ceramics (such as titanium, zinc, aluminum, and iron oxides, to mention a few prominent examples) and silicate nanoparticles (usually in the form of nanoscale flakes of clay), depending on the applications. The performance of the refrigeration system is enhanced by the addition of nanoparticles to the refrigerant, which improves the thermophysical and heat transport characteristics of the refrigerant. Nanoparticles may be added to the lubricant in a vapour compression refrigeration system.

The most popular substitute refrigerant in refrigeration devices, including air conditioners and home refrigerators, is HFC 134a. Despite HFC134a's relatively significant potential for global warming, several nations have confirmed that it is a long-term substitute refrigerant. In order to calculate the refrigeration effect and test rig coefficient of performance and identify possible locations to improve the refrigeration effect, an experiment on a vapour compression refrigeration test rig was carried out. Partial differential equations are used to represent the test portion of an evaporator tube mathematically. The evaporator test portion has undergone theoretical study. The mesh of the evaporator test section is created using the GAMBIT program, and the heat transfer study for different CuO nanoparticle concentrations is carried out using the FLUENT program.

Literature Survey

Numerous researchers have studied vapour compression refrigeration systems and how the performance of the refrigerant and lubricant is affected by nanoparticles. In their research on nanofluids, Pawel et al. (2005) discovered that the inclusion of nanoparticles significantly increases the critical heat flow and that the thermal conductivity of the nanofluid is much higher than that of the base fluid. Bi et al. (2007) used nanorefrigerants to study a home refrigerator. They used a blend of mineral oil TiO2 as the lubricant and R134a as the refrigerant in their investigations. They discovered that the refrigeration system using the nanorefrigerant reduced energy usage by 21.2% while operating regularly and effectively. in contrast to the R134a/POE oil system. Following that, Bi et al. (2008) discovered a notable improvement in freezing capacity and a notable decrease in power usage. They noted that the presence of nanoparticles in the refrigerant and the improved thermophysical characteristics of mineral oil are responsible for the increase in system performance. Jwo et al. (2009) studied a refrigeration system that used hydrocarbon refrigerant and mineral lubricant instead of R-134a refrigerant and polyester lubricant. Al2O3 nanoparticles were added to the mineral lubricant to enhance its lubricating and heat-transfer capabilities. According to their research, the best nanoparticles were 60% R-134a and 0.1 weight percent Al2O3. In these circumstances, the coefficient of performance rose by 4.4% and the power usage decreased by around 2.4%. The flow boiling heat transfer of R134a-based nanofluids in a horizontal tube was experimentally analyzed by Henderson et al. (2010). CuO nanoparticles were found to disperse well with R134a and POE oil, and the heat transfer coefficient increased by more than 100% compared to baseline R134a/POE oil values.

Bi et al. (2011) used TiO2-R600a nanorefrigerant as the working fluid in an experimental investigation of a home refrigerator's performance. They demonstrated that the TiO2-R600a system saved 9.6% of energy while operating regularly and effectively in the refrigerator. Senthilkumar and Elansezhian (2012) used Al2O3-R134a nanorefrigerant as the working fluid in an experimental investigation of a home refrigerator's performance. They discovered that the Al2O3-R134a system performed better than pure lubricant with R134a working fluid, using 10.30% less energy with 0.2%V of the concentration and increasing the heat transfer coefficient when nano Al2O3 was utilized. The performance of a home refrigerator employing TiO2-R12 nanorefrigerant as the working fluid was investigated experimentally by Krishna Sabareesh et al. (2012). They discovered that when nanoparticles were added to the

lubricating oil, the freezing capacity rose, the heat transfer coefficient improved by 3.6%, the compression work decreased by 11%, and the coefficient of performance increased by 17%. Reji Kumar and Sridhar (2013) used TiO2-R600a nanorefrigerant as the working fluid in an experimental investigation of a home refrigerator's performance. They discovered that the coefficient of performance increased by 19.6% and the energy usage decreased by 11%.
Cuo is the nanoparticle and R134a is the refrigerant used in this investigation. Due to its superior energy and environmental efficiency, R134a is more often used in home refrigerators. This document describes the development of a new refrigerator test system in accordance with the National Standard of India. A household R134a refrigerator was chosen. CuO-R134a nano-refrigerant was made and used as a working fluid. to calculate the heat transfer coefficients for various Cuonano particle concentrations.
Basic Experimental Observation of a Refrigeration Process
Equipment Used
Evaporator, Reciprocating Compressor, Condenser, Expansion valve – Capillary Tube, solenoid Valve, Refrigerant – R134a

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.

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

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

Conclusions

As an expansion device, capillary tubes may be better than solenoid valves. The evaporator may improve the refrigeration effect.We should utilize a superior refrigerant to increase the refrigeration effect. Cuo nanoparticles are usable. In an evaporator section that has been developed, we may increase the heat transfer coefficient.

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.

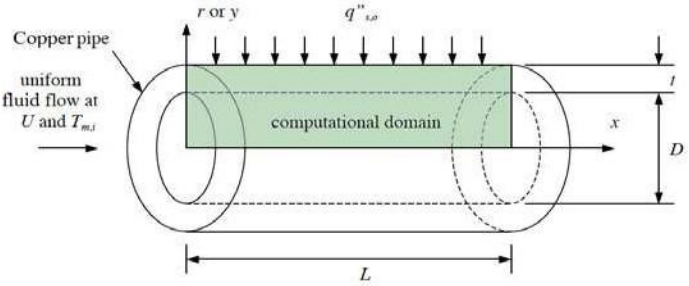


Fig. 2: Evaporator test section.

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

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

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).

$$\frac{X_{fd,h}}{D} = 0.05\,\mathrm{Re}_D \quad \frac{D}{} \geq 20 \quad (2)$$

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

$$T(r,x) = T_s(x) - \frac{2pUR^2q}{k}\left[\frac{3}{4} - \left(\frac{r}{R}\right)^2 + \frac{1}{2}\left(\frac{r}{R}\right)^4\right] \quad (3)$$

$$\frac{kmL}{pR^2q} = 16 - 16 + R^4 - R^2 + \frac{1}{2}$$

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

$$\frac{X_{fd,t}}{D} = 0.05\,\mathrm{Re}_D \quad \mathrm{Pr} \geq 15 \quad (4)$$

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):

$$T_m(x) = T_{m,i} + \frac{q''P}{\dot{m}c_p}x \quad (5)$$

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:

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.

Design Using Gambit Software
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.

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

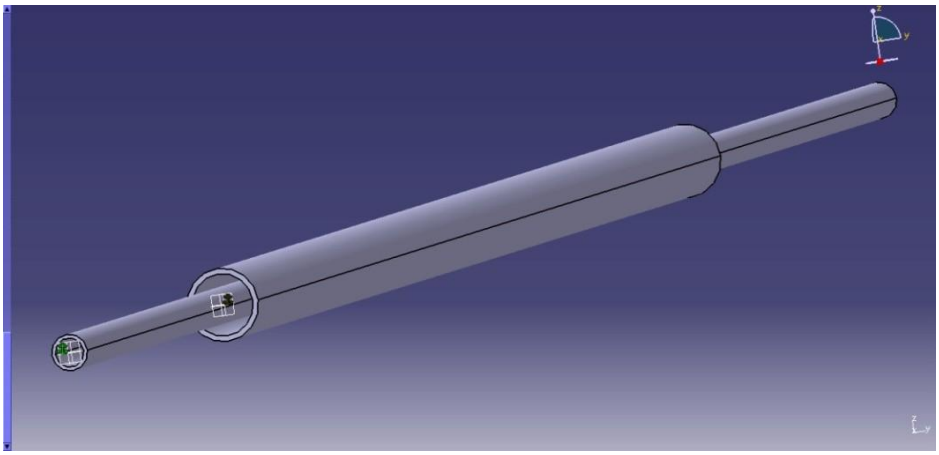


Fig. 3: Evaporator test section.

Mathematical Modeling
6.1. Heat transfer coefficient
The formulae for the heat transfer coefficient is given below

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

$$Q = m_w C_w (T_{wo} - T_{wi}) \quad (8)$$

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

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

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

$$P_{nf} = (P_p) + (1 -)P_{bf} \quad (9)$$

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.

$$C_{pnf} = (C_p) + (1 -)C_{bf} \quad (10)$$

Thermal conductivity of nano fluid

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

$$k_{nf} = k_{bf}\left\{\frac{(k_{bf} + 2k_{cuo}) - 2(k_{bf} - k_{cuo})}{(k_{bf} + 2k_{cuo}) + (k_{bf} - k_{cuo})}\right\} \quad (11)$$

Viscosity of nano fluid

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

$$\mu_{nf} = \mu_{bf}(1 + 2.5) \quad (12)$$

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

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.

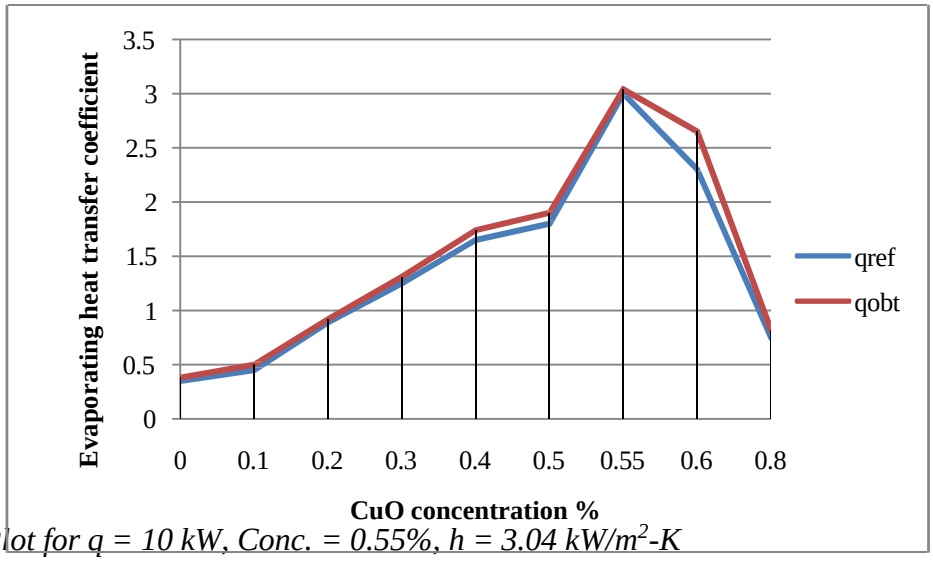


Fig. 4 *Plot for q = 10 kW, Conc. = 0.55%, h = 3.04 kW/m^2-K*

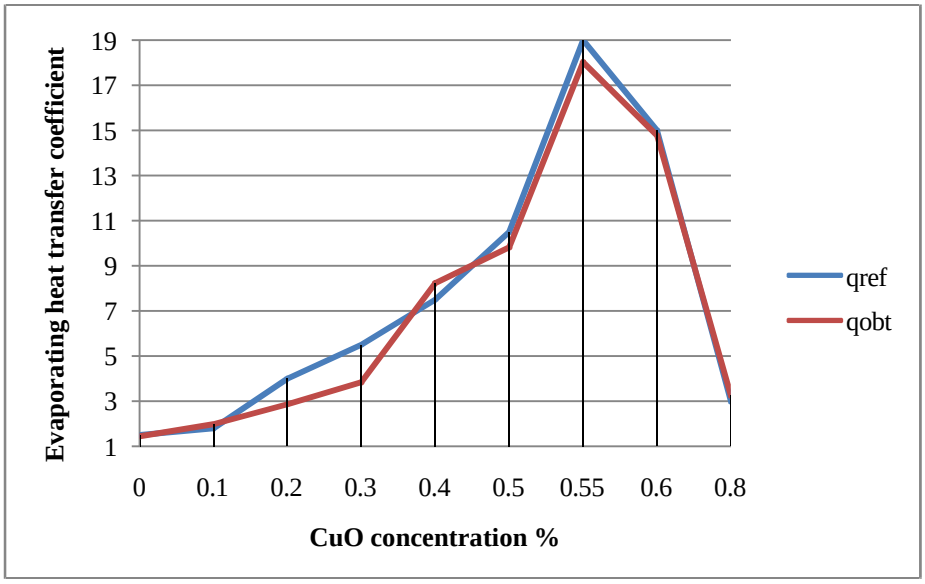


Fig. 5: Plot for q = 20 kW, Conc. = 0.55%, h = 18.03 kW/m^2-K.

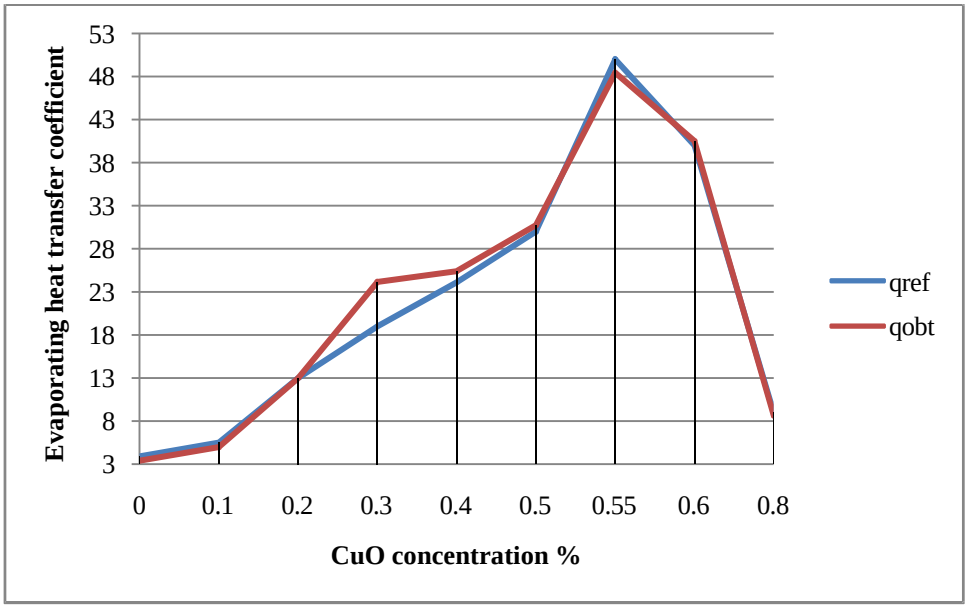


Fig. 6: Plot for q = 30 kW, Conc. = 0.55%, h = 48.45kW/m^2-K.

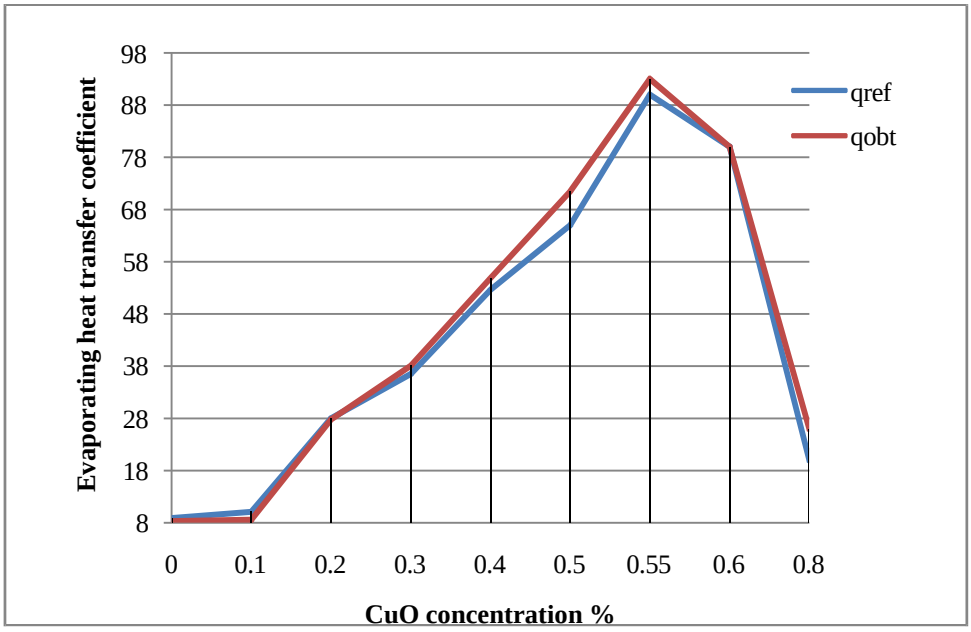


Fig. 7: Plot for q = 40 kW, Cone. = 0.55%, h = 93.02 kW/m^3-K.

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.

Conclusion

Cuo nanoparticles combined with R134a refrigerant are a great way to enhance a refrigeration system's heat transfer properties. The refrigeration system's fundamental theoretical heat transfer study has been completed, and a successful model has been created. GAMBIT software has been used to create a successful mesh for the planned test area. Heat transfer study using computational fluid dynamics (CFD) for the intended test Using FLUENT software, the section has been completed successfully. When nanoCuo is used, the resulting evaporating heat transfer coefficient rises.

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