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Heat Transfer Enhancement Using Different Nanofluid Materials in the Vapor Compression Refrigeration Systems

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Abstract: This paper aims to study the effect of the addition of Al2O3, CuO and ZnO nano particles to R134a on the evaporative heat transfer coefficient. A horizontal copper tube in a tube heat exchanger is designed and constructed here as a part of the experimental test rig. The heating load is provided by hot water passing through an annulus surrounding the inner copper tube. Measurements were carried out using heat flux ranged from 40 to 80 kW/m2 and nano fluid concentrations ranged from 0.25 % to 1.2 % and nano particle size 25 of nm for all material samples. It is worth mentioning that the evaporative heat transfer coefficient increases and reaches its maximum value at 0.5 % of nanoparticles concentration and then decreases for all nano particles sample this is due to the high thermal conductivity of the material used here.

Keywords: Evaporative Heat Transfer Coefficient, Heat Flux, Mass Flux, Nano Concentration

Nomenclature

Symbols	Description	SI units	Symbols	Description	SI units
C	specific heat	kJ/kg	$.Kq$	heat flux	kW/m^2
Dinner	diameter of refrigerant tube	m	T_w	average temperature of tube wall	K
G	mass flux	$kg/m^2.s$	$T_{w,i}$:	inlet temperature of water	K
h	heat transfer coefficient	kW/m^2	$.T_{w,o}$	outlet temperature of water	K
K	thermal conductivity	kW/m	V_w	Volume flow rate	m^3/s
K_{eff}	effective thermal conductivity	W/m.K	Z	nano particle concentration	%
m_w	cooling water mass flow rate	kg/s	β	nano particle size	nm
Pr	Prandtl number		μ_m	Dynamic viscosity of nanofluid	Pa.s

1. INTRODUCTION

The main problems of today are the damage of the ozone layer and global warming, as well as the rapidly rising price of oil [1].There is a need to use energy effecient thermal systems due to the impending shortage of energy resources.Thermal systems, such as air conditioners and refrigerators, use a lot of electricity.Therefore, researches are directed to environmentally friendly refrigerants for refrigeration and air conditioning systems is necessary concentrating on improving heat performance [2].

Nanosized particles (1-100 nm) [3] are suspended in conventional fluids to create nanofluids, a new generation of heat transfer fluids that have higher thermal conductivity than the base fluids [1] due to the rapid enhancement in heat transfer using nanotechnology.The following characteristics of nano fluids are different from those of normal solid-liquid suspensions heat transfer between particles and basefluids due to the high surface area of the particles.

1- Improved dispersion stability due to the high concentration of Brownian motion reduces particle clogging.
2- To achieve equivalent heat transfer, reducing pumping power in comparisontothe base fluid and adding nanoparticlesimprove the characteristic of thebase fluid.

Because of their remarkable improvements in thermophysical and heat transfer properties, nanoparticles can be used in refrigeration systems to improve their heat transfer performance [4].In order to improve this heattransfer in the vapor compression refrigeration system, nanoparticles can be added to the lubricant oil used in the compressor. High thermal conductivity nanoscale metallic or non-metallic particles suspended in base fluid have been shown to have superior heat transfer capabilities [1].[5] studied the refrigeration effect and the quantity of effort required by the compressor to determinethevapor compression refrigeration systems (VCRS) and coefficient of performance (COP). In addition to completing an experiment on a ducted air conditioning system using various mass fractions of CuO nanoparticles (0.25%, 0.50%, 0.75%, and 1%), this paper investigates the concept, use, and properties of nanofluids. [6] showed the performance evaluation, when compared to compressor oil without nano additives, the lubricant's tribological enhancement with the best quantities of 0.5% by volume Cu/Ag alloy and Al2O3 nano lubricants COP gave an increase of 20.88% and 14.55%, respectively.[7] the results showed that using a standard condenser with a 1:1 ratio of nano particles and each 2 gm of Cerium Oxide (CeO2) and Zinc Oxide (ZnO) in the experiment, the real COP of a household refrigeration system increased by 33.3%. [8] used R134a-ZrO2 nano refrigerant, the system's energy consumption was reduced due to higher COP and compressor power.[9] found that freezing capacity and power consumption both increased, and the power consumption decreased by 25%. [10] found that the refrigerator performed better than the HFC134a and POE oil systems when using TiO2 nano particles, consuming 26.1% less energy and using 0.1% less power. [11]made a comparison of heat transfer performance for the HFC 134a/mineral oil system, the mineral oil/nano refrigerant system showed a reduction in energy consumption by 26%, while the HFC 134a/mineral oil system reduced energy consumption by 30%. [12]maximum value of the heat transfer coefficient is observed at void fractions of 0.09% CuO nanoparticle and 0.5% Al2O3.

2. EXPERIMENTAL TEST RIG

The compressor used in this test rig is a TECUMSEH reciprocating type of 1 HP, 50 Hz and 220 Volts. The thermocouples type "T" are connected to a digital indicator with a selector switch to record the temperature at the desired locations, as shown in Fig.1, on the outside of the evaporator, twenty thermocouples are used. These thermocouples were distributed in six different locations in the test section (evaporator), two of them are fixed on the outer surface of the refrigerant tube just before and after the condenser to measure the inlet and exit temperatures of the refrigerant, and another two thermocouples are fixed the first on to the inlet water tube with an average temperature 20 ± 1.0 oC and a reading 17.5 ± 1.0 oC for the second at the exit water tube from the hot water. Four pressure gauges with a range of 0 to 10 bar with a resolution of 0.001 are used in the test rig to measure the refrigerant pressure; two of them are connected to the high-pressure side of the test rig. The experimental test rig consists of two different loops: the refrigerant loop and the hot water loop. In the refrigeration loop, the refrigerant is taken from the evaporator and goes to the compressor in it nano particles are mixed with oil and then passes through water cooled condenser. the expansion valve, where the mixture is throttled to the evaporator, receives the refrigerant after passing through the condenser. The hot water moves counterclockwise around the refrigerant tube. A hot water tank provided with an electric heater and pump to circulate the hot water. The evaporator is a horizontal, straight tube in a tube heat exchanger with an inner tube made of copper that has an outer diameter of 9.52 mm and an inner diameter of 7.72 mm. It has a length of 1090 mm. While the refrigerant passes through the inner tube, hot water flows through the annulus. The outer tube is made of copper which has an inner diameter of 17 mm. The evaporator is divided into six separate sections, each of which has its own independent inlet and exit water terminals. Rubber hoses connect these sections so that cooling water can pass through them.

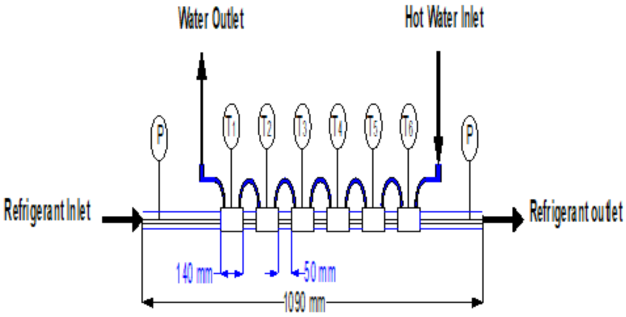

Fig.1 Evaporator (Test section)

3. NANOFLUID PREPARATION

The particles used in the nanofluid experiments areAl2O3, CuO, ZnOprepared by Tabbin Institute for Metallurgical, Cairo. Thermo physical properties of nano particlesare shown in Table 1. Transmission electron microscope(TEM) micrographs which clearly as show in Fig 3illustratestructure of nano particles, the prepared Nanoparticles are mixtures of particles of spherical shape.

Table 1. Properties of Nano fluid [13]

Nano particle types	**C (J/kg.K)**	**Kn (W/m.K)**	**μ_n (Pa.s)**
Al_2O_3	773	30	0.2
CuO	525	40	0.188
ZnO	610	13	0.887

Where, C specific heat, Kn thermal conductivity of nano fluid, μ_n dynamic viscosity

4. CALCULATIONS OF THERMAL CONDUCTIVITY OF NANOFLUID

The volume fraction of nanofluid is given as:[13]

$$\Phi \ = z\rho R134a \, / \, (z\rho R134a+(1-z)\rho n)$$

Where Φ volume fraction, $z\rho R134a$ concentration of refrigerant, ρn concentration of nano particles

The effective density of nanofluid is given form the literature[13]

$$\rho eff.=(1-\Phi)\rho R134a+\Phi \ \rho n$$

The effective viscosity of nanofluid is given by

$$\mu eff.=\mu r/(1-\Phi)2.5 \qquad [13]$$

The effective specific heat of nanofluid is given form the literature [13]

$$Ceff.=(1-\Phi) \ CR134+\Phi Cn$$

The effective thermal conductivity of nanofluid is given by [13]

$$keff=kr(R134) \ [(kn+2k \ R134- 2\Phi(k \ R134-kn) \ /(Knf+2kr, 1+\Phi(k \ R134-kn)]$$

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

Prandtl number can be calculated from

$$Pr=\mu * C/K \qquad [14]$$

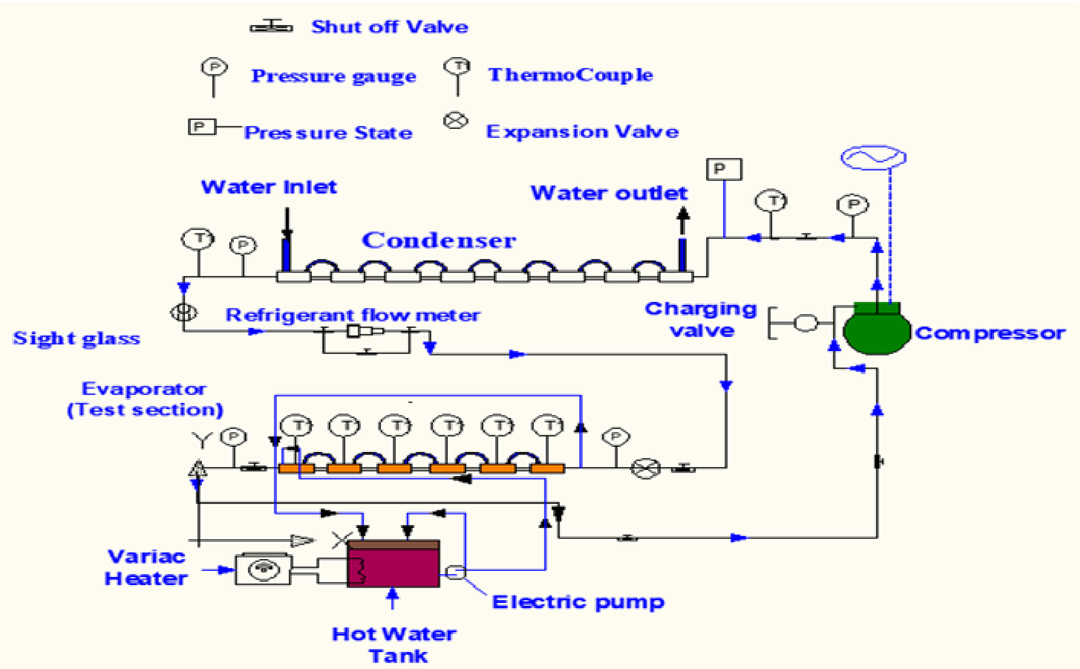

Fig.2 Experimental test rig

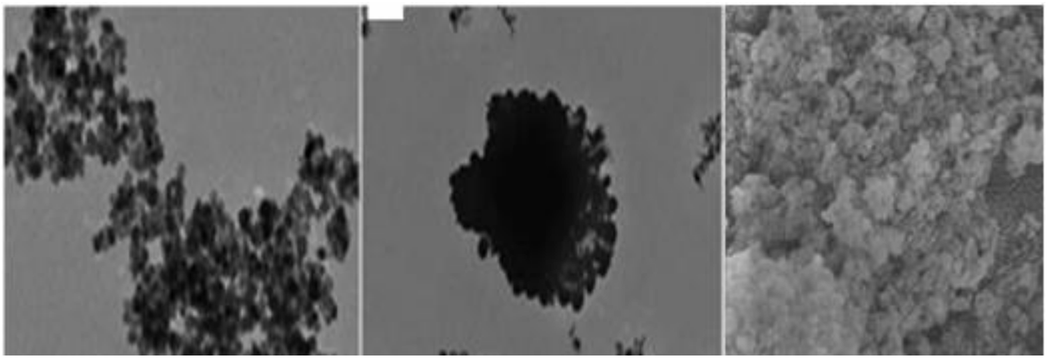

Fig. 3 Transmission electron microscope (TEM) micrographs of nanoparticle

5. EMPIRICALDEDUCED CORRELATION

Empirical correlation equations are deduced here to calculate the evaporative heat transfer coefficient based on the measurements obtained in the present study. The experimental measurements were taken for three types of nano particles mainly Al2O3, CuO, andZnOat heat flux ranged from 40 to 80 kW/m2, mass flux ranged from 255 to 350 kg/m2s. All values of nanoparticles concentrations ranged from (0.25 to 1.2 %) by weight respectively, based on the experimental measurements given in Fig. 4, 5, and6 empirical correlation equations are deduced for the evaporative heat transfer coefficient as a function of heat flux, mass flux, and nanoparticles concentration using computational Software (Table Curve 3D).In the present research, the first empirical correlation equation is deduced to estimate the heat transfer coefficient as a function of the heat flux for different values nanoparticles concentration. The dependent variable, the heat transfer coefficient (h)as a function of independent variables heat flux (q) and nanoparticles concentration (z), nano fluid material types are given by the following equation.

h=f (z , q, nano fluid material) at const G (1)

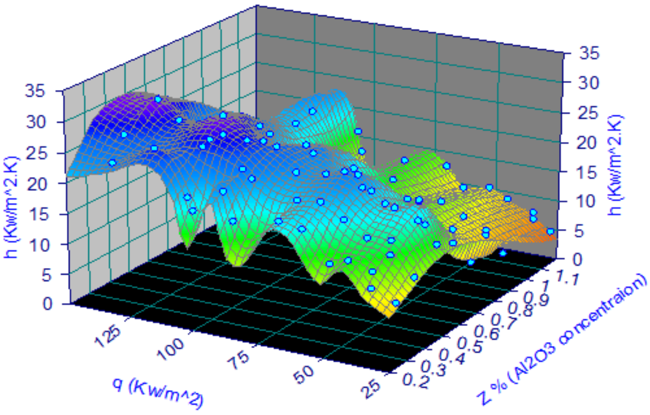

Fig 4. Heat flux, Al2O3 concentrations and heat transfer coefficient at mass flux of 255,300, 350 kg/m2s as plotted by Table Curve 3D

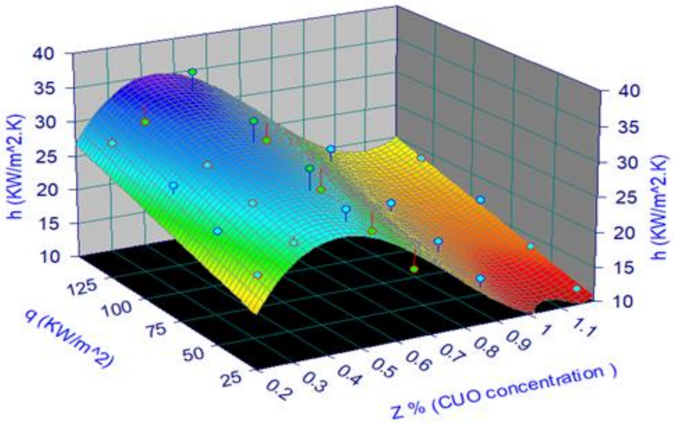

Fig 5. Heat flux, CuO concentrations and heat transfer coefficient at mass flux of 255 kg/m2s as plotted by Table Curve 3D

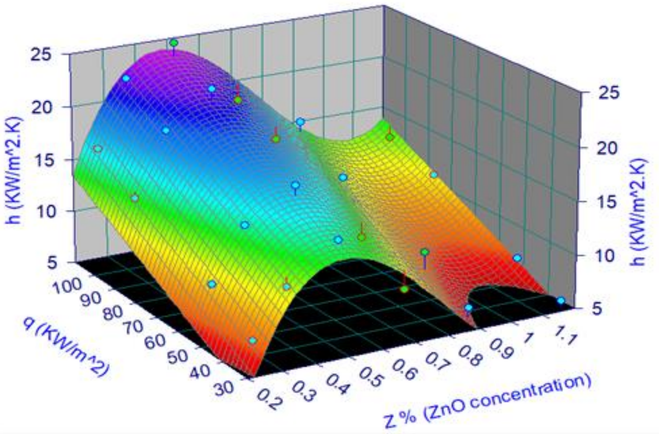

Fig 6. Heat flux, ZnO concentrations and heat transfer coefficient at mass flux of 255 kg/m2s as plotted by Table Curve 3D

The data of the above figures are fitted the following equation.

h_{avg}= a+ b(z) + c(z)^2+ d(z)^3+ e(q) (2)

The data of these equations are fitted with the following equation.

h_{avg}=A(G)+B(G)(Z) + C(G)(Z)^2+D(G)(z)^3+E(G)(q) (3)

at G=255 kg/m^2. s

Pr for Al_2O_3=5

Pr for CuO=2.5

Pr for ZnO=41

The constants of equation (3) vary with the nano fluid types, and presented in Table (2) which shows the values of these constants for the three nanoparticles materials used here

Table 2Values of the constants of equation (3) according to the types of nano fluid particles as plotted by Table curve 3d software

Const.	**Al_2O_3**	**CuO**	**ZnO**
A	10.3	-8.885	-25.6
B	143.7	173.19	174.3
C	-233.2	-275.6	-260.7
D	102.5	119.7	111.1
E	0.0892	0.0736	0.125

These constants are fitted to the Prandtl number according to the properties of each type of nano particle to the following equations.

a= -7.97 – 0.43 (Pr) (4)

b=158.4 + 0.0002 (Pr)^3 (5)

c= - 246.2 – 154.2/ (Pr)^2 (6)

d= 106 + 75/(Pr)^2 (7)

e= 0.14 - 0.11 /(Pr)$^{0.5}$ (8)

from equation (4) to (8) are substituted in equation (3) to produce equation (9), which deals with the heat flux, Prandtl number, and nano particles concentrations of Al2O3, CuO, ZnO (0.25, 0.35, 0.5, 0.7, 0.9, 1.2) as an input to compare the value of the average heat transfer coefficient, and nano fluid material at constant evaporation pressure

h=f (z , q , Pr, nano fluid material) at const p_e (9)

Equation (9) correlated theheat transfer coefficient at different values of heat flux, concentration, Prandtl number, nano fluid material, and finally, a general formula was produced to deal with the heat flux, concentration, Prandtl number for Al2O3, CuO, and ZnO to compare the value of the average heat transfer coefficient, as given by the following equation below.

h_{avg}=A(P_r)+B(P_r)(Z)+C(P_r)(Z)^2++D(P_r)(Z)^3+E(P_r)(q) (10)

The above correlation equation (10) is plotted in Fig (7) to Compare the measured values of the average heat transfer coefficient, h measured with the calculated average heat transfer coefficient, h calculated for three types of nano particles. The results shown in Fig (7) indicate that the scatter of the data points around the45o line is ± 10 %, maximum deviation.

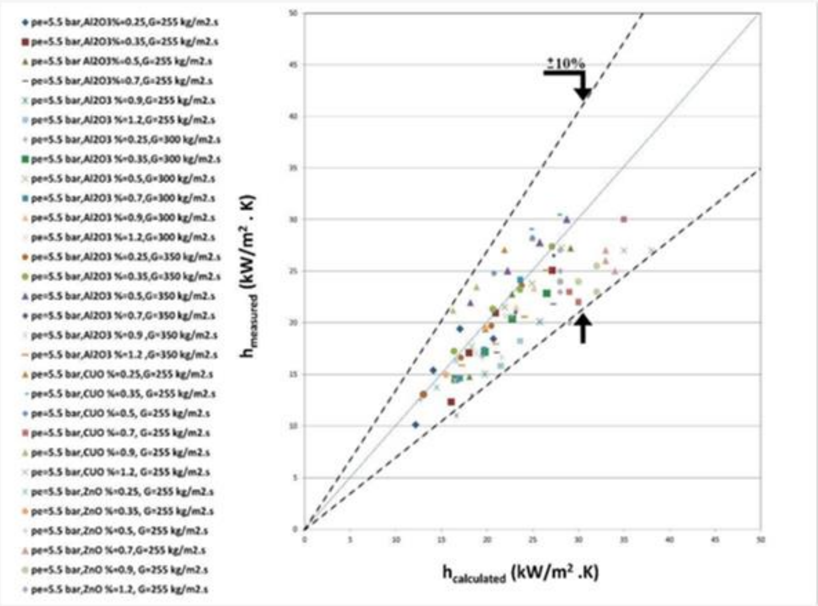

Fig. 7 Comparison between Measured and Calculated Heat Transfer Coefficient

6. VARIATION OF DYNAMIC VISCOSITY WITH CONCENTRATION

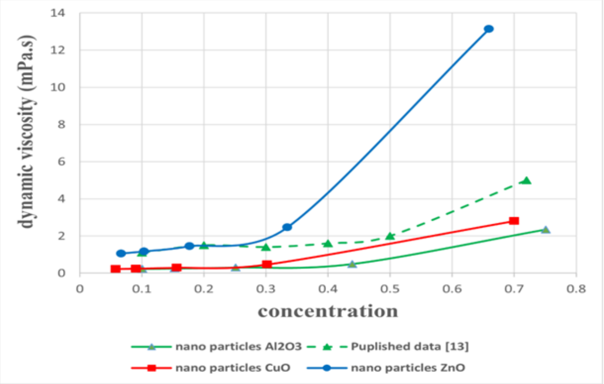

Fig 8 Variation of dynamic viscosity with nano particle of Al2O3, CuO andZnO concentration

$$\boldsymbol{\mu_{rn}=\mu_{r}\,(1/(1-\varnothing))^{2.5}} \qquad [13]$$

it is clear from Fig.8 that the dynamic viscosity of the nano fluid increases with the concentration, whileZnO nano particle showsthe highest value with concentration because ofthe higher viscosity of the element.This increase in viscosity is enlarged with the surfactant mass fraction that depends on the temperature.

7. VARIATION OF THERMAL CONDUCTIVITY WITH CONCENTRATION

The volume fraction of nanofluid is given as:

$$\Phi = Z(\rho R134a) / (Z\rho R134a+(1-Z)\rho n) \qquad [13]$$

The effective thermal conductivity of nanofluid is given by

$$keff=kr\ [(kn+ 2kr - 2\Phi(kr-kn) /(Kn+2kr+\Phi(kr-kn)] \qquad [13]$$

As can be observed in Fig.9,the base fluids homogenized with nanoparticles have been found to significantly improve the heat transfer potential of nanofluids. Thermal conductivity variations of Liquefied petroleum gas (LPG) refrigerant with pure base fluid and the chosen nano-lubricant at the suction and discharge line of the compressor demonstrate a direct proportion between thermal conductivity and concentration of each type of nano particles. It’s noticed from Fig 9 that Al2O3 shows the highest value of nanofluid thermal conductivity and CuO show the lowest value of nanofluid thermal conductivity.

8. EFFECT OF DIFFERENT TYPES OF NANOPARTICLES CONCENTRATIONS ON THE EVAPORATIVE HEAT TRANSFER COEFFICIENT

Measurements wereperformed for heat flux ranged from 40 to 80 kW/m2, using nano particles of Al2O3, CuO andZnO concentrations ranged from 0.5 to 1.2 %, particle size 25 nm, and mass flux=255 kg/m2s.The measurements as shown inFig 10showed that the evaporative heat transfer coefficient increases with increasing heat flux and mass flux for a specific nano concentration. Furthermore, according to the measurements, the evaporative heat transfer coefficient increases with increasing the nano concentrations up to 0.5%. then decreases for all values for all nano particles type. Also, its noticed that CuO shows the highest value for the heat transfer coefficient due to increase of the surface area of nano particleswhileZnO shows the lowest value due to the small surface area of nano.

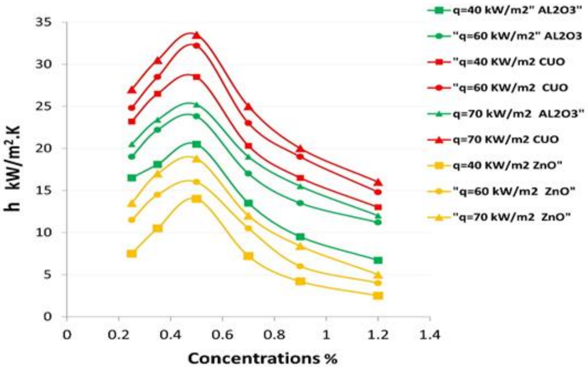

Fig 10Variation of heat transfer coefficient with Nanoparticles Concentration of Al2O3 ,CuO, ZnO (for β =25 nm and q= 40, 60, 70 kW/m2, G=255 kg/m2.s)

9. CONCLUSIONS

From the experimental results performed here, the following conclusions can be deduced:

1. The evaporative heat transfer coefficient increases with the increase in heat and mass fluxes for the experimental range.
2. The evaporative heat transfer coefficient increases with nanoparticles concentration ranged from 0.25 to 0.5 % then decreases for all values of nano particle types.
3. At mass flux G=255 kg/m2.s and nano particle size β =25 nm , CuO nano particles concentrations show the highest value of enhancement of heat transfer coefficient by 40 %.
4. The use of Al2O3 nanoparticles of size 15 nm shows higher performance than other sizes of nanoparticles.
5. An empirical correlation equation was deduced based on the experimental results using software (3D table curve) which calculates the heat transfer coefficient as a function of the heat flux, nanoparticles concentration, and Prandtl number for three types of nano fluid materials (Al2O3, CuO, ZnO)
6. Heat transfer coefficient is improved when using Al2O3 nano particles with R134a compared to CuO and ZnO nano particles.
7. Thermal conductivity for using Al2O3 shows better enhancement compared with the other nano particles materials by 25 %.

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