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Influence of Nanoparticle Sizes Added to Refrigerant on the Evaporative Heat Transfer Coefficient of the Cooling Systems

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Abstract: : In this paper, nano particle based refrigerant R134a has been used to increase the heat transfer performance of base refrigerant in the vapor compression refrigeration system. Various types of solid and oxide materials could be used as nano particles suspended in conventional and non-conventional refrigerants. The purpose of this research is to investigate the performance of vapor compression refrigeration system with and without using nano refrigerant. In air conditioners and refrigerators used in urban, R134a is the most popular alternative refrigerant. Due to these limitations, this refrigerant's heat transfer capacity is insufficient, which increases power consumption. Nanoparticles improve the refrigerant by enhancing it, which increases its heat transfer capacity and lowers power consumption. Here, an experimental test rig is designed and built with this objective in mind. The test section is an evaporator made of copper representatives and a horizontal tube in tube heat exchanger. The refrigerant is evaporated inside the inner tube furthermore, hot water passing through the inner tubes annulus supplies the heat load. Measurements were performed for heat flux ranged from 40 to 80 kW/m^2, mass flux ranged from 255 to 350 kg/m^{2}s using nano Al_2O_3 concentrations ranged from 0.25 to 1.2% and sizes 15, 25, 40 nm. The measurements showed that nanoparticles have a high thermal conductivity when suspended in the base fluid, they enhance the thermophysical properties and heat transfer characteristics of the base fluid when added to refrigerants.

Keywords: Heat Flux and Mass Flux, Nano particles, Al_2O_3 Concentration, R134a.

Nomenclature

Symbols	Description	SI units	Symbols	Description	SI units
m_w	mass flow rate of cooling water	kg/s	V_w	rate of volume flow	m^3/s
$T_{w,i}$	water temperature at the inlet	K	ρ	Water density	kg/m^3
d_i	inner diameter of refrigerant tube	m	β	nano particle size	nm
T_w	average temperature of tube wall	K	Z	nano particle concentration	%
K	thermal conductivity	kW/m.K	G	mass flux	kg/m^{2}s
C_w	specific heat of water	kJ/kg.K	q	heat flux	kW/m^2
$T_{w,o}$	water temperature at the outlet	K	h	heat transfer coefficient	kW/m^2 K
$T_{ref,\,av}$	average refrigerant temperature	K	ω	mass fraction	
µ	Dynamic viscosity	pa.s	d_o	outer diameter	m

1. INTRODUCTION

Thermal systems, like air conditioners and refrigerators, consume a lot of electricity.Therefore, energy-saving refrigeration and cooling systems are needed. Nanofluids are a new generation of heat transfer fluids that have been created as a result of the rapid progress in nanotechnology. Nanofluids, which have a higher thermal conductivity than the base fluids, are made by suspending nanosized particles (1-100nm) in conventional fluids [1]. The following characteristics identify nanoparticles from typical solid liquid suspensions.

i) greater heat transfer between the particles and fluids as a result of the particles' high surface area

ii) improved dispersion stability due to a predominance of Brownian motion

when compared to base fluid

iii) lessens particle clogging

iv) requires less pumping power to achieve an equivalent heat transfer.

Due to their remarkable enhancement in thermo-physical and heat transfer capabilities, nanoparticles can be used in vapor compression refrigeration systems to enhance the performance of vapor compression refrigeration systems This article aims to present the results of experimental investigations into refrigeration systems that use vapor compression. Aluminum oxide is the nanoparticle and R134a is the refrigerant used in this study as a base fluid. Thermal conductivity is a basic fundamental used to choose nano particles for use in Nano refrigerant applications. The main objectives of the paper are (i) To improve the heat transfer characteristics in refrigerator system by adding Al_2O_3 nano particles to the R134a refrigerant. (ii) To carry out the performance and heat transfer study in a vapor compression refrigeration system using a nanofluid as the refrigerant. (iii) To develop a Correlation Equation for such a system. **Avesahemad Husainy et al., 2019 [2]** The VCRS coefficient of performance (COP) is determined by the refrigeration effect and the amount of work required compressor. This study investigates the idea, use, and properties of nanofluids while also conducting an experiment on a ducted air conditioning system using different mass fractions of CuO nanoparticles (0.25%, 0.50%, 0.75%, and 1.00. **Ali Can Yilmaz, 2020 [3]** The study showed that the lubricant's nanoparticles' tribological enhancement, the most suitable amounts of 0.5 % by Vol Cu/Ag alloy and Al_2O_3 nano lubricants COP provided increments of 20.88 % and 14.55 %, respectively, when compared to compressor oil without nano additives. **Satheshkumar et al., 2022 [4]** the study shows that 2 gm each of cerium oxide (CeO2) and zinc oxide (ZnO) nanoparticles were used in the experiment, the actual COP of a domestic refrigeration system using a normal condenser with a 1:1 ratio of nanoparticles increased by 33.3%. **R Krishna et al., 2012 [5]** An enhancement in the COP of the refrigeration system has been observed and the existence of an optimum volume fraction noticed with using TiO_2/R12. **N.Subramani et al., 2011 [6]** it is found that both the freezing capacity and power consumption increase and the power consumption is reduced by 25%. **Shan Bi et al., 2008 [7]** The refrigerator performance was better than the HFC134a and POE oil system, with 26.1% less energy consumption used with 0.1%. **R.Saidur et al., 2010 [8]** The energy consumption of the HFC134a refrigerant using mineral oil and nanoparticles mixture as lubricant saved 26.1% energy with 0.1% mass fraction TiO_2 nanoparticles compared to the HFC134a and POE oil system. **Teshome et al., 2014 [9]** The HFC 134a/mineral oil/DPHE system reduced the energy consumption by 30% and mineral oil/nano refrigerant system reduced the energy consumption by 26 % when compared with the HFC134a/mineral oil system. **Kristen et al., 2008 [10]** results in a still larger improvement in heat transfer coefficient of between 50% and 101%.

2EXPERIMENTAL TEST RIG MEASUREMENTS

A performance test is conducted for 150 gm. of pure R134a arrangement which is treated as the foundation for comparison with others, the compressor used in the present test rig is TECUMSEH reciprocating Type of 1 Hp, 220 Volts and 50 Hz. The thermocouples type "T" is connected to a digital indicator that has a selector switch to record the temperature at the desired locations as shown in Fig.2 fixed with a depth 0.2 mm from the outer circumference of the refrigerant tube to measure the temperatures in the various areas of the experimental test rig. A recording interface with a resolution of 0.1 ºC is offered for thermocouple readings in the temperature range of 1 to 100 ºC. Twenty-two thermocouples are fixed on the outer surface of the evaporator as mentioned above. eighteen 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 refrigerant. Another two thermocouples are fixed one to the inlet water tube with an average temperature 20 ºC and a reading 17.5 ºC for the second at the exit water tube from the hot water. Four pressure gauges with a range of 0 to 10 bar 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 first one is fixed at the flow meter's inlet, and the second one is attached to the compressor's discharge tube. Two additional gauges are attached to the low-pressure side of the refrigeration cycle; one is attached to the compressor's suction tube, and the other is fixed at the expansion valve's exit, The pressure range for these two gauges is 0 to 10 bar. Any experimental run involves adjusting the heat flux applied to the evaporator to the specified value. Users can achieve this by modifying the rate at which hot water flows through the evaporator. By selecting a specific volume of the refrigerant mass flux flowing through the expansion valve, evaporating pressure can be changed. For each run, the refrigeration circuit is left running for about 0.5 hour to reach steady state conditions before adding Al_2O_3 nanoparticles. Addition of nanoparticles takes place by filling the calibrated tube then mixed with oil in compressor and passes through refrigeration circuit

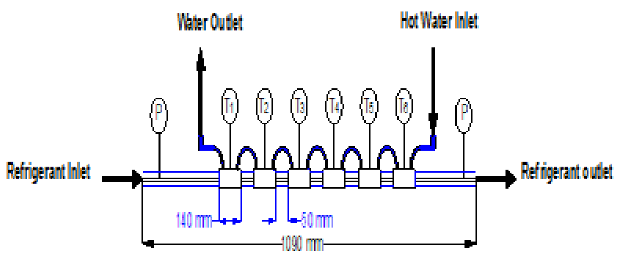

Fig 1. Evaporator (test section)

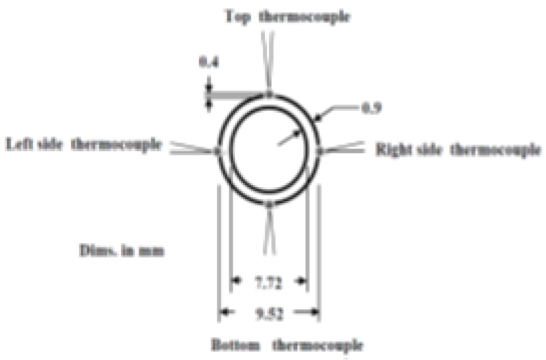

Fig 2.Thermocouples fixations

3. PREPARATION OF NANO REFRIGERANT

The detailed methodology to prepare the nano particle dispersed refrigerant is presented in this section. Because of high thermal characteristics, spherical shaped Al_2O_3 nanoparticles with 15,25 and 40 nm and 99.5% purity were procured from Tabbin Institute for Metallurgical, R134a is selected as a base refrigerant in this research. During this study, six different mass fractions (i.e., ω 0.25, 0.35, 0.5, 0.7, 0.9 and 1.2 %) of Al_2O_3/R134a nano refrigerants were prepared and its thermophysical properties were analyzed. The mass of the Al_2O_3 nano particles required to prepare these nano refrigerants is calculated by using the equation (1) and measured using high precision digital weighing machine. The measured nano particles were dispersed in Polyolester oil (POE) and stirred using magnetic stirrer for about 2 hours. Then this mixture is injected into R134a refrigerant. Finally, the stability test was carried out and small quantity of sedimentation was observed after 24 hours. Thus, it can be concluded that the pre-pared nano refrigerant is suitable to use in the vapor compression system

$$\omega = \frac{mn}{mn+mr} \qquad \text{Equ (1) Aly Soliman et al. [11]}$$

TABLE 1. Thermo physical properties of Al_2O_3-R134a nano refrigerant [12]

ω	h_{rn}	K_{rn}	Cp_{rn}	μ_{rn}
0.5	0.6502	0.1706	1239	2280

*Where ω = Mass fraction of nano particles, m_n=Mass of nano particles, m_r=Mass of refrigerant h_{rn} = Heat transfer coefficient of nano refrigerant, K_{rn} = Thermal conductivity of nano refrigerant, Cp_{rn} = Specific heat capacity of nano refrigerant, and μ_{rn} = Dynamic viscosity

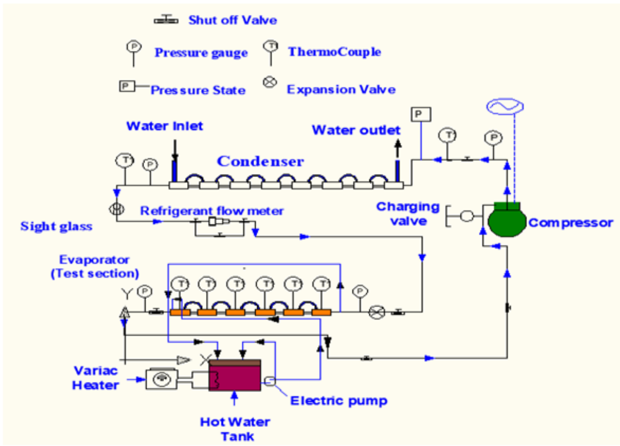

Fig 3. Test rig

4. DATA REDUCTION

The procedures of calculating the average heat transfer coefficient are presented in the following part:
Cooling water mass flow rate, m_w is given by

$$m_w = \rho_w V_w \qquad \text{Eed A Abdel-Hadi et al. [13]} \quad (1)$$

The total rate of heat absorbed from the refrigerant Q_{total} is calculated from the following equation:

$$Q_{total} = m_w Cp_{,w} (T_{w,o} - T_{w,i}) \qquad \text{Eed A Abdel-Hadi et al. [13]} \quad (2)$$

The heat flux, q is estimated by the equation

$q = \frac{Q_{total}}{\pi diL}$ Eed A Abdel-Hadi et al. [13] (3)

To calculate the average refrigerant temperature, $T_{r,av}$, average the following equation is applied.

$$T_{W,avg} = \frac{(T_{W,av,1} + T_{W,av,2} + T_{W,av,3} + T_{W,av,4} + T_{W,av,5} + T_{W,av,6})}{6}$$

Eed A Abdel-Hadi et al. [13] (4)

The average heat transfer coefficient, h is given as:$T_{R,av}$ from thermodynamic chart (ESS software)

$$\frac{1}{h} = \frac{\pi\, d_i\, L(T_{R \cdot av} - T_{\,w})}{Q_{total}} \frac{d_i}{2k} \ln \frac{d_o}{d_i}$$

Eed A Abdel-Hadi et al. [13] (5)

$Q_e = m_w * C_{p,w} * \Delta Te, w$ Faizan Ahmed et al. [14] (6)

$Wc_{,in} = m_{ref} * \Delta h$ Faizan Ahmed et al. [14] (7)

$Q_c = Q_e + W_{c,in}$ Faizan Ahmed et al. [14] (8)

*where $W_{c,in}$ is the compressor power, Q_e is the heat transferred across evaporator section, A_e is the area of evaporator, $C_{p,w}$ is the specific heat of water, ΔTe,w is the change in temperature of water in the evaporator, m_{ref} mass flow rate of refrigerant, Q_c heat transfer across condenser

$COP = \frac{Qe}{Wc,in}$ Faizan Ahmed et al. [14] (9)

TABLE 2. coefficient of performance of Al_2O_3-R134a nano refrigerant

Nano particles concentration	0 % (pure) R134a	0.5 % R134a+Al_2O_3	1.2 % R134a+Al_2O_3
COP	0.45	0.56	0.6

Nano refrigerant with 0.5% Al_2O_3 and 1.2% Al_2O_3 was used, the COP changes to 0.56 and 0.6, respectively Thus, the COP is found to be improved by 20% using R134a/Al_2O_3 (0.5%), and 25% for nano refrigerant R134a/Al_2O_3 (1.2%), while the result show that the COP for pure refrigerant (R134a) show lowest value

.

5. RESULTS AND DISCUSSION

5.1. Effect of Heat Flux on the Evaporative Heat Transfer Coefficient

Figures 4, 5 and 6 Show how the evaporator heat transfer coefficient varies with heat flux for different value and concentrations of 15 nm Al_2O_3 nanoparticles at 255 kg/m²s mass flux. It has been noticed that the forced boiling heat transfer coefficient varies linearly, with the heat transfer coefficient and increasing directly as the heat flux increases. Additionally, the heat transfer coefficient rises for all concentrations of Al_2O_3 nanoparticles up to 0.5% then decrease for all values. The heat transfer coefficient is shows lowest value for pure refrigerant (0%) concentration

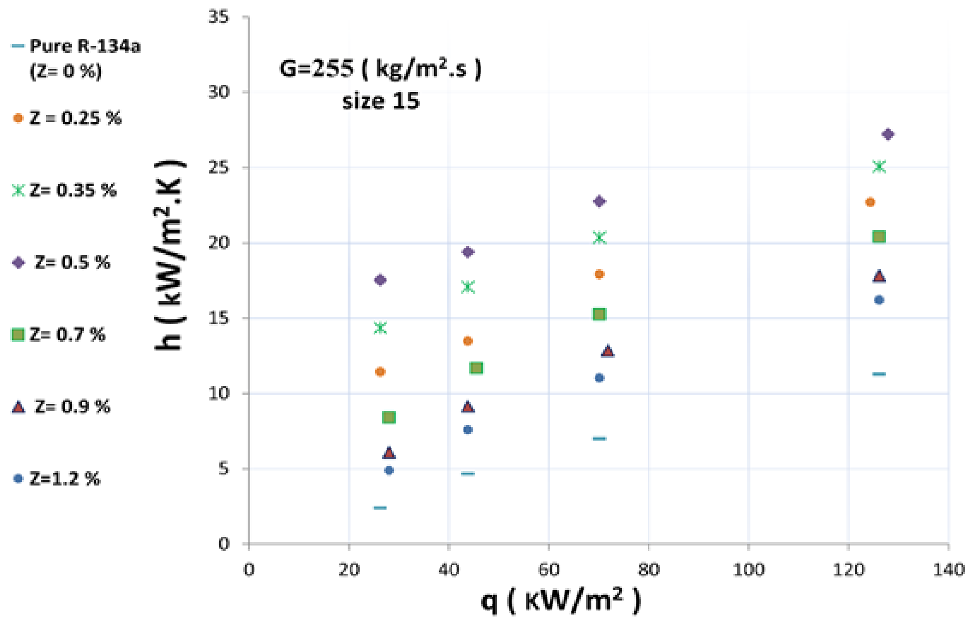

Fig 4. Heat transfer coefficient variation with heat flux at various concentrations of Al_2O_3 (for β =15 nm) and mass flux 255 kg/m². S

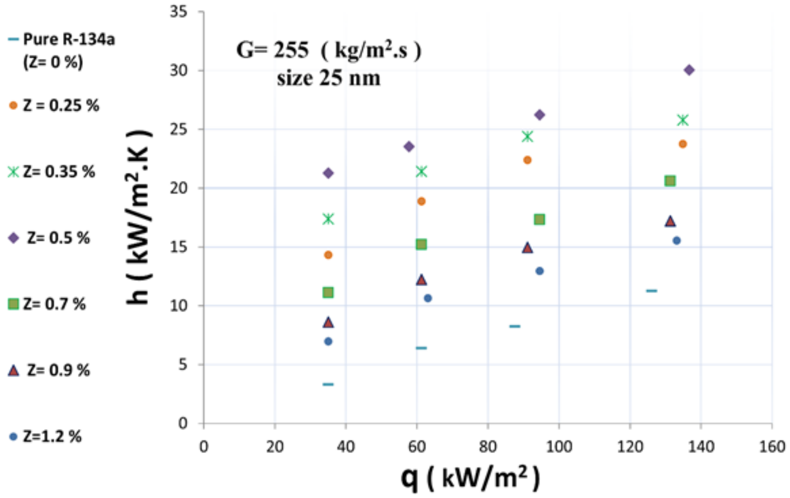

Fig 5. Heat transfer coefficient variation with heat flux at various concentrations of Al_2O_3 (for β =25 nm) and mass flux 255 kg/m^2. S

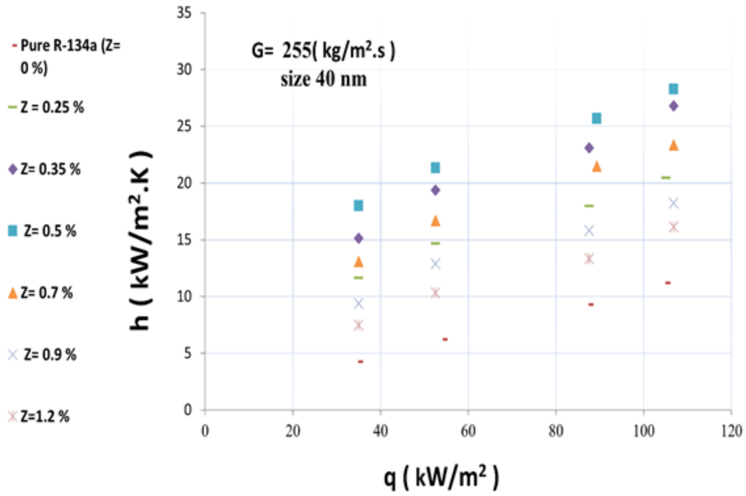

Fig 6. Heat transfer coefficient variation with heat flux at various concentrations of Al_2O_3 (for β =40 nm) and mass flux 255 kg/m^2. S

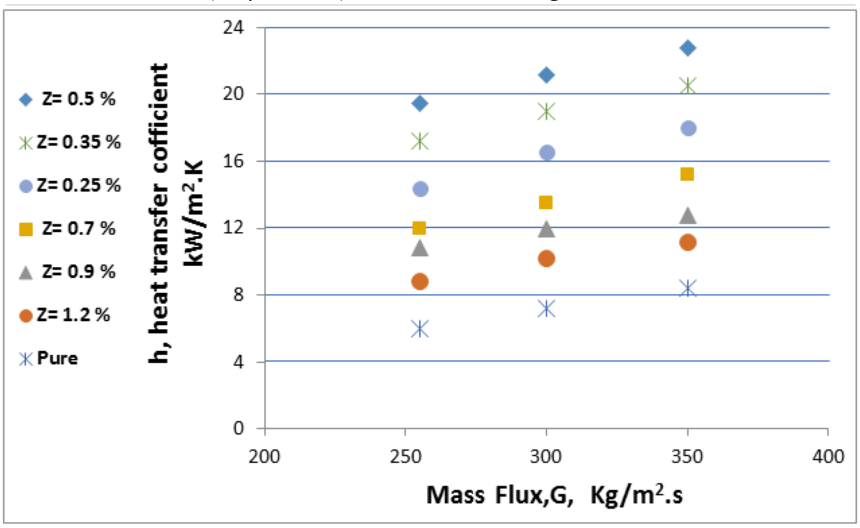

Fig 7. Variation of heat transfer coefficient with mass flux at different Concentrations of Al_2O_3 for B=15 nm, q=40-50-60 kW/m^2

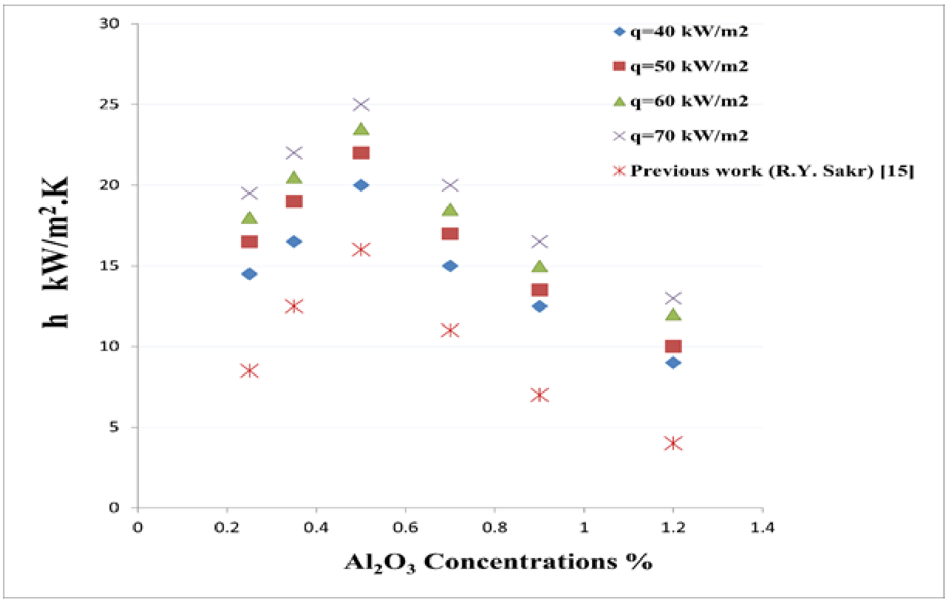

Fig 8. Variation of evaporative heat transfer coefficient with Al_2O_3 Particle size

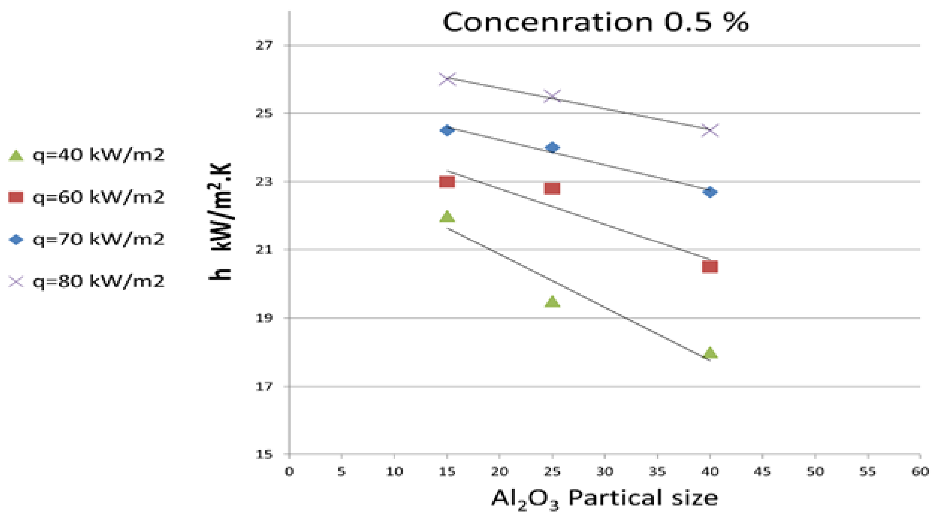

Fig 9. Variation of heat transfer coefficient with Nanoparticles Concentration of Al_2O_3 (for β =15 nm)

5.3. Effect of Al_2O_3 Nanoparticles Size on the Evaporative Heat Transfer Coefficient

Figure 8 illustrates how the evaporating heat transfer coefficient varies with Al_2O_3 particle size for various heat flux values for (40-80) kW/m^2 at mass flux of 255 kg/m^2. s. It is noticed that the heat transfer coefficient decreases with Increasing of nano particle size. It is noticed that the heat transfer coefficient shows high value with 15 nm size and lowest value in 40 nm

5.4. Effect of Al_2O_3 Nanoparticles Concentrations on the Evaporative Heat Transfer Coefficient

Figure 9 indicates that for different heat flux values (40-80) kW/m^2, the evaporating heat transfer coefficient varies with the concentration of Al_2O_3 nanoparticles. It is observed that the evaporating heat transfer coefficient increases with the increase in Al_2O_3 concentration up to 0.5%, then decreases for all values. For all values of heat flux, the evaporating heat transfer coefficient reaches its maximum value at 0.5% concentration. Comparison with literature [15] show Same trend for the present results which means similar behavior as that of the available literature.

6. The Deduced Correlation Equation for the Evaporating Heat Transfer Coefficient

Empirical correlation equations are obtained to calculate the evaporating heat transfer coefficient based on the different measurements obtained in the present study. The experimental measurements were taken for heat flux ranged from 40 to 80 kW/m^2, mass flux ranged from 255 to 350 kg/m^2s on the evaporating heat transfer coefficient at various concentrations of nanoparticles of Al_2O_3 ranged from (0.25 to 1.2 %) by weight respectively. From the above discussion of the experimental results obtain in the current work and empirical equation. It is deduced here by the following equation

$$h_{avg} = A + B(Z) + C(Z)^2 + D(Z)^3 + E(q). \qquad (1)$$

The constants of equation (1) vary with the mass flux of the refrigerant, as presented in table (1) which shows the values of these constants for different values of the mass Fluxes used here resulted by using Table 3d Curve software.

Const.	255 kg/m^2s	300 kg/m^2s	350 kg/m^2s
A	-13.4	-16.69	-11.83
B	140.03	150	121.35
C	-218	-239	-196.72
D	93.87	105	85.43
E	0.11204	0.1057	0.1073

Table 1 Values of the constants of equation (1) according to mass flux work condition. These constants are fitted to the mass flux of refrigerant G according to the following equations

$$A = -17.83 + 0.00073\,(G)^{1.5} \qquad (2)$$

$$B = 169.6 - 0.00035\,(G)^2 \qquad (3)$$

$$C = -256.3 + 0.00041(G)^2 \qquad (4)$$

$$D = 110.4 - 0.00016(G)^2 \qquad (5)$$

$$E = 0.1 + 716/(G)^2 \qquad (6)$$

Equation (2) to equation (6) are substituted in equation (1) to produce equation (8), that deals with the heat flux, mass flux, and the Al_2O_3 concentrations as an input to compare the value of the average heat transfer coefficient, at constant evaporation pressure

$$h = f\ (z, q, G) \text{ at const Pe} \qquad (7)$$

$$h_{avg} = A(G) + B(G)(Z) + C(G)(Z)^2 + D(G)(Z)^3 + E(G)(q) \qquad (8)$$

The above correlation equation (8) is plotted in Fig (10) this figure compares the measured values of the average heat transfer coefficient, $h_{measured}$ with the calculated average heat transfer coefficient, $h_{calculated}$. The results shown in Fig (10) indicate that the scatter of the data points around the 45° line is ± 10 %, maximum deviation. This comparison shows a good presentation for the deduced correlation equation

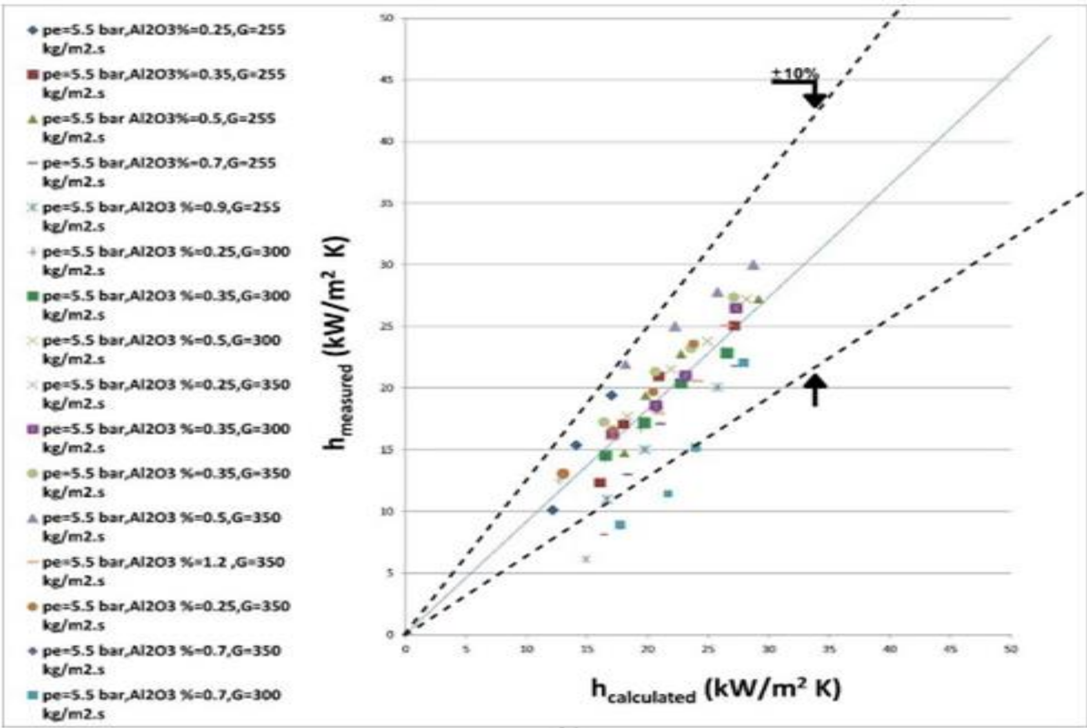

Fig 10 Measured heat transfer coefficient versus corelated heat transfer coefficient

7.Conclusions

According to the investigation, using Al_2O_3 nanoparticles with R134a refrigerant improves the system's heat transfer and performance characteristics when compared to using a pure refrigeration cycle. Also, COP for Al_2O_3/R134a (0.5%) and (1.2%) concentrations improve by 20%,25% respectively. From the experimental results it is noted that the evaporative heat transfer coefficient increases with:

a. performed heat flux within the used range from 40 to 80 kW/m^2

b. Al_2O_3 nanoparticle of size 15 nm and show the highest value

c. with a concentration of Al_2O_3 nanoparticles up to 0.5 % then decreases for all values.

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