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Research paper

Numerical investigation and comparison for heat transfer coefficient for two eco-friendly Nano refrigerants in horizontal tube

Ammar H. Soheel [1] *, Karam Hashim Mohammed [1], Ahmed H.Ghanim [1]

[1] *Technical Engineering College of Mosul, Refrigeration and Air-Conditioning Department, Northern Technical University, Mosul, Iraq*
**Corresponding author E-mail: karam.hashim@ntu.edu.iq*

Abstract

This paper presents a numerical investigation and comparison for heat transfer coefficient for eco-friendly refrigerants R134a and R600a with Al2O3 and TiO2 nanoparticles at (1, 2, 3 and 4 %) concentration, flowing through a horizontal tube with a constant wall temperature at (310, 320 and 330 0K) using in vapor compression system. The numerical investigation is simulated by CFD model using FLUENT ANSYS 14.5 software. The numerical results indicate, when increasing the nanoparticles, the heat transfer coefficient of nanorefrigerants increases and the R134a+TiO2 nanorefrigerant was selected an optimal nanorefrigerant used in vapor compression system. Finally, the agreement seems to be acceptable between this study and other studies in literature with MPE 7.82 %.

Keywords: *Heat Transfer Coefficient; Nanorefrigerant; Eco-Friendly Refrigerant; CFD; Nanoparticles; Nanofluid; Horizontal Tube; Thermo Physical; FLUENT ANSYS*

1. Introduction

Nanofluid turns out to be one of the interesting subjects for engineers who work for a period of some time to grow more effective heat transfer in a variety of applications. Nanofluid that is another type of heat transfer fluid through functional nanoparticles suspended in liquid traditional host, nanorefrigerant is a type of nanofluid, and liquid host nanorefrigerant is the emission of refrigerant.

In recent times, nanorefrigerants have turned into contributions for the vast amount of exploration and pressure steam system in view of the lack of youthfulness, contemplations and natural heat transfer coefficient, and it very well may be used to improve the implementation of the cooling system.

Refrigerants custom that has real part in increases the temperature of the earth around and use the ozone layer [1]. Along these lines, there is a need to improve the implementation of the cooling system pressure steam with the help of suitable refrigerant use.

R134a and R600a is the most widely used refrigerants exchange as different replacement of refrigerants in cooling local type of gear. Global warning potential (GWP) and ozone depleting potential (ODP) of R134a and R600a are lower than the different refrigerants [2]. The development of nanoparticles for refrigerants present cause changes in physical properties of thermo and heat transfer properties of refrigerants, in this way the implementation of cooling system already upgraded to extraordinary levels of certain [1].

In view of the application of nanoparticles are made of various materials, the most famous new age nanoparticles be pottery, which is the best part into ceramic metal oxides, for example, titanium and aluminium [3].

Al_2O_3 and TiO_2 nanoparticles most widely used in the use of the cooling system because they have no expensive, less challenging scatter and not responding in have refrigerant, solid and better implementation of [4].

Examination of coefficient of heat transfer is important to build the level of efficiency of the cooling system, particularly in the heat exchangers which includes stage liquid changes work. With the suspension of nanoparticles to the refrigerant, coefficient of heat transfer which is extended as a mixture of changing properties of nanorefrigerants [5].

Literature basically exploring the centre around the implementation of the type of nanorefrigerants to be used in the cooling system of the local. BI, et al. 2008 [6] explored tentatively cold execution with TiO_2 nanoparticles on HFC134a as liquid work. Implementation of a refrigerator is superior to any HFC134a, with less energy used with 0.1% mass of TiO_2 nanoparticles division in contrast to the HFC134a 26.1%. Hadi et al., 2011 [7] examined the nanorefrigerant effects tentatively focusing go from 0.05 - 1% copper horizontal tubes in parallel flow heat exchanger tube in a steam pressure system. The show that is followed by an increase in heat exchange coefficient fade with expanding the focus of nanoparticles up to certain confidence at that time will be reduced. BI et al., 2011 [8] inspected tentatively energy use and local limit freezing fridge using TiO_2 - R600a nanorefrigerant as liquid work. The results indicate that cold using TiO_2 – R600a can spend 9.6% energy consumption. Kumar and Elansezhian, 2012 [9] considered tentatively testing the use of energy and the freezing test limits in the system pressure steam using Al_2O_3 - R134a nanorefrigerant. The results indicate that the reduction of 10.32% of energy consumption from cooling system that uses nanorefrigerant. Javadi and Saidur, 2013 [10] reviewed hypothetically effect using a mixture of R134a refrigerant with TiO_2 nanoparticles and Al_2O_3 with various parts of grand energy vigorously in the fridge in the Malaysia and emanation the reduction of ozone-damaging substances. The results show that the nanorefrigerant can build local refrigera-

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tor implementation and reduce energy consumption. Impact reduction and appropriate economic justification is complete. Kumar, et al. 2013 [11] used Al_2O_3 with R600a to increase the limit of heat transfer in the cooling system tentatively. The results found that the freezing limit is higher and reduced power consumption. R600a with Tiny working regularly in the residential refrigerators. Mahbubul et al., 2013 [12] examined and physical properties of thermo heat exchange coefficient of Al_2O_3 + R134a nanorefrigerant in flat-tube smooth for a bevy of nanoparticles 1 to 5 vol.%. Physical effects and heat exchange coefficient thermo showed increases with the total breakdown of the increase. Mahbubul, et al. 2013 [13] reviewed heat conductivity and consistency of nanorefrigerant Al_2O_3/R141b to 0.5 to 2 Vol.% fixations at temperatures from 5 to 20 °C. Results of exploration, indicating that the heat conductivity of the nanorefrigerants with increases with the development of nanoparticle fixations volume and temperature. Plus, consistency of nanorefrigerant that grew with the expansion of the fraction of volume. Namely as it that, it decreases with increase in temperature. Mahbubul, et al. 2013 [5] decided the heat exchange and pressure fall properties Al_2O_3 - R141b nanorefrigerants to fixations volume range in a tube of circular flat smooth. They found that both the exchange of heat and the weight of the falling qualities that has grown with the increase of nanoparticle total fixations. Fadhilah et al., 2014 [14] used numerical models to explore the physical properties of thermo and heat exchange rate in nanorefrigerant evaporator container. The results indicate physical characteristics improved thermo and expand the heat exchange characteristics of nanorefrigerant. Coumaression and Palaniradja, 2014 [15] explored the heat exchange coefficient by investigation using CFD and FLUENT programming tentative nanorefrigerant in the system pressure Steam. The result shows the heat Exchange coefficient increased by using nanorefrigerant. Singh and Lal, 2014 [16] reviewed the implementation of the nanorefrigerant (R134a + Al_2O_3) in the cooling system. Test results found a change coefficient of performance (COP) is the maxi. Papade is Wale and 2015 [17] considered the implementation of the system of ventilating with nanorefrigerant R134a - Al_2O_3. The test results show that the coefficient of implementation of expanded by 14% and power consumption reduced about 20% when nanorefrigerant is used.

Jaiswal and Mishra, 2015 [18] studied theoretically and experimentally the effect of nanoparticles titanium oxide, aluminum oxide mixed into eco friendly refrigerant R134a on the enhancement thermal performance in the vapor compression system. They observed that the convective heat transfer coefficient enhance from 10 to 80 %. Kushwaha et al, 2016 [19] investigated experimentally the coefficient of performance in refrigeration system using nanorefrigerant (R134a + Al_2O_3). They observed that improvement in coefficient of performance from 1.17 % to 9.14 %. Coumaressin, et al. 2016 [20] investigated the influence of Al_2O_3, TiO_2 and CuO nanoparticles (from 0 - 1% concentration) with nature friendly refrigerant 1234yf on the heat transfer coefficient and performance of the vapor compression refrigeration system experimentally and by using TK solver. The results shows that the heat transfer coefficient of the nanorefrigerant is higher than that of pure refrigerant and the performance of the system is higher with usage of Al_2O_3 nanoparticles with R1234yf refrigerant compared to other nanoparticles. Hernandez et al, 2016 [21] presented simulation in ANSES FLUENT 14.5 were performed the analysis of mixture of eco friendly refrigerant with Al_2O_3 nano particles at 1% & 5 % fraction volume concentration to improve thermal efficiency of refrigeration system. The results show that improvement in the thermal efficiency and the heat transfer coefficient is higher at the 1 % fraction volume concentration. Mahdi, 2017 [22] investigated experimentally the performance of 1 ton refrigeration system using Al_2O_3 + R134a with 0.01 % & 0.02 % volume fraction. From experimental calculation, when the volume fraction of Al_2O_3 concentration increase the heat transfer coefficient increases from 0.54 to 1.1. Pawale, 2017 [1] studied the improvement of performance of vapor compression system by using Al_2O_3 + R134a nanorefrigerant.

From above, the researchers demonstrate the nanorefrigerant enhancement the performance of vapour compression system. But, the objective of this paper, investigate the heat transfer coefficient by CFD heat transfer analysis using ANSYS FLUENT 14.5 software of two types of eco friendly refrigerant (R134a & R600a) mixed with two types of nanoparticles (Al_2O_3 & TiO_2) for each other in the horizontal tube using in evaporative vapor compression system and determine the optimal type of nanorefrigerant.

2. Physical model

Consider a copper smooth horizontal tube of an evaporator in vapor compression system with inner diameter (di), outer diameter (do), and length (L) being 0.00772m, 0.0095m and 1.44m, as shown in figure (1). The nanoparticles diapered in refrigerant with inlet constant temperature (T_{in}) and velocity (u_{in}) flows through tube and the surrounding air flows around of the tube and represents load on evaporator at constant temperature (T_w).

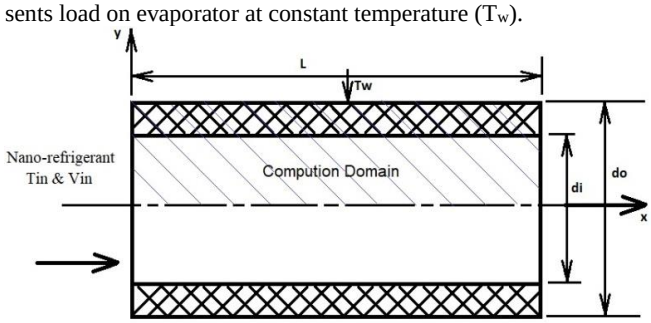


Fig. 1: Schematic of Copper Horizontal Tube.

3. Theoretical analysis

a) Calculation of thermo physical properties of nanorefrigerant:

In order to calculate the heat transfer coefficient, the nanorefrigerant properties which include density, specific heat viscosity and thermal conductivity can be calculated. This properties depended on the concentration (φ) of nano particles in the refrigerant. The following correlations [15] are used to calculate the thermo physical of nanorefrigerant:

The density of the nanorefrigerant is developed by pak and cho and given by

$$\rho_{nf} = \varphi\, \rho_p + (1-\varphi)\rho_f \tag{1}$$

Also, pak and cho developed the specific heat of the nanorefrigerant and given by

$$Cp_{nf} = \varphi\, Cp_p + (1-\varphi)Cp_f \tag{2}$$

Einstein developed the viscosity of the nanorefrigerant and given by [23]

$$\mu_{nf} = \mu_f(1 + 2.5\,\varphi \tag{3}$$

The thermal conductivity of the nanorefrigerant is given by [15]

$$K_{nf} = K_f\left[\frac{\left[\frac{(1+2\,\varphi)\left(1-\left(\frac{K_f}{K_p}\right)\right)}{2\left(\frac{K_f}{K_p}\right)+1}\right]}{\left[\frac{(1-\varphi)\left(1-\left(\frac{K_f}{K_p}\right)\right)}{\left(\frac{K_f}{K_p}\right)+1}\right]}\right] \tag{4}$$

b) Mathematical model

The Newtonian nanorefrigerant with constant properties flows through smooth horizontal circular tube under uniform, laminar and steady state flow. The flow is incompressible, two dimensional and symmetrical with respect to horizontal plane. The equations

of conservation (mass, momentum and energy) for fully developed for single phase fluid can be applied to the nanorefrigerant [24].

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \quad (5)$$

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+\frac{\mu}{\rho}\left[\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right] \quad (6)$$

$$u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}=-\frac{1}{\rho}\frac{\partial p}{\partial y}+\frac{\mu}{\rho}\left[\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right] \quad (7)$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{K}{\rho C_p}\left[\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right] \quad (8)$$

c) Computational program

The horizontal tube of an evaporator is designed, meshing and simulation using FLUENT ANSYS 14.5.

Varied meshes was used to approve the precision and consistency of results, filtering work and heat Exchange coefficient and quality components for each different case.

Quality factor of digits for each component model (restrictions on component lines and dots). Selection of quality elements provide a composite quality metric until somewhere in the range of 0 and 1. The metric depends on the ratio of the total length of the edges for a particular component. Estimated 1 shows a good block or Square while the estimate of 0 indicates that the component has zero or negative volumes [25].

In this study, the independence mesh of 133000 element because the change of results for heat transfer coefficient is significantly with mesh (shown Figures (2 & 3) and element quality is 0.999395, as shown in Table (1).

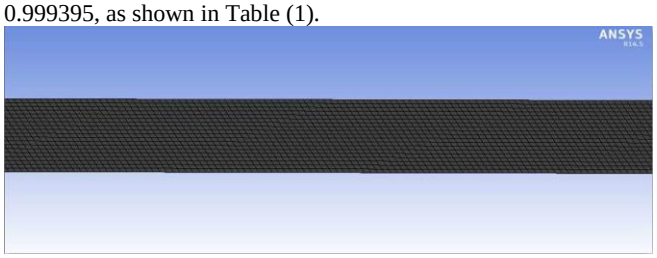


Fig. 2: The Configuration Mesh of the Horizontal Tube.

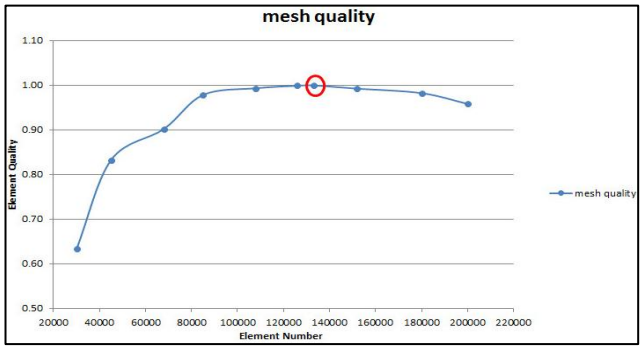


Fig. 3: Mesh Quality (Stability of Mesh).

Table 1: Shows Element Quality

Element	element quality	
30000	0.6333	
45000	0.8323	
68000	0.9019	
85000	0.9781	
108000	0.9931	
126000	0.99861	
133000	0.999395	best mesh
152000	0.99219	
180000	0.98214	
200000	0.95806	

d) Calculation of average heat transfer coefficient

The formula for average heat transfer coefficient of fully developed for tube at uniform surface temperature as given below:

$$h_{avg}=\frac{q}{\pi\, di\, L\,(T_w-T_{m,avg})} \quad (9)$$

Where

(h_{avg}) is the average heat transfer coefficient, KW/m^2.^{o}K

q= heat transfer rate, KW.

$T_{m,avg}$ = average mean temperature of nanorefrigerant = $\frac{T_{in}+T_{o,avg}}{2}$, ^{o}K.

T_w = Wall (surface) temperature, ^{o}K.

di = inner diameter of the tube, m.

L = length of the tube, m.

4. Results and discussion

This study deals with the influence of the concentration of Al_2O_3 and TiO_2 nanoparticles in the R134a and TiO_2 eco friendly refrigerants used in vapor compression system on the heat transfer coefficient numerically. Based on the author's studies selected four concentration of nanoparticles dispersed in the refrigerant (0.01, 0.02, 0.03, and 0.04) with inlet velocity 0.5 m/s and inlet nanorefrigerant temperature 281 ^{o}K are used in this study. The results are simulated in the CFD technique applied with FLUENT ANASYS 14.5 software.

The temperature contour of R134a + Al_2O_3 nanorefrigerant of the horizontal tube is shown in Figure (4). The Figure (4a) illustrates the simulation of nanorefrigerant temperature at first part of the tube from inlet, the middle part and last part of the tube are illustrates in Figures (4b & 4c) respectively. The outlet of R134a+Al_2O_3 temperature simulation gradually of the tube is shown in figure (4d).

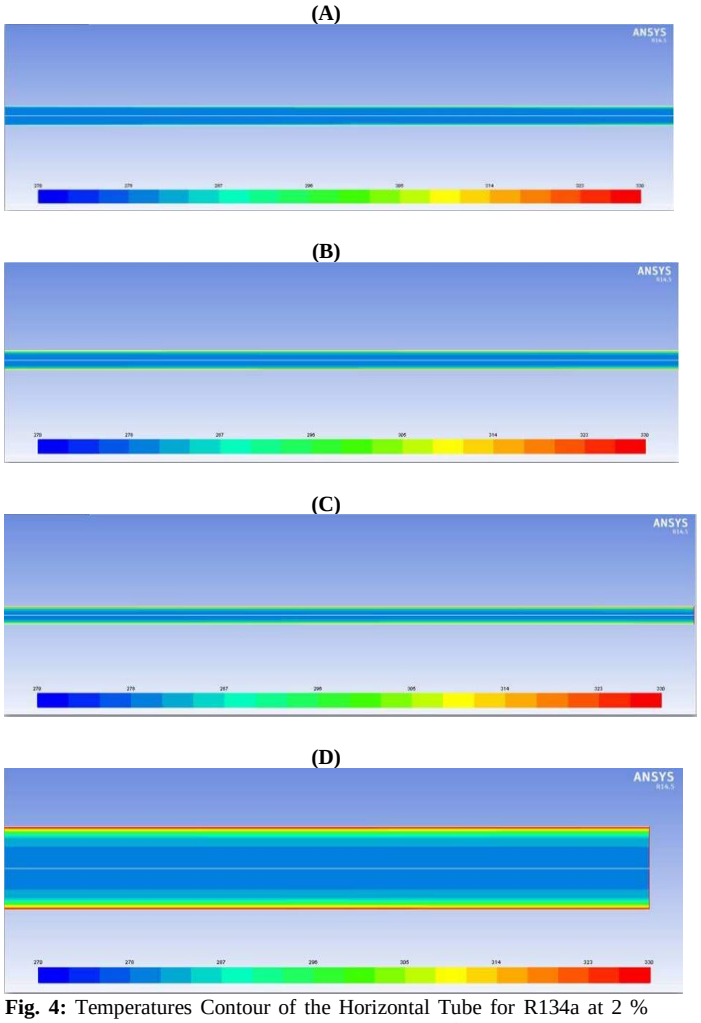


Fig. 4: Temperatures Contour of the Horizontal Tube for R134a at 2 % Al_2O_3 Nanoparticles with 0.5 M/S. A- Inlet Part of the Tube. B- Middle Part. C- Last Part. D- Outlet Part of the Tube.

Figure (5) illustrates the influence nanoparticles concentration on the average heat transfer coefficient of nanorefrigerants at constant wall temperature 310 ^{o}K. It can be observed that the heat transfer coefficient for all nanorefrigerants increased with the concentration increased because better thermal conductivity of nanoparticles and more heat transfer due to high contact surface area of nanoparticles with refrigerant.

The heat transfer coefficient of R134a + TiO_2 & R134a + Al_2O_3 higher than the R600a + TiO_2 & R600a + Al_2O_3 with average 113 % & 83 %, respectively and the heat transfer coefficient of R134a + TiO_2 nanorefrigerant is the highest.

But the increment of the heat transfer coefficient of R600a refrigerant with TiO_2 & Al_2O_3 nanoparticles concentration approximately 18.81 % & 17 %, respectively more than the increment of R134a refrigerant with TiO_2 & Al_2O_3 nanoparticles concentration which approximately equal 4.5 % & 4 %, respectively.

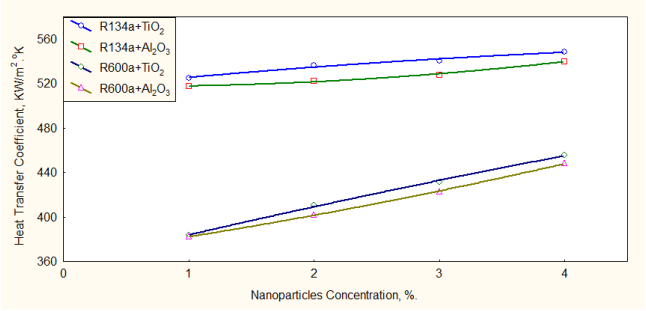


Fig. 5: Variation of the Heat Transfer Coefficient of Different Nanorefrigerants with Different Nanoparticles Concentration at T_w = 310 ^{O}k, T_{in} = 281 ^{O}k and U_{in} = 0.5 M/S.

The heat transfer coefficient decreases as wall (surface) temperature increases due to the decrease in the heat transfer rate, as shown in Figures (6 & 7) which are demonstrate the variation of heat transfer coefficient of nanorefrigerants with different nanoparticles concentration at constant wall temperature 320 ^{o}K & 330 ^{o}K, respectively.

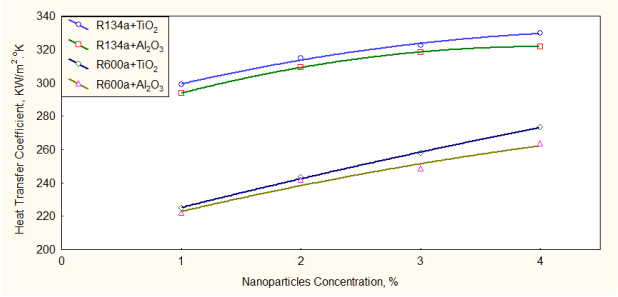


Fig. 6: Variation of the Heat Transfer Coefficient of Different Nanorefrigerants with Different Nanoparticles Concentration at T_w = 320 ^{O}k, T_{in} = 281 ^{O}k and U_{in} = 0.5 M/S.

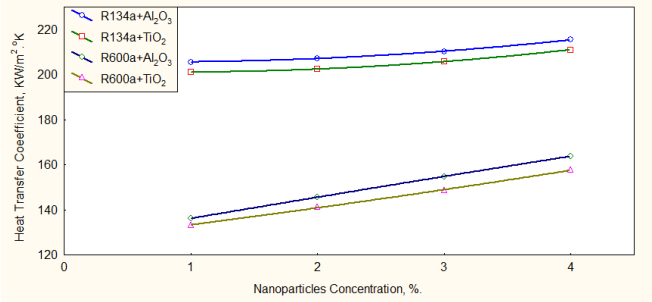


Fig. 7: Variation of the Heat Transfer Coefficient of Different Nanorefrigerants with Different Nanoparticles Concentration at T_w = 330 ^{O}k, T_{in} = 281 ^{O}k and U_{in} = 0.5 M/S.

In order to validate the FLUENT ANSYS software program results, which represent a simulation & investigation of smooth horizontal tube, a comparison between this numerical study and Mahbubul [12] study is made as shown in Figure (8) which illustrate the influence nanoparticles concentration on the heat transfer coefficient of R134a + Al_2O_3 nanorefrigerant at wall temperature 320 ^{o}K. In spite of different tube dimensions and some boundary conditions, acceptable agreement between two results studies and the 7.82 % mean percentage error (MPE) is showed between them.

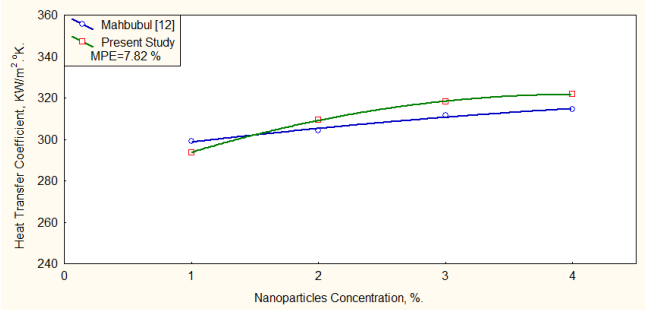


Fig. 8: Comparison between the Numerical Results of Present Study and Mahbubul Study [12] For Variation Heat Transfer Coefficient of R134a + Al2O3 Nanoferigerant with Influence Nanoparticles Concentration at Wall (Surface) Temperature 320 ^{O}k.

5. Conclusions

Numerical model were conducted to investigate the effect of nanoparticles concentration on the heat transfer coefficient of R134a+Al_2O_3, R134a+TiO_2, R600a+Al_2O_3 and R600a+TiO_2 nanorefrigerants and compare the heat transfer coefficient between them. From numerical model results we concluded:

1) Computational Fluid Dynamics (CFD) Heat Transfer analysis for the designed horizontal tube has been successfully performed using FLUENT software.
2) The best behaviors for nanorefrigerants temperature simulation from FLUENT ANSYS software are obtained.
3) The higher heat transfer coefficient increased with nanoparticles concentration increased.
4) R134a+TiO_2 nanorefrigerant used as an excellent nanorefrigerant in a vapor compression system because have higher heat transfer coefficient than other nanorefrigerants.
5) The increment of the heat transfer coefficient of R600a refrigerant with TiO_2 & Al_2O_3 nanoparticles concentration 18.81 % & 17 %, respectively, but the increment of R134a refrigerant with TiO_2 & Al_2O_3 nanoparticles concentration equal to 4.5 % & 4 %, respectively.
6) The heat transfer coefficient of nanorefrigerants decreases as wall (surface) temperature increases.
7) There is an acceptable agreement between present numerical results and Mahbubul study [12] with MPE 7.82 % in the behavior of heat transfer coefficient with nanoparticles concentration.

Nomenclature:

Abbreviations:

Al_2O_3 Aluminum Oxide.
CFD Computation Fluid Dynamic.
COP Coefficient of Performance.
GWP Global Warning Potiental.
MPE Mean Percentage Error.
ODP Ozone Depleting Potential.
TiO_2 Titanium Oxide.

Symbols:

Cp Specific Heat, J/kg.^{o}K
din Inner Diameter of the tube, m.
do Outer Diameter of the tube, m.
h Heat Transfer Coefficient, KW/m^2.^{o}K.
K Thermal Conductivity, W/m.^{o}K.
L Length of the tube, m.
p Depended Pressure, N/m^2.
q Heat Transfer Rate, KW.
T Temperature of Nanorefrigerant, ^{o}K.
u,v Nanorefrigerant Velocity in x- & y- direction receptivity, m/s.

Subscripts:

avg Average.
f Host Refrigerant.

in Inlet Refrigerant to the tube.
m Mean.
nf Nanorefrigerant.
o Oulet Nanorefrigerant from the tube.
p Nanoparticles.
w Wall (or Surface) of the tube.
Greek symbols:
φ Concentration, %.
ρ Density, kg/m^3.
μ Viscosity, Pa.s

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