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The Uniform Magnetic Field Efficacy on Heat Transfer of Nanofluid Flow in A Flat Tube

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Somayeh Davoodabadi Farahani[1,*], Mahdi Alibeigi[1], Hamed Hossienabadi Farahani[1]

[1] School of Mechanical Engineering, Arak University of Technology, 38181-41167, Arak, Iran

ABSTRACT

In this study, the effect of magnetic field on temperature field and nanofluid current in a flat tube is investigated numerically. The water-based fluid and nanoparticles are iron oxide, copper oxide and aluminum oxide with a diameter of 1 nm. The finite volume method has been used for numerical modeling. Nanofluid is considered as single phase. Both flow regimes are considered laminar and turbulent. With the addition of nanoparticles and increasing the volume fraction, the amount of heat transfer and pressure drop in the turbulence flow is more than the laminar flow. Applying a magnetic field changes the velocity field in the flat tube by creating a Lorentz force. By applying a magnetic field and increasing its intensity, the amount of Nusselt number in the turbulent current increases by about 40%. In the state with and without magnetic field, nanofluid water-iron oxide has the highest heat transfer rate compared to other states.

Keywords:
heat transfer; magnetic field; Nano
-fluid; flat tube

1. Introduction

In the last two decades, many research studies have shown that nano – science engineering and nano - science are very promising in the evolution of technology in the new century.
Recent advances in Micro-electromechanical systems (MEMS), Nanoelectromechanical systems (NEMS), Ferrofluids, microfluids and nanofluids represent the high importance of this new scientific field. The various and complex factors reduce heat transfer. The low heat transfer coefficient in ma ny fields of heat transfer such as small systems become a concealable concerning [1].The Flat tubes are the most prevalent type of heat exchangers used in air conditioning, refrigeration, industries, cooling system, microchannel and thermal power plants[2-4]. Wajiha et al. [5] studied the numerical study of a three - dimensional flow and heat transfer in a tube containing nano oxide nanofluid and copper oxide on the basis of ethylene glycol and water in a two - phase mixing method. their research shows that in the developing and developing area of flat tube, the thermal displacement coefficient has been increased, which causes an increase in cross - sectional area.

Wilson et al. [6] investigated in an empirical study on the copper flatten tubes with diameter of 9 mm and the various flat intensity to investigate the thermal and hydrodynamic with properties of

*Corresponding author.
E-mail address: sdfarahani@arakut.ac.ir

R134a and R410a Refrigerant. The volume fraction was about 75 - 400 kg / m3 and the quality between 10 % and 80 %. The results show that pressure drop has been increased by increasing the rate of flatting, the volume flow rate, and quality. furthermore, it is shown that the heat transfer enhancement is directly dependent on the mass flow rate of the tube. Falsafi et al. [7] investigated the numerical investigation of the forced convection heat transfer within a circular copper tube under an alternating magnetic field. It flows from a tube under the uniform heat flux and with the laminar flow regime. they found that the use of ferrofluid in the absence of magnetic field causes an increase in heat transfer coefficient as well as increasing the frequency of the field to improve the heat transfer and lower Reynolds numbers due to higher magnetic field. Rahmati and Nemati [8] investigated using the lattice Boltzmann method (LBM) for the first time to transfer the conjugate heat transfer of nanofluids into a K - shaped enclosure under the magnetic field. Their boundary conditions include the right and left side of the chamber at the cold constant temperature, the lower wall at constant temperature and the high horizontal wall temperature changes linearly. They report that the increase in the size of the chamber size causes an increase in heat transfer. also, in a Reynolds number and the steady dimensions of the chamber, increasing the Hartman number leads to decreasing flow rate and reducing heat transfer, in addition, the varied volume fraction has a direct effect on heat transfer. Zendehboudi et al.[9] investigated , the impact of various parameters on the thermal conductivity performance of the NPCM-based (Nano phase change material) with graphene nano-composites filer to attain increased thermal conductivity.

Aghaei et al. [10] investigated the effect of a magnetic field on the flow of heat transfer and entropy generation on a combination of water - copper nanofluid by considering the effect of Brownian motion within a trapezoidal enclosure. They cover the side wall of the enclosure and the upper left side is cold and moving towards the left and right and the lateral wall angle with the horizon of 45 degrees. their study was at the Grashof number of 104, different Reynolds numbers and different Hartman numbers in the laminar flow. the results showed that applying the magnetic field and increasing the rate of nanofluid and flow strength decreases and the behavior of convection varies. for this reason, in all the Reynold's numbers and volume fraction, the average Nusselt number is decreased by increasing the Hartman number. for this reason, in all the Reynolds numbers and volume fraction. In all the studied states, the entropy generated due to very small friction and the main entropy of production entropy due to heat transfer is irrevocable and also suggests that the changes of total production entropy with Hartman number are analogous to those of average Nusselt number.

Pourfard [11] studied the hydrodynamic and hydrodynamic behavior of a non - Newtonian fluid with the assumption of non - Newtonian fluids and iron oxide particles in a vertical rectangular channel in the presence of different magnetic fields using a mixed - phase model and volume method. considering electrical conductivity for the base fluid in addition to the hydrodynamic principle of hydrodynamic dogma and finally, the study of the numerical conditions of this study is between non - Newtonian fluid and Newtonian fluid. the magnetic field also considered the magnetic field as a uniform and uniform axial field where both fields were applied at the same time. due to the results, all changes for the non - Newtonian fluid and friction coefficient for non - Newtonian fluid are the same as Newtonian fluid, in this study, the effect of shear stress on the velocity profile and the coefficient of friction coefficient are more than non - Newtonian fluid. also, the results show that electrical conductivity has a significant impact on ferrofluid behavior and that the axial field with negative gradient and cross - field is the same effect on the Nusselt number and friction coefficient.

Chitsaz and Fathi [12] investigated the numerical investigation of the effect of external magnetic field on the properties of a two - dimensional isotropic two - dimensional isotropic flow and its dynamic characteristics, and for this purpose, numerical simulation has been contributed by the pseudo - spectral method for solving the two - dimensional hydromagnetic equations. the results show that the steady and steady external magnetic field causes vortex deformation along the lines of field, increasing the intensity of the magnetic field of this transformation. these changes affect the dynamic characteristics as well as the mixing efficiency and increasing the intensity of the mixing efficiency. also, the results show that the viscous dissipation rate is decreased in the presence of the external magnetic field relative to the state where the field is not present. The total energy dissipation rate is, of course, increasing compared to the state of non - presence of the magnetic field. also, in the presence of the external magnetic field due to the Lorentz force energy, the fluid is transferred from the fluid to the magnetic field, both of which cause large and small vortex shedding and fluid mixing. Aslfattahi et al.[13] studied new nanocomposites with Four different types of samples including pure binary molten salt and binary molten salt-based hexagonal boron nitride (hBN) nanocomposites with loading concentrations of 0.5, 1 and 1.5 wt.% were prepared. hBN was comprising the pre-defined mass ratio of binary molten salt (NaNO3-KNO3: 60-40 wt.%) as phase change materials (PCM) to enhance specific the heat capacity. Diao et al.[14] experimentally studied paraffin PCM (Phase change material) in a new copper foam latent heat storage unit (LHSU)-based on multichannel flat tube. They Compared it with the shell-and-tube LHSU which, features a larger contact area by adjusting the heat transfer fluid (HTF)injection. They concluded that Changing the HTF flow has a huge effect on the effectiveness of the LHSU than changing the inlet temperature. The temperature difference between the HTF inlet temperature and the PCM melting point can increase the effectiveness, although increasing the HTF volume flow reduces the effectiveness.

Dibaei et al. [15] studied the transfer of forced convection heat transfer nanofluid on water fluid based on variable magnetic field in laminar flow. They reported that by applying an alternating magnetic field and increasing it, the heat transfer coefficient has a momentum and downtrend, which attributed this phenomenon to a decrease in the velocity of the magnetic field during the application of the magnetic field and the increase in conduction heat transfer, as well as in further distances with the application of the magnetic field to further decrease the displacement coefficient and increase the steering mechanism. Tehrani et al. [16] investigated numerical modeling of mixed convection water - oxide nanofluid in a rectangular channel from two single - phase and two phases (discrete phase model). In comparison between single - phase and two phases, they concluded that the two-phase model has more accurate results than the single-phase model. the results show that increasing percentage of nanoparticles volume increases the heat transfer coefficient, but this effect is higher in aspect ratios. Shariat et al. [17] studied the numerical study of the water - oxide nano - oxide in an elliptical canal under constant heat flux and using a two - phase mixture model. due to the Brownian motion of nanoparticles, their results show that the particle size fraction increases the number of nanoparticles. also, by changing the shape of the cross section, the heat transfer increases but the coefficient of friction increases. Lavanya [18] investigated heat and mass transfer on the unsteady two dimensional MHD (magneto-fluid dynamics or hydromagnetic) flow through porous medium in a rotating parallel plate channel . They concluded that the velocity decreased with increasing Hartmann number, and it increased with permeability parameter. Sharma et al. [19] numerically studied on the performance of a flat tube with copper oxide (CuO) nanofluids. It was detected that the heat transfer performance of a flat tube improved with increase in particle concentration, temperature and Reynolds number. Also, they showed that the pressure drops across flat tube increased with increasing nanoparticle volumetric concentration and Reynolds number.

According to previous studies, there are few studies to investigate the effect of magnetic field on heat transfer and nanofluid flow in a flat tube and there is a lack of knowledge in this field. In this study, the effect of magnetic field on temperature field and nanofluid flow in a flattened tube is investigated. The finite volume method has been used to solve the governing equations. The nanofluid is modeled as single phase. The effect of three types of nanofluids has been investigated, in all of which water is assumed to be the base fluid. Reynolds numbers intended for investigations are in the range of laminar and turbulent flow. The effect of changing the intensity of the magnetic field and the volume fraction of nanoparticles on heat transfer and pressure drop in the flat tube has been investigated.

2. Methodology and Numerical Modeling

A schematic of the problem under study with boundary conditions is shown in Figure 1.

a)

b)

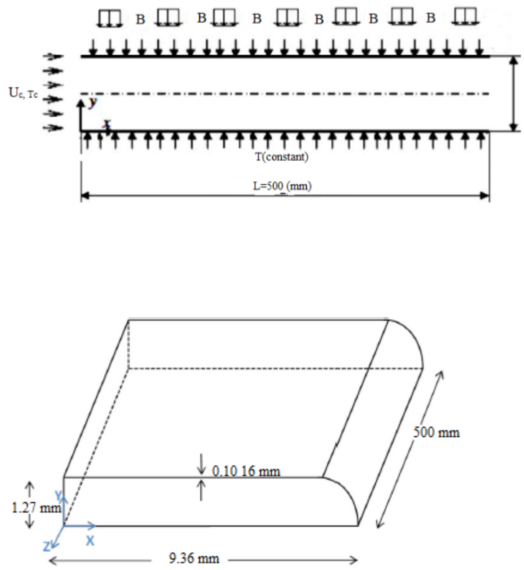


Fig.1. a schematic of the problem and boundary condition

The Single phases model for nanofluid are applied by some equation including solving the equations of continuity, momentum, energy, and, attention to the relative velocity. The Governing Equation present in the study presented in table 1.

Table 1

Governing equation of solver

Number	Equation	Description	Ref.
(1)	$\nabla.(\rho V) = 0$	continuity equation	[20]
(2)	$\rho V.\nabla T = -\nabla P + \nabla.(\mu.\nabla V)$	Momentum equation	[20]
(3)	$\rho V.\nabla T = \nabla.(k\ \nabla T)$	Energy equation	[20]
(4)	$\rho(\vec{V}.\nabla\vec{V}) = -\vec{\nabla}P + \mu\nabla^2\vec{V} + \mu_0(\vec{M}.\nabla)\vec{B} + \vec{J}\times\vec{B}$	Momentum equation in the attendance of the magnetic field	[21]
(5)	$\rho C\vec{V}.\nabla T = k\nabla^2 T + \frac{\vec{J}\times\vec{B}}{\sigma_m}$	Energy equation in the attendance of the magnetic field	[21]
(6)	$\vec{J} = \frac{\nabla\times B}{\mu_B}$	electric current intensity Equation	[21]

In these equations, the parameters including ρ, μ, k, P, and T are density, dynamic viscosity, thermal conductivity coefficient, pressure, velocity, and fluid temperature, respectively. By applying the magnetic field, Momentum equation in the attendance of the magnetic field, Energy equation in the attendance of the magnetic field, and electric current intensity Equation deliberated in the equations (4-6).In these equations, the symbols of its such as μ_0, $\vec{M}$, σ_m, and μ_B are the vacuum Magnetic permeability in the vacuum, Magnetic susceptibility, electrical conductivity, magnetic field intensity, and the magnetic permeability respectively. The nano fluid is applied as the working fluid, the single model is simulated. In this regard, the equations of solver are presented in table 2.

Table 2

Nanofluid formula for thermal properties in one-phase model

Number	Equation	Description	Ref.
(7)	$\rho_m = (1-\emptyset)\rho_f + \emptyset\rho_p$	Density of nanofluid	[4]
(8)	$Cp_m = \frac{1}{\rho_m}[(1-\emptyset)\rho_f Cp_f + \emptyset\rho_p Cp_p$	Heat Capacity of nanofluid	[22]
(9)	$k_{eff} = (\frac{(k_p + (n+1) + k_f - (n-1)(k_f - k_p)\emptyset_p}{k_p + (n+1) + k_f - (k_f - k_p)\emptyset_p}$	Thermal conductivity coefficient of nanofluid	[22]
(10)	$\mu_m = \mu_f(1 + 7.3\emptyset + 123\emptyset^2)$	Viscosity of nanofluid	[22]
(11)	$\beta_{eff} = (\frac{1}{1+\frac{(1-\emptyset_p)\rho_f}{\rho_p\emptyset_p}}\frac{\beta_p}{\beta_f} + \frac{1}{1+\frac{\rho_p\emptyset_p}{(1-\emptyset_p)\rho_f}})\beta_f$	Thermal expansion of coefficient nanofluid	[22]
(12)	$\mathrm{Re} = \frac{\rho_m V_{in} D}{\mu_m}$	Reynolds number	[4]
(13)	$Nu = \frac{hD}{k_{eff}}$	Nusselt Number	[4]

Where, n is the shape factor and it equals to 3 in this case. The indexes of m,f and p show the nano fluid, basic fluid and nanoparticle respectively. The symbols in these equations including V_{in} ,$\emptyset$,ρ,D, k,h,Cp, μ, and β eff are inlet velocity, volume friction, density, diameter of tube, thermal conductivity coefficient, convection heat transfer coefficient and heat capacity, dynamic viscosity, and effectiveness thermal expansion coefficient respectively. The diameters of all chosen nanofluids are 0.1 nm. In table 3 the usage working fluids thermophysical properties of fluids are presented.

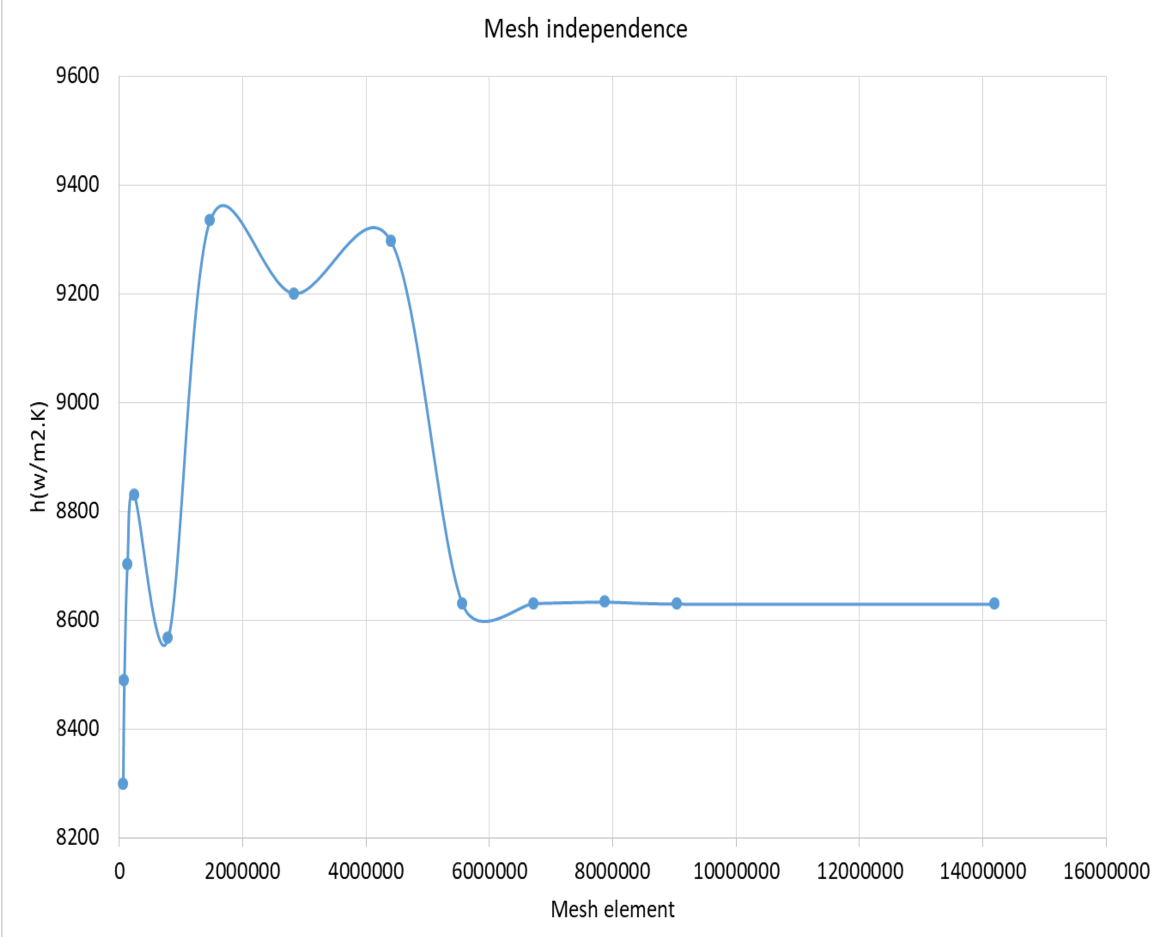
Table 3
Properties of material and passing fluid[23, 24]

Properties	Cp [J.kg-1K-1]	ρ [kg.m-3]	k [W.m-1. K-1]	μ [Pa.s]
Pure Water	4182	998	0.6	0.000855
Al2O3	796	3600	36	-
Fe3O4	670	5200	6	-
CuO	540	6500	18	-
Steel	0.87	2719	2024	-

3. Results and Discussion

The finite volume method (FVM) is a discretion method of the momentum and energy equations. The FVM order are chosen second-order upwind and the pressure discretize a standard form. The SIMPLE algorithm couples the pressure with Under-Relaxation Factor of 0.3 and velocity. Also, The Under-Relaxation Factor of density, volume, and energy collection are 1, and this factor equals 0.7. The k-ω SST turbulence model is utilized for the state where the flow is turbulent. This model simultaneously has the capability of the k-ω model in zones with low Reynolds and the high quality of the k-ε model in areas with high Reynolds The first discussion is the grid independency for boundary conditions and usual geometrical variables, and then for the same process recurrent several mesh sizes. To find a appropriate grid that consequences are in the mesh-grid independency for a flat tube comprising a water fluid for the meshes with different points with a forced conversion coefficient attained in Fig. 2 a. The solution domain in meshing has been strained to be small enough near the wall. According to the gotten fallouts, the 8million nodes are preferred to study. To approve the numerical modeling obtained in this study with similar study which is Vajjha et al.[5] have been done. The validation results of this assessment for the water and water-nanoparticle 3% exposed in Fig. 2b. The validation have a difference almost 7 % with results Vajjha et al.[5]. There is also a good point with the same results in this method.

a)



b)

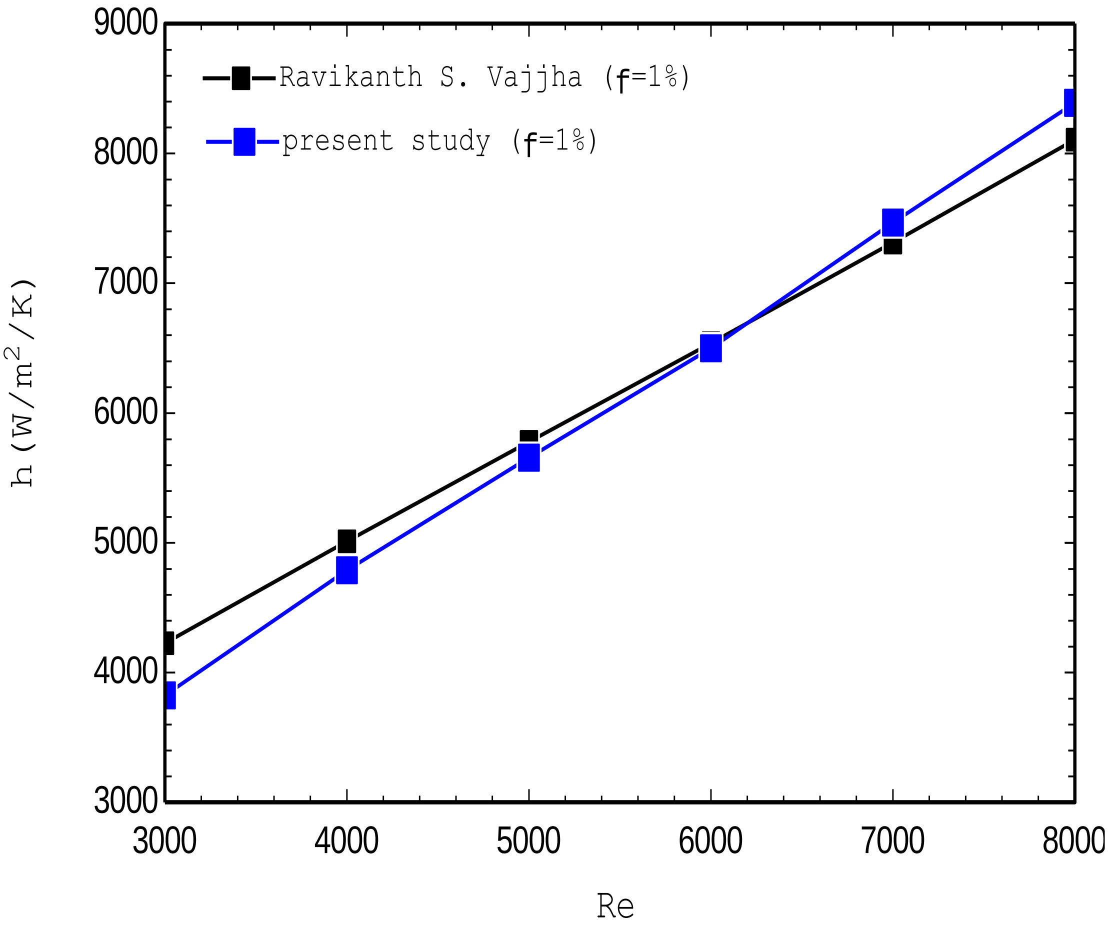


Fig.2. a) Check grid independency and **b)** validation

In this section, using the modeling presented before, the heat transfer and pressure drop in the tube and flat tube have been discussed. The considered Reynolds numbers cover both the ranges of laminar flow and turbulent flow. the properties of nano – fluids for one phase flow are calculated using the equations presented previous section.

Fig. 3 shows the variation of the Nusselt number and pressure drop in terms of the Reynolds number and the volume fraction of the particles on the tube and the flat tube. In Fig 3. observed that the heat transfer coefficient and pressure drop have increased with increasing the Reynolds number and increasing the volume fraction. By adding nano particles to the fluid, the thermo physical properties such as thermal conductivity, viscosity and etc. are changed. increasing of fluid viscosity causes an increase in the friction coefficient and finally increases the pressure drop. increasing the thermal conductivity of the base fluid increases the heat transfer coefficient. also, heat transfer coefficient is higher compared to the circular tube. The effect of this behavior is the increase in the ratio of the heat transfer rate to the volume and the impact of the wall. but the pressure drop in the circular tube mode is almost unchanged. in the Flat tube, changes of heat transfer coefficient and pressure drop with Reynolds number and volume fraction are similar to the sample tube. Treatment of nano - Al2 O3 causes a wall effect in laminar and turbulent flow in terms of three discussed volume fraction for the tube, Heat Transfer increased, 6 %, 22 % and 25 % respectively, and for flat tube it increased 8 %, 23 % and 28 %, respectively.

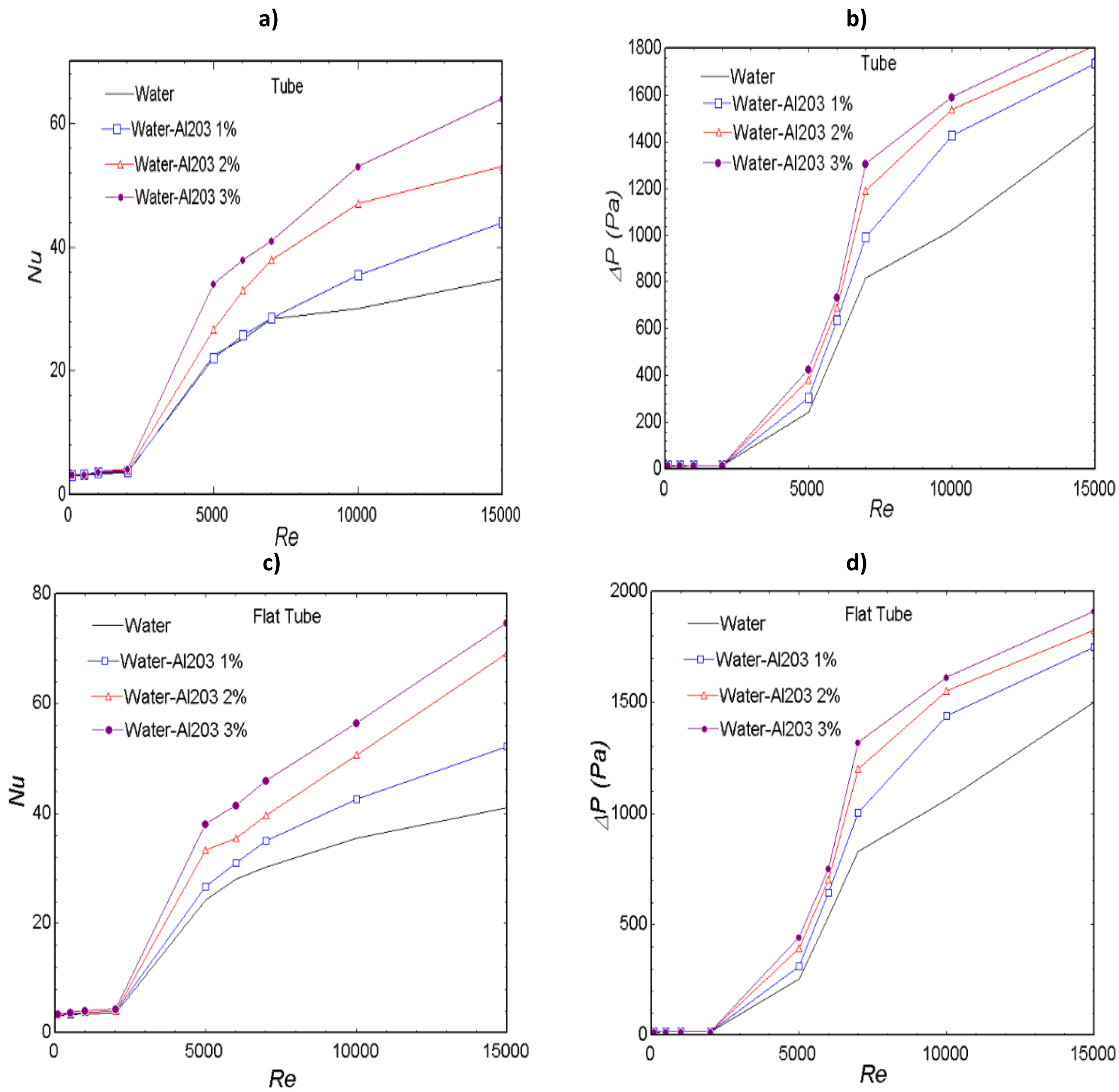


Fig. 3 a) Changes of Nusselt number in tube **b)** Pressure drop in tube **c)** Nusselt number in flat tube **d)** Pressure drop in flat tube

The effect change of Nanoparticles on heat transfer and pressure drop is shown in the volume fraction of 3 % in fig.4 by changing the nanoparticles, the thermophysical properties of nanofluids are changed, including thermal conductivity, density and viscosity of nanofluid. the thermo physical properties of nanoparticles are presented in Fig.4 and are calculated for a volume fraction of 3 % using the equations presented in the third chapter of the thermo physical properties. The nano-CuO, Fe3O4, and Al2O3 are considered for calculation. The rate of heat transfer to the base fluid and in the Reynolds number of laminar and turbulent flow for nano - Al2 O3, CuO, Fe3O4, and Al2O3 in the tube increased by 25 %, 30 % and 34 % respectively. Also, in the flat tube it increased 28 %, 32 % and 35 % respectively for these nanofluids. also, the rate of pressure drops in average ratio to the base fluid and in the Reynolds number of laminar and turbulent flow for nano - Al2 O3, CuO, Fe3O4and Al2O3 increased by 22 %, 28 % and 30 %, respectively, also for flat tube this increase is 29 %, 29 %, and 32 % respectively. the results show that nano particles have no significant effect on heat transfer and pressure drop.

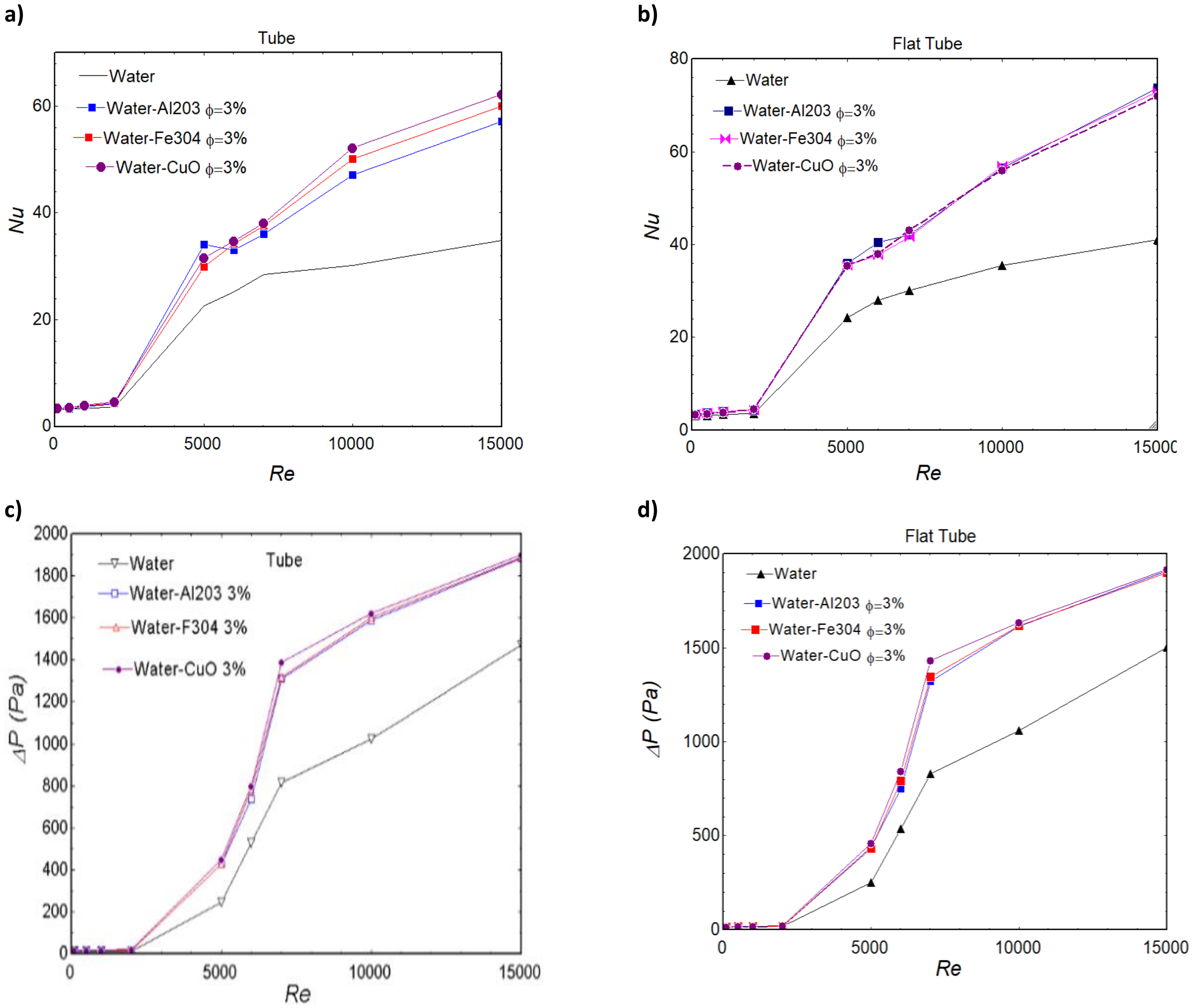


Fig .4. a) Changes of Nusselt number in tube **b)** Pressure drop in tube **c)** Nusselt number in flat tube **d)** Pressure drop in flat tube in terms of Reynolds number with different volume fraction

In this section, the effect of magnetic field on heat transfer and pressure drop in the tube is investigated by applying the magnetic field of two Kelvin and Lorentz force in momentum equations. Fig.5 and fig.6 show the variation and change of the magnetic field at Re=500 for different nanoparticles and with different volume fraction on heat transfer and pressure drop. Fig.7 and fig.8 show the effect of applying the magnetic field on the Re=10,000 for different particle nanoparticles on heat transfer and pressure drop.

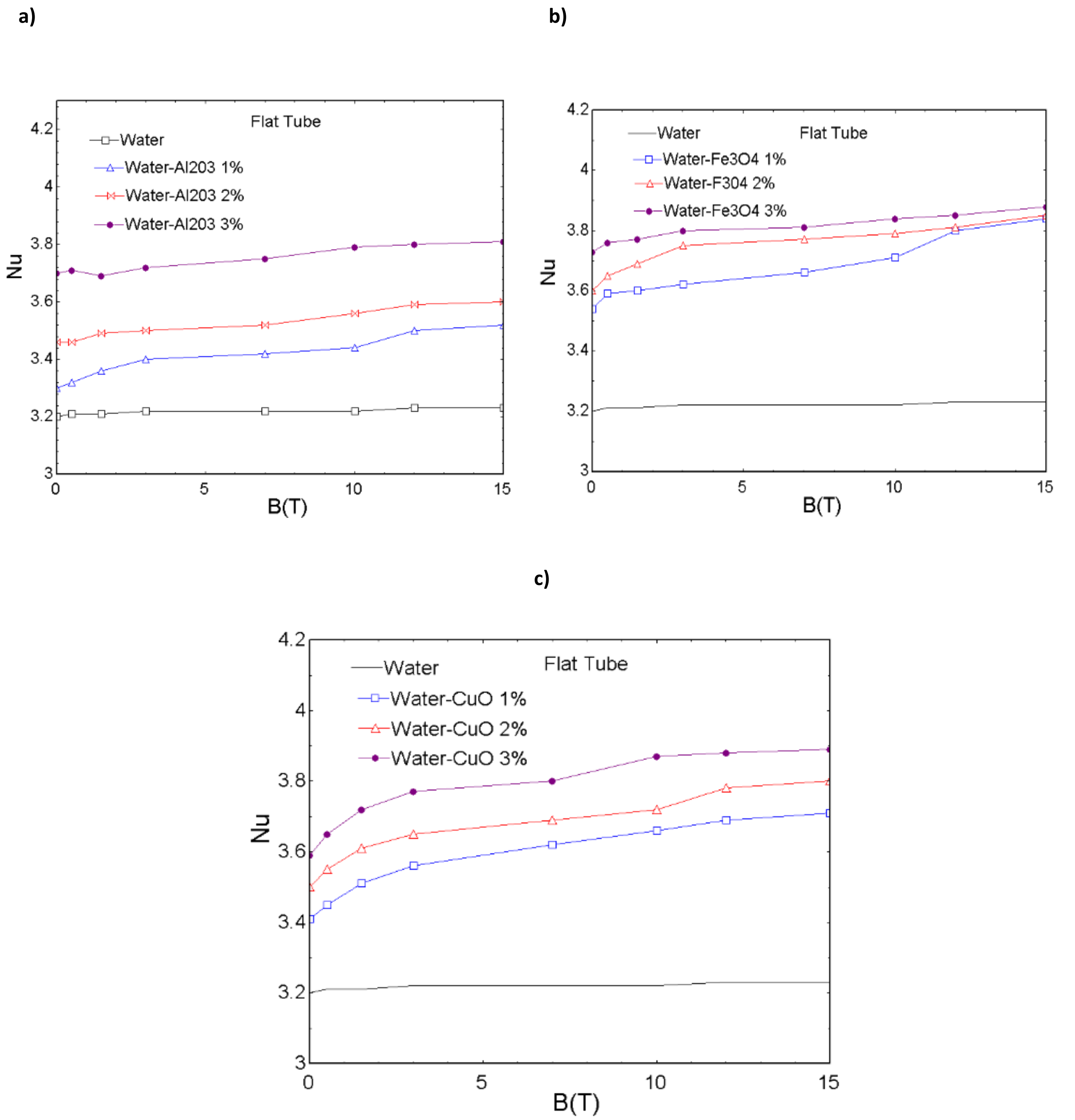


Fig.5. the effect of magnetic field effect on heat transfer of different particles with different volume fraction at Re=500 **a)** Al2O3 **b)** Fe3O4 **c)** CuO

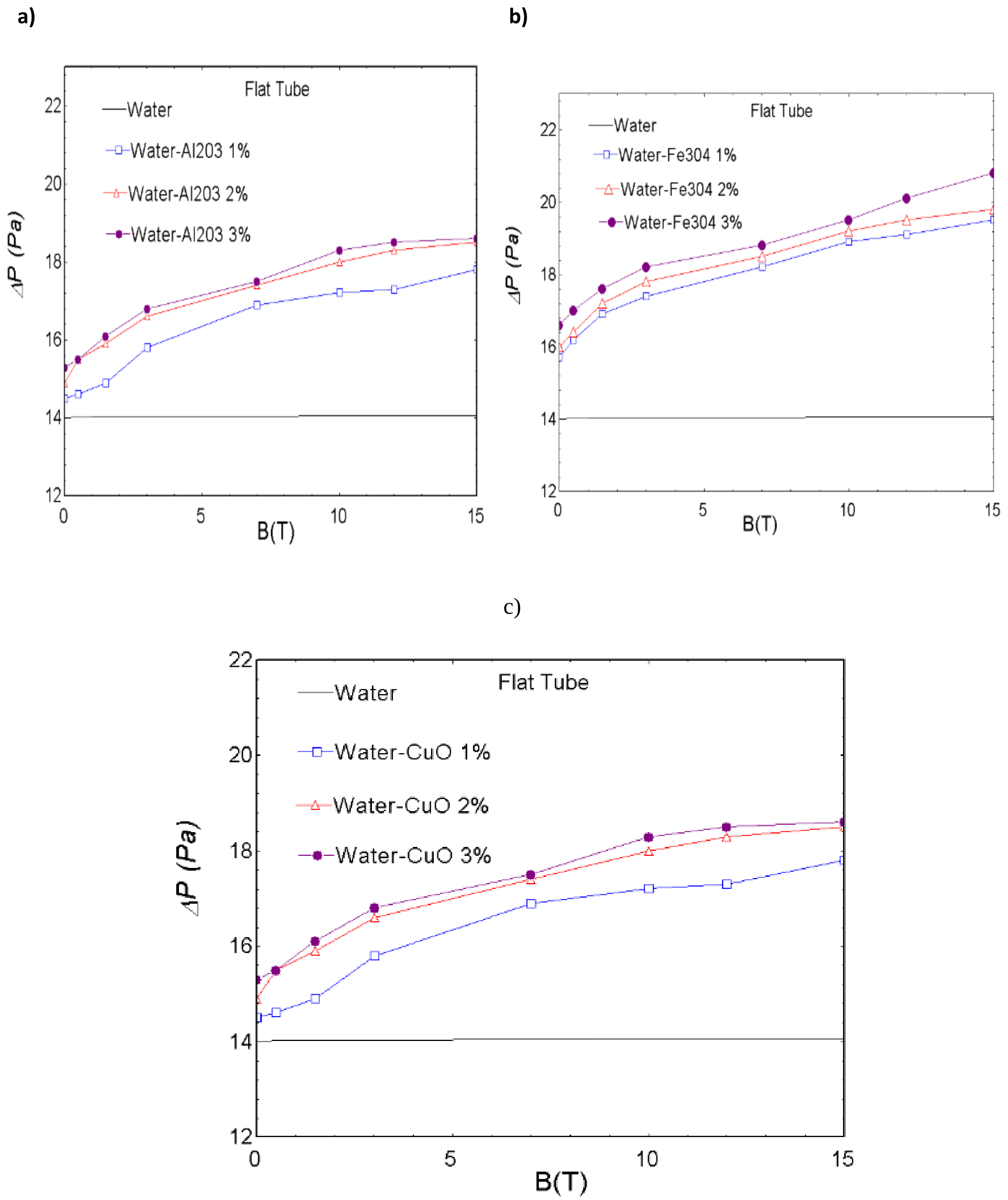


Fig.6. the effect of applying the magnetic field on the pressure drop of different particles with different volume fraction at 500 = Re **a)** Al2O3 **b)** Fe3O4 **c)** CuO

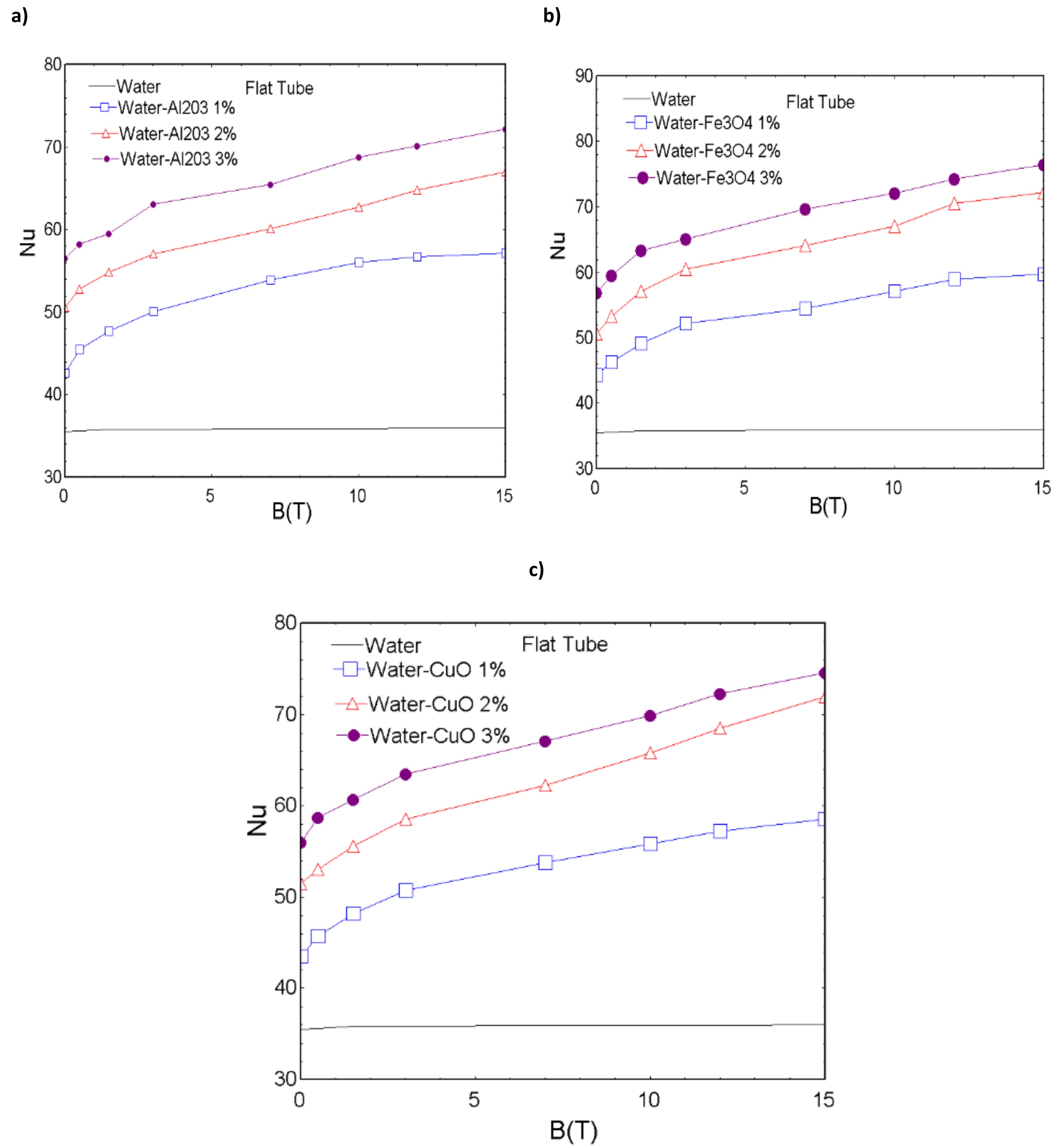


Fig.7. the effect of magnetic field effect on heat transfer of different particles with different volume fraction in Re=10^4 **a)** Al2O3 **b)** Fe3O4 **c)** CuO

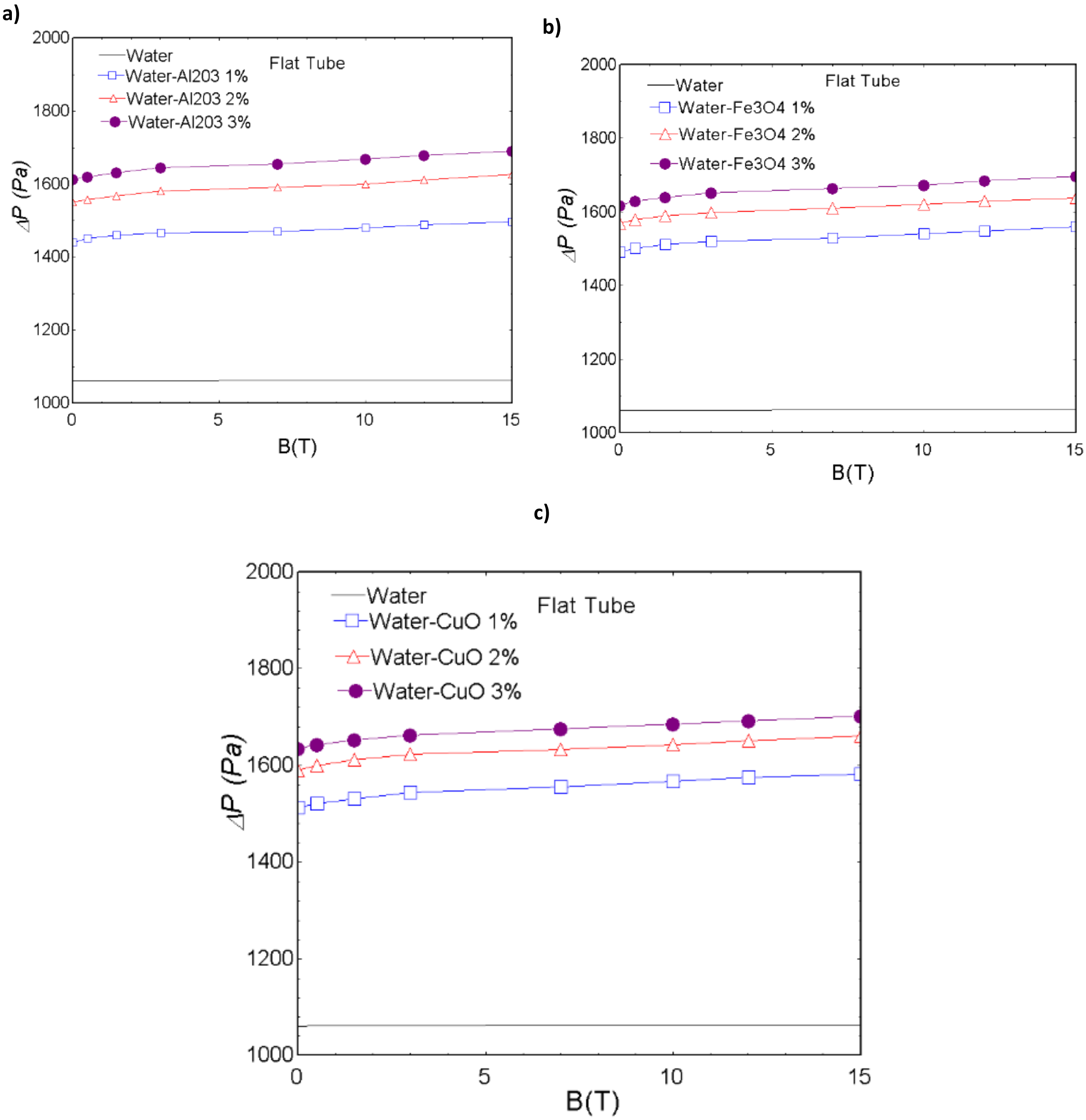


Fig.8, the effect of applying the magnetic field on the pressure drop of different particles with different volume fraction in Re=10^4 **a)** Al2O3 **b)** Fe3O4 **c)** CuO

The results show that the pressure drop and heat transfer coefficient have increased with increasing the magnetic field. The application of the magnetic field is cause of the Lorentz force action on momentum. and in the area near the wall, it causes the velocity and flow of the flow. The higher the field value, the higher the value and the gradient of this change will be near the wall, which affects the pressure drop and increases it. reducing the flow rate causes the fluid inside the bed tube to find more time for heat transfer and the average fluid temperature increases and eventually leads to heat transfer. Fig.8 shows the variation of pressure drop and heat transfer for Al2 O3, Fe3O4, and CuO as nanoparticles with a volume fraction of 3 % in terms of Reynolds number and 10 Tesla's magnetic field. the results show that on average, by applying the magnetic field of 10 Tesla for nano - Al2 O3, Fe3O4, and copper oxide in the laminar and turbulent regime for these nanofluids, heat transfer was changed 11 %, 15 % and 15 % and pressure drop was changed 10 %, 9 % and 9 %, respectively.

a) **b)**

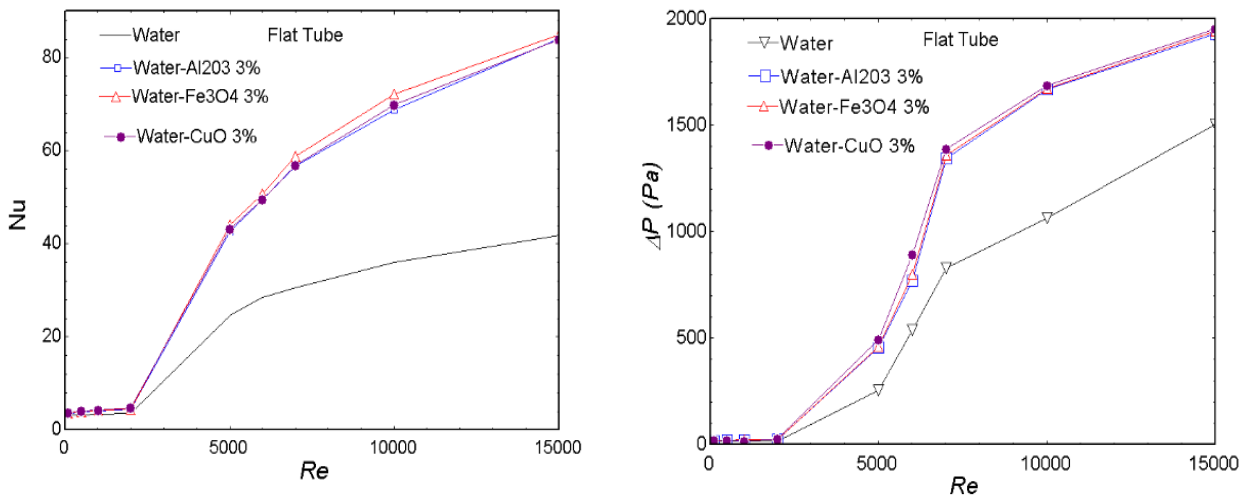


Fig.9. a) Changes of Nusselt number **b)** Pressure drop with different nanoparticles in terms of Reynolds Number with magnetic field of 10 Tesla

The speed and pressure contours for Re= 500 and Re=104 are shown for different fields for 3 % Al2 O3, 3 % Fe3O4 and 3 % copper oxide, respectively, in Figures 4-10, respectively.

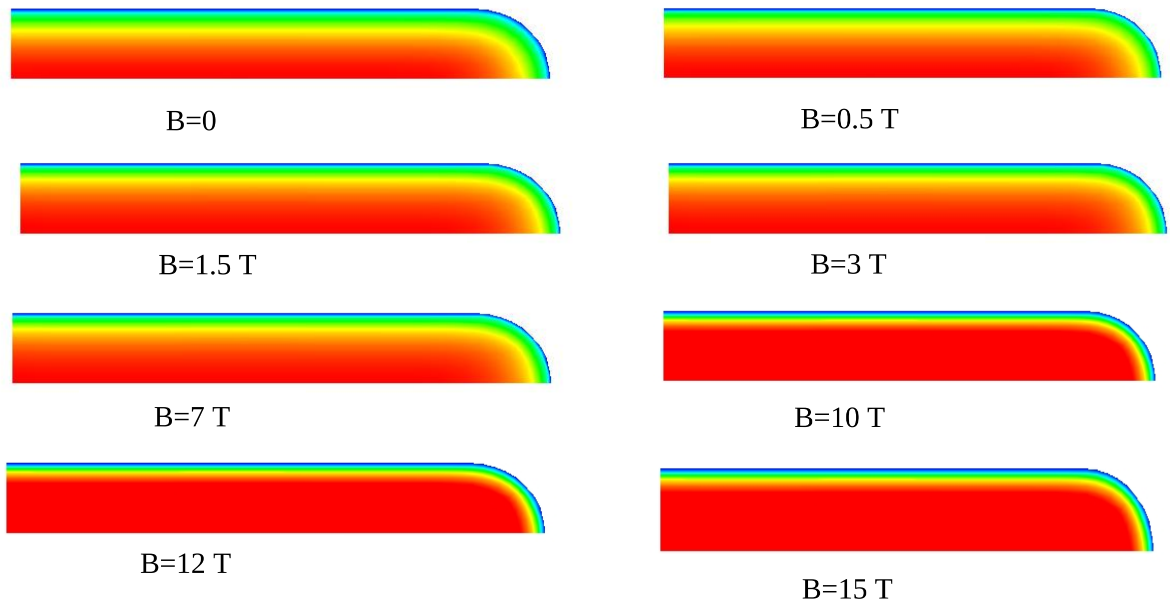


Fig.10. Velocity contour for Re=10^4 in mm250 = L with different fields for Al2O3-3 %

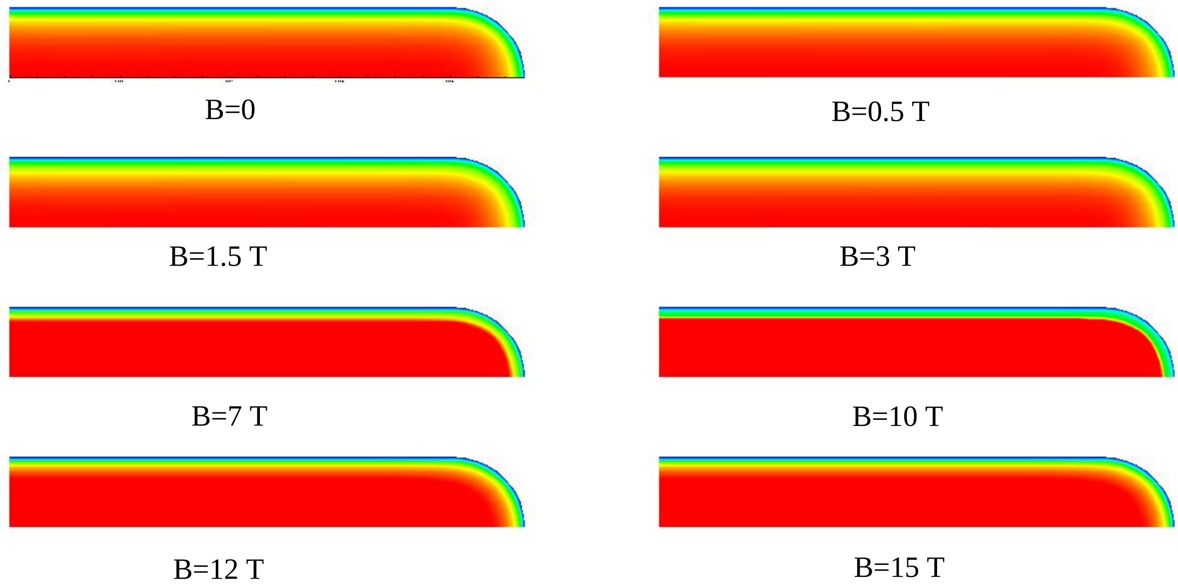


Fig.11. Velocity contour for Re=104 in mm250 = L with different fields for Fe3O4-3 %

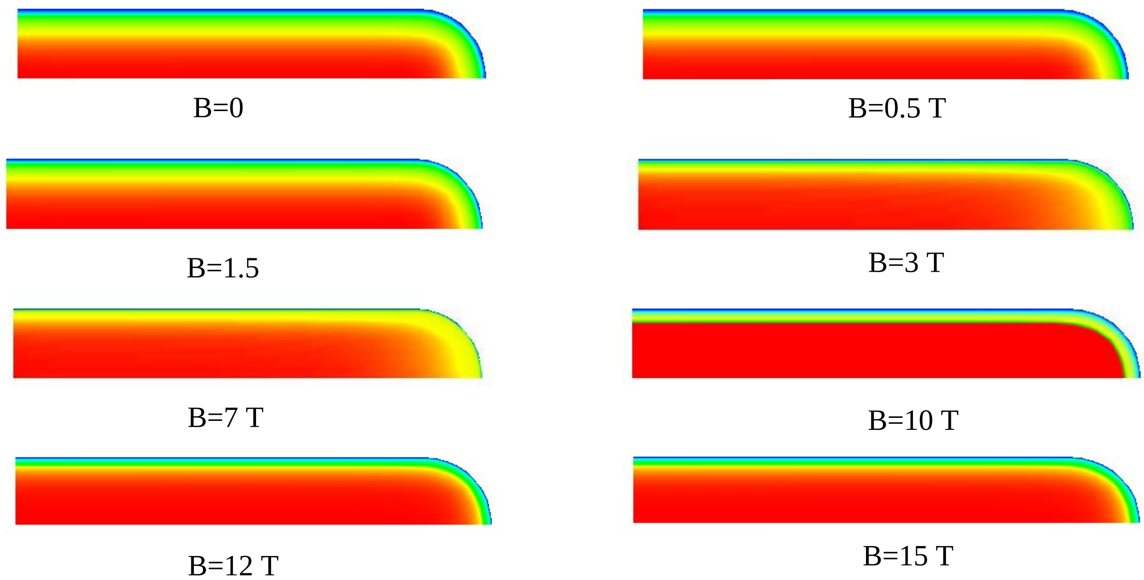


Fig.12. Velocity contour for Re=104 in mm250 = L with different fields for CuO-3 %

Fig.10, fig.11 and fig.12, respectively, showed the velocity contour of the tube in the middle of the tube in volume fraction 3 % for the three nanoparticles under different magnetic fields. As it is clear, the aluminum oxide of iron to two other fluids has a lower rate of velocity in same Reynolds number due to its different thermodynamic properties rather than two other fluids. As it is known from these three forms, the velocity of the magnetic field in the areas close to the magnetic field decreases due to the absorption of magnetic particles near the wall, and in the central areas of the particles with greater freedom of action continue to move and the heat transfer increases. In fact, by increasing the velocity gradient at the center of the tube, the convection heat transfer increases.

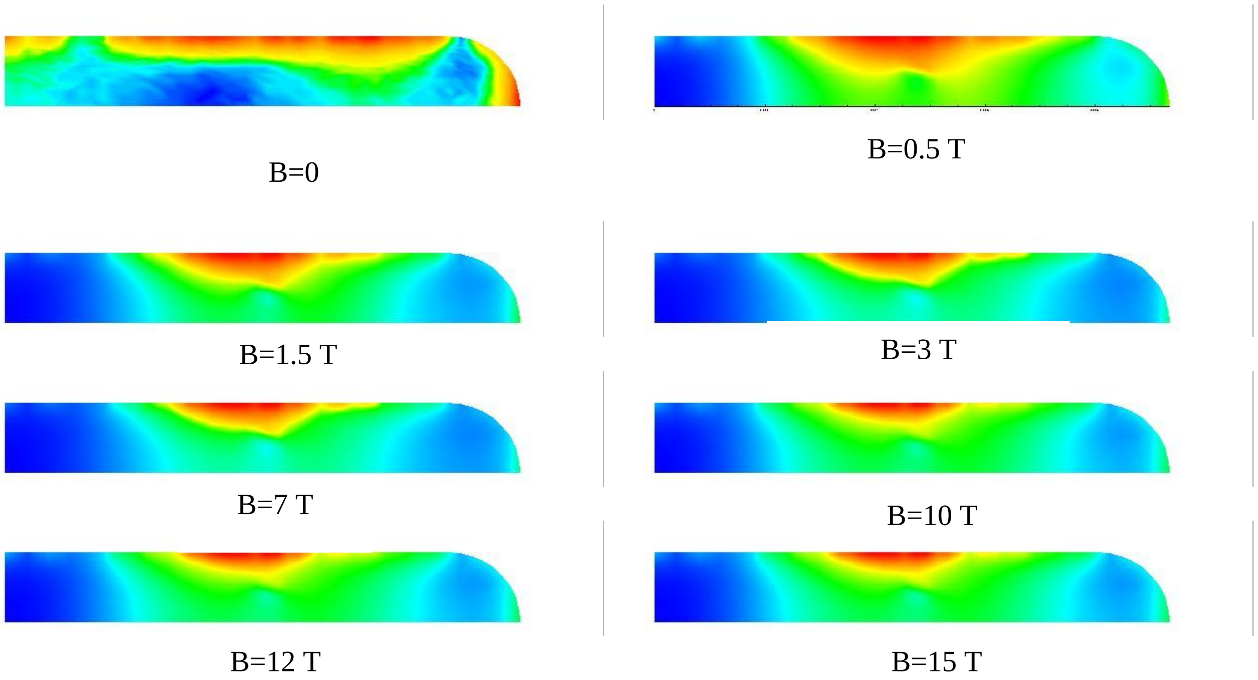


Fig.13. Impact of pressure for Re=104 in mm250 = L with different fields for Al2O3-3 %

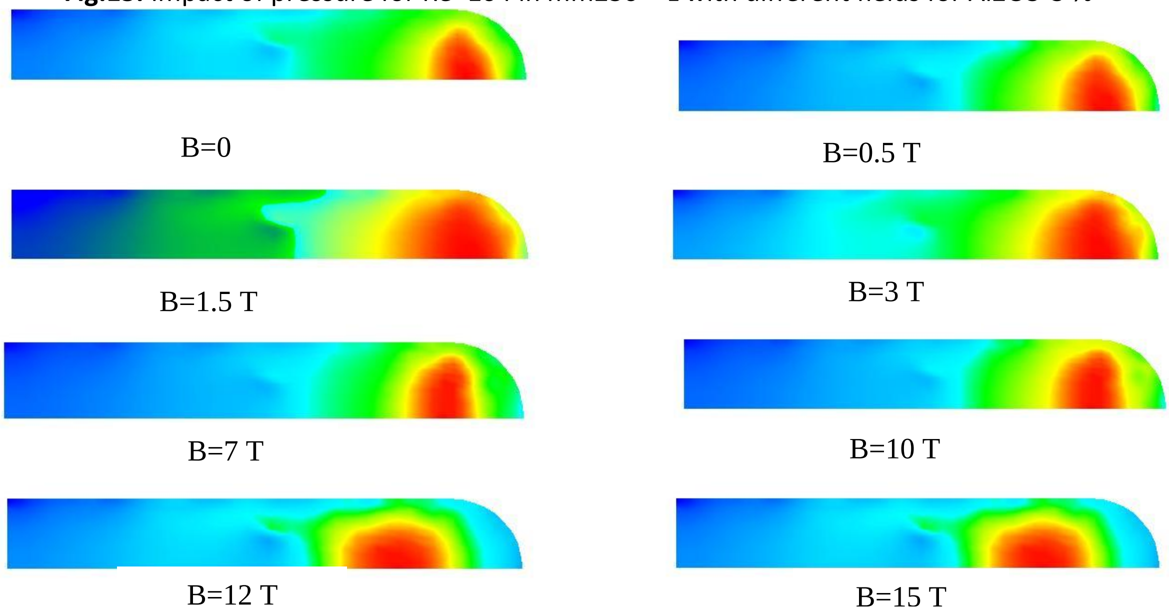


Fig.14. Impact of pressure for Re=104 in mm250 = L with different fields for Fe3O4-3 %

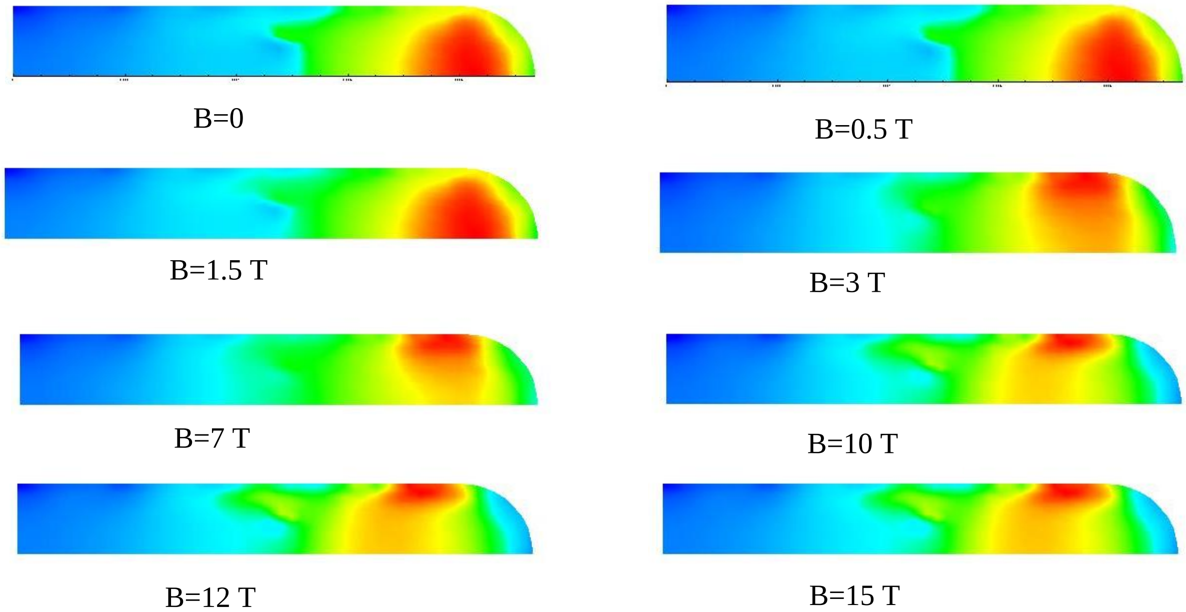


Fig. 15. Impact of pressure for Re=104 in mm250 = L with different fields for CuO-3 %

Figs.13-15 show the pressure contour for a hypothetical paragraph in the middle of the flattened tube, by increasing the supremacy of the magnetic field and increasing the viscosity gradient to the wall, the concentration of the particles near the wall and especially the flattened region increased because of its geometrical feature and the pressure drop has decreased by increasing the magnetic field.

4. Conclusions

In the present study, the effect of magnetic field on temperature field and nanofluid flow in a flat tube has been investigated. The limited volume method is used for simulation. First, forced convective heat transfer and nanofluid pressure drop in Reynolds 100-15000, which includes laminar and turbulent flow, are simulated numerically. By applying magnetic field with different power for different nanoparticles and in Reynolds 15000-100, for different nanoparticles in flat tube, heat transfer and pressure drop have been extracted and the results have been investigated. The results show that by increasing the volume fraction of Al2O3 nanoparticles in flat tube from 1% to 3%, in laminar flow heat transfer 3% and pressure drop. 2% and in turbulent flow heat transfer 11% and pressure drop 3% and nanoparticles. Fe3O4 from 1% to 3% in laminar flow heat transfer 4% and pressure drop 4% and in turbulent flow heat transfer 15% and pressure drop 5% and CuO nanoparticles from 1% to 3% in laminar flow heat transfer 5% and The pressure drop was 4% and in turbulent flow the heat transfer was 17% and the pressure drop was 6% relative to the base fluid (water). By applying a magnetic field, the pressure drops and heat transfer for all nanofluids is increased and has the greatest effect on Fe3O4 nanoparticles. In general, Fe3O4 nanoparticles in field and no-field mode had the greatest effect on heat transfer.

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