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Enhancement of Natural Convection Heat Transfer Using Magnetic Nanofluid in a Square Cavity

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Abstract

Researchers in heat transfer are paying close attention to nanofluids because of their potential as high-performance thermal transport media. In light of natural convection's enormous significance, the addition of nanoparticles significantly enhances the thermophysical properties of the nanofluids compared to the base fluid. In this study, numerical work was used to evaluate the influence of CuO nanoparticles on natural convection with the magnetohydrodynamic (MHD) flow in a square cavity. The hollow's left and right vertical walls were maintained at different temperatures, and the top and bottom walls of the cavity were each insulated. This numerical study applied a horizontal magnetic field with uniform strength. Results were obtained for a variety of Hartmann numbers ranging from 0–300, Rayleigh numbers going from 2.76E+8 to 6.89E+8, and solid volume fractions ranging from 0 to 1.5%. Results showed that the heat transfer coefficient and Nusselt number values decreased with the increase in the values of the Hartmann number, except for the heat transfer coefficients at Ha=100 and 150 were larger than the heat transfer coefficients at Ha= 0. The maximum heat transfer coefficient enhancement was 40.8% at 1.5% volume concentration of CuO nanoparticles, Ra= 6.7E+8 and Ha=100 compared to water at Ha=0. The maximum enhancement of the Nusselt number was found to be 28.5% at a 1.5% volume concentration of CuO nanoparticles Ra= 6.7E+8 and Ha=100 compared to water at Ha=0. At a 1.5% volume concentration of CuO nanoparticles, Ra= 6.7E+8 and Ha=100, the increase in the heat transfer coefficient was 56 %, and the rise in the Nusselt number was 43 % compared to water at Ha=100.

Keywords: Natural convection, Heat Transfer, Magnetic Nanofluids, Square Cavity.

الخلاصة: يولي الباحثون في مجال نقل الحرارة اهتمامًا وثيقًا بالسوائل النانوية نظرًا لإمكانياتها كوسائط نقل حراري عالية الأداء. في ضوء الأهمية الهائلة للحمل الحراري الطبيعي، فإن إضافة الجسيمات النانوية تعزز بشكل كبير الخصائص الفيزيائية الحرارية للسوائل النانوية مقارنةً بالسائل الأساسي. في هذا البحث، اجريت دراسة عددية لتقييم تأثير جزيئات CuO النانوية على الحمل الحراري الطبيعي بتدفق مغناطيسي هيدروديناميكي (MHD) في تجويف مربع. تم الحفاظ على الجدران الرأسية اليمنى واليسرى للجوف في درجات حرارة مختلفة، وتم عزل كل من الجدران العلوية والسفلية للتجويف. استخدمنا في هذه الدراسة العددية مجالًا مغناطيسيًا أفقيًا بقوة موحدة. تم الحصول على النتائج لمجموعة متنوعة من أرقام هارتمان تتراوح من 0-300، وأرقام رايلي تتراوح من 2.76E+8 إلى 6.89E+8، وبتراكيز السوائل النانويه تتراوح من 0 إلى 1.5٪. أظهرت النتائج أن معامل الانتقال الحراري وقيم رقم نسلت تتناقص مع زيادة قيم رقم هارتمان، فيما عدا معامِلات انتقال الحرارة عند Ha = 100 و150 أكبر من معاملات انتقال الحرارة عند Ha = 0. اعلى تحسين في معامل انتقال الحرارة كان 40.8٪ عند تركيز حجمي 1.5٪ من جزيئات CuO النانوية، و Ra = 6.7E + 8 و Ha = 100 مقارنة بالماء عند Ha = 0. وقد وجد أقصى تحسين لرقم Nusselt ليكون 28.5٪ عند تركيز حجم 1.5٪ من جزيئات CuO النانوية عند Ra = 6.7E + 8 و Ha = 100 مقارنة بالماء عند Ha = 0. وقد وجد الزيادة القصوى لمعامل انتقال الحرارة 56٪، ونمو رقم نسلت كان 43٪ عند تركيز حجم 1.5٪ من جسيمات النحاس النانوية CuO عند Ra = 6.7E + 8 و Ha = 100 مقارنة بالماء عند Ha = 100

1. INTRODUCTION

In recent decades, there has been a growing recognition that fluid movements and transport processes caused or influenced by buoyancy are of interest and relevance in a wide range of scientific and technological domains, particularly in engineering and science. This topic is currently being discussed in conferences and journals that cover a wide range of issues, including meteorology, geophysics, astrophysics, nuclear reactor systems, materials processing, solar energy systems, energy storage and conservation, fire control, and the chemical, food, and metallurgical industries, as well as the more traditional fields of fluid and thermal sciences, among others. In order to meet the ever-increasing power requirements, it is imperative that every method of enhancing the efficiency of power generating cycles be explored. It's worth considering the working fluid utilized while improving the power cycle. There should be further research into whether nanofluids can be used in any thermal transport system, not only power generating cycles, due to their potential as a novel heat transfer fluid and their relative simplicity of integration into an existing design.

In recent decades, researchers have looked at using 'micro' or 'Nanosized particles to improve heat dispersion[1]. Solids have superior thermal conductivity properties to liquids. As a result, current scientific technology uses nanometer-sized solid particles, often with a diameter of less than 50 nm. Choi [2] is the first to use the word Nanofluid, which refers to a colloidal mixing of nanoparticles and a base fluid that has been described before. The majority of the studies have demonstrated that metallic particles transmit more heat energy than non-metallic particles when compared to one another.

Pordanjani et al., 2019 [3] investigated the effect of a heat source and its location on natural convection in a C-shaped enclosure saturated with a nanofluid. Different Rayleigh numbers (103-106) and solid volume percentages of the nanofluid were considered (0-0.05). The results are shown with streamlines, isothermal lines, velocity profiles, and local and average Nusselt values. The numerical solution is compared to previously published results and found to be in good agreement. The results show that the highest Nusselt number is achieved with the heat source in the top horizontal cavity at Ra = 103. Therefore, using high Rayleigh numbers (Ra = 10^6) and vertical cavities is recommended. High Rayleigh numbers cause the highest increase when the heat source is in the vertical axis's upper part. Mohebbi et al. 2019[4] used the lattice Boltzmann approach to measure the heat transfer from a nanofluid thermos-gravitational enclosure to a local heater (LBM). The influence of the Rayleigh number (103–106), cavity aspect ratio (0.2–0.6), nanofluid solid volume fraction (0–0.05), heater height and placement, as well as other liquid circulation and heat transfer factors, were studied in this work. The mean Nusselt number climbed as the Rayleigh number and nanoparticle concentration grew. The mean Nusselt number is highest when the heater is on the left border, consistent with earlier studies. (Izadi et al., 2018 [5] studied the natural convection of Cu-water nanofluid within a wavy wall enclosure with a cylindrical heater. The results indicated that raising the solution's temperature reduces homogeneity. Moreover, the average Nusselt number of both porous phases increases with the Brownian parameter but decreases with the thermophoresis factor.

Torki and Etesami, 2020 [6] investigated the natural convection heat transport of SiO2/water nanofluids in a rectangular container at varied concentrations and tilt degrees. The findings demonstrated that nanofluid heat transfer characteristics did not change significantly at low concentrations. However, when the volume % of nanoparticles is more than 0.005, the heat transfer coefficient declines with nanofluid concentration. The Nusselt number was highest at 0° or horizontal and decreased with increasing inclination angle. Roy et al. 2018[7] proposed a model for exploring the spontaneous convection of a nanofluid between two square enclosures. The finite-difference technique is used to solve the resulting equations. The intensity of streamlines rises with the volume of nanoparticles and the Rayleigh number. The Nusselt number increases roughly linearly at the inner and outer cylinders as the nanoparticle volume % increases, yet the Rayleigh number increases exponentially. The strength of the streamlines increases as the internal geometries grow more rectangular, circular, and elliptical.

A magnetic field may impact natural convection in various practical applications, including crystal formation in fluids, metal casting, fusion reactors, and geothermal energy [8]. Consequently, interest in the flow behavior and heat transfer mechanism of enclosures filled with electrically conducting fluids and subjected to a magnetic field has increased [9]–[16]. These investigations agree that the fluid inside the enclosure feels a Lorentz force due to the magnetic effects. This force affects both the buoyant flow field and heat transfer rate.

Mourad et al., 2021 [17] investigated numerical simulations of the natural convective flow and heat transfer in the cold wavy enclosure and the hot elliptic cylindrical object, both cold and hot. Alumina nanoparticles are added to the water to improve heat exchange. A drop in the Nusselt number values of up to 22.22 percent is offered when Ha is changed from 0 to 100.

Dogonchi et al., 2020[13] studied the heat transport in a square enclosure under a magnetic field and nanoparticles using natural convection. Heat transfer rate in the presence of magnetic fields on the inner wall of the annulus increases as the Rayleigh number, nanoparticle volume fraction increases, and decreases as the Hartmann number increases.

Alsabery et al., 2018[18] used the two-phase model of Buongiorno to numerically study the issue of conjugate MHD natural convection of Al2O3-water Nanofluid in a square cavity with a conductive inner block. According to the findings, the heat and mass transfer mechanisms and the flow characteristics within the enclosure are substantially influenced by the magnetic field intensity and the amount of heat generated.

Employing a velocity-vorticity formulation, Reddy and Murugesan, 2017 [11] examined double-diffusive natural convection in a square cavity with an external magnetic field. The results showed that the increase from zero to 30 Ha had reduced Nusselt and Sherwood numbers by around 72 percent and 78 percent, respectively.

Mahmoudi, Mejri, and Omri, 2016[16] have studied the natural convection of a water-Al2O3 nanofluid numerically in two heat sinks vertically and horizontal walls subjected to the magnetic field. The results showed that the heat transfer rate increases as the Hartmann number grows and the Rayleigh number increases. Furthermore, the heat transmission rate rises linearly as the solid volume percentage of nanoparticles increases.

Dimitrienko and Li, 2020[19] investigated the laminar natural convection of a non-Newtonian Carreau fluid numerically in a square cavity with a uniform magnetic field. The new numerical technique has investigated the Rayleigh number (104 and 105) and Prandtl number (Pr=0.065). The findings indicated that the heat transfer rate rises as the Hartmann number lowers and the Rayleigh number increases.

Mehran et al., 2017[20] numerically explored the topic of unsteady natural convection inside a square cavity separated by a flexible impermeable membrane. At varying temperatures, the horizontal walls of the cavity are maintained adiabatic, while the vertical walls are kept isothermal. A homogeneous magnetic field with varying orientations is applied to the cavity. The Hartmann number affects the form of the membrane and heat transport inside the hollow. The magnetic field orientation angle also has a substantial impact in the form of the membrane and heat transport inside the cavity.

Liao and Li, 2021[21] quantitatively examined natural convection inside a square cavity under an angled magnetic field, emphasizing the heat transfer transition. The findings demonstrate that increasing the magnetic field strength alters streamlines and isotherms significantly. The average Nusselt number (Nu_{mean}) and the maximum streamline dropped with growing magnetic fields.

It was shown that numerical studies had a problem obtaining correct findings since most of these research failed to account for the change in temperature on fluid characteristics. Changing the fluid's thermal and physical qualities may significantly alter the findings. Moreover, earlier research has mainly studied Nanofluid as a single-phase fluid. Because this theory relies on a nanofluid, the magnetic flux will ultimately deal with the fluid, causing inaccurate findings. In the current study, all these gaps observed in previous studies were considered and addressed by selecting a UDE file that deals with changing fluid properties. The fluid has also been studied on the basis that it is two-phase.

2. PROBLEM DESCRIPTION

The scenario of a two-dimensional, steady, and incompressible natural convection flow in a square cavity filled with a water-CuO nanofluid was considered in this inquiry. Figure (1) displays a schematic depiction of the issue under investigation and the problem's boundary conditions. In the case of the cavity's two parallel walls AB and CD, the wall BC is kept at a low-temperature Tc (cold wall), while the wall DA is maintained at a high-temperature Th (hot wall) (hot wall). A uniformly strong magnetic field B0 is applied to the fluid in a direction perpendicular to the flow direction, with the intensity of the field remaining constant during the experiment. The gravitational force is indicated by the symbol g, which acted vertically downward.

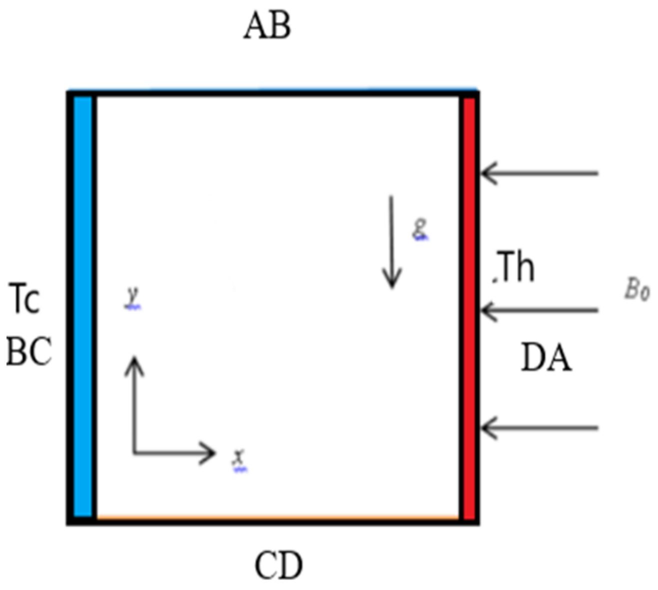


Figure 1. Schematic diagram of the model

3. GOVERNING EQUATIONS OF MHD

The classical fluid dynamics equations, such as mass continuity, Navier-Stokes momentum, and energy equations, may be changed to incorporate magnetic effects when modeling the MHD flow.

Continuity equation

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0, \tag{1}$$

x-momentum equation

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial x}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+v\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+g\beta(T-T_c)\,sin\emptyset, \tag{2}$$

y- momentum equation

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial x}=-\frac{1}{\rho}\frac{\partial p}{\partial x}+v\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)+g\beta(T-T_c)\,sin\emptyset, \tag{3}$$

Energy equation

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\propto\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right) \tag{4}$$

Kinematic fluid viscosity is represented by v, fluid density by ρ, thermal diffusivity by α, expansion coefficient by β, the temperature of the fluid by T, cold right wall temperature by Tc, acceleration by gravity by g, fluid pressure by p, and fluid velocity components by u, v are all represented here.

Velocity and temperature fields on either hollow wall have dimensional boundary conditions.

On the horizontal walls AB and CD:

$$\mathrm{u(x,y)=o,v(x,y)=0,}\frac{\partial T}{\partial n}=0 \tag{5}$$

On the right wall BC:

$$\mathrm{u(x,y)=o,v(x,y)=0,T}=T_c \tag{6}$$

On the left wall DA:

$$\mathrm{u(x,y)=o,v(x,y)=0,T}=T_h \tag{7}$$

Where n denotes the average vector.

3.1 Dimensionless from of the governing equations

Utilizing the following dimensionless parameters, the dimensionless version of Eqs. (8) - (9) may be derived.

$$\mathrm{X}=\frac{x}{L},\quad Y=\frac{y}{L},\quad U=\frac{vL}{\alpha},\quad V=\frac{vL}{\alpha},\quad P=\frac{pL^2}{p\alpha^2},\quad \theta=\frac{T-T_c}{T_h-T_c} \tag{8}$$

$$Pr=\frac{v}{\alpha},\qquad Ra=\frac{g\beta(T_h-T_c)L^3Pr}{v^2} \tag{9}$$

The above parameters lead to the following dimensionless governing equations.

$$\frac{\partial U}{\partial X}+\frac{\partial V}{\partial Y}=0, \tag{10}$$

$$U\frac{\partial U}{\partial X}+V\frac{\partial V}{\partial Y}=-\frac{\partial P}{\partial X}+\mathrm{Pr}\left(\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2}\right)+Ra\,\mathrm{Pr}\,\theta\sin\emptyset, \tag{11}$$

$$U\frac{\partial U}{\partial X}+V\frac{\partial V}{\partial Y}=-\frac{\partial P}{\partial Y}+\mathrm{Pr}\left(\frac{\partial^2 V}{\partial X^2}+\frac{\partial^2 V}{\partial Y^2}\right)+Ra\,\mathrm{Pr}\,\theta\cos\emptyset, \tag{12}$$

$$U\frac{\partial \theta}{\partial X}+V\frac{\partial \theta}{\partial Y}=\frac{\partial^2 \theta}{\partial X^2}+\frac{\partial^2 \theta}{\partial X^2} \tag{13}$$

The dimensionless boundary conditions on each wall of the cavity for velocity and temperature fields are given by

• Temperature is adiabatic along the horizontal walls:

$$U(X,Y)=0,\qquad V(X,Y)=0,\qquad \frac{\partial\theta}{\partial n}=0 \tag{14}$$

• Wall BC is maintained at a cold temperature:

$$U(X,Y)=0,\qquad V(X,Y)=0,\qquad \theta=0 \tag{15}$$

• Wall DA is maintained at a hot temperature:

$$U(X,Y)=0,\qquad V(X,Y)=0,\qquad \theta=1 \tag{16}$$

The present pilot investigation was conducted in a small room model. The roof and all of the room's walls are composed of sandwich panel material with a thickness of 5 cm and a thermal conductivity of (0.034W/m K), while the floor is 17 mm thick wood. The room's dimensions are (2 m long, 2 m wide, and 2.4 m high) and all of its walls are in close contact with the environment. In the southwest wall, an opening of dimensions (1 m in height and 0.3 m in width) was made in Figure 1.

4 PARAMETRIC BASE MESH STUDY

An ANSYS Fluent 21 r1 computer software was used to gather data on the base mesh quality. Table 1 shows the parameters for the parametric base mesh research. A study of the parametric base mesh indicated that the best models for the analyses are those with the smallest mesh sizes for the cavity. When the CPU time, the smaller the mesh size is smaller. Therefore, the accuracy of the findings and the CPU time required for this investigation depend on the optimized mesh's quality and size. Analyzing the issue and comparing the findings would have allowed us to determine the accuracy of the results and the amount of CPU time required. Different mesh-sized models without magnetic effects have been studied in this regard. Due to the findings, researchers examined the local flow velocity profiles and determined the optimal analytical mesh size. The physical parameters of Liquidmetal and the boundary conditions of flow models must be determined in order to analyze the base mesh.

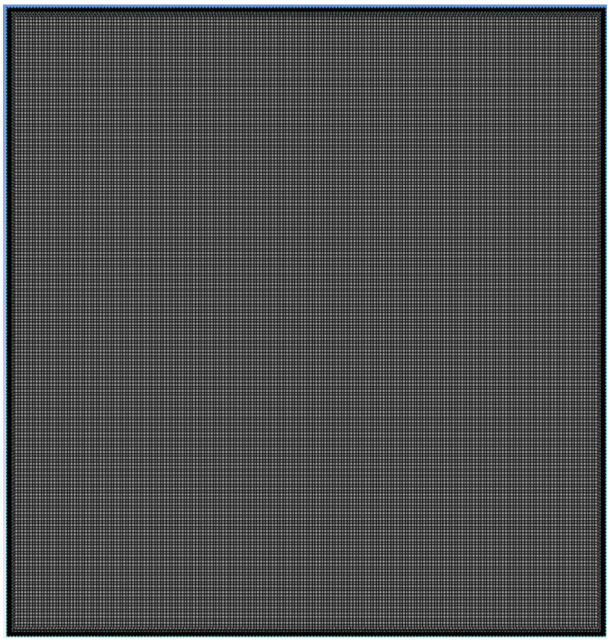


Figure 2. Mesh models

Table 1. lists the mesh quality evaluation criteria and quality scale values.

Model	Mesh size	Aspect ratio	Skewness	Orthogonal quality	Number of cells	Number of nodes
Square cavity	0.3 mm	1	0.5	0.70711	124916	125585

4.1 Grid independence test

Several different grid sizes were tested to confirm the correctness and validity of the solution scheme. There are four distinct grid sizes being tested: 0.5, 0.4 0.3 and 0.2 mm. There is no difference in the results of the three finest grids, and there is no difference in the relative error between the third and fourth grid size (0.1 %). As a result, as indicated in Table 3.2, a grid size of 0.3mm is used in this investigation. It should be noted that the finest grid (third grid) is examined to ensure no change in the average Nusselt number throughout the testing process. The computations were carried out on aP2–4GH and RAM 16Gb, with CPU times averaging around 30 min for each scenario.

Table 2. Grid independence test for turbulent flow regime.

Grid size	NuavgRelative	error (%)
0.5	25.21	0
0.4	25.86	2.5%
0.3	26.477	2.3%
0.2	26.51	0.1%

5 EFFECTIVE THERMOPHYSICAL PROPERTIES OF THE NANOFLUIDS

The dynamic viscosity was studied by Corcione [22], who created an empirical correlation for it based on a vast quantity of experimental data from the literature. Nanoparticles with diameters ranging from 25 were included in the database and suspended in base fluids. With temperature ranges ranging from 293 K to 333 K, , nanoparticles concentrations were ranging from 0.001 percent to 1.5 percent were used in the experiments. Therefore, it is possible to write it as follows:

$$\frac{\mu_{nF}}{\mu_F} = \frac{1}{1 - 34.87(\frac{d_p}{d_F})^{-0.3}\emptyset^{1.03}} \tag{17}$$

where μnf is the effective dynamic viscosity of the nanofluid, μf is the dynamic viscosity of the base fluid, and df is the equivalent diameter of the base fluid. The molecule is given by:

$$d_F = 0.1\left[\frac{6M}{N\pi p_F}\right]^{1/3} \tag{18}$$

Where M is the molecular weight, N is the Avogadro number, which is is the number of atoms, molecules, or other objects that makes up one mole of a substance, and f is the base fluid mass density approximated at 293 K. There is a standard variation of 1.84 percent in the preceding effective viscosity equation.

5.1 Effective thermal conductivity

By using the correlation reported in the work of Koo and Kleinstreuer (2004, 2005) and further improved by Vajjha and Das (2009, Vajjha et al.), the effective thermal conductivities of nanofluids may be determined (2010a; 2010b). Static and Brownian motion are two separate words correlated with another one in this correlation. Nanoparticle volume percentage, nanoparticle density, base fluid heat capacity, nanoparticle size, and nanofluid temperature are included in the second term. Eq. (19) – Thermal conductivity correlation (22).

$$k_{nF} = k_{static} + k_{Brownian} \tag{19}$$

The effective density of the Nanofluid is given by Pack and Cho (1998)

$$\rho_{nF} = \emptyset\rho_P + (1-\emptyset)\rho_F \tag{20}$$

$$f(T,\emptyset) = (0.028217\emptyset + 3.917\times10^{-3}\left(\frac{T}{T_o}\right) + (-3.0669\times10^{-2}\emptyset - 3.91123\times10^{-3}) \tag{21}$$

Where ρ_p and ρ_f are the densities of the nanoparticles and the base fluid, respectively. The effective specific heat at a constant pressure of the nanofluid (c_p)nf is computed using the following equation Khanafar et al. (2003)

$$C_{p,nF} = \frac{(1-\emptyset)\left(\rho C_p\right)_F + \emptyset\left(\rho C_p\right)_{,p}}{(1-\emptyset)\rho F + \emptyset\rho_p} \tag{22}$$

6 RESULTS AND DISCUSSIONS

Finite volume-based computational investigation of natural convection was carried out on a differentially heated cubical enclosure filled with water and CuO-water nanofluid and subjected to an external magnetic field. The buoyancy forces created by the differential heating of the two side walls and the Lorentz forces generated by the external magnetic field impacted the flow inside the cavity.

The Prandtl number is set to 6.5 for the sake of this investigation. The Rayleigh number (Ra), Hartmann number (Ha), and solid volume fraction (φ) are all assumed to be within the following ranges: 2.76E+8 ≤Ra ≤ 6.89E+8 and 100≤Ha ≤300. The study showed and analyzed the influence of Hartmann number on streamlines and isotherms contour; the effect of average Nusselt number on Hartmann number; the impact of magnetic field on heat transfer performance; and a comparison of various nanofluids. In this numerical study, the change in water and Nanofluid's thermal and physical properties was taken into account by constructing the UDF file in the C++ language. This choice was based on the fact that natural heat transfer convection is highly dependent on the change of these properties.

6.1 Effect of Hartmaan number on the streamlines and isotherms

The magneto-convection in the square enclosure is investigated by considering the temperature dependence of the thermal properties of the Cuo-water Nanofluid in the square enclosure. A wide variety of parameters, including the Rayleigh number (2.76E+8 ≤Ra≤6.89E+8), the Hartman number (100 ≤ Ha ≤ 300), and the volume percent of CuO nanoparticles, are taken into consideration in the calculations (1.5 %). The streamlines contour and velocity and isotherms contour are shown in Figures (3). The streamline contour shows two primary transfer modes for various Rayleigh numbers, as shown in the Figure below. In reality, the conduction regime predominates at low Rayleigh numbers, with horizontal isotherms and little clockwise circulation in the cavity. In addition, we see that the circulation intensity rises with increasing Rayleigh number and decreases with increasing Hartmann number.

Since these two parameters in the source term of the Momentum conservation equation have the opposite sign, they have the opposite influence on the flow regime. Observe that the cell approaches the hot wall from the cavity bottom and leaves the cavity top at Rayleigh number Ra $=10^5$ (i.e., the flow cell grows stronger) when the Rayleigh number is Ra = 10^5. Furthermore, convection fluxes become weaker with higher Hartmann numbers because the vortex's velocity and intensity become weak, indicating that the conduction mode is more prevalent.

One of the most critical challenges not considered in numerical studies is the fluid's properties change when the temperature changes. Nanofluid is also often studied as a single-phase fluid. This change in the fluid's thermal and physical properties, considering that the fluid is a two-phase fluid, significantly impacts the validity of the results.

To some level, the magnetic flux can attract the nanoparticles to the walls, which means that the nanoparticles can absorb more heat from the hot wall and vice versa and can quickly release heat to the cold wall, depending on the quantity of nanoparticles suspended in the base fluid. In other words, the quantity of suspended nanoparticles in the base fluid and the temperature differential between the surfaces both play a significant role in deciding whether or not there is an advantage of exposing the fluid to magnetic flux to promote heat transfer.

As a result of this research, it was discovered that the heat transfer rate is primarily determined by the fluid's velocity, which is regulated by the concentration of nanoparticles suspended in the fluid and its temperature to the magnetic flux. As a result, if the highest rate of nanofluid velocity is achieved at a given concentration and temperature, it is possible to obtain a specific magnetic flux that does not significantly restrict the flow velocity of the fluid; in this instance, heat transmission may increase due to the reasons stated above.

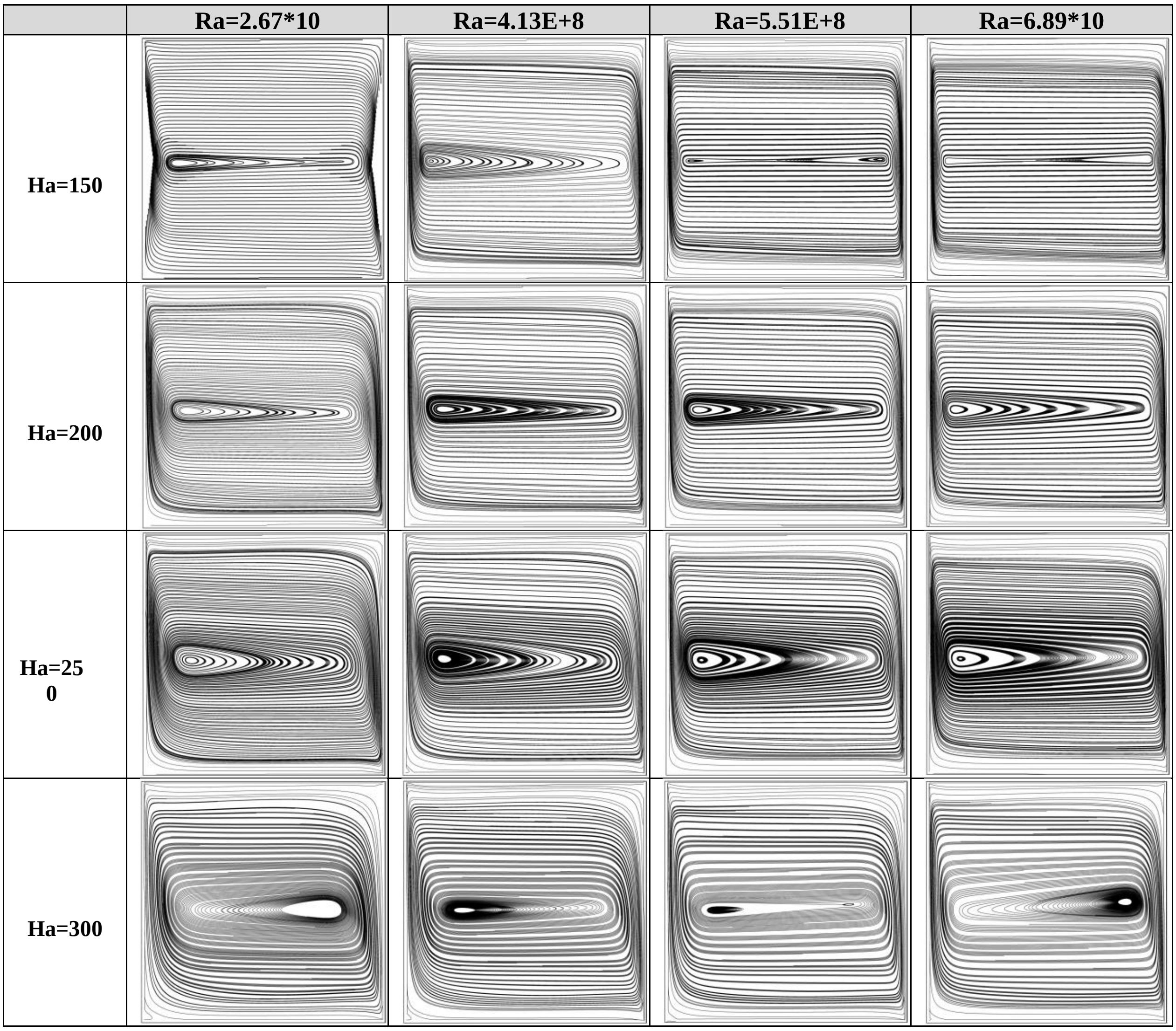
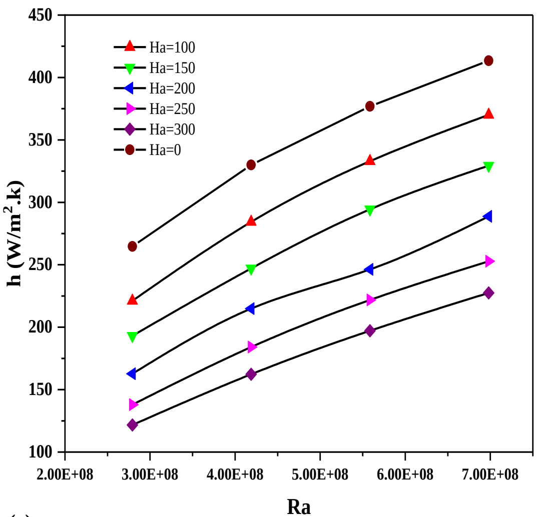


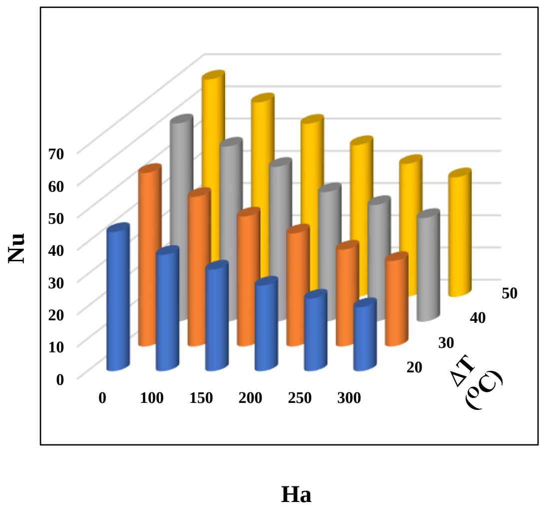
Figure 3. Effect of Ha and Ra on the Streamlines and Isotherms

6.2 Effect of nanoparticles concentration on heat transfer coefficient

The impact of adding nanoparticles of CuO to water on the heat transfer coefficient when both the magnetic flux and the temperature differential on the cube's walls are varied is investigated in this research section. Nanoparticle concentrations in water ranged from 0.1% to 1.5%, Ha=100 to 300, and Ra=2.76E+8to6.89E+8. The effect of the Nanofluid on the heat transfer rate has been compared with water. The heat transfer rate generally increased when the Rayleigh number increased, while the heat transfer rate decreased as the Hartmann number increased. In addition, previous studies have shown that adding nanoparticles to conventional fluids can increase heat transfer due to increased thermal conductivity. So the study sought to take advantage of these investigations to reach a point through which it is possible to increase the heat transfer rate in the free natural convection with magnetic flux. Figure 4 shows the state of the fluid without the addition of nanomaterials and the effect of the change of magnetic flux and temperature difference on the surfaces of the cube's wall. Note that the heat transfer coefficient increases with the increase of Rayleigh number while decreasing in heat transfer coefficient with the increase of Hartmann number due to the increase in the velocity of flow of the fluid with the increase of Rayleigh numbers and thus the maximum absorption of heat while the increase of Hartmann numbers inhibits the movement of the fluid and reduces the heat transfer coefficient. In Figure (4), a 0.5% concentration of nanomaterials was added to the water. Numerical results showed that the heat transfer coefficient increased compared to water due to its higher thermal conductivity.

In Figure (4), the heat transfer coefficient may also improve when the concentration of nanomaterials increases to 0.005. But the heat transfer coefficient also increased with the magnetic flux at Hartmann= 100 compared to water. Although the cube is exposed to magnetic flux (Ha=100) at this concentration, there is an increase in the heat transfer coefficient. In contrast, there was no improvement in Hartmann numbers above 100. This can be explained by the fact that the heat transfer coefficient increased with Ha=100 to the fact that this magnetic flux did not significantly inhibit the movement of the fluid but attracted nanoparticles to the walls, contributing to the absorption of higher heat from the hot wall. There was no improvement in the heat transfer coefficient at Hartmann values above 100 because the magnetic flux inhibited the movement of the fluid. Figure (4) shows that the heat transfer coefficient has also increased with water. Numerical results show that the coefficient of heat transfer has grown with the increase of Hartmann numbers to the limit of 150 as a result of the increase in thermal conductivity of the fluid with the increase in the concentration of nanomaterials and the increase in Hartmann numbers to attract nanoparticles towards the walls without a decrease in their





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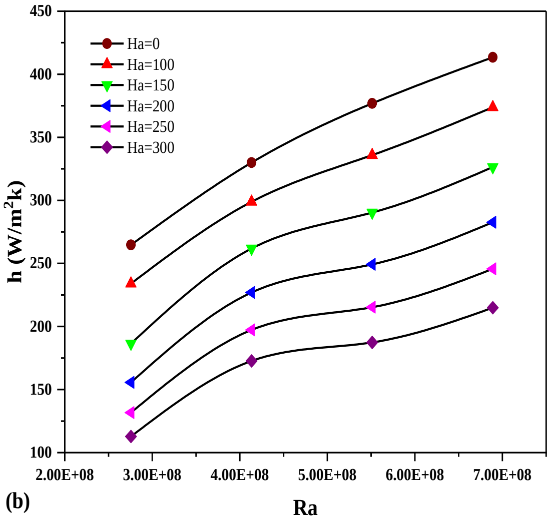
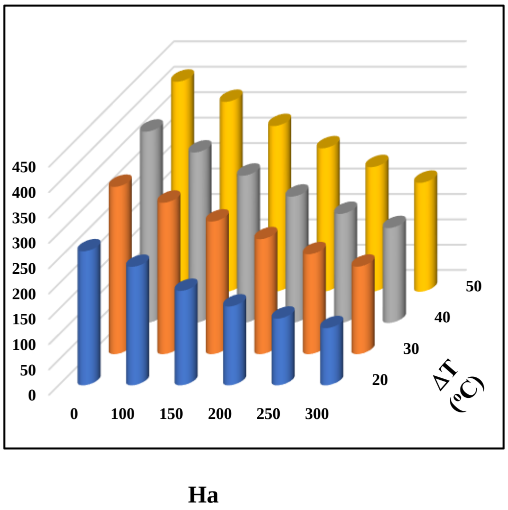
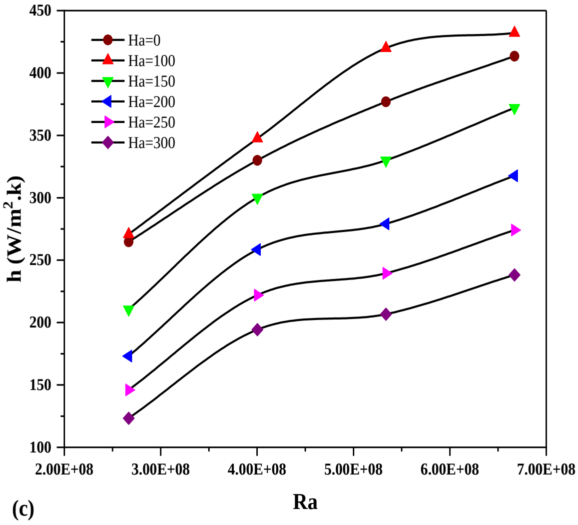
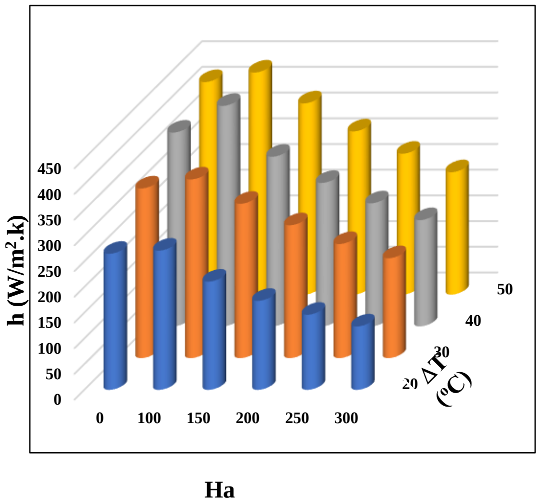

Ha=0
Ha=100
Ha=150
Ha=200
Ha=250
Ha=300
h (W/m^{2}k)
Ra

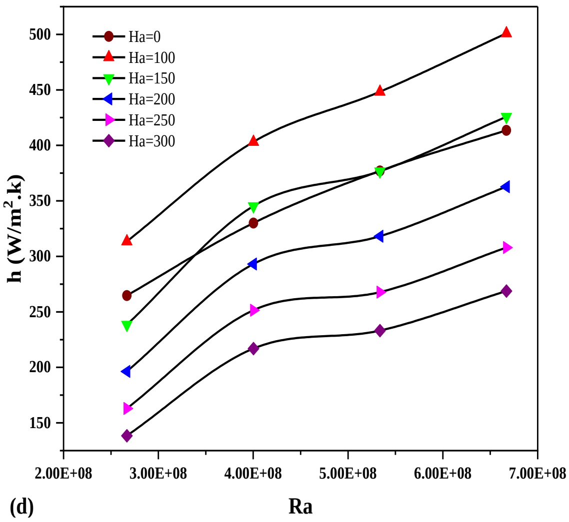

h (W/m^2.k)
ΔT (^{o}C)
Ha

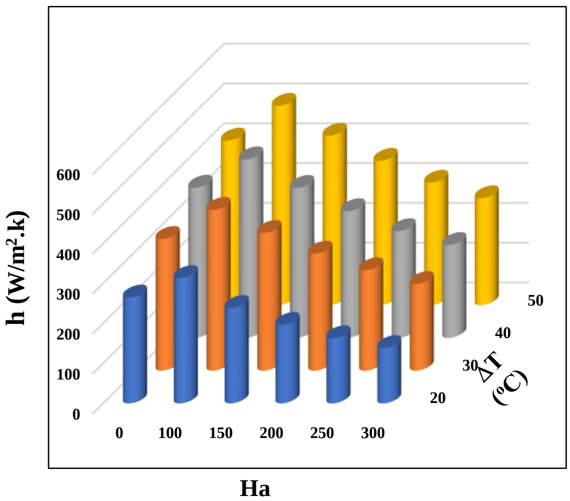
(b)


Ha=0
Ha=100
Ha=150
Ha=200
Ha=250
Ha=300
h (W/m^2.k)
Ra


h (W/m^2.k)
ΔT (^{o}C)
Ha

(c)


Ha=0
Ha=100
Ha=150
Ha=200
Ha=250
Ha=300
h (W/m^2.k)
Ra


h (W/m^2.k)
ΔT (^{o}C)
Ha

(d)

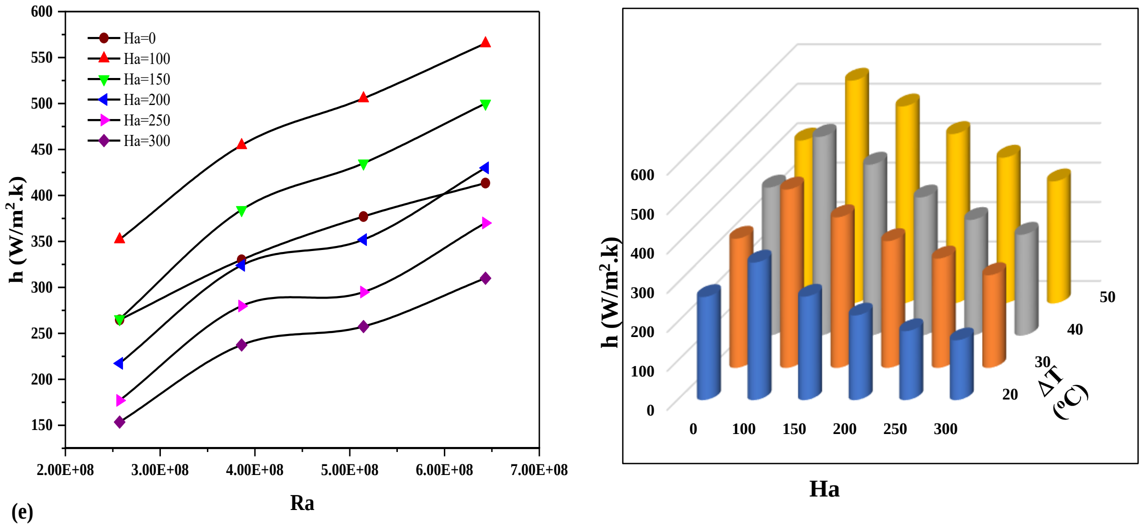
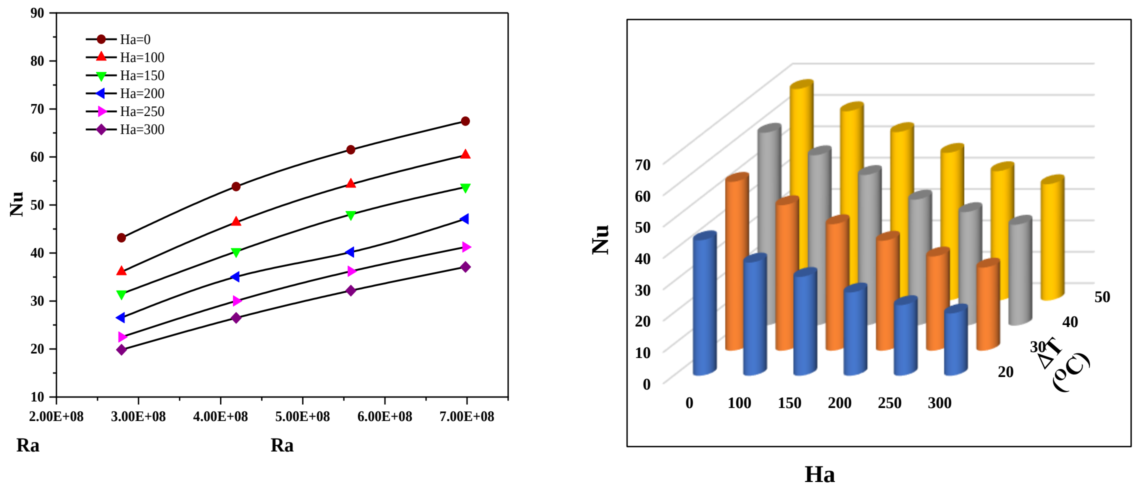
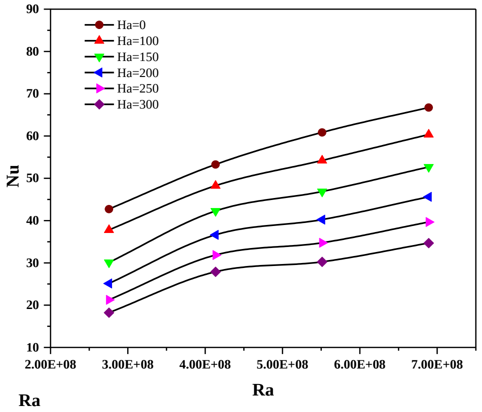


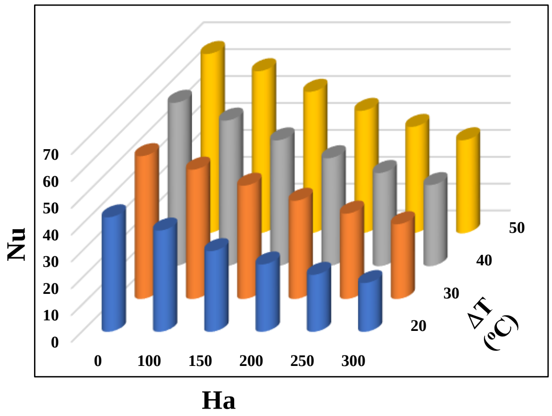
Figure 4. effect on nanoparticles concentration on h

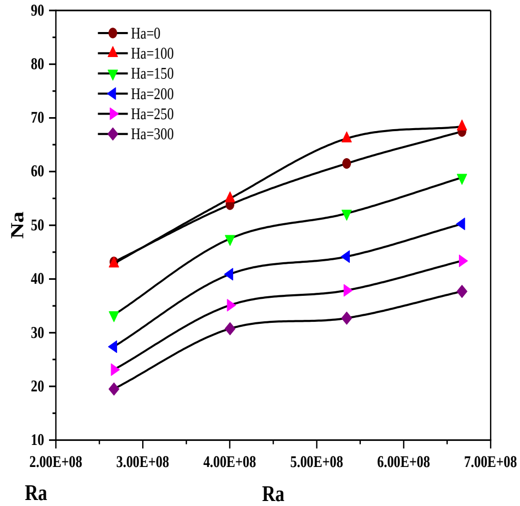
6.3 Effect of Nusselt number

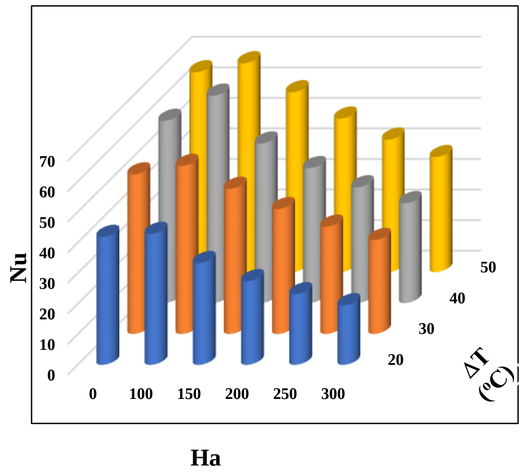
Figure (5) shows the effect of magnetic flux represented by the Hartmann numbers and the temperature of the walls defined by the Rayleigh numbers at different concentrations of CuO nanoparticles suspended in water on the Nusselt number. The results show that the values of the Nusselt numbers change dramatically as both Hartmann numbers and Ra numbers change, as previously described. Figure (5) a,b shows that Nusselt number values increase as Ra numbers increase and decrease as Ha numbers increase at a concentration of 0.1% compared to water. This is because the velocity of the flow of fluid along the walls increases with increasing Ra numbers and, in fact, decreases with increasing Hartmann numbers. In other words, an increase in Hartmann numbers caused the nanofluid to move towards heat transfer by conduction, which leads to a decrease in the rate of Nusselt numbers, which could increase in the thermal conductivity of the fluid. In Figure (5) c, the magnetic flux begins to positively affect the change in the number of Nusselt numbers at 0.005 nanoparticles concentration, where a rise in the number of Nusselt is observed at the Ha=100. Convective heat transfer becomes dominant, as mentioned earlier. The Nusselt numbers values initiated to rise as the concentration of nanomaterials in water and Reilly numbers increase. Nusselt number at Hartmann values=100 and 150 are high. The results showed that the increase in the number of Nusselt numbers is due to its high thermal conductivity as well as the mechanism of attraction of nanoparticles to walls that are exposed to magnetic flux and thus absorb the largest amount of heat from the hot wall.

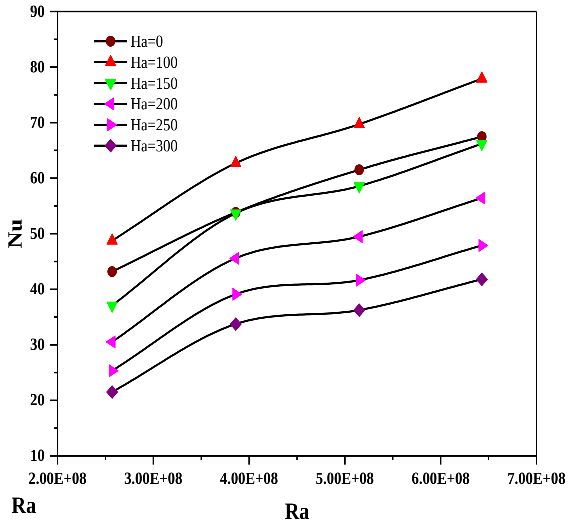


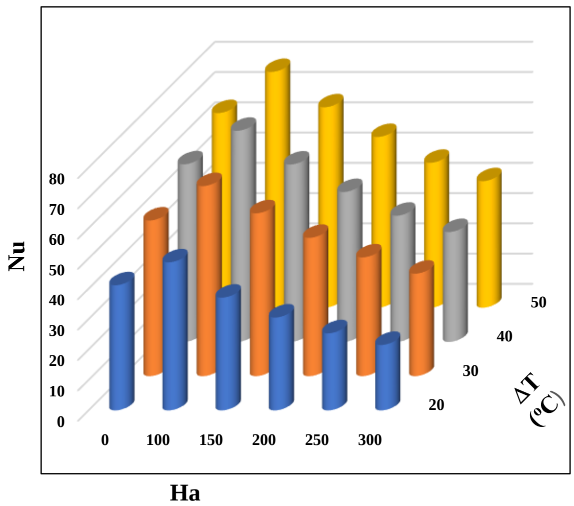

Ha=0
Ha=100
Ha=150
Ha=200
Ha=250
Ha=300
Nu
Ra
Ra


Nu
Ha
ΔT (°C)


Ha=0
Ha=100
Ha=150
Ha=200
Ha=250
Ha=300
Na
Ra
Ra


Nu
Ha
ΔT (°C)


Ha=0
Ha=100
Ha=150
Ha=200
Ha=250
Ha=300
Nu
Ra
Ra


Nu
Ha
ΔT (°C)

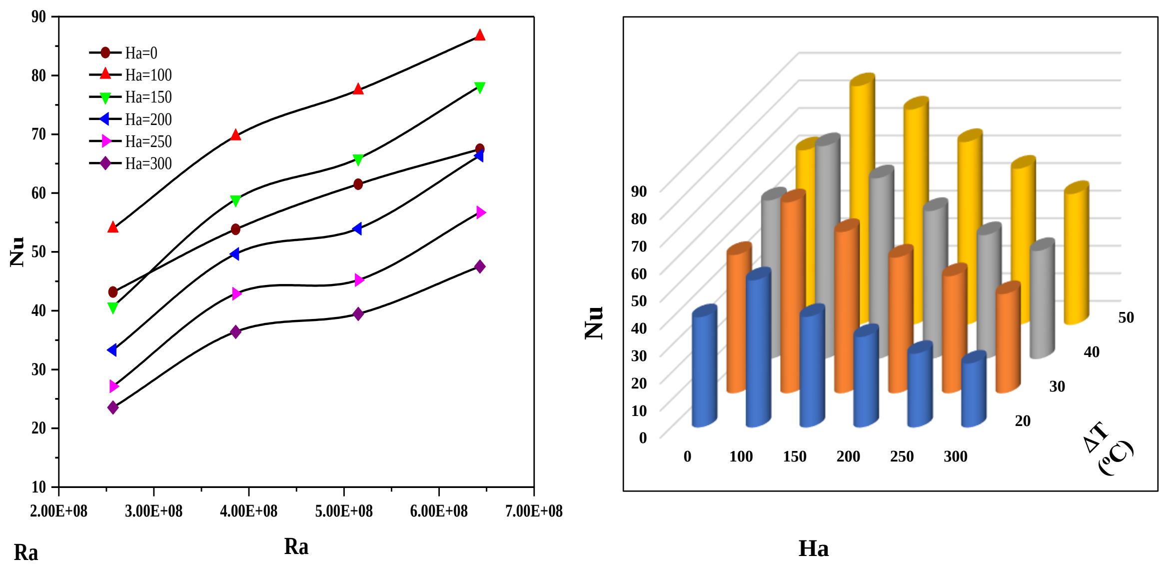
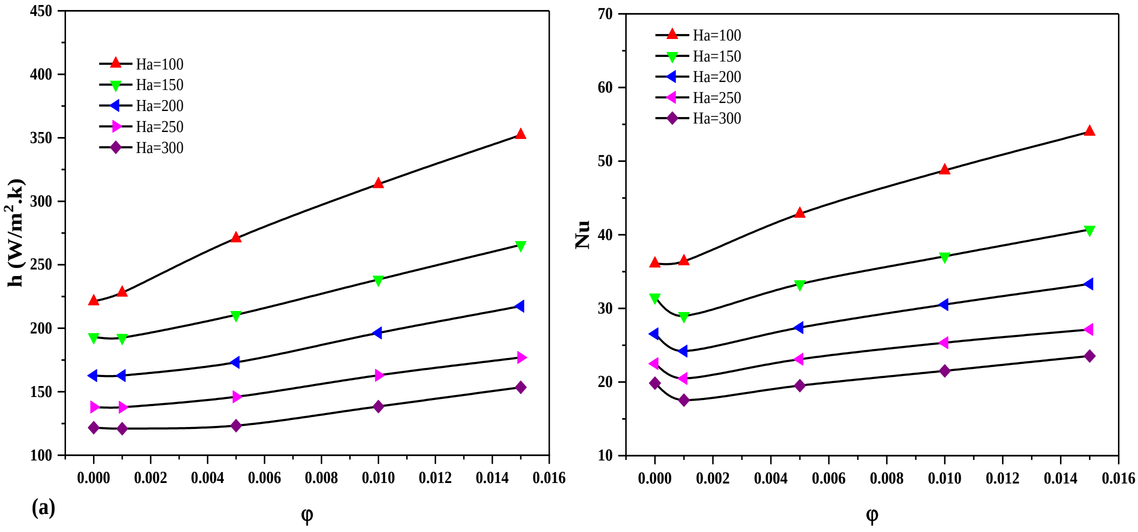


Figure (5). Effect of nanoparticles concentration on Nu

6.4 Effect of nanoparticles concentration on the h and Nu

This part of the numerical study seeks to clarify the effect of changing the concentration of suspended nanomaterials in water. It also showed how the fluid's nanomaterials affect the heat transfer rate as its temperature changes and exposure to magnetic flux. As noted above, the rate of heat transfer represented by the Nusselt number and the coefficient of heat transfer increased with the addition of nanoparticles to water as well as increases with the concentration of nanoparticles. Previous studies have shown that the high temperature of the fluid led to a decrease in its density and viscosity and therefore increased its velocity accordingly. Thus, the addition of nanoparticles was essential to increase heat transfer in the fluid because it improved thermal conductivity. However, the problem was if the Nanofluid was exposed to a magnetic flux. Most previous studies have shown that the heat transfer rate decreases as the fluid is exposed to magnetic flux. This is because the magnetic flux inhibits the velocity of the fluid and thus decreases the rate of heat transfer. This study has proven this hypothesis, as shown in figures 5a-d



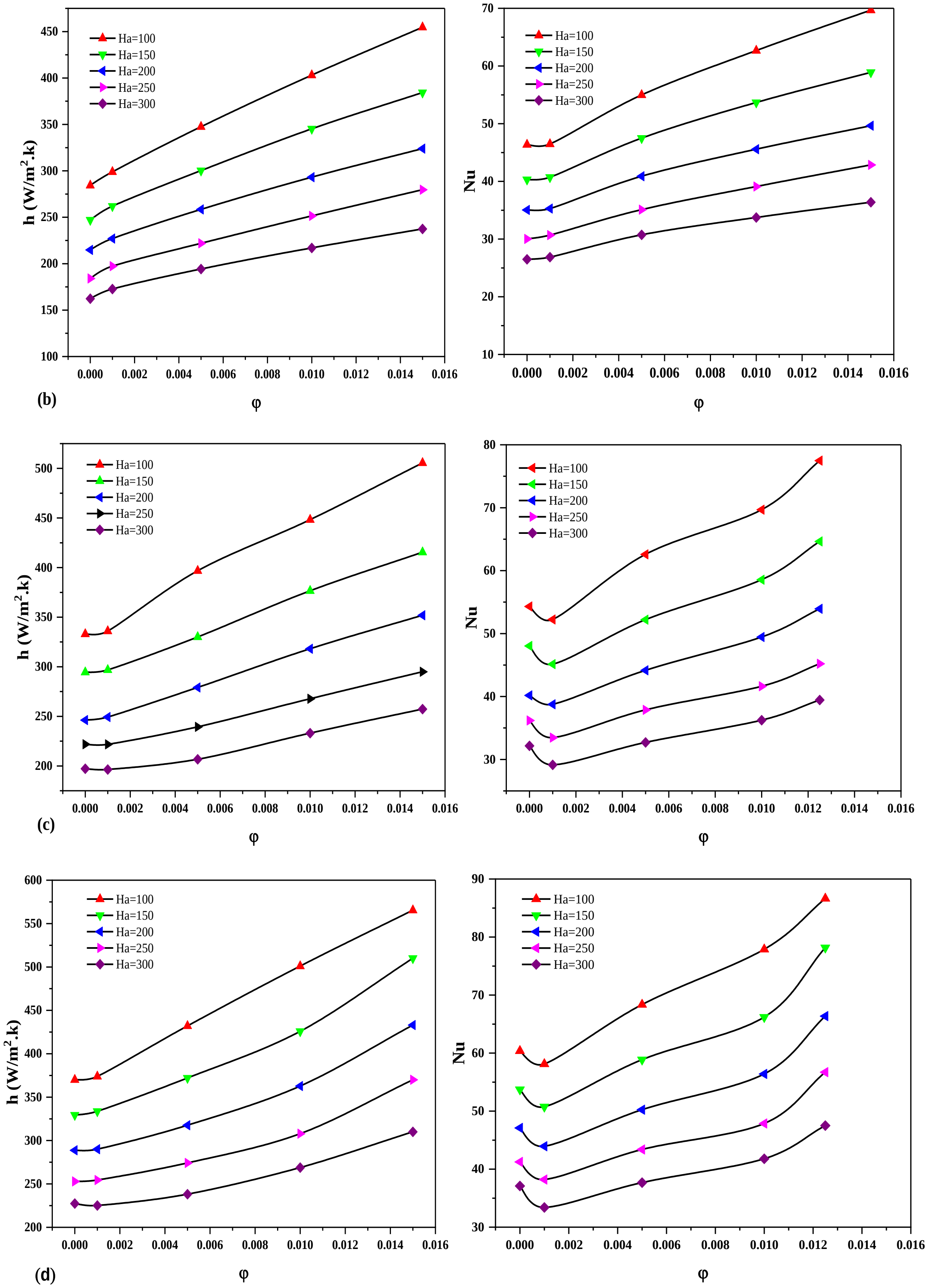


Figure (6). Effect of nanoparticles concentration on the h and Nu

7 CONCLUSIONS

The numerical findings can be summarised as follows

1 The nanofluid temperature with the highest concentration beside the hot wall is the highest compared to the other nanofluid sections, while its temperature is the lowest beside the Cold Wall.

2 Adding CuO particles enhances the buoyancy, and the sizes of the vortices increase.

3 The magnetic flux on the sidewalls of the cube attracts nanoparticles, thereby increasing its temperature at the hot wall and decreasing it at the Cold Wall.

4 The rate of heat transfer increases as the concentration of nanoparticles in the fluid increases when the vertical wall temperature difference is fixed.

5 The heat transfer rate increases as the temperature difference between the hot and cold walls increases.

6 CuO nanoparticles with a concentration of 1.5, a Ra=6.7E+8 and Ha=100 have been shown to boost the Nusselt number by up to 28.5% compared to water with a Ha=0.

7 The heat transfer coefficient increased by 56%, and the Nusselt number increased by 43 % when CuO nanoparticles were added to water at a volume concentration of 1.5%, Ra=6.7E+8 compared to water at Ha=100.

8 The magnetic flux on the walls of the cube lowered the fluid temperatures.

9 The heat transfer coefficients at Ha=100 and 150 are larger than those at Ha= 0.

10 Nusselt number values decrease as Hartmann numbers increase more than 150.

11 The higher the values of the Hartmann numbers, the velocity of the fluid along with the walls decreases.

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