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ORIGINAL ARTICLE

Ferrofluid convective heat transfer under the influence of external magnetic source

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KEYWORDS

Nanofluid;
Natural convection;
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CVFEM;
Sinusoidal wall

Abstract Ferrofluid convective heat transfer in a cavity with sinusoidal cold wall is examined under the influence of external magnetic source. The working fluid is Fe_3O_4-water nanofluid. Single phase model is used to estimate the behavior of nanofluid. Vorticity stream function formulation is utilized to eliminate pressure gradient source terms. New numerical method is chosen namely Control volume base finite element method. Influences of Rayleigh, Hartmann numbers, amplitude of the sinusoidal wall and volume fraction of Fe_3O_4 on hydrothermal characteristics are presented. Results indicate that temperature gradient enhances as space between cold and hot walls reduces at low buoyancy force. Lorentz forces cause the nanofluid velocity to reduce and augment the thermal boundary layer thickness. Nusselt number augments with rise of buoyancy forces but it decreases with augment of Lorentz forces.

1. Introduction

New kinds of fluid were required to reach more efficient performance in new days. Nanofluid was proposed as innovative way to enhance heat transfer. Teamah and Shehata [1] reported the Lorentz forces effect on free convection in trapezoidal enclosure. Hsiao [2] investigated electrical MHD nanofluid flow over a plate. He utilized FDM for simulation. Sheikholeslami and Ganji [3] presented various applications of nanofluid in their review paper. Sheremet et al. [4] simulated the unsteady MHD flow in an enclosure. They used FDM to simulate that paper. Kandasamy et al. [5] examined the reaction of nanofluid versus chemical reaction. Ahmad and Mustafa [6] investigated the rotating nanofluid flow induced by an exponentially stretching. Their results revealed that temperature gradient reduces with augment of angular velocity. Awais et al. [7] simulated the slip effect on nanofluid motion in the presence of magnetic field. Hussein et al. [8] analyzed the natural convection of nanofluid in T-shaped cavity. They concluded that temperature gradient decreases with augment of heat source length. Radiation heat transfer over a sensor surface has been studied by Hamzah et al. [9]. They indicated the 30% augmentation in Nusselt number with use of nanofluid.

Selimefendigil and Oztop [10] examined nanofluid conjugate conduction-convection mechanism in a titled cavity. They proved that temperature gradient rises with augment of Grashof number. Sheikholeslami and Ellahi [11] selected

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Nomenclature

B	magnetic induction
Ec	Eckert number
H	the magnetic field strength
$\vec{g}$	gravitational acceleration vector
Nu	Nusselt number
Ha	Hartmann number
T	fluid temperature
Ra	Rayleigh number
V, U	vertical and horizontal dimensionless velocity
Y, X	vertical and horizontal space coordinates

Greek symbols

β	thermal expansion coefficient
μ_0	magnetic permeability of vacuum
α	thermal diffusivity
$\Omega \& \Psi$	dimensionless vorticity & stream function
Θ	dimensionless temperature
ρ	fluid density
μ	dynamic viscosity
σ	electrical conductivity

Subscripts

nf	nanofluid
f	base fluid
loc	local
c	cold

LBM to simulate Lorentz force influence on nanofluid temperature distribution. They depicted that temperature gradient reduces with augment of Hartmann number. Kefayati [12] considered second law analysis for nanofluid laminar natural convection in a permeable enclosure. He proved that irreversibilities augment as Rayleigh number enhances. MHD nanofluid free convective hydrothermal analysis in a tilted wavy enclosure was presented by Sheremet et al. [13]. Their results illustrated that change of titled angle causes convective heat transfer to enhance. Influence of non-uniform Lorentz forces on nanofluid flow style has been studied by Sheikholeslami Kandelousi [14]. He concluded that improvement in heat transfer reduces with rise of Kelvin forces. Sheikholeslami et al. [15] examined about the impact of radiation of nanofluid free convective heat transfer in existence of magnetic field. They showed that rate of heat transfer decreases with augment of Lorentz forces. Malvandi et al. [16] analyzed the fluid flow on a sheet. They presented the thermodynamic optimization of this problem. Several authors investigated about nanofluid heat transfer augmentation [17–33,1].

The purpose of this article was to investigate impact of magnetic source on hydrothermal behavior of nanofluid in a cavity with sinusoidal cold wall. CVFEM is chosen to simulate this paper. Effects of Rayleigh and Hartmann numbers, volume fraction of Fe_3O_4 on hydrothermal treatment are considered.

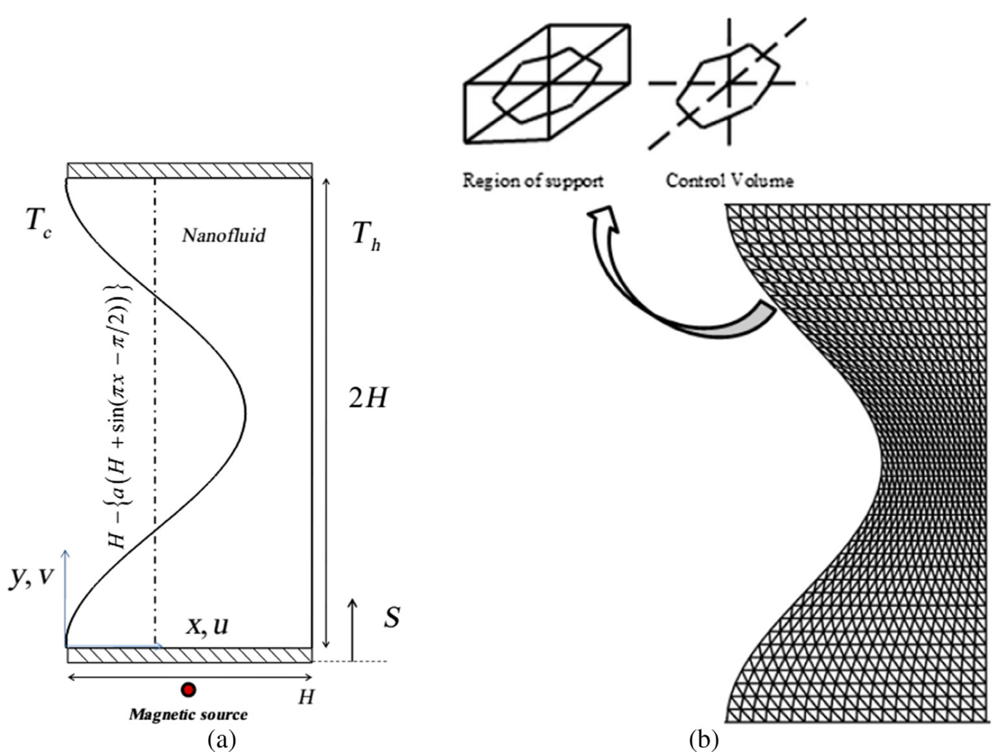

Figure 1 (a) Geometry and the boundary conditions; (b) the mesh of enclosure considered in this work.

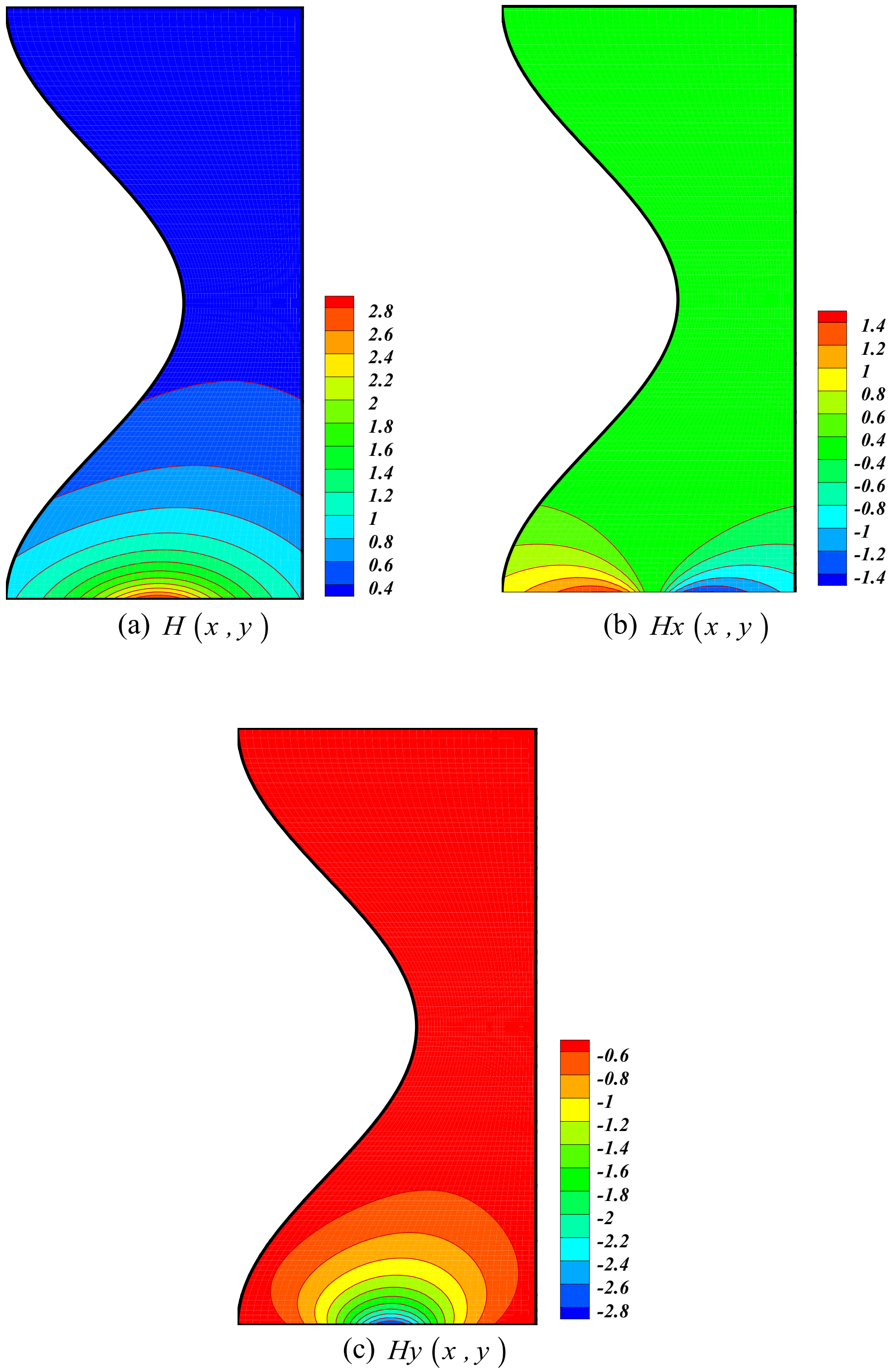

Figure 2 Contours of the (a) magnetic field strength H; (b) magnetic field intensity component in x direction Hx; (c) magnetic field intensity component in y direction Hy.

Table 1 Thermo-physical properties of water and nanoparticles.

	ρ (kg/m^3)	C_p (J/kg K)	k (W/m K)	d_p (nm)	σ (Ω m)$^{-1}$
Pure water	997.1	4179	0.613	–	0.05
Fe_3O_4	5200	670	6	47	25,000

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Table 2 Comparison of the average Nusselt number Nu_{ave} along lid wall for different grid resolutions at $Ra = 10^5$, $a = 0.3$, $\phi = 0.04$, $Ha = 20$, $Ec = 10^{-5}$ and $Pr = 6.8$.

51 × 151	61 × 181	71 × 211	81 × 241	91 × 271	101 × 301
2.759311	2.766715	2.769861	2.775131	2.776103	2.779106

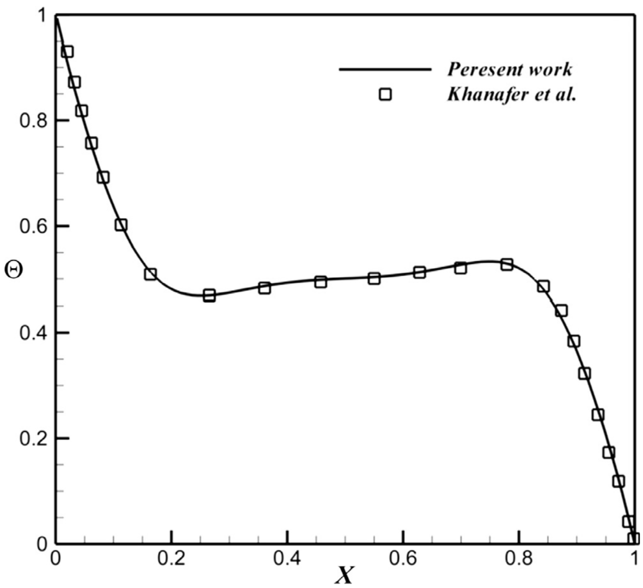

Figure 3 Comparison of center line temperature between the present results and numerical results by Khanafer et al. [36] $Gr = 10^4$, $\phi = 0.1$ and $Pr = 6.8$(Cu–Water).

2. Problem statement

An enclosure with hot inner walls is considered. Fig. 1(a) depicts the boundary conditions. To obtain the shape of the left sinusoidal wall profile, the following equation should be used:

$$\frac{x}{H} = 1 - \left\{ a\left(1 + \sin\left(\pi\frac{y}{H} - \pi/2\right)\right)\right\} \tag{1}$$

Magnetic source has been considered as shown in Fig. 2. $\overline{H}_x, \overline{H}_y, \overline{H}$ can be calculated as follows [34]:

$$\begin{aligned} \overline{H}_x &= (y - \overline{b})\left[(\overline{a} - x)^2 + (\overline{b} - y)^2\right]^{-1} \frac{\gamma}{2\pi}, \\ \overline{H}_y &= (\overline{a} - x)\left[(\overline{a} - x)^2 + (\overline{b} - y)^2\right]^{-1} \frac{\gamma}{2\pi}, \end{aligned} \tag{2}$$

$$\overline{H} = \sqrt{\overline{H}_x^2 + \overline{H}_y^2} \tag{3}$$

3. Simulation method

3.1. Governing formulation

2D laminar nanofluid flow and forced convective heat transfer are taken into account. The governing PDEs can be considered as follows:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0, \tag{4}$$

$$\left(\frac{\partial u}{\partial x}u + \frac{\partial u}{\partial y}v\right) = (\rho_{nf})^{-1}\left[\left(\frac{\partial^2 u}{\partial y^2} + \frac{\partial^2 u}{\partial x^2}\right)\mu_{nf} - \frac{\partial P}{\partial x} - \sigma_{nf}B_y^2 u + \sigma_{nf}B_x B_y v\right] \tag{5}$$

$$\begin{aligned} \rho_{nf}\left(\frac{\partial v}{\partial x}u + \frac{\partial v}{\partial y}v\right) = &+\mu_{nf}\left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right) - \frac{\partial P}{\partial y} + B_y\sigma_{nf}B_x u \\ &- B_x\sigma_{nf}B_x v + (T - T_c)\beta_{nf} g\rho_{nf} \end{aligned} \tag{6}$$

$$\begin{aligned} (\rho C_p)_{nf}\left(v\frac{\partial T}{\partial y} + u\frac{\partial T}{\partial x}\right) = &\ \sigma_{nf}(B_x v - B_y u)^2 + k_{nf}\left(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}\right) \\ &+\mu_{nf}\left\{2\left(\frac{\partial u}{\partial x}\right)^2 + 2\left(\frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}\right)^2\right\}, \end{aligned} \tag{7}$$

$B = \mu_0 H.$

ρ_{nf}, $(\rho C_p)_{nf}$, α_{nf}, β_{nf}, μ_{nf}, k_{nf} and σ_{nf} are calculated as

$$\rho_{nf} = \rho_f(1 - \phi) + \rho_s\phi, \tag{8}$$

$$(\rho C_p)_{nf} = (\rho C_p)_f(1 - \phi) + (\rho C_p)_s\phi, \tag{9}$$

$$\alpha_{nf} = \frac{k_{nf}}{(\rho C_p)_{nf}}, \tag{10}$$

$$\beta_{nf} = \beta_f(1 - \phi) + \beta_s\phi. \tag{11}$$

Table 3 Average Nusselt number versus at different Grashof number under various strengths of the magnetic field at $Pr = 0.733$.

Ha	$Gr = 2 \times 10^4$		$Gr = 2 \times 10^5$	
	Present	Rudraiah et al. [37]	Present	Rudraiah et al. [37]
0	2.5665	2.5188	5.093205	4.9198
10	2.26626	2.2234	4.9047	4.8053
50	1.09954	1.0856	2.67911	2.8442
100	1.02218	1.011	1.46048	1.4317

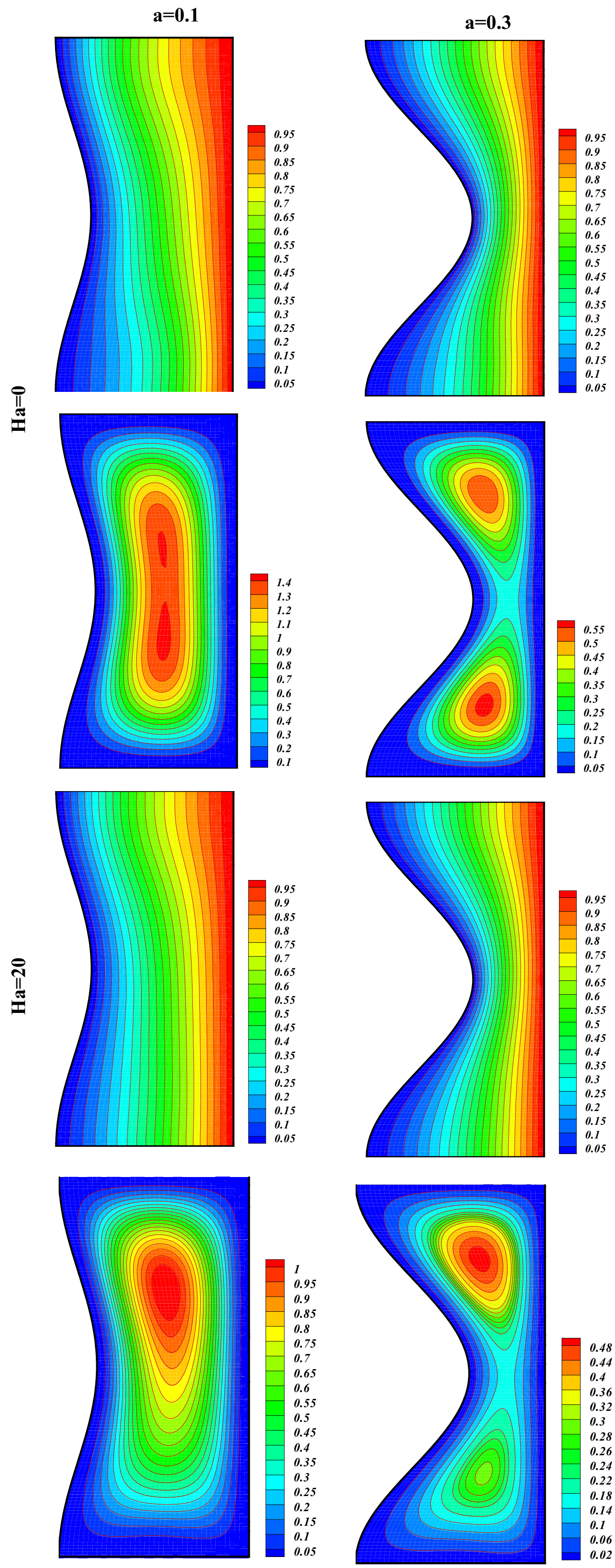

Figure 4 Isotherms (up) and streamlines (down) contours for different values of Hartmann number and amplitude of the sinusoidal wall when $Ra = 10^3,\ \phi = 0.04$.

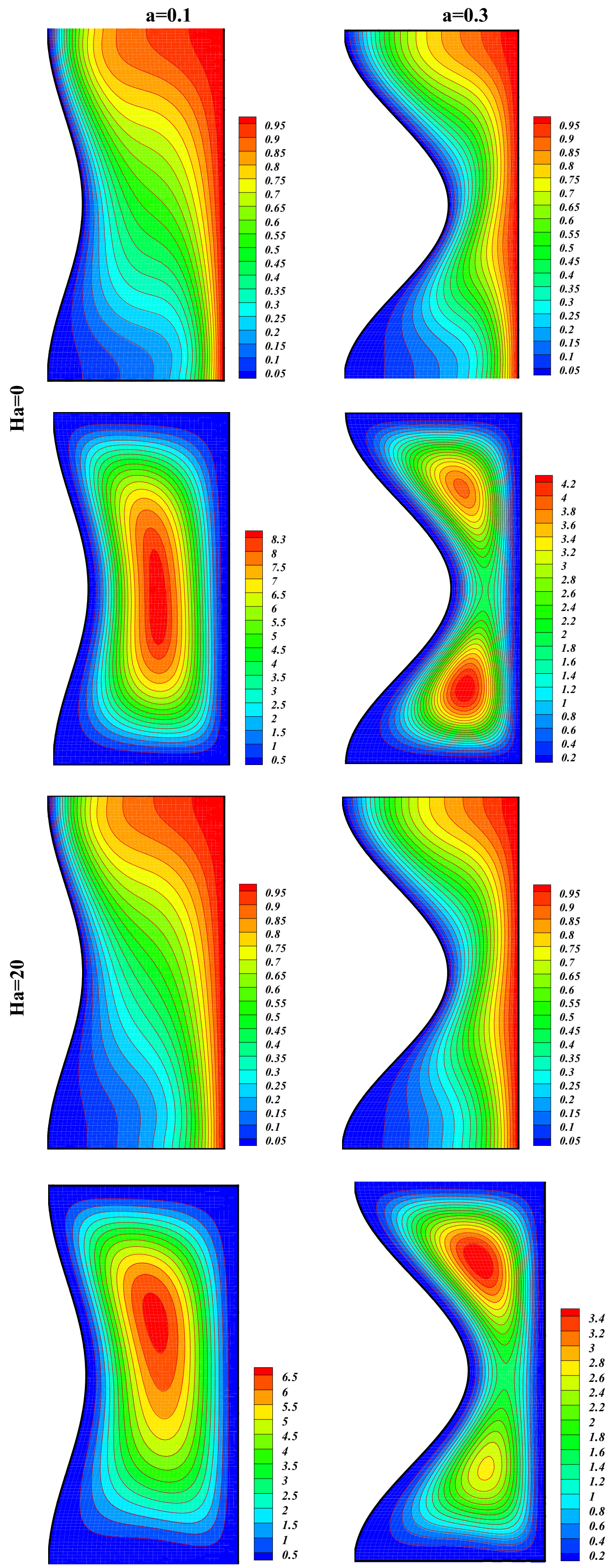

Figure 5 Isotherms (up) and streamlines (down) contours for different values of Hartmann number and amplitude of the sinusoidal wall when $Ra = 10^4$, $\phi = 0.04$.

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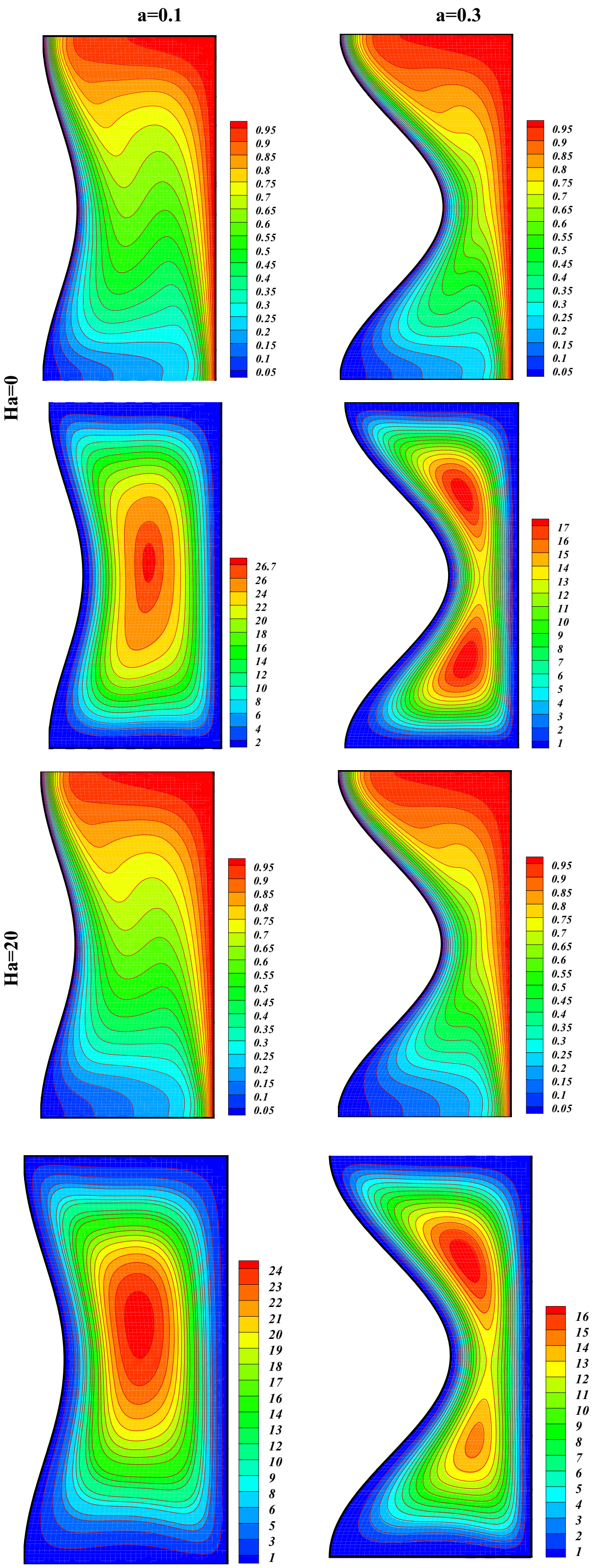

Figure 6 Isotherms (up) and streamlines (down) contours for different values of Hartmann number and amplitude of the sinusoidal wall when $Ra = 10^5$, $\phi = 0.04$.

$$\mu_{nf} = \frac{\mu_f}{(1-\phi)^{2.5}}. \tag{12}$$

$$k_{nf} = \left(\frac{k_s + 2k_f - 2\phi(k_f - k_s)}{k_s + 2k_f + \phi(k_f - k_s)}\right) k_f, \tag{13}$$

$$\frac{\sigma_{nf}}{\sigma_f} = 1 + \frac{3\left(\frac{\sigma_s}{\sigma_f} - 1\right)\phi}{\left(\frac{\sigma_s}{\sigma_f} + 2\right) - \left(\frac{\sigma_s}{\sigma_f} - 1\right)\phi}. \tag{14}$$

Dimensionless parameters are defined as follows:

$$\begin{aligned} &(a,b) = \frac{(\bar{a},\bar{b})}{L}, (H, H_x, H_y) = \frac{(\overline{H}, \overline{H_x}, \overline{H_y})}{H_0}, (X, Y) = \frac{(x,y)}{L} \\ &U = \frac{uL}{\alpha_f}, V = \frac{vL}{\alpha_f}, \ \Theta = \frac{T - T_c}{(q''L/k_f)}, P = \frac{p}{\rho_f(\alpha_f/L)^2} \end{aligned} \tag{15}$$

So final equations are as follows:

$$\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} = 0, \tag{16}$$

$$\begin{aligned} \frac{\partial U}{\partial X}U + \frac{\partial U}{\partial Y}V = Pr\left[\frac{\mu_{nf}/\mu_f}{\rho_{nf}/\rho_f}\right]\left(\frac{\partial^2 U}{\partial Y^2} + \frac{\partial^2 U}{\partial X^2}\right) \\ - Ha^2 Pr\left[\frac{\sigma_{nf}/\sigma_f}{\rho_{nf}/\rho_f}\right]\left(H_y^2 U - H_x H_y V\right) - \frac{\partial P}{\partial X}, \end{aligned} \tag{17}$$

$$\begin{aligned} &V\frac{\partial V}{\partial Y} + U\frac{\partial V}{\partial X} = Pr\left(\frac{\partial^2 V}{\partial Y^2} + \frac{\partial^2 V}{\partial X^2}\right)\left[\frac{\mu_{nf}/\mu_f}{\rho_{nf}/\rho_f}\right] \\ &-Ha^2 \ Pr\left[\frac{\sigma_{nf}/\sigma_f}{\rho_{nf}/\rho_f}\right]\left(H_x^2 V - H_x H_y U\right) - \frac{\partial P}{\partial Y} + Ra \ Pr\left[\frac{\beta_{nf}}{\beta_f}\right]\Theta, \end{aligned} \tag{18}$$

$$\begin{aligned} &V\frac{\partial \Theta}{\partial Y} + U\frac{\partial \Theta}{\partial X} = \left(\frac{\partial^2 \Theta}{\partial Y^2} + \frac{\partial^2 \Theta}{\partial X^2}\right)\left[\frac{\frac{(\rho C_P)_{nf}}{(\rho C_P)_f}}{\frac{k_{nf}}{k_f}}\right]^{-1} \\ &\quad + Ha^2 \ Ec\left[\frac{\frac{\sigma_{nf}}{\sigma_f}}{\frac{(\rho C_P)_{nf}}{(\rho C_P)_f}}\right]\{VH_x - UH_y\}^2 \\ &\quad + \left[\frac{\frac{\mu_{nf}}{\mu_f}}{\frac{(\rho C_P)_{nf}}{(\rho C_P)_f}}\right] Ec\left\{2\left(\frac{\partial U}{\partial X}\right)^2 + 2\left(\frac{\partial V}{\partial Y}\right)^2 + \left(\frac{\partial U}{\partial Y} + \frac{\partial V}{\partial X}\right)^2\right\}, \end{aligned} \tag{19}$$

and dimensionless parameters are

$$\begin{aligned} Ra_f = g\beta_f L^3 (q''L/k_f)/(\alpha_f \upsilon_f),\ Pr_f = \upsilon_f/\alpha_f,\ Ha = L\mu_0 H_0\sqrt{\sigma_f/\mu_f}, \\ Ec = (\mu_f \alpha_f)/[(\rho C_P)_f \Delta T\, L^2] \end{aligned} \tag{20}$$

The thermo-physical properties of Fe_3O_4 and water are presented in Table 1 [34]. Pressure gradient source terms discard by vorticity stream function.

$$\Omega = \frac{\omega L^2}{\alpha_f},\ \Psi = \frac{\psi}{\alpha_f},\ \omega = -\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x},\ (u, v) = \left(\frac{\partial \psi}{\partial y}, -\frac{\partial \psi}{\partial x}\right) \tag{21}$$

According to Fig. 1, boundary conditions are

$$\begin{aligned} &\text{on left wall} \quad \Theta = 0.0 \\ &\text{on all walls} \quad \Psi = 0.0 \\ &\text{on right wall} \quad \Theta = 1.0 \\ &\text{on other walls} \quad \frac{\partial \Theta}{\partial n} = 0.0 \end{aligned} \tag{22}$$

Nu_{local}, Nu_{ave} along left wall are as follows:

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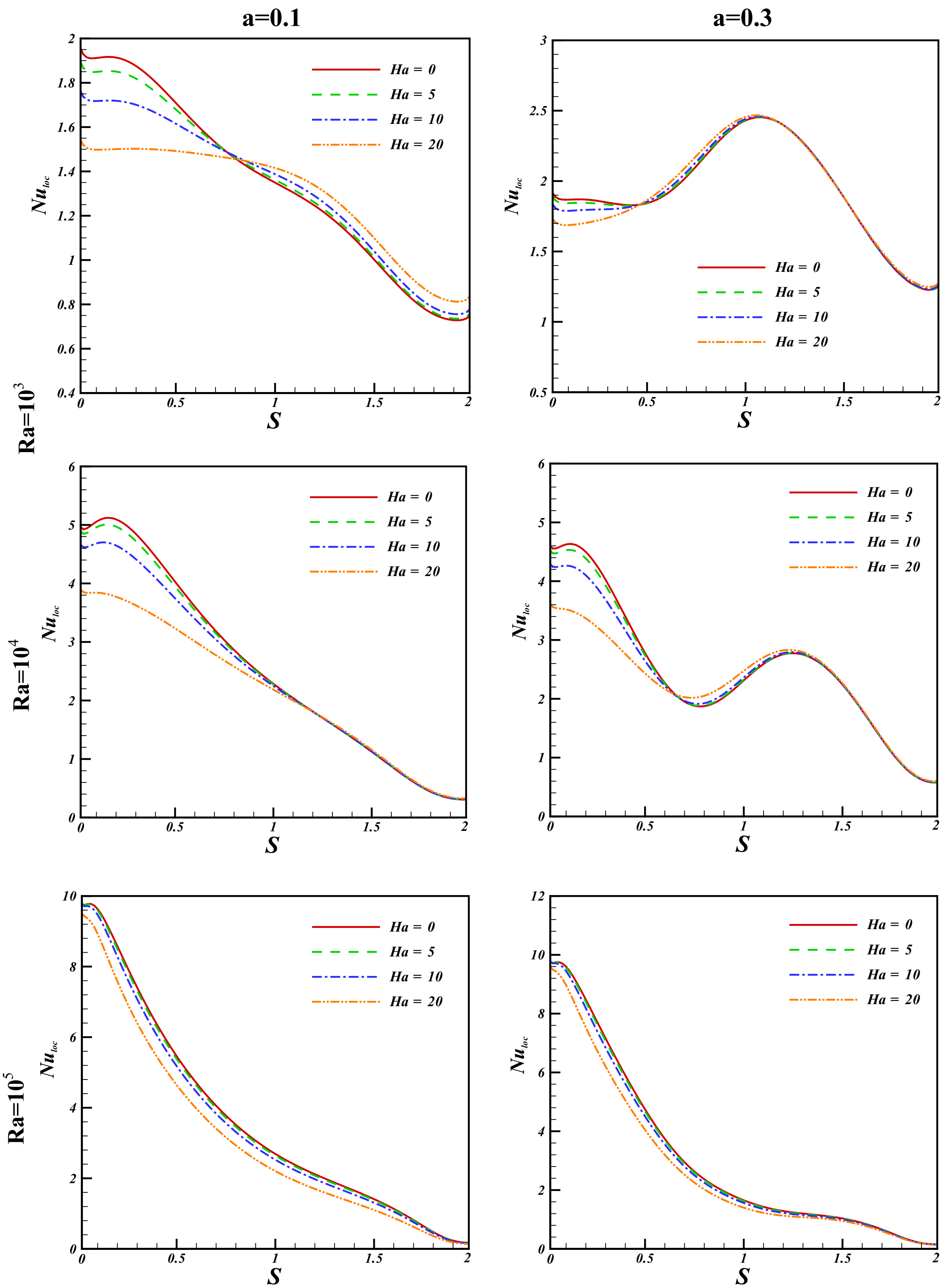

Figure 7 Effects of Hartmann number, amplitude of the sinusoidal wall and Rayleigh number on local Nusselt number Nu_{loc} along right wall.

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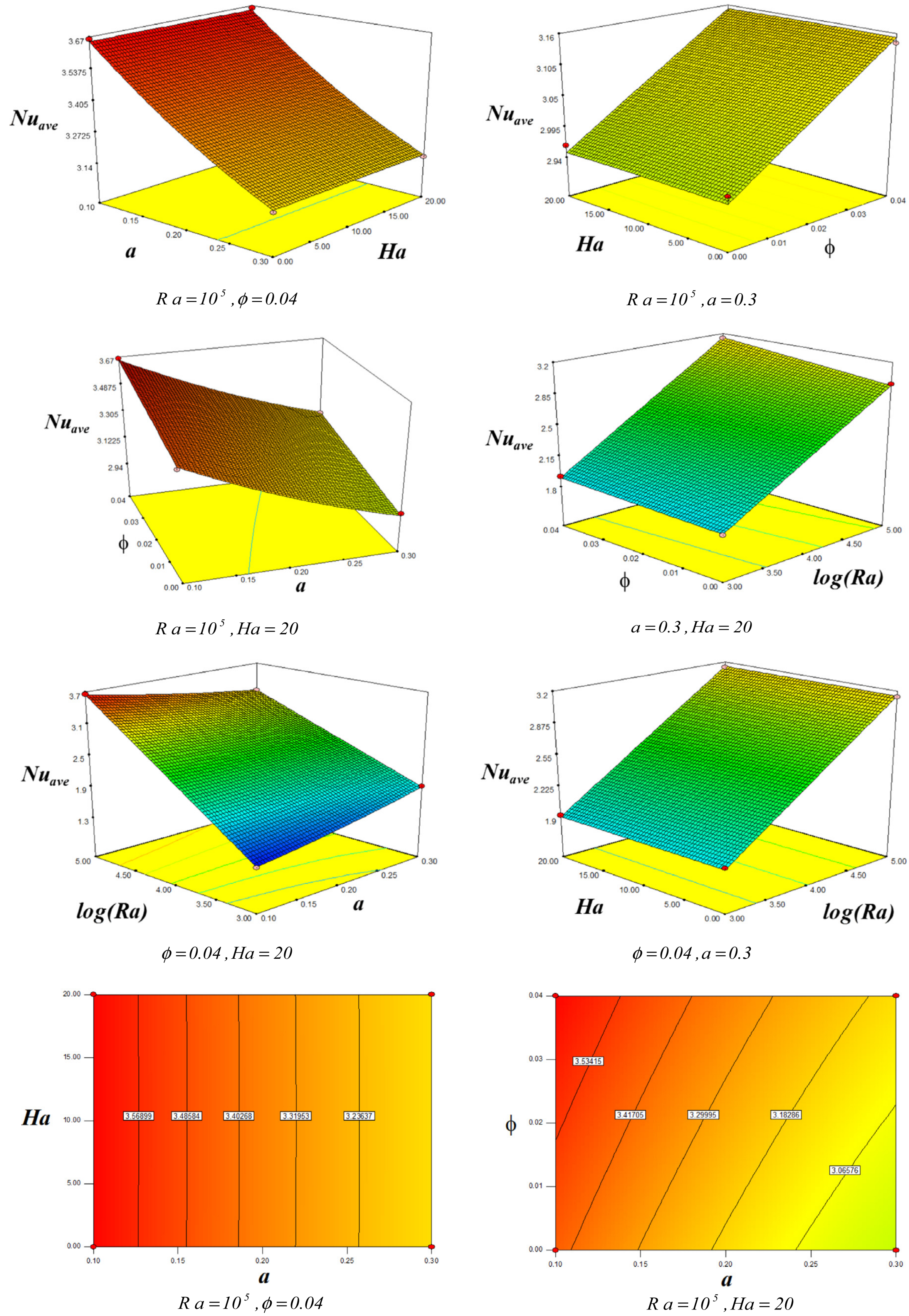

Figure 8 Effects of Hartmann number, amplitude of the sinusoidal wall and Rayleigh number on local Nusselt number Nu_{ave} along right wall.

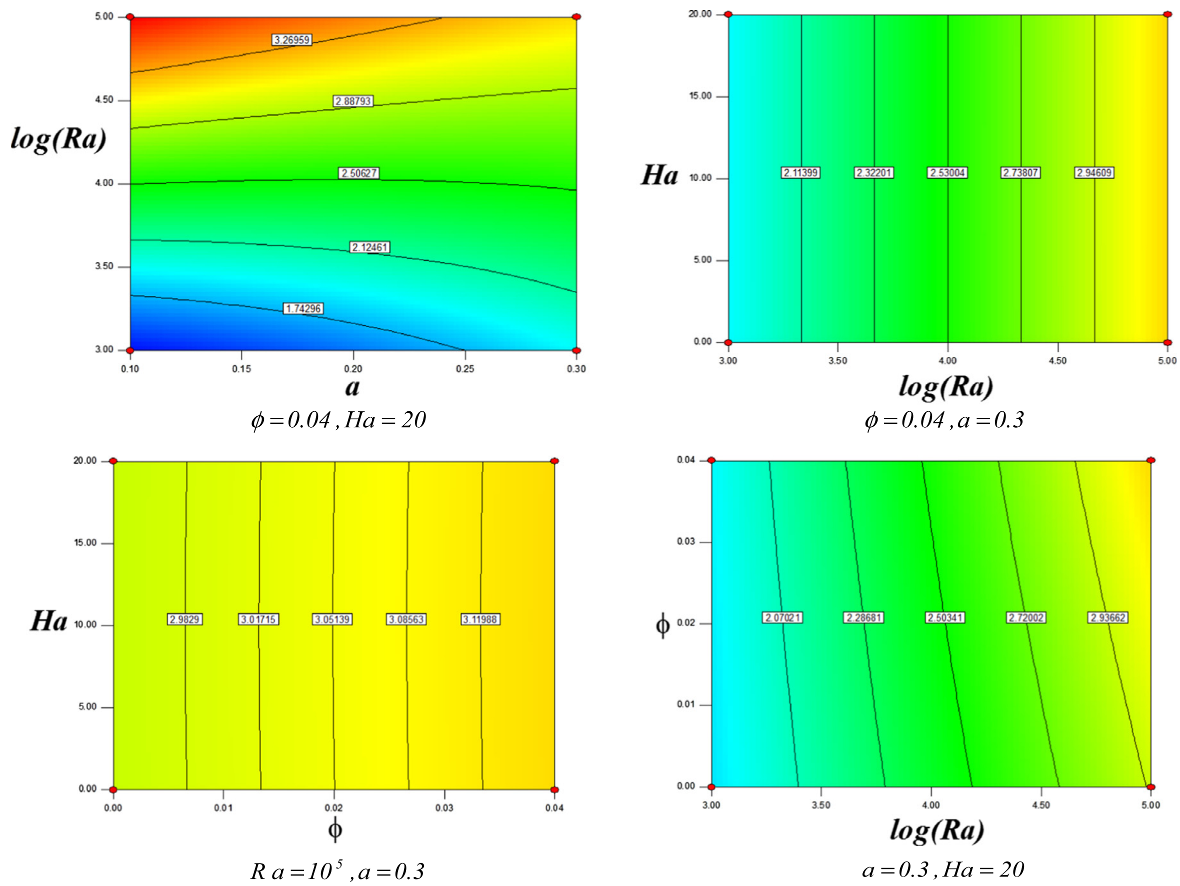

Fig. 8 (*continued*)

$$Nu_{loc} = \left(\frac{k_{nf}}{k_f}\right)\frac{\partial\Theta}{\partial n} \tag{23}$$

$$Nu_{ave} = \frac{1}{2}\int_0^2 Nu_{loc}\, dS \tag{24}$$

3.2. Numerical procedure

Linear interpolation is utilized for approximation of variables in the triangular element which is considered as building block (Fig. 1(b)). Algebretic equations are solved via Gauss-Seidel method. More details exist in reference book [35].

4. Mesh independency and validation

For selecting the mesh size to access mesh independency outputs, different grids are tested. As shown in Table 2, a grid size of 71×211 should be chosen. Fig. 3 shows the accuracy of FORTRAN code for nanofluid heat transfer [36]. Table 3 illustrates that our code is validated for magnetohydrodynamic heat transfer [37].

5. Results and discussion

A cavity filled with nanofluid in existence of magnetic source is studied. Cold wall has sinusoidal shape. Various amounts of Hartmann number (Ha = 0–20), Rayleigh number ($Ra = 10^3$, 10^4 and 10^5), amplitude of the sinusoidal wall (a = 0.1–0.3) and volume fraction of Fe_3O_4 ($\phi = 0$ and 0.04) have been considered. Ec and Pr are 10^{-5} and 6.8, respectively.

Figs. 4–6 depict the impacts of amplitude of the sinusoidal wall, Rayleigh and Hartmann numbers on streamlines and isotherms. At a = 0.1, one main eddy appears. As amplitude of the sinusoidal wall augments, the main eddy turn into two eddies. By applying magnetic field, Lorentz forces generate. This force causes the nanofluid flow to retard. Increasing Lorentz forces causes eddies to stretch vertically. In weak buoyancy forces, the domination mode is conduction. So reducing distance between cold and hot walls, rate of heat transfer augments but opposite behavior can be seen for stronger buoyancy forces. As buoyancy forces enhances, eddies become stronger and isotherms become nonparallel together. So temperature gradient near the right wall enhances. As Lorentz force augments, the velocity reduces and this force makes isotherms to become parallel together.

Figs. 7 and 8 depict the influence of the Fe_3O_4 volume fraction, amplitude of the sinusoidal wall, Lorentz and buoyancy forces on Nu_{loc}, Nu_{ave}. The correlation for Nu_{ave} corresponding to active parameters is as follows:

$$\begin{aligned} Nu_{ave} = & -2.85 + 9.12a + 1.33(\log(Ra)) - 4.34\phi + 1.79 \times 10^{-4} Ha \\ & - 2.6a(\log(Ra)) - 0.13a\phi - 1.6 \times 10^{-16} aHa \\ & + 1.9(\log(Ra))\phi - 1.15 \times 10^{-17}(\log(Ra))Ha \\ & - 1.18 \times 10^{-15}\phi Ha + 3.5a^2 - 7.5 \times 10^{-4}(\log(Ra))^2 \\ & - 0.45\phi^2 - 8.9 \times 10^{-6} Ha^2 \end{aligned} \tag{25}$$

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As buoyancy forces augment, temperature gradient near the right wall enhances and in turn Nu_{ave} enhances with augment of Rayleigh number. Enhancing Lorentz forces leads to reduce Nu_{ave} due to domination of conduction mode. Adding Fe_3O_4 nanoparticle into water makes Nusselt number to enhance. Nu_{ave} enhances with rise of a in low Ra but opposite changes occur for high Ra.

6. Conclusions

Ferrofluid heat transfer in a cavity with sinusoidal cold wall is presented under the impact of external magnetic field. CVFEM has been chosen as simulation method. Isotherms and streamlines are depicted for different values of volume fraction of Fe_3O_4, amplitude of the sinusoidal wall, Rayleigh and Hartmann numbers. Results indicate that impact of adding Fe_3O_4 is more sensible for lower buoyancy forces. Temperature gradient enhances with rise of amplitude of the sinusoidal wall when buoyancy force is weak. Temperature augments with rise of Lorentz forces but it reduces with augment of volume fraction of Fe_3O_4 and buoyancy forces.

References

[1] Mohamed A. Teamah, Ali I. Shehata, Magnetohydrodynamic double diffusive natural convection in trapezoidal cavities, Alexandria Eng. J. 55 (2016) 1037–1046.
[2] Kai-Long Hsiao, Stagnation electrical MHD nanofluid mixed convection with slip boundary on a stretching sheet, Appl. Therm. Eng. 98 (2016) 850–861.
[3] M. Sheikholeslami, D.D. Ganji, Nanofluid convective heat transfer using semi analytical and numerical approaches: a review, J. Taiwan Inst. Chem. Eng. 65 (2016) 43–77.
[4] Mikhail A. Sheremet, Ioan Pop, Natalia C. Roşca, Magnetic field effect on the unsteady natural convection in a wavy-walled cavity filled with a nanofluid: Buongiorno's mathematical model, J. Taiwan Inst. Chem. Eng. 61 (2016) 211–222.
[5] R. Kandasamy, Hatem Sabeeh Altaie, Izzatun Nazurah Binti Zaimuddin, Irregular response of nanofluid flow subject to chemical reaction and shape parameter in the presence of variable stream conditions, Alexandria Eng. J. 55 (2016) 2485–2495.
[6] R. Ahmad, M. Mustafa, Model and comparative study for rotating flow of nanofluids due to convectively heated exponentially stretching sheet, J. Mol. Liq. 220 (2016) 635–641.
[7] M. Awais, T. Hayat, Aamir Ali, S. Irum, Velocity, thermal and concentration slip effects on a magneto-hydrodynamic nanofluid flow, Alexandria Eng. J. 55 (2016) 2107–2114.
[8] Ahmed Kadhim Hussein, M.A.Y. Bakier, Mohamed Bechir Ben Hamida, S. Sivasankaran, Magneto-hydrodynamic natural convection in an inclined T-shaped enclosure for different nanofluids and subjected to a uniform heat source, Alexandria Eng. J. 55 (2016) 2157–2169.
[9] Nor Shamsidah bte Amir Hamzah, R. Kandasamy, Radiah Muhammad, Thermal radiation energy on squeezed MHD flow of Cu, Al_2O_3 and CNTs-nanofluid over a sensor surface, Alexandria Eng. J. 55 (2016) 2405–2421.
[10] Fatih Selimefendigil, Hakan F. Öztop, Conjugate natural convection in a cavity with a conductive partition and filled with different nanofluids on different sides of the partition, J. Mol. Liq. 216 (2016) 67–77.
[11] M. Sheikholeslami, R. Ellahi, Three dimensional mesoscopic simulation of magnetic field effect on natural convection of nanofluid, Int. J. Heat Mass Transf. 89 (2015) 799–808.
[12] G.H.R. Kefayati, Heat transfer and entropy generation of natural convection on non-Newtonian nanofluids in a porous cavity, Powder Technol. 299 (2016) 127–149.
[13] M.A. Sheremet, H.F. Oztop, I. Pop, MHD natural convection in an inclined wavy cavity with corner heater filled with a nanofluid, J. Magn. Magn. Mater. 416 (2016) 37–47.
[14] Mohsen Sheikholeslami Kandelousi, Effect of spatially variable magnetic field on ferrofluid flow and heat transfer considering constant heat flux boundary condition, Eur. Phys. J. Plus (2014) 129–248.
[15] M. Sheikholeslami, T. Hayat, A. Alsaedi, MHD free convection of Al_2O_3–water nanofluid considering thermal radiation: a numerical study, Int. J. Heat Mass Transf. 96 (2016) 513–524.
[16] A. Malvandi, F. Hedayati, D.D. Ganji, Thermodynamic optimization of fluid flow over an isothermal moving plate, Alexandria Eng. J. 52 (2013) 277–283.
[17] M. Sheikholeslami, S.A. Shehzad, Magnetohydrodynamic nanofluid convection in a porous enclosure considering heat flux boundary condition, Int. J. Heat Mass Tran. (2016), http://dx.doi.org/10.1016/j.ijheatmasstransfer.2016.10.107.
[18] Nilankush Acharya, Kalidas Das, Prabir Kumar Kundu, The squeezing flow of Cu-water and Cu-kerosene nanofluids between two parallel plates, Alexandria Eng. J. 55 (2016) 177–1186.
[19] M. Sheikholeslami, H.R. Ashorynejad, P. Rana, Lattice Boltzmann simulation of nanofluid heat transfer enhancement and entropy generation, J. Mol. Liq. 214 (2016) 86–95.
[20] Mohsen Sheikholeslami, Kuppalapalle Vajravelu, Mohammad Mehdi Rashidi, Forced convection heat transfer in a semi annulus under the influence of a variable magnetic field, Int. J. Heat Mass Transf. 92 (2016) 339–348.
[21] Mohsen Sheikholeslami, Shirley Abelman, Two phase simulation of nanofluid flow and heat transfer in an annulus in the presence of an axial magnetic field, IEEE Trans. Nanotechnol. 14 (3) (2015) 561–569.
[22] Mohsen Sheikholeslami Kandelousi, KKL correlation for simulation of nanofluid flow and heat transfer in a permeable channel, Phys. Lett. A 378 (45) (2014) 3331–3339.
[23] Mohsen Sheikholeslami, Davood Domiri Ganji, M. Younus Javed, R. Ellahi, Effect of thermal radiation on magnetohydrodynamics nanofluid flow and heat transfer by means of two phase model, J. Magn. Magn. Mater. 374 (2015) 36–43.
[24] Mohsen Sheikholeslami, Ali J. Chamkha, Influence of Lorentz forces on nanofluid forced convection considering Marangoni convection, J. Mol. Liq. (2016), http://dx.doi.org/10.1016/j.molliq.2016.11.001.
[25] B. Mahanthesh, B.J. Gireesha, Rama Subba Reddy Gorla, Heat and mass transfer effects on the mixed convective flow of chemically reacting nanofluid past a moving/stationary vertical plate, Alexandria Eng. J. 55 (2016) 569–581.
[26] M. Sheikholeslami, Influence of Coulomb forces on Fe_3O_4-H_2O nanofluid thermal improvement, Int. J. Hydrogen Energy (2016), http://dx.doi.org/10.1016/j.ijhydene.2016.09.185.
[27] M. Sheikholeslami, T. Hayat, A. Alsaedi, Numerical study for external magnetic source influence on water based nanofluid convective heat transfer, Int. J. Heat Mass Transf. (2016), http://dx.doi.org/10.1016/j.ijheatmasstransfer.2016.09.077 (in press).
[28] M. Sheikholeslami, D.D. Ganji, Nanofluid hydrothermal behavior in existence of Lorentz forces considering Joule heating effect, J. Mol. Liq. 224 (2016) 526–537.
[29] M. Sheikholeslami, D.D. Ganji, Influence of magnetic field on CuO-H_2O nanofluid flow considering Marangoni boundary layer, Int. J. Hydrogen Energy (2016), http://dx.doi.org/10.1016/j.ijhydene.2016.09.121.
[30] Mohsen Sheikholeslami, Ali J. Chamkha, Flow and convective heat transfer of a ferro-nanofluid in a double-sided lid-driven cavity with a wavy wall in the presence of a variable magnetic

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field, Numer. Heat Transf., Part A 69 (10) (2016) 1186–1200, http://dx.doi.org/10.1080/10407782.2015.1125709.

[31] Mohsen. Sheikholeslami, Ali J. Chamkha, Electrohydrodynamic free convection heat transfer of a nanofluid in a semi-annulus enclosure with a sinusoidal wall, Numer. Heat Transf., Part A 69 (7) (2016) 781–793, http://dx.doi.org/10.1080/10407782.2015.1090819.

[32] Padam Singh, Manoj Kumar, Mass transfer in MHD flow of alumina water nanofluid over a flat plate under slip conditions, Alexandria Eng. J. 54 (2015) 383–387.

[33] M. Sheikholeslami, M.M. Rashidi, D.D. Ganji, Effect of non-uniform magnetic field on forced convection heat transfer of Fe_3O_4-water nanofluid, Comput. Methods Appl. Mech. Eng. 294 (2015) 299–312.

[34] M. Sheikholeslami, D.D. Ganji, Ferrohydrodynamic and magnetohydrodynamic effects on ferrofluid flow and convective heat transfer, Energy 75 (2014) 400–410.

[35] Mohsen Sheikholeslami, Davood Domairry Ganji, Hydrothermal Analysis in Engineering Using Control Volume Finite Element Method, Academic Press, Print Book, 2015, pp. 1–226 (ISBN: 9780128029503).

[36] K. Khanafer, K. Vafai, M. Lightstone, Buoyancy-driven heat transfer enhancement in a two-dimensional enclosure utilizing nanofluids, Int. J. Heat Mass Transf. 46 (2003) 3639–3653.

[37] N. Rudraiah, R.M. Barron, M. Venkatachalappa, C.K. Subbaraya, Effect of a magnetic field on free convection in a rectangular enclosure, Int. J. Eng. Sci. 33 (1995) 1075–1084.

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