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Macroscopic modeling for convection of Hybrid nanofluid with magnetic effects

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HIGHLIGHTS

- Hybrid nanofluid free convection within a permeable media has been examined.
- FEM and Gauss–Seidel scheme has been used to determine the numerical results.
- Outcomes prove that dispersing nanoparticles is good way for enhancing discharge rate.
- An excellent graphical comparison is present to validate the current results.

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ABSTRACT

Hybrid nanofluid free convection within a permeable media was presented with CVFEM (control volume finite element method) including magnetic effect. Momentum equations have been updated with adding non-Darcy model terms. Hybrid nanoparticles (Fe_3O_4+MWCNT) with a base fluid of water have been considered. Impacts of Darcy number, magnetic, radiation, and Rayleigh number on migration of nanomaterial were depicted. A numerical and graphical comparison is also presented to make sure that the present analysis is correct. From the graphical results it is found that radiation parameter and magnetic boosts the Nusselt number whereas the magnetic effect shows converse relation.

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Nomenclature

k	Thermal conductivity
C_p	Heat capacity
Ha	Hartmann number
B_o	Magnetic field
Rd	Radiation parameter
Da	Darcy number
Nu	Nusselt number
T	Fluid temperature
K	Permeability
v, u	Vertical and horizontal dimensionless velocity
MWCNT	Multi-walled carbon nanotubes
q_r	Radiation parameter
CVFEM	Control volume finite element method

Greek symbols

φ	Concentration of nanofluid
μ	Dynamic viscosity
β	Thermal expansion coefficient
α	Thermal diffusivity
ρ	Fluid density
Ω & Ψ	Dimensionless Vorticity stream function
Θ	Dimensionless temperature
λ	Rotation angle

Subscripts

nf	Nano enhanced PCM
f	Fluid
p	Solid

1. Introduction

In the recent years, nanotechnology introduced a novel feature to augment thermal treatment of fluid [1–4]. The nanofluids have outstanding applications in modern disciplines in multiple fields of biological, agriculture, applied sciences and engineering. Nanofluids have significantly reduced the budget and enhanced efficiency of heat and cooling structures. Multiple types of Nano sized materials are helpful in numerous applications including extraction of geothermal power, cooling of micro-sized chips, nano drug delivery system, environmental sectors, industrial cooling systems, and cancer therapy, etc. According to the literature survey [5–10], it is found that fluids play a favorable role to augment thermal behavior of fluids. Bhatti et al. [11] used an efficient numerical scheme to scrutinize the simultaneous treatment of Williamson nanofluid radiative flow through a stretching sheet. Makinde et al. [12] scrutinized the features of variable viscosity in a nanofluid passing through a plate with radiation impacts. Shit et al. [13] scrutinized the irreversibility and discussed the thermal characteristics on a nanofluid propagating through an exponential porous stretching surface. The impact of rib on turbulent intensity with a water-Ag nanomaterial propagating through a trapezoidal three-dimensional micro-duct has been elaborated by Alipour et al. [14]. Hassan et al. [15] inspected the performance of hybrid nanofluids in multiple geometrical structures. Sheikholeslami [16,17] used a numerical approach to scrutinize the irreversibility analysis on the nanofluid flow using a novel computational scheme. Further, they also considered the effects of Darcy law and Lorentz force. Sheikholeslami et al. [18,19] discussed the heat transfer features on multiple types of fin using improved PCM solidification with different kinds of nanoparticles suspended in the governing fluid. Beneficial additive metallic powders were applied in various sciences [20–26]. The thermal radiation impact and Lorentz forces also an essential and novel part in numerous scientific applications of science and technology. Simultaneous influence of electric and magnetic field on a point charge due to electromagnetic fields is called as *Lorentz force*. In recent years, different authors investigated this mechanism on different kinds of nanofluids. Sheikholeslami and Ellahi [27] discussed the Electrohydrodynamic and hydrothermal nanofluid flow propagating through a closed structure with a sinusoidal upper wall.

Makinde and Animasaun [28] explored the behavior of bioconvection on magnetized nanomaterial flow with chemical reaction propagating through a parabolized surface. Recent decade, scientists utilized different techniques to augment the efficiency of systems [29–32]. Safaei et al. [33] presented a survey on convective simulation within a closed structure filled

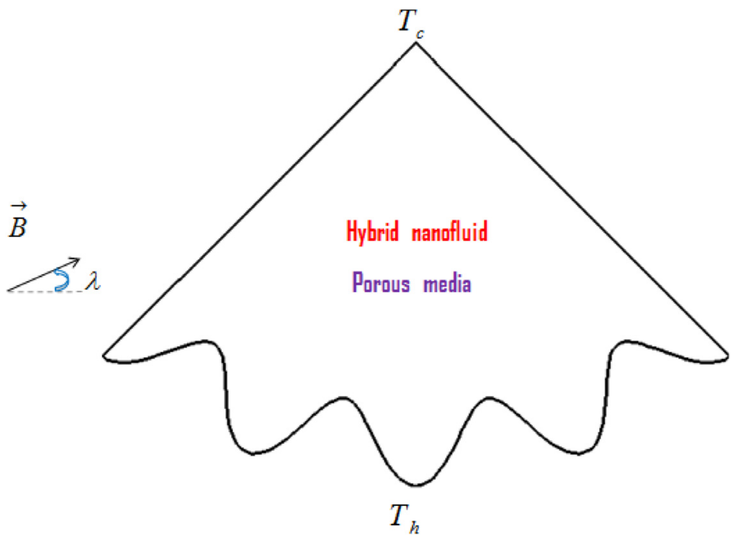

Fig. 1. Geometrical shape of porous enclosure.

with nanofluids. To reach the best design in term of irreversibility, stretching plate was examined by Bhatti et al. [34] in appearance of nanoparticles. Nanomaterial with combination of microorganisms was scrutinized by Shahid et al. [35] and they utilized SLM approach for solving the problem. Application of CNT for minimization of irreversibility was demonstrated by Akbar et al. [36]. They provided porous channel and utilized analytical technique. Changing temperature as consequence of imposing magnetic impact has been illustrated by Tripathi et al. [37] and they assumed their carrier fluid mixed with nanoparticles and channel has wavy walls. Various numerical simulations for achieving the optimized unit have been done [38–44].

The chief theme of this article is to analyze the macroscopic convection of the hybrid nanofluid (Fe_3O_4 + MWCNT) involving magnetic effect. The nanomaterial mechanism and the heat augmentation in a closed structure are more complicated as compared with the open flow structure. Such type of structure involves in energy conversion process/phase change, fabrication of solar collectors, etc. Therefore, in the present analysis, we considered a closed form structure with permeable impact. CVFEM technique is applied to examine the inclusion of all the essential parameters namely; magnetic number, Darcy number, Rayleigh number, and radiation parameter.

2. Problem definition

In current article, not only wavy wall as demonstrated in Fig. 1, but also hybrid nanomaterial have been employed to achieve the best performance of porous enclosure. The wavy wall was maintained at T_h and two other surfaces are cold walls. MWCNT and Fe_3O_4 were mixed together and provide new nanoparticles. More details for predicting the properties of combination of water with hybrid nanoparticles were listed in [45].

3. Mathematical formulation

3.1. Governing formulation

In the current paper, non-Darcy model for porous zone were involved in appearance of magnetic effect and buoyancy forces. As a consequence of assumption of nanomaterial as single phase material, the below equations have been achieved:

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

$$\begin{aligned} &\frac{\mu_{nf}}{\rho_{nf}}\left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right) - \frac{1}{\rho_{nf}}\frac{\partial P}{\partial x} - \frac{1}{\rho_{nf}}\frac{\mu_{nf}}{K}u - (T_c - T)\,\beta_{nf} g\ \sin\gamma \\ &+ \sigma_{nf} B_0^2\left[-u\,(\sin\lambda)^2 + v\,(\sin\lambda)\,(\cos\lambda)\right] = v\frac{\partial u}{\partial y} + u\frac{\partial u}{\partial x} \end{aligned} \tag{2}$$

$$\frac{\mu_{nf}}{\rho_{nf}}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right)-(T_c-T)\,\beta_{nf}g\;\cos\gamma-\frac{\partial P}{\partial y}\frac{1}{\rho_{nf}}-\frac{1}{\rho_{nf}}\frac{\mu_{nf}}{K}v$$
$$+\sigma_{nf}B_0^2\left[-v\,(\cos\lambda)^2+u\,(\sin\lambda)\,(\cos\lambda)\right]=v\frac{\partial v}{\partial y}+u\frac{\partial v}{\partial x} \tag{3}$$

$$\frac{\partial q_r}{\partial y}\left(\rho C_p\right)_{nf}^{-1}+\left(v\frac{\partial T}{\partial y}+u\frac{\partial T}{\partial x}\right)=k_{nf}\left(\rho C_p\right)_{nf}^{-1}\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right), \tag{4}$$
$$\left[T^4\cong 4{T_c}^3T-3{T_c}^4,\,q_r=-\frac{4\sigma_e}{3\beta_R}\frac{\partial T^4}{\partial y}\right]$$

According to the literature survey, it is found that to analyze the thermo features of such types of new suspension there is no specific relation. Therefore, in the present investigation, we consider the experimental data of hybrid nanofluid MWCNT-Fe_3O_4. MWCNT and Fe_3O_4 were mixed together and provide new nanoparticles. More details for predicting the properties of combination of water with hybrid nanoparticles were listed in [45] and [46]. Pressure terms discard as a consequence of using Eq. (6):

$$\begin{cases} v=-\dfrac{\partial\psi}{\partial x}, \\ u=\dfrac{\partial\psi}{\partial y} \\ -\dfrac{\partial v}{\partial x}+\omega+\dfrac{\partial u}{\partial y}=0, \end{cases} \tag{5}$$

For better description of equation, it is reasonable to rewrite all of them in non-dimensional forms with help of:

$$\alpha_{nf}u=Lu,\;v\alpha_{nf}=Lv,\;\theta=\frac{T-T_c}{\Delta T},\,\Delta T=\frac{q''L}{k_f},\,(X,Y)=(x,y)\,L^{-1},\,\Psi=\frac{\psi}{\alpha_{nf}},\,\Omega=\frac{\omega L^2}{\alpha_{nf}} \tag{6}$$

According to the above equations, we have:

$$\frac{\partial^2\Psi}{\partial X^2}+\frac{\partial^2\Psi}{\partial Y^2}=-\Omega, \tag{7}$$

$$U\frac{\partial\Omega}{\partial X}+\frac{\partial\Omega}{\partial Y}V=\Pr\frac{A_5}{A_1}\frac{A_2}{A_4}\left(\frac{\partial^2\Omega}{\partial Y^2}+\frac{\partial^2\Omega}{\partial X^2}\right)$$
$$+\Pr Ha^2\frac{A_6}{A_1}\frac{A_2}{A_4}\left(\frac{\partial U}{\partial X}\cos\lambda\sin\lambda-\frac{\partial V}{\partial X}(\cos\lambda)^2+\frac{\partial U}{\partial Y}(\sin\lambda)^2-\frac{\partial V}{\partial Y}\cos\lambda\sin\lambda\right)$$
$$+\Pr Ra\frac{A_3{A_2}^2}{A_1{A_4}^2}\left(\frac{\partial\theta}{\partial X}\cos\gamma-\frac{\partial\theta}{\partial Y}\sin\gamma\right)-\frac{\Pr}{Da}\frac{A_5}{A_1}\frac{A_2}{A_4}\Omega, \tag{8}$$

$$\frac{\partial\Psi}{\partial X}\frac{\partial\theta}{\partial Y}+\left(\frac{\partial^2\theta}{\partial X^2}\right)+\left(1+\frac{4}{3}\left(\frac{k_{nf}}{k_f}\right)^{-1}Rd\right)\frac{\partial^2\theta}{\partial Y^2}=\frac{\partial\theta}{\partial X}\frac{\partial\Psi}{\partial Y}, \tag{9}$$

In Eqs. (9) and (8), the following parameters have been used:

$$\Pr=\upsilon_f/\alpha_f,\,Ra=g\,(\rho\beta)_f\,\Delta TL^3/\left(\mu_f\alpha_f\right),\;Ha=LB_0\sqrt{\sigma_f/\mu_f} \tag{10}$$
$$A_1=\frac{\rho_{nf}}{\rho_f},A_2=\frac{\left(\rho C_p\right)_{nf}}{\left(\rho C_p\right)_f},A_3=\frac{(\rho\beta)_{nf}}{(\rho\beta)_f},$$
$$A_4=\frac{k_{nf}}{k_f},A_5=\frac{\mu_{nf}}{\mu_f},A_6=\frac{\sigma_{nf}}{\sigma_f}$$

Required boundary conditions for solving Eqs. (7)–(9) can be summarized as:

$$\begin{aligned} &\theta=1.0,\,\Psi=0.0 &&\text{on wavy wall}\\ &\theta=0.0,\,\Psi=0.0 &&\text{on other walls}\end{aligned} \tag{11}$$

One good factor for predicting thermal performance is Nusselt number and can be defined as:

$$Nu_{loc}=\frac{\partial\theta}{\partial n}\left(1+\frac{4}{3}\left(\frac{k_{nf}}{k_f}\right)^{-1}Rd\right)\left(\frac{k_{nf}}{k_f}\right) \tag{12}$$

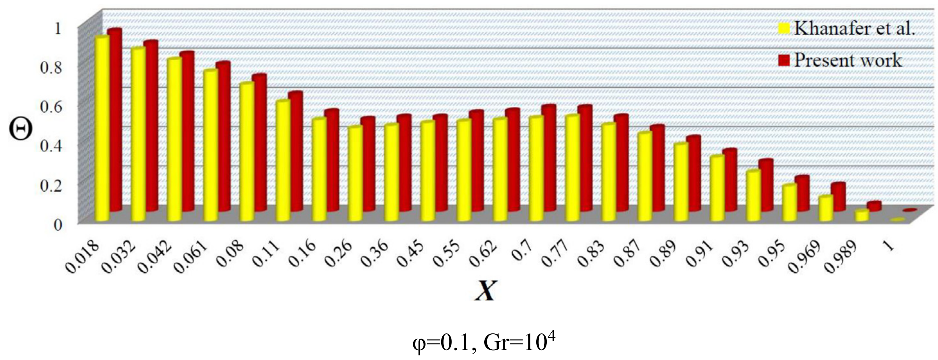

Fig. 2. Validation of CVFEM code with comparison of [29].

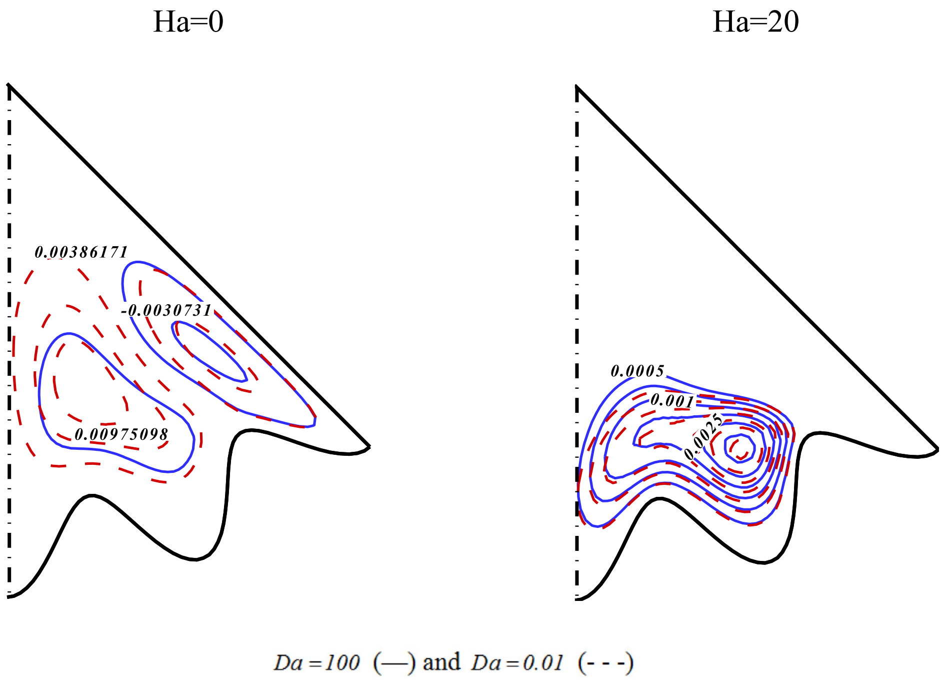

Fig. 3. Impact of Da on nanofluid treatment at $Ra = 10^3$, $Rd = 0.8$.

$$Nu_{ave} = \frac{1}{S}\int_0^S Nu_{loc}\, ds \tag{13}$$

3.2. CVFEM procedure

Sheikholeslami [10] presented a new powerful scheme to solve highly nonlinear heat transfer problems. This scheme is known as CVFEM. We used linear interpolation to determine the scalars with triangular elements. This scheme is beneficial for both FVM and FEM. In the last step, the Gauss–Seidel scheme is used to determine the scalar values. More details about solution procedure step-by-step, the reader can consult the following Ref. [10].

4. Graphical analysis, code validation and mesh analysis

Treatment of Hybrid nanomaterial under the impact of magnetic forces has been discussed in current article. To examine the inclusion of all the leading parameters, "FORTRAN" was applied. The behaviors of all the interesting parameters are plotted in Figs. 2–6. Table 1 depicts the results of Nu_{ave} for different mesh size in an angular and radial

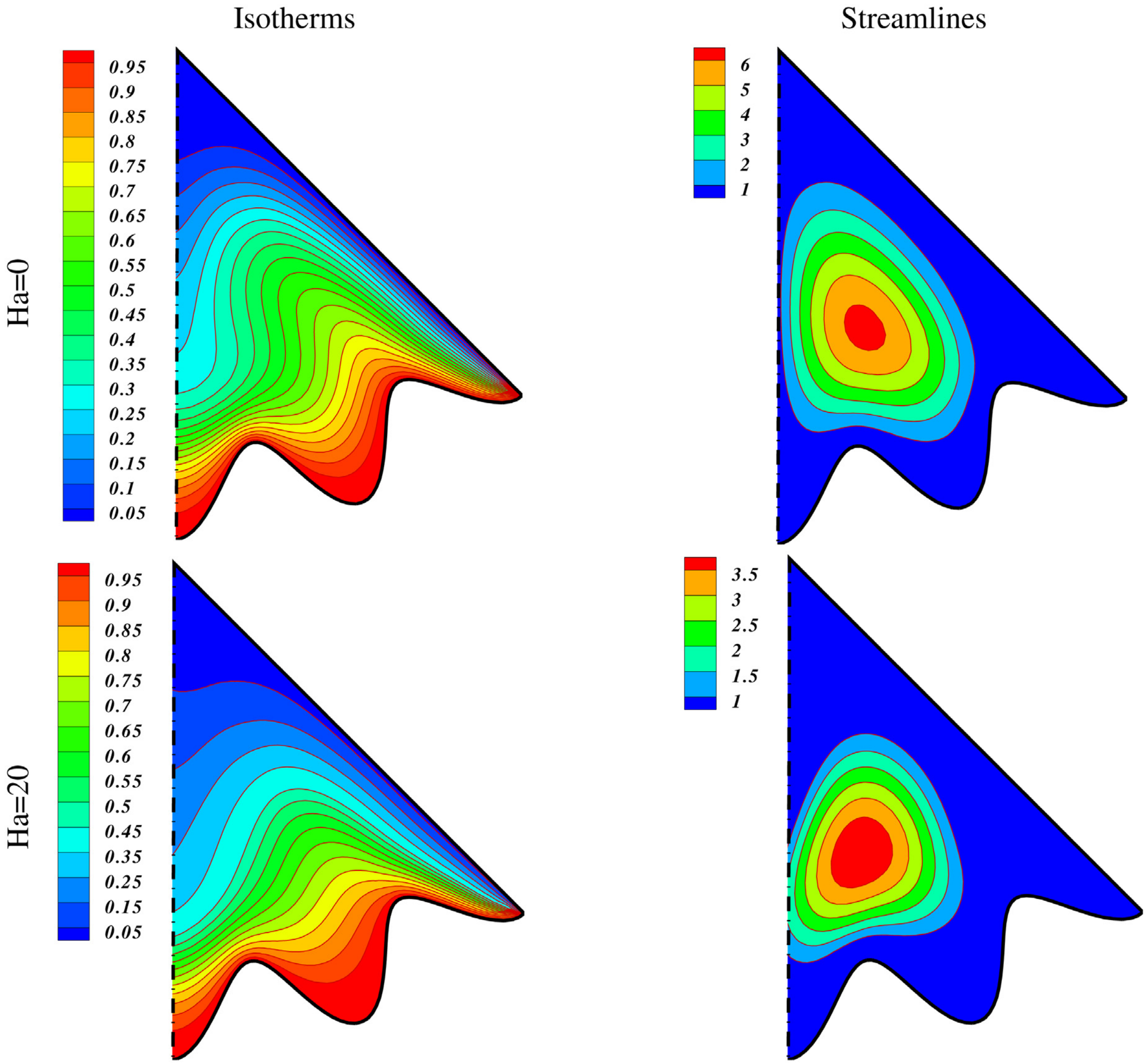

Fig. 4. Treatment of nanomaterial with changing Ha at $Ra = 10^5$, $Da = 0.01$, $Rd = 0.8$.

Table 1
Changing Nu_{ave} with altering grid size at $\phi = 0.003$, $Da = 100$, $Ha = 20$, $Rd = 0.8$, and $Ra = 10^5$.

4.7591	91 × 271
4.7566	81 × 241
4.7478	61 × 181
4.7405	51 × 151
4.7522	71 × 211
4.7478	61 × 181
4.7405	51 × 151

direction. As displayed in Fig. 2, the obtained results are correct and ensure the convergence of the solutions. Reliable outcomes are independent of grid size. So, all the states must have a grid analysis step. Furthermore, to ensure the validity of CVFEM, this code was also used in published problem [47].

Fig. 3 illustrates the role of the Darcy number on nanofluid flow against the absence and presence of the Hartmann number. As we can see from this figure that in Ha = 0, streamlines occurred in the center of the structure whereas, in non-zero Ha, the number of streamlines significantly rises and moved close to the walls of the structure. Fig. 4 reveals that the behavior of the Hartmann number does not cause a significant impact on the isotherms while its action is more essential and prominent on streamlines. As we can see from the streamlines, the stronger impact of the *Ha* tends to

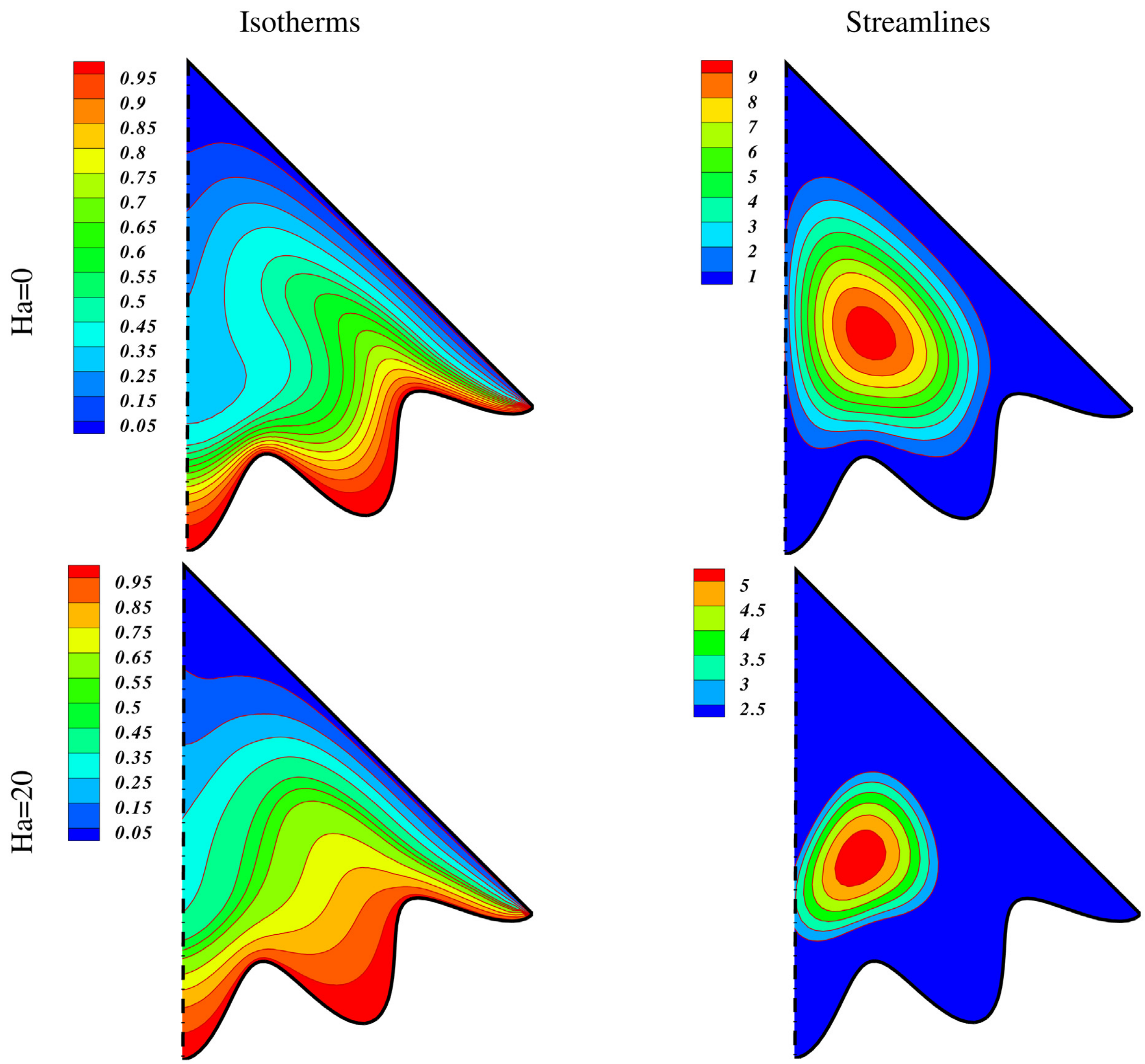

Fig. 5. Treatment of nanomaterial with changing Ha at $Ra = 10^5$, $Da = 100$, $Rd = 0.8$.

enhance the number of streamlines. Fig. 5 shows the variation for the Ha at $Da = 100$. In this figure, we noticed that at Ha = 20 the streamlines disappear more as compared with zero magnetic fields. We also noticed that the higher impact of Darcy number also creates a significant on streamlines as compared with the small value of Darcy number $Da = 0.01$ (see Fig. 4), while the isotherms performed in a similar manner. Changes of Nu_{ave} as displayed in Fig. 6 are plotted with the help of Eq. (14) utilizing the following expression

$$\begin{aligned} Nu_{ave} &= 3.09 + 1.23Rd + 0.064\log(Ra)Da^* + 0.02Da^* + 0.029Da^*Rd \\ &-0.09Ha^* - 0.031Rd\,Ha^* + -0.015Da^*Ha^* + 0.46\log(Ra) \end{aligned} \tag{14}$$

Fig. 6 shows that an enhancement in Radiation parameter and permeability tends to boost the Nu_{ave} while the behavior of Ha is converse and produces resistance for the Nusselt number.

5. Conclusions

In this paper, hybrid nanofluid (Fe_3O_4 + MWCNT) free convection within a permeable media has been modeled via CVFEM including magnetic effect. The behavior of radiation parameter, magnetic, Darcy, and Rayleigh number were analyzed with graphically. A numerical and graphical comparison is also illustrated to make sure that the present analysis is correct. From the graphical results, it is found that radiation significantly boosts the Nusselt number whereas the *Ha* shows converse impact.

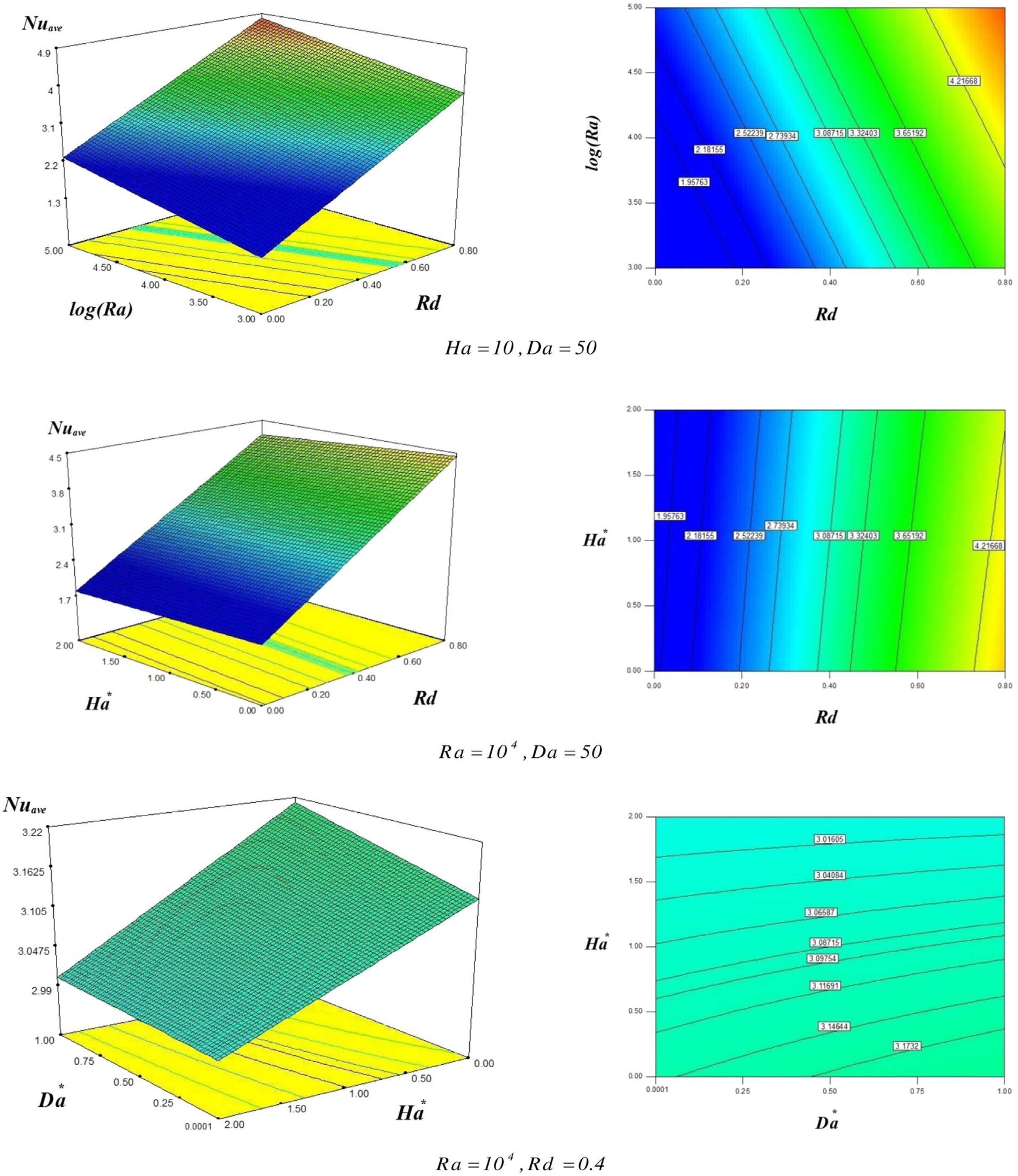

Fig. 6. Treatment of Nu_{ave} with changing Rd, Ha, Da, Ra.

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