Convection Heat Transfer of MgO-Ag /Water Magneto-Hybrid Nanoliquid Flow into a Special Porous Enclosure

Fateh Mebarek-Oudina[1,*], Fares Redouane[2] and Choudhari Rajashekhar[3]

[1]Department of Physics, Faculty of Sciences, University of 20 Août 1955-Skikda, Skikda, Algeria
[2]Department of Physics, LGIDD, University Center Ahmed Zabana, Relizane, Algeria
[3]Department of Mathematics, Vijayanagara Sri Krishnadevaraya University, Ballari, Karnataka, India.
[*]Corresponding author; Email: oudina2003@yahoo.fr; f.mebarek_oudina@univ-skikda.dz

Article Info

Article history:

Received 20 Jully 2020
Revised, 13 October 2020
Accepted 06 December 2020

Keywords:

Magnetic field
Natural convection
Hybrid-Nanofluids
Grooved Porous enclosure
FEM

ABSTRACT

This work explores numerically a computational study of free convection in a grooved porous enclosure filled with water-based hybrid-nanoliquid in the presence of an external magnetic field. To solve the governing equations of the problem, the Galerkin finite element technique is utilized. For a several governing parameters such as Rayleigh number ($10^2 \leq Ra \leq 10^6$), magnetic field parameter ($0 \leq Ha \leq 100$), Darcy number ($10^{-2} \leq Da \leq 10^{-4}$) the results are obtained and discussed via streamlines, isotherms and average Nusselt number. The magnetic field has a good regulating effect for the fluid flow and the heat transfer in porous media.

I. Introduction

The various applications of the free convection in industrial and engineering fields such as solar technology, heat exchangers, mobile device cooling, house heating and cooling systems, aeronautics, nuclear reactors, petrochemical industries and geophysical fluid dynamics are receiving significant attention from researchers and scientists around the world. The efficiency of thermal output depends on the creation of heat transfer mechanisms, especially as most engineering processes produce high temperatures. To do this, several approaches have been used to rise the efficiency of heat transfer in thermal engineering. Recently, referencing to Choi [1], nanoliquid, a colloidal blend of *NP*s into base liquids (such as water, ethylene glycol and oil), has been used to boost the effectiveness of heat transport mechanisms. As the rise in heat flow is an important problem for energy efficiency, free convection plays a crucial role in thermal engineering in nanolquid inside enclosures. In this way, a variety of computational and experimental studies are performed. The research conducted by Khanafer et al. [2] listed as the initial efforts of heat transport improvement using nanoliquid. They simulated the problem of the nanofluid heat transfer characteristics in a two-dimensional enclosure, in their investigation the heat transfer rate increases significantly with the suspended nanoparticles at any value of Grashof. Mebarek-Oudina [3] inspected the thermal and hydrodynamic characteristics of Titania nanoparticles with different base fluids utilizing cylindrical annulus. Laterly Jou and Tzeng [4] applied a model to evaluate a related analysis in nanofluid-filled rectangular cavities. The heat transfer coefficient is important in nanofuids relative to pure fluids and grows with the rise of *Ra*. In a two-sided lid-driven square enclosure, Tiwari and Das [5] built a model to study the heat transport properties of nanofuids. The suspended nanoparticles improve the base liquid's heat transfer potential, which is more pronounced with an augment in the solid volume fraction. Also, the differing *Ri* numbers and the moving walls directions influenced fluid flow and heat transfer within the cavity. Various studies using different nanoparticles and base fluids are published by different authors [6-31]. Kakac and Pramuanjaroenkij [32] found that nanofluids dramatically increase the ability of thermal processes to transfer heat. Izadi et al. [33] utilized the numerical method to analyze the effect of nanoparticles concentration and inclination angle of on mixed convection in an inclined square enclosure with a moving top wall. In another publication, Izadi et al. [34] analyzed the thermal non-equilibrium model with free convection inside a porous cavity in a micropolar nanoliquid. The heat transfer rate in the porous medium rises with a reduce in the thermal resistance of the fuel domain with an augment in the thermal conductivity ratio. Sabour et al. [35] examined the free convection of nanofuid in a square enclosure. They revealed that the improvement in heat transfer is ensured as the volume of nanofuid increases with Rayleighs number. The efficiency of the employ of nanoliquids influenced by the nanoparticles shape as well as the base liquid is also observed. In a nanofluid square cavity with separate inner geometries, Roy [36] conducted a computational analysis of free convection, the Nusselt number increases linearly with the rise in the nanoparticle volume fraction. He noticed that the form of various inner geometries influences the rising rate of the heat transfer coefficient. Bondarenko et al. [37] studied a free convection cooling device utilizing a heat-generating source and a heat-conducting portion at diverse positions on the bottom wall of a square enclosure. They found that the cooling efficiency depends on the position of the heat source due to the addition of nanoparticles in the base liquid. Using Buongiorno's nanofuid model, Elshehabey and Ahmed [38] annalyzed the mixed convection in a lid-driven enclosure. Noghrehabadi et al. [39] investigated the free convection flow of nanoliquid in a square cavity in the presence of heat source and sink. On the other hand, the study of electrically conducting fluid in the presence of magnetic field effect has signifcant applications in industrial and engineering fields such as crystal growth in liquids, cooling of microelectronic devices and nuclear reactors. Bourantas and Loukopoulos [40] utilized mesh less point collocation with velocity correction technique to simulate the transient free convection flow of micropolar nanoliquid in an inclined square enclosure subjected to a magnetic feld. The flow and temperature are affected significantly by the strength and orientation of magnetic feld. Kasaeipoor et al. [41] studied the effect of magnetized Cooper-Water nanoliquid mixed convection flow in a T-shaped cavity and proposed that some range of *Re* number and *Ha* number depends on rising heat transport rate with augmenting volume fraction. With magnetic field, Job and Gunakala [42] studied the impact of joule dissipation and viscous on two-dimensional unstable buoyancy-driven Alumina-water and SWCNT-water nanoliquids in a wavy trapezoidal enclosure. They reported that the flow propagation diminishes and the rate of heat transfer rises for greater wavy bottom wall amplitude. As the intensity values and the inclination angle of the magnetic field increase, the rate of heat transfer decreases. The flow and thermal fields influenced by the variable thermal boundary conditions are also analyzed. In a differentially heated hexagonal enclosure, Ali et al. [43] introduced the finite element method to analyze MHD free convection flow. They studied the effect of the magnetic field on free nanoliquid convection in a grooved cavity with varying thermal conditions. Due to the varying thermal conditions, flow and thermal fields are greatly affected. Also with the increase in the Rayleigh number and the nanoparticles volume fraction, the rate of heat transfer increases. An experimental investigation of the effect of the free convection in a differentially heated cubic enclosure is made by Dixit and Pattamatta [44]. They also shown that due of the magnetic field effects, the heat transport rate turns down. Alsoy-Akgün [45] later extended the Dual Reciprocity Boundary Element Approach (DRBEM) to model unstable free convection in Alumina-water nanofluid into square enclosure subjected to an uniform magnetic field. Due to *Ra* number, the effect of magnetic field on heat transfer efficiency and temperature profiles depends on buoyancy power. The effect of the concentration of nanoparticles on the liquid behaviors associated with the magnetic field parameter effect is also observed. Izadi et al. [46] are numerically studied the free convection in magnetized hybrid nanoliquid-filled porous enclosure. With rising porosity coefficient and *Ha* number, the heat transfer rate increases and decreases. The fractional volume of nanoparticles affects the streamlines. Ideal geometric modifications with additional surfaces such as fins, grooves, corrugations and baffles can also increase the performance of thermal devices. Therefore, for a basic geometric model, the disadvantage of the lower heat transfer rate motivated us to create a new geometric model with square grooves to improve the heat transport rate. In this respect, numerous experiments with various configurations are carried out to study the activities of flow and heat transfer. Han and Rhi analyzed experimentally the thermal efficiency of a grooved heated pipe filled with nanoliquid and hybrid nanoliquid [47]. They found that thermal resistance is high with increasing concentrations of nanoparticles. With the presence of an adiabatic baffle, Sharma et al. [48] studied mixed convection in a grooved channel. They concluded that the rate of heat transfer rises due to the presence of a baffle in this mode of convection. Kumar et al. [49] published an experimental analysis on turbulent free convection in a cavity with a smooth or grooved bottom area in the presence of heat fux. A numerical study on the mixed convective flow of nanoliquids in a grooved channel like solid cylinders with the efffect of magnetic field is carried out by Job and Gunakala [50]. They showed that the diverse groove geometries, cylinder radius and other related parameters influenced flow and thermal fields.

It is clear from the analysis of the literature that there is no research on free convection in a special enclosure filled with MgO-Ag / water hybrid nanofluid (50%-50%). Additionally, it is possible to use the magnetic field to regulate fluid flow and heat transfer.

The object of this work is to analyze numerically the thermal and dynamic field of the flow in terms of streamlines, and isotherms in the presence of a magnetic field in a porous medium.

In the construction of thermal equipment such as heat exchangers, electronic cooling equipment and biomedical equipment where high temperatures and fluid flow need to be controlled, the forecasts and even the results of this type of study can be a useful reference.

II. Problem Description

Figure 1 describes the physical model of the present investigation. The working fuid inside the enclosure is assumed as water. Ag, MgO are the nanoparticles used here [52], where T_c is the initial temperature.

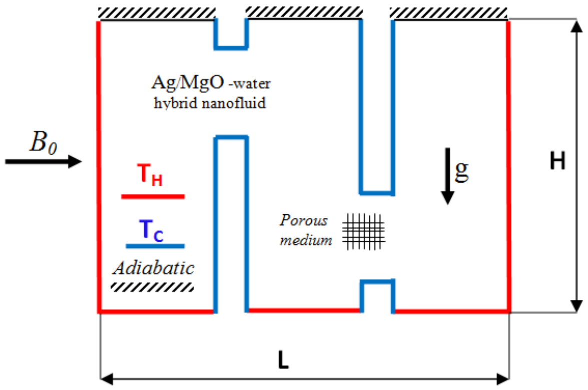


Figure 1. Scheme of the grooved enclosure used.

The thermo-physical properties of the base fluid and nanoparticles used here are detailled in Table 1.

Table 1. Base liquid and nanparticules properties. [52]

	H_2O	MgO	Ag
C_p (J/kg· k)	4179	765	383
ρ(kg/m^3)	997.1	3600	8954
K (W/m· k)	0.6	46	400
$\beta\cdot 10^{-5}$ (K^{-1})	21	0.63	1.67
$\sigma \cdot 10^{-6}(\Omega^{-1}\mathrm{m}^{-1})$	5.5	2.7	59.6

III. Validation and Grid Test Analysis

This numerical simulation is validated by comparing the present numerical results with the previously published results. We have used our numerical code to simulate the identical problem of those Ghasemi et al. [51]. The comparison shows that the results are consistent with each other. From the Fig. 2 the contours of total entropy generation are almost identical.

a b

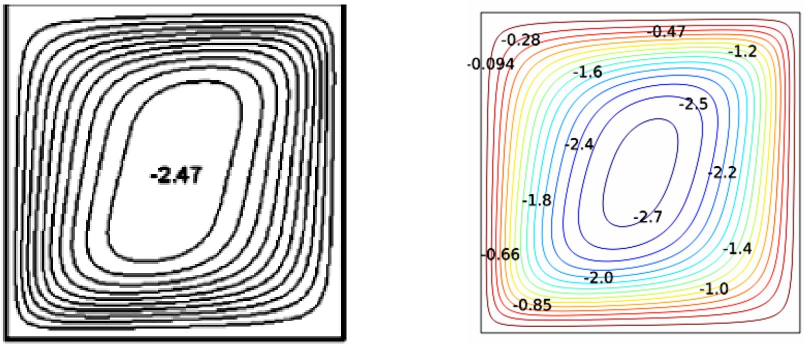


Figure 2. Streamlines results at Ra = 10^5, a)Ghasemi et *al*. [51], b)Present work.

Table 2. Grid dependency of ψ_{max} at the left heated wall when Ra = 10^6, Ha = 0, φ= 0.05 and Da = 0.1.

Number of elements	1898	4678	7258	17248	**42548**	53190
ψ_{max}	7.2665	7.2275	7.2143	7.1994	**7.1977**	7.1976

IV. Developement model

The dimensionless governing equations are:

$$\frac{\partial U}{\partial X}+\frac{\partial V}{\partial Y}=0 \quad (1)$$

$$\frac{1}{\varepsilon^2}\frac{\rho_{hnf}}{\rho_{bf}}\left(U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}\right)=-\frac{\partial P}{\partial X}+\frac{1}{\varepsilon}\frac{\upsilon_{hnf}}{\upsilon_{bf}}\frac{Pr}{\sqrt{Ra}}\left(\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2}\right)-\frac{\upsilon_{hnf}}{\upsilon_{bf}}\frac{Pr}{Da\sqrt{Ra}}U-\frac{F_c}{\sqrt{Da}}|u|U \quad (2)$$

$$\frac{1}{\varepsilon^2}\frac{\rho_{hnf}}{\rho_{bf}}\left(U\frac{\partial V}{\partial X}+V\frac{\partial V}{\partial Y}\right)=-\frac{\partial P}{\partial Y}+\frac{1}{\varepsilon}\frac{\upsilon_{hnf}}{\upsilon_{bf}}\frac{Pr}{\sqrt{Ra}}\left(\frac{\partial^2 V}{\partial X^2}+\frac{\partial^2 V}{\partial Y^2}\right)-\frac{\upsilon_{hnf}}{\upsilon_{bf}}\frac{Pr}{Da\sqrt{Ra}}V-\frac{F_c}{\sqrt{Da}}|u|V+ Pr\frac{\beta_{nf}}{\beta_f}g\theta+\frac{\sigma_{hnf}}{\rho_{hnf}}\frac{\rho_{bf}}{\rho_{hnf}}\frac{PrHa^2}{\varepsilon\sqrt{Ra}}V \quad (3)$$

Energy:

$$U\frac{\partial \theta}{\partial X}+V\frac{\partial \theta}{\partial Y}=\frac{\sigma_{hnf}}{\sigma_{bf}}\left(\frac{\partial^2 \theta}{\partial X^2}+\frac{\partial^2 \theta}{\partial Y^2}\right) \quad (4)$$

Where $\alpha_{hnf}=\frac{(\rho c_p)_{bf}k_{hnf}}{(\rho c_p)_{hnf}k_f}$ is the thermal diffusivity of the nanoliquid, $|u|=\sqrt{u^2+v^2}$ amplitude velocity $F=\frac{b}{\sqrt{a}\varepsilon^{3/2}}$ denotes the Forchheimer coefficient (where a = 150 and b = 1.75. k_{eff}) defines the operative thermal conductivity of porous medium saturated with nanofluid, where for the porous medium K is the permeability, and ε is the porosity of the medium, that can be described as: $K=\frac{\varepsilon^2 d_m^2}{150(1-\varepsilon)^2}$,The following dimensionless variables are employed to transform these governing equations:

$$X=\frac{x}{L}, Y=\frac{y}{L}, U=\frac{u.L}{\alpha_{bf}}, V=\frac{v.L}{\alpha_{bf}}, \theta=\frac{T-T_f}{T_h-T_f}, P=\frac{(p+\rho_{0bf}gy)L^2}{\rho_{bf}\alpha_{bf}^2} \quad (5)$$

Dimensionless numbers are written as:

$$Pr=\frac{\upsilon_{bf}}{\alpha_{bf}}, Da=\frac{K}{L^2}, Ha=LB_0\sqrt{\frac{\sigma_{bf}}{\mu_{bf}}}, Ra=\frac{\beta_{bf}g(T_h-T_f)L^3}{\alpha_{bf}\upsilon_{bf}} \quad (6)$$

The associated dimensionless boundary conditions are :

1. On the internal walls:

$$U=V=0, \theta=0 \quad (7)$$

2. On the top horizontal walls

$$U = V = 0, \frac{\partial \theta}{\partial Y} = 0 \tag{8}$$

3. On the bottom horizontal and vertical walls:

$$U = V = 0, \theta = 1 \tag{9}$$

IV.1. Nanofluid Thermophysical Caracteristics

Designed for nanoparticles MgO and Ag, the properties are obtained :

$$\varphi = \varphi_{MgO} + \varphi_{Ag} \tag{10}$$

$$\rho_{np} = \frac{\varphi_{MgO}\rho_{MgO} + \varphi_{Ag}\rho_{Ag}}{\varphi} \tag{11}$$

$$(c_p)_{np} = \frac{\varphi_{MgO}(c_p)_{MgO} + \varphi_{Ag}(c_p)_{Ag}}{\varphi} \tag{12}$$

$$\beta_{np} = \frac{\varphi_{MgO}\beta_{MgO} + \varphi_{Ag}\beta_{Ag}}{\varphi} \tag{13}$$

$$k_{np} = \frac{\varphi_{MgO}k_{MgO} + \varphi_{Ag}k_{Ag}}{\varphi} \tag{14}$$

$$\sigma_{np} = \frac{\varphi_{MgO}\sigma_{MgO} + \varphi_{Ag}\sigma_{Ag}}{\varphi} \tag{15}$$

$$\sigma_{hnf} = (1-\varphi)\sigma_{bf} + \varphi\sigma_{np} \tag{16}$$

$$\rho_{hnf} = (1-\varphi)\rho_{bf} + \varphi\rho_{np} \tag{17}$$

$$(\rho\beta)_{hnf} = (1-\varphi)(\rho\beta)_{bf} + \varphi(\rho\beta)_{np} \tag{18}$$

$$(\rho c_p)_{hnf} = (1-\varphi)(\rho c_p)_{bf} + \varphi(\rho c_p)_{np} \tag{19}$$

$$\alpha_{hnf} = \frac{k_{hnf}}{(\rho c_p)_{hnf}} \tag{20}$$

$$\frac{k_{hnf}}{k_{bf}} = \frac{k_{np} + (n-1)k_{bf} - (n-1)(k_{bf} - k_{np})\varphi}{k_{np} + (n-1)k_{bf} + (k_{bf} - k_{np})\varphi} \tag{21}$$

The effective dynamic viscosity based on the Brinkman mode is considered as

$$\mu_{hnf} = \frac{\mu_{bf}}{(1-\varphi)^{2.5}} \tag{22}$$

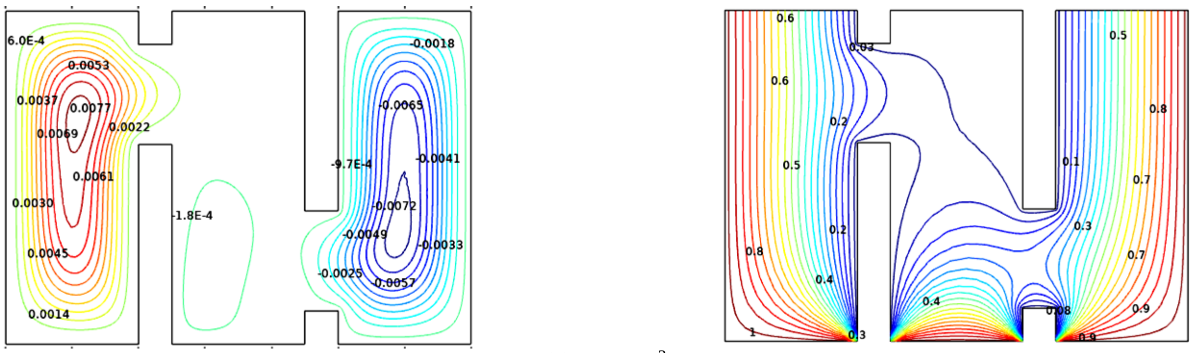
The electric conductively and the thermal conductivity respectively:

$$\frac{\sigma_{hnf}}{\sigma_{bf}} = 1 + \frac{3(\sigma_{np} - \sigma_{bf})\phi}{(\sigma_{np} + 2\sigma_{bf}) - (\sigma_{np} - \sigma_{bf})\phi} \tag{23}$$

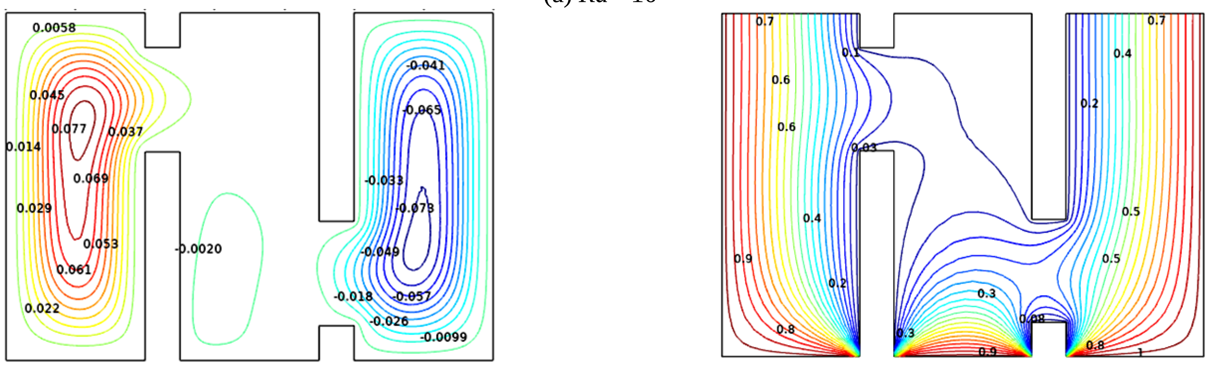
$$Nu_{local} = \frac{k_{hnf}}{k_{bf}} \frac{\partial T}{\partial y} \tag{24}$$

$$Nu_{average} = \frac{1}{L} \int_{0}^{L} Nu_{local} \, dL \tag{25}$$

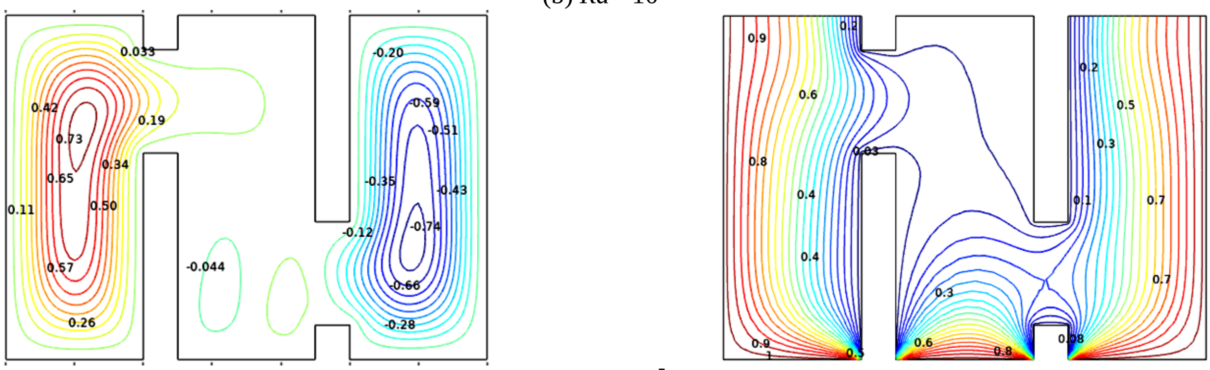
V. Graphical illustration & Discussion



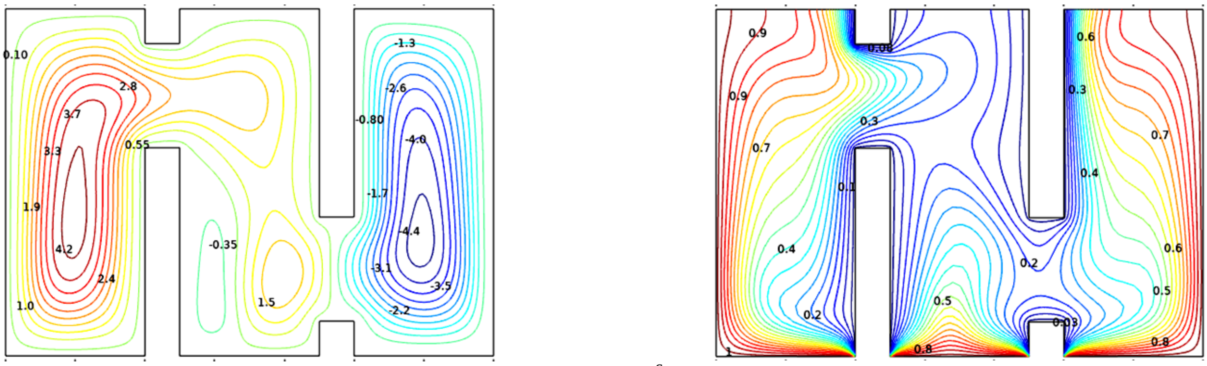
(a) $Ra = 10^3$



(b) $Ra = 10^4$

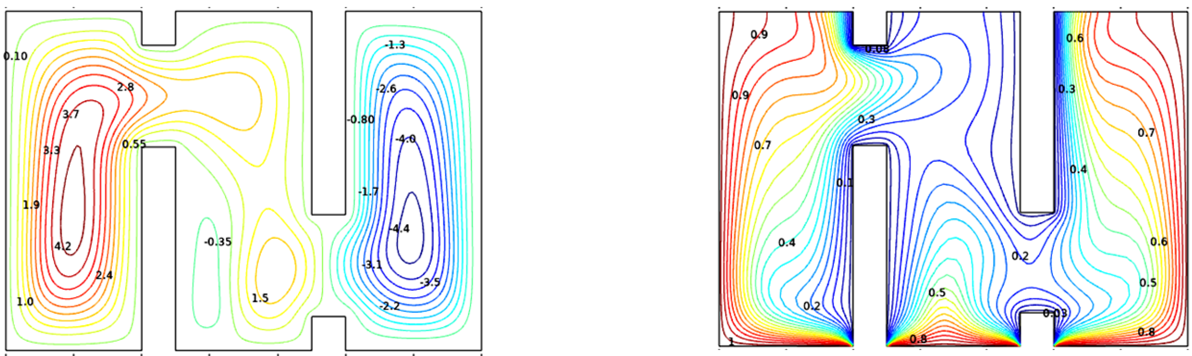


(c) $Ra = 10^5$

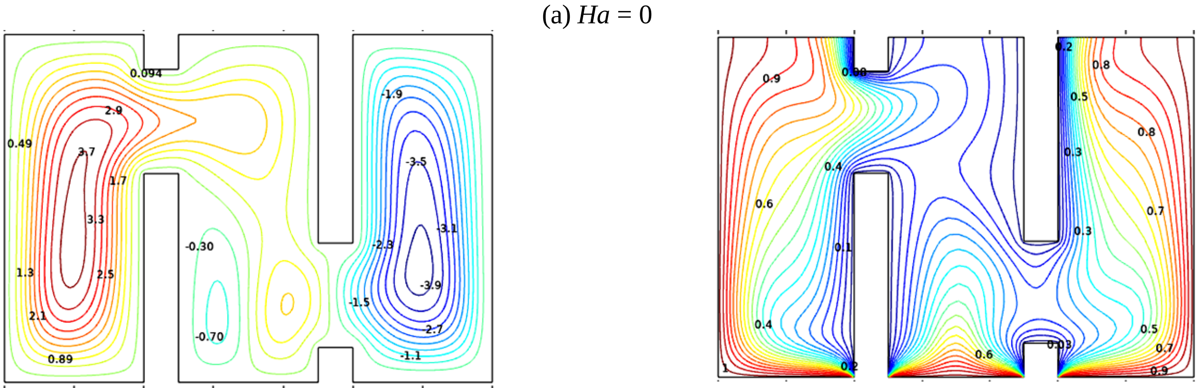


(d) $Ra = 10^6$

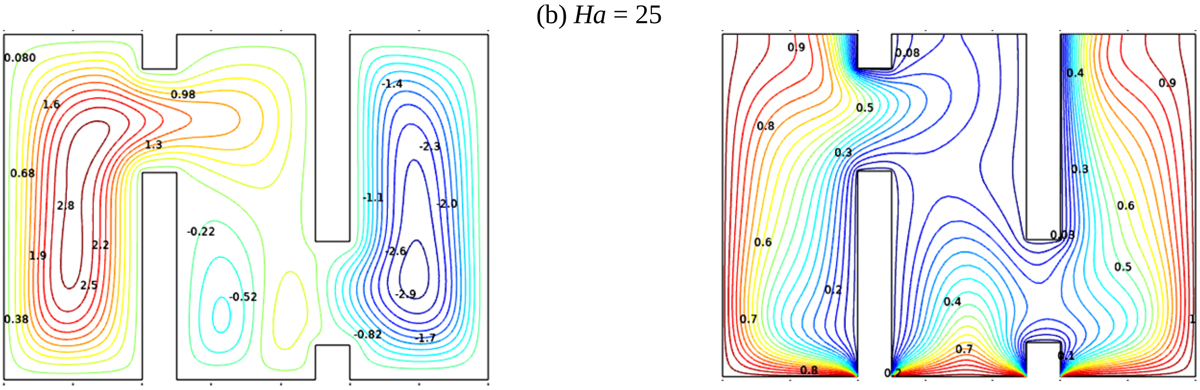
Figure 3. Variations of the streamlines (left) and isotherms (right) with various Rayleigh number (Ra), Ha = 0, Da = 0.1, ε = 0.4 and φ = 0.05.



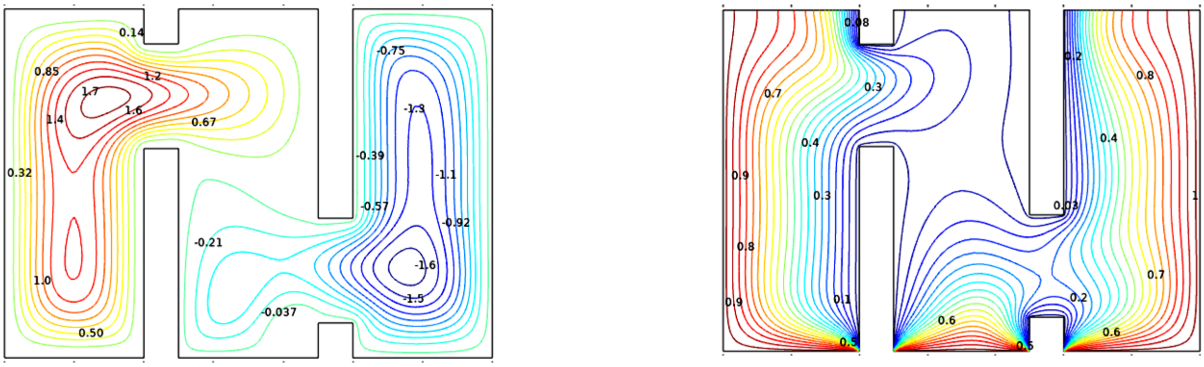
(a) Ha = 0



(b) Ha = 25



(c) Ha = 50



(d) *Ha* =100

Figure 4. Variations of the streamlines (left) and isotherms (right) with various Hartmann number (*Ha*), φ= 0.02, *Ra* =10^6 and *Da* = 0.1.

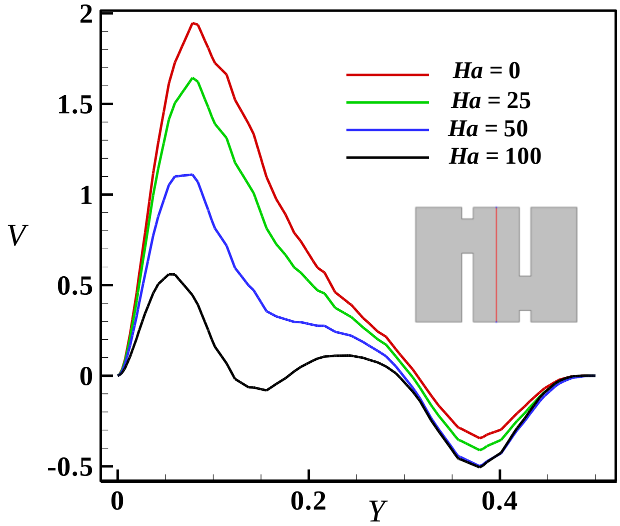


Figure 5. Vertical velocity component (*V*) vs *Ha* for φ=0.02, *Ra*=10^5.

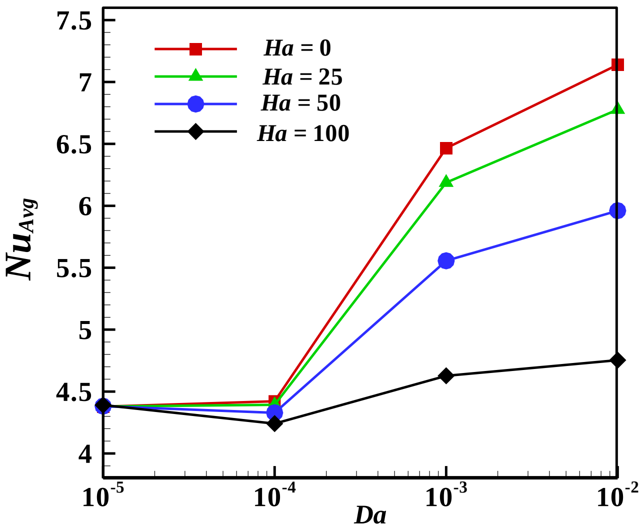


Figure 6. Nu_{Avg} vs *Da* for various *Ha*.

Figures 4 and 3 illustrate the effect of the *Ra* numbers and *Ha* numbers on the of the streamlines and isotherms, respectively. For various Rayleigh numbers (10^2 - 10^6) the study are perfomed.
For the low numbers of *Ra* the lines of the isotherms are vertical straight lines without deformation, this is very well explained by the dominant of the conductive mode. (Figs. 3 a and b)
But with the increase in the value of the *Ra* number the lines of the isotherms are deformed favoring the convective mode, and this mode of transfer persists for large values of *Ra* where the deformation of the isotherms is clear. (Fig. 3d).
Two large separate towing cells; the negative (on the right) and the positive (on the left) appear in the studied system. Keeping in mind that the maximum and minimum values are located at the center of the cells, we can clearly notice that:
1. this value increases with the increase in the *Ra* number where the voltex widens and the convective mode reigns in the flow, of which: Ψ_{max}=0.0069 for $Ra = 10^2$ and Ψ_{max}= 4.1 for $Ra = 10^6$. (Fig. 3)
2. this value increases with the rise in the intensity of the magnetic field, of which without magnetic field: Ψ_{min}=-4.4 and for $Ha = 100$ Ψ_{min}= -1.6. (Fig. 4)
In order to study the effect of the application of the magnetic field on this porous enclosure, values of *Ha* between 0 and 100 and *Da* between 10^{-2} and 10^{-4} are used. Figure 5 shows the vertical velocity profiles (*V*) for a horizontal plane located at the mid-section of the enclosure. Here, the plotted values of the velocity components indicate the direction of the fluid movement within the enclosure. By comparing the velocity profiles in the two figures, it is evident that the amplitude of the velocity components decreases with rising strength of the magnetic field. The substitution in the Nu_{avg} is demonstrated by Figure 6 along with the hot wall for various *Da* and *Ha* values, at $Ra = 10^5$, φ = 0,02, ε = 0.4. Similarly, it can be concluded that when the *Da* augments, the Nu_{avg} enhanced. Accordingly, for the *Da* at high values (i.e., $Da = 10^{-2}$), it is noticed that the process of the heat exchange is sufficient. Regarding the effect of *Ha* on heat transfer, it can be predicted that as *Ha* increases, Nu_{avg} decreases, this is due to the external magnetic field, which dominates at the suppression of the flow field. As results, for a good transfer we must lower the *Ha* number.
Regarding the effect of *Ha* on the Nu_{avg} findings, it can be predicted that as the *Ha* increases, they would decrease. This behavior can be attributed to the outside magnetic field, which dominates to the suppression of the flow field. As a consequence, the Nu_{avg} is predicted to drop with the *Ha*.

VI. Main results

In this investigation, the effects of magnetic feld on natural convection in a special enclosure filled with nanofuid are studied numerically. The dimensionless governing equations are solved using Galerkin fnite element method. Computations are performed to analyze the effects of pertinent parameters on the fluid fow, temperature and heat transfer rate, respectively.
The important conclusions can be compiled as:
1. Fluid flow strength accelerates significantly with rising *Ra* and decelerates with an augmentation in magnetic feld strength. Isotherms distributions become more concentrated with greater *Ra* and lower *Ha*.
2. The rise in *Ra* increases the convective heat transfer coefficient, and the convectif mode perciste in the range of 10^5 to 10^6.
3. The maximum and minimum values of the stream function rise with the increase in the value of the *Ra* number and the *Ha* number.
4. The magnetic field is a good regulator for the fluid flow and the heat transfer.
5. For good heat transfer, it is necessary to reduce the Hartmann number and increase the *Da* number.

References

[1] Choi, S.U.S., & Estman, A.J. (1995). Enhancing thermal conductivity of fuids with nanoparticles. *ASME-Publications-Fed*, *231*, 99–106.

[2] Khanafer, K.,Vafai, K., & Lightstone, M. (2003) Buoyancy-driven heat transfer enhancement in a two-dimensional enclosure utilizing nanofuids. *Int. J. Heat Mass Transf.*, *46*(19), 3639–3653.

[3] Mebarek-Oudina, F. (2019) Convective heat transfer of Titaniananofluids of different base fluids in cylindrical annulus with discrete heat source. *Heat Transfer—Asian Research*, *48*, 135-147. https://doi.org/10.1002/htj.21375

[4] Jou, R.Y., & Tzeng, S.C. (2006) Numerical research of nature convective heat transfer enhancement flled with nanofuids in rectangular enclosures, *Int. Commun. Heat Mass Transfer*, *33*(6), 727–736.

[5] Tiwari, R.K., & Das, M.K. (2007) Heat transfer augmentation in a twosided lid-driven diferentially heated square cavity utilizing nanofuids. *Int. J. Heat Mass Transf.*, *50* (9–10), 2002–2018.

[6] Mebarek-Oudina, F. (2017) Numerical Modeling of the Hydrodynamic Stability in Vertical annulus with Heat Source of different Lengths. *Engineering Science and Technology, 20* (4), 1324-1333. http://dx.doi.org/10.1016/j.jestch.2017.08.003

[7] Mebarek-Oudina, F., Aissa, A., Mahanthesh, B., & Öztop, F. H. (2020) Heat Transport of Magnetized Newtonian Nanoliquids in an Annular Space between Porous Vertical Cylinders with Discrete Heat Source. *International Communications in Heat and Mass Transfer*, *117*, 104737. http://dx.doi.org/10.1016/j.icheatmasstransfer.2020.104737

[8] Laouira, H., Mebarek-Oudina, F., Hussein, A., K. Kolsi, L., Merah, A., &Younis, O. (2020) Heat transfer inside a horizontal channel with an open trapezoidal enclosure subjected to a heat source of different lengths. *Heat Tran. Asian Res.*, *49* (1), 406-423. https://doi.org/10.1002/htj.21618

[9] Mebarek-Oudina, F., & Makinde, O. D. (2018) Numerical simulation of oscillatory MHD natural convection in cylindrical annulus Prandtl number effect. *Defect and Diffusion Forum*, *387*, 417-427. http://dx.doi.org/10.4028/www.scientific.net/DDF.387.417

[10] Gourari, S., Mebarek-Oudina, F., Hussein, A. K., Kolsi, L., Hassen, W., & Younis, O. (2019) Numerical Study of Natural Convection Between Two Coaxial Inclined Cylinders. *International Journal of Heat and Technology*, *37* (3), 779-786.https://doi.org/10.18280/ijht.370314

[11] Mebarek-Oudina, F., Bessaih, R., Mahanthesh, B., Chamkha, A. J., & Raza, J. (2020) Magneto-Thermal-Convection Stability in an Inclined Cylindrical Annulus filled with a Molten Metal. *International Journal of Numerical Methods for Heat & Fluid Flow*, https://doi.org/10.1108/HFF-05-2020-0321

[12] Marzougui, S., Mebarek-Oudina, F., Aissa, A., Magherbi, M., Shah, Z., & Ramesh, K. (2020) Entropy Generation on Magneto-Convective Flow of Copper-Water Nanofluid in a Cavity with Chamfers, *Journal of Thermal Analysis and Calorimetry*, http://dx.doi.org/10.1007/s10973-020-09662-3

[13] Zaim, A. Aissa, A. Mebarek-Oudina, F. Rashad, A. M. Hafiz, M. A. Sahnoun, M. El Ganaoui, M. (2020) Magnetohydrodynamic natural convection of hybrid nanofluid in a porous enclosure: Numerical analysis of the entropy generation. *Journal of Thermal Analysis and Calorimetry*, *141* (5), 1981-1992. https://doi.org/10.1007/s10973-020-09690-z

[14] Raza, J., Mebarek-Oudina, F., Ram, P., Sharma, S. (2020) MHD Flow of Non-Newtonian Molybdenum Disulfide Nanofluid in a Converging/Diverging Channel with Rosseland Radiation, *Defect and Diffusion Forum*, *401*, 92-106. http://dx.doi.org/10.4028/www.scientific.net/DDF.401

[15] Khan, U., Zaib, A., & Mebarek-Oudina, F. (2020) Mixed convective magneto flow of SiO_2-MoS_2/$C_2H_6O_2$ hybrid nanoliquids through a vertical stretching/shrinking wedge: Stability analysis, *Arabian Journal for Science and Engineering*, *45* (11), 9061-9073, https://doi.org/10.1007/s13369-020-04680-7

[16] Raza, J., Mebarek-Oudina, F. & Chamkha, A. (2019) Magnetohydrodynamic flow of molybdenum disulfide nanofluidin a channel with shape effects. *Multidiscipline Modeling in Materials and Structures*, *15* (4), 737-757.http://dx.doi.org/10.1108/MMMS-07-2018-0133

[17] Zaim, A., Aissa, A., Mebarek-Oudina, F., Mahanthesh, B., Lorenzini, G., Sahnoun, M. (2020) Galerkin finite element analysis of magneto-hydrodynamic natural convection of Cu-water nanoliquid in a baffled U-shaped enclosure. Propulsion and Power Research, https://doi.org/10.1016/j.jppr.2020.10.002

[18] Farhan, M., Omar, Z., Mebarek-Oudina, F., Raza, J., Shah, Z., Choudhari, R.V., & Makinde, O. D. (2020) Implementation of one Step one Hybrid Block Method on Nonlinear Equation of the Circular Sector Oscillator. *Comput. Math. Model.*, *31* (1), 116-132, https://doi.org/10.1007/s10598-020-09480-0

[19] Mebarek-Oudina, F., Laouira, H., Aissa, A., Hussein, A. K., El Ganaoui, M. (2020) Convection Heat Transfer Analysis in a Channel with an Open Trapezoidal Cavity: Heat Source Locations effect. *MATEC Web of Conference*, *330*, 01006, https://doi.org/10.1051/matecconf/202033001006

[20] Raza, J., Mebarek-Oudina, F., & Mahanthesh, B. (2019) Magnetohydrodynamic Flow of Nano Williamson Fluid Generated by Stretching Plate with Multiple Slips. *Multidiscipline Modeling in Materials and Structures*, *15* (5), 871-894, https://doi.org/10.1108/MMMS-11-2018-0183

[21] Swain, K., Mahanthesh, B., & Mebarek-Oudina, F. (2020) Heat transport and stagnation-point flow of magnetized nanoliquid with variable thermal conductivity with Brownian momentand thermophoresis aspects. *Heat Transfer*, https://doi.org/10.1002/htj.21902

[22] Hamrelaine, S., Mebarek-Oudina, F., Sari, M. R. (2019) Analysis of MHD Jeffery Hamel Flow with Suction/Injection by Homotopy Analysis Method, *J. Adv. Res. Fluid Mech. Therm. Sciences*, *58* (2) 173-186.

[23] Raza, J., Farooq, M., Mebarek-Oudina, F., & Mahanthesh, B. (2019) Multiple Slip Effects on MHD Non-Newtonian Nanofluid Flow Over a Nonlinear Permeable Elongated Sheet : Numerical and Statistical Analysis. *Multidiscipline Modeling in Materials and Structures*, *15* (5) 913-931, https://doi.org/10.1108/MMMS-11-2018-0190

[24] Alkasassbeh, M.,Omar, Z., Mebarek-Oudina, F., Raza, J.& Chamkha, A. J. (2019) Heat transfer study of convective fin with temperature-dependent internal heat generationby hybrid block method. *Heat Transfer-Asian Research*, *48* (4), 1225-1244. https://doi.org/10.1002/htj.21428

[25] Marzougui, S., Bouabid, M., Mebarek-Oudina, F., Abu-Hamdeh, N., Magherbi, M., & Ramesh, K. (2020) A computational analysis of heat transport irreversibility phenomenon in a magnetized porous channel. *International Journal of Numerical Methods for Heat & Fluid Flow*, https://doi.org/10.1108/HFF-07-2020-0418

[26] Mebarek-Oudina, F., Keerthi Reddy N., & Sankar, M. (2021) Heat Source location Effects on Buoyant Convection of Nanofluids in an Annulus. Advances in Fluid Dynamics. *Lecture Notes in Mechanical Engineering*, 923-937. https://doi.org/10.1007/978-981-15-4308-1_70

[27] Mebarek-Oudina, F., & Bessaïh, R. (2007) Magnetohydrodynamic Stability of Natural Convection Flows in Czochralski Crystal Growth. *World Journal of Engineering*, *4*(4), 15-22.

[28] Swain, K., Mebarek-Oudina, F., & Abo-Dahab, S.M. (2020) Influence of MWCNT/Fe_3O_4 hybrid-nanoparticles on an exponentially porous shrinking sheet with variable magnetic field and chemical reaction. *Journal of Thermal Analysis and Calorimetry*, https://doi.org/10.1007/s10973-020-10432-4

[29] Abo-Dahab, S. M., Abdelhafez, M. A., Mebarek-Oudina, F., & Bilal, S. M. (2020) MHD Casson Nanofluid Flow over Nonlinearly Heated Porous Medium in presence of Extending Surface effect with Suction/Injection. *Indian Journal of Physics*, https://doi.org/10.1007/s12648-020-01923-z

[30] Mebarek-Oudina, F., & Bessaïh, R. (2010) Oscillatory Mixed Convection Flow in a Cylindrical Container with Rotating Disk Under Axial Magnetic Field and Various Electric Conductivity Walls. *I. Review of PHYSICS*, *4* (1), 45-51.

[31] Rajashekhar, C., Vaidya, H., Mebarek-Oudina, F., Prasad K. V., & Balachandra, H. (2020) Combined effects of homogeneous and heterogeneous reactions on peristalsis of Ree-Eyring liquid: application to hemodynamic flow. *Heat Transfer*, https://doi.org/10.1002/htj.21995

[32] Kakaç, S., & Pramuanjaroenkij, A. (2009) Review of convective heat transfer enhancement with nanofuids. *Int. J. Heat Mass Transf.*, *52*(13–14), 3187–3196.

[33] Izadi, M., Behzadmehr, A., & Shahmardan, M.M. (2015) Efects of inclination angle on mixed convection heat transfer of a nanofuid in a square cavity. *Int J Comput Methods Eng. Sci. Mech.*, *16*(1), 11–21.

[34] Izadi, M., Mehryan, S.A.M., & Sheremet, M.A. (2018) Natural convection of CuO-water micropolarnanofuids inside a porous enclosure using local thermal non-equilibrium condition. *J. Taiwan Inst. Chem. Eng.*, *88*, 89–103.

[35] Sabour, M., Ghalambaz, M., & Chamkha, A. (2017) Natural convection of nanofuids in a cavity: criteria for enhancement of nanofuids. *Int. J. Numer. Meth. Heat Fluid Flow*, *27*(7), 1504–1534.

[36] Roy, N.C. (2018) Natural convection of nanofuids in a square enclosure with diferent shapes of inner geometry. *Physics of Fluids*, *30*(11), 113605.

[37] Bondarenko, D.S., Sheremet, M.A.,Oztop, H.F., & Ali, M.E. (2019) Naturalconvection of Al_2O_3/H_2O nanofuid in a cavity with a heat-generating element Heatline visualization. *Int. J. Heat Mass Transf.*, *130*, 564–574.

[38] Elshehabey, H.M., & Ahmed, S.E. (2015) MHD mixed convection in a lid-driven cavity filled by a nanofuid with sinusoidal temperature distribution on the both vertical walls using Buongiorno'snanofuid model. *Int. J. Heat Mass Transf*., *88*, 181–202.

[39] Noghrehabadi, A., Samimi Behbahan, A., & Pop, I. (2015) Thermophoresis and Brownian efects on natural convection of nanofuids in a square enclosure with two pairs of heat source/sink. *Int. J. Numer. Methods Heat Fluid Flow*, *25*(5), 1030–1046.

[40] Bourantas, G.C., & Loukopoulos, V.C. (2014) MHD natural-convection fow in an inclined square enclosure flled with a micropolar nanofuid. *Int. J. Heat Mass Transf.*, *79*, 930–944.

[41] Kasaeipoor, A., Ghasemi, B., & Aminossadati, S.M. (2015) Convection of Cu-water nanofuid in a vented T-shaped cavity in the presence of magnetic feld. *Int. J. Therm. Sci.*, *94*, 50–60.

[42] Job, V.M., & Gunakala, S.R. (2016) Unsteady MHD free convection nanofuidfows within a wavy trapezoidal enclosure with viscous and Joule dissipation efects. *Numer. Heat Transf. Part A Appl*., *69*(4), 421–443.

[43] Ali, M.M., Alim, M.A., Akhter, R., & Ahmed, S.S. (2017) MHD natural convection fow of CuO/water nanofuid in a diferentially heated hexagonal enclosure with a tilted square block, *Int. J. Appl. Comput. Math.*, *3*(1), 1047–1069.

[44] Dixit, D.D. & Pattamatta, A. (2019) Natural convection heat transfer in a cavity flled with electrically conducting nano-particle suspension in the presence of magnetic feld, *Phys Fluids*, *31*(2), 023302.

[45] Alsoy-Akgün, N. (2019) Effect of an uniform magnetic feld on unsteady natural convection of nanofuid, *J. Taibah Univ. Sci.*, *13*(1), 1073–1086.

[46] Izadi, M.,Maleki, N.M., Pop, I., & Mehryan, S.A.M. (2019) Natural convection of a hybrid nanofuid subjected to non-uniform magnetic feld within porous medium including circular heater. *Int J Numer Methods Heat Fluid Flow*, *29*(4), 1211–1231.

[47] Woo-Sung, H.A.N., & Seok-Ho, R.H.I. (2011) Thermal characteristics of grooved heat pipe with hybrid nanofuid.Thermal Science, *15*(1), 195–206.

[48] Sharma, A.K., Mahapatra, P.S., Manna, N.K., & Ghosh, K. (2015) Mixed convection heat transfer in a grooved channel in the presence of a bafle. *Numerical Heat Transf Part A*, *67*, 1097–1118.

[49] Kumar, L.G.K., Kumar, S.R., & Subudhi, S. (2016) Experimental study of the turbulent free convection over horizontal smooth or grooved surfaces in an open cavity. *Heat Mass Transfer*, *52*(2), 245–253.

[50] Job, V.M., & Gunakala, S.R. (2017) Mixed convection nanofuidfows through a grooved channel with internal heat generating solid cylinders in the presence of an applied magneticfeld. *International Journal of Heat Mass Transfer*, *107*, 133–145.

[51] Ghasemi, B. Aminossadati, S.M. Raisi, A. Magnetic feldefect on natural convection in a nanofuid-flled square enclosure. Int. J. Therm Sci., 2011, 50, 1748–1756.

[52] Davarnejad, R., & Jamshidzadeh, M. (2015) CFD modeling of heat transfer performance of MgO-water nanofluid under turbulent flow. *Eng. Sci. Technol. Int. J.*, *18*, 536–42. https://doi.org/10.1016/j.jestch.2015.03.011

How to cite this paper:
Mebarek-Oudina F, Fares R, Choudhari R. Convection Heat Transfer of MgO-Ag /Water Magneto-Hybrid Nanoliquid Flow into a Special Porous Enclosure. Algerian Journal of Renewable Energy and Sustainable Development, 2020, 2(2),84-95. https://doi.org/10.46657/ajresd.2020.2.2.1