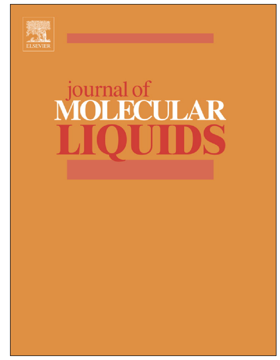


Numerical investigation of Fe3O4 nanoparticles transportation due to electric field in a porous cavity with lid walls

Dongming Zhao, Mohammadali Hedayat, Azeez A. Barzinjy, Rebwar Nasir Dara, Ahmad Shafee, Iskander Tlili

PII: S0167-7322(19)32227-5

DOI: https://doi.org/10.1016/j.molliq.2019.111537

Reference: MOLLIQ 111537

To appear in: *Journal of Molecular Liquids*

Received date: 18 April 2019

Revised date: 6 August 2019

Accepted date: 7 August 2019

Numerical investigation of Fe_3O_4 nanoparticles transportation due to electric field in a porous cavity with lid walls

Dongming Zhao [a], Mohammadali Hedayat [b], Azeez A. Barzinjy [c,d], Rebwar Nasir Dara [e], Ahmad Shafee [f], Iskander Tlili [1,g,h]

[a] School of Automation, Wuhan University of Technology, Hubei Wuhan 430070, China
[b] J. Mike Walker '66 Department of Mechanical Engineering, Texas A&M University, College Station, USA
[c] Computer Department, Cihan University-Erbil, Iraq
[d] Physics Department, College of Education, Salahaddin University-Erbil, Kurdistan Region – Iraq
[e] Department of Petroleum Engineering, College of Engineering, Knowledge University, Erbil, Iraq
[f] Public Authority of Applied Education & Training, College of Technological Studies, Applied Science Department, Shuwaikh, Kuwait
[g] Department for Management of Science and Technology Development, Ton Duc Thang University, Ho Chi Minh City, Vietnam
[h] Faculty of Applied Sciences, Ton Duc Thang University, Ho Chi Minh City, Vietnam

Abstract

Impact of electric-field with Fe_3O_4 nanoparticles transportation through porous cavity with lid walls is examined. The ethylene glycol as pure fluid with nanoparticles shape and radiation are used. The characteristics of testing fluid strongly rely on voltage and nanoparticles' shape. The CVFEM is utilized to obtain numerical results aftermaths. Plots are acquired for voltage, radiation and nanoparticles' shape. Outcomes demonstrate that higher values of permeability lead to greater Nusselt number. It is also found that convection enhances with rise of electric force.

Keywords: Nanofluid; Radiation; EHD; CVFEM; Shape factor; Permeable space.

[1] Corresponding author: Department for Management of Science and Technology Development, Ton Duc Thang University, Ho Chi Minh City, Vietnam

Email: iskander.tlili@tdtu.edu.vn (Iskander Tlili)

1. Introduction

Magnetite Fe3O4 nanoparticles are synthesized, characterized and applied as magnetic adsorbing transporters in this investigation. In recent times, Fe3O4 nanoparticles are probably the most explored magnetic material by several researchers due to its application such as, carters for drug delivery, biomolecules separation, treating cancerous cells of lung by hyperthermia, bone cancer treatment, magnetic separation in detoxification of biological fluids, magnetic resonance imaging, removal of organic/inorganic pollutants, coating materials including polymers, spin polarization and noble metals [1-7]. More uses pertaining to Fe3O4 nanoparticles embrace contrast enrichment in repeated adsorption trials, tunable optical fiber, optical modulators and switches [8-14]. Thus, one can conclude that Fe3O4 nanoparticles are very much promising due to the massive advantages of high dispersion and extraordinary reactivity. Ferrofluid becomes more popular in previous years [15-23]. Yan et al. [24] investigated experimentally and numerically the heat conductivity property of water (as fluid) with SiO_2 (as nanoparticle) as a nanofluid in the vacuum tube which use in the solar unit. Thermal conductivity raised by increasing of nano-sized-particles in the experimental investigation which was performed by varied mass of nano-sized-particles. On the other hand, the numerical study indicated improvement in the temperature, working fluid velocity and process of the heat conductivity process elevated as well. An investigation which is done experimentally and numerically by Rashed et al. [25] to cool down CPU by nanofluid CuO, the values of thermal and conductance resistance numerically gained, were in a good match with those results that were achieved from experimental. The convection effects in the appearance of entropy in a permeable tank packed with nanoliquid are examined by Baghaz et al. [26]. Significant efforts on the study of ferrofluids have been devoted but the interaction of ferrofluids with an electrical field has neither received sufficient attention experimentally nor on theoretical side.

Kumar et al. [27] have reported the resistance of magneto Fe3O4 nanoparticles. They found that utmost resistance of ferromagnetic near to its magnetic coercivity. Effects of magnetic with nanofluid filled inside the wavy surface is examined by Cho [28]. For improving thermal treatment, researchers were developed innovate ways [29-49]. The permeability affects heat transfer from a porous media. A relation between permeability and Kn number was developed for the first time by Dehdashti [50] for meso-scale problems. Extending the relation to the heat transfer problems, the impact of Darcy can be studied. PTSC utilizing the method of minimizing entropy generation was investigated by Mwesigye et al. [51], while the tube as a receiver, is filled by the heat transferring nanofluid named oil-Al_2O_3. They revealed that not only the heat transfer function rocketed considerably by 35%, 54% and 76% while the fraction of mass went up from zero to 4%, 6% and 8% respectively, the thermal efficiency experienced 7.6% improvement. To simulate behavior of fluid, various computational approaches can be used [52-86]. CVFEM is the new technique and it uses for various field of sciences [87-101] and in all of them were successful. The report which was presented by Azmi et al. [102], revealed that the nanofluid TiO2 with a concentration of 1.0% volume in the lack of inserts, rose 23.2% the transfer of heating, while transfer of heating enhanced 48.1% utilizing the twisted ribbon inserts because friction parameter was nearly twice in comparison with pure water.

The existing literature bears witness that Fe3O4 nanoparticles in the presence of electric field through lid walls having porous cavity with ethylene glycol and radiation is yet not examined. Inspired by the said truth, this effort is devoted to fill the gap in existing literature. The nonlinear governing equations are tacked efficient method, CVFEM with triangular element. After brief literature survey given in introduction, the subsequent steps are designed as: Second segment talks about mathematical formulation. Next part offers solutions procedure. The code validation, mesh analysis and graphical interpretation are specified in second last. Key findings sum up in last phase.

2. Problem explanation

The porous shell linked with allied boundary situations are exposed in Fig. 1(a). Sample element which was used in CVFEM were shown in Fig. 1(b). For higher Darcy number, more complex contour for electrical density is considered and demonstrated in Fig. 2. The simulation in this graph indicated that the electric density contour goes up due to increase of Da.

3. Governing equations and CVFEM

3.1. Formulation

First we have to obtained electric- force by mans of the following equations [103]:

$$\vec{\mathrm{J}} = q\vec{V} + \sigma\vec{E} - D\nabla q \tag{1}$$

$$\nabla.\varepsilon\vec{E} = q \tag{2}$$

$$\vec{E} = -\nabla\varphi \tag{3}$$

$$\nabla.\vec{\mathrm{J}} = -\frac{\partial q}{\partial t} \tag{4}$$

Initial format of equations respect to [103] are:

$$\begin{cases} q - \nabla.\varepsilon\vec{E} = 0, -\nabla\varphi = \vec{E}, \dfrac{\partial q}{\partial t} + \nabla.\vec{\mathrm{J}} = 0, \\ -\dfrac{\nabla p}{\rho_{nf}} - \dfrac{\vec{V}\,\mu_{nf}}{K\,\rho_{nf}} + \dfrac{\mu_{nf}}{\rho_{nf}}\nabla^2\vec{V} = \left(\dfrac{\partial\vec{V}}{\partial t} + \left(\vec{V}.\nabla\right)\vec{V}\right) - \dfrac{q\,\vec{E}}{\rho_{nf}}, \\ \left(\left(\vec{V}.\nabla\right)T + \dfrac{\partial T}{\partial t}\right) = \dfrac{k_{nf}}{\left(\rho C_p\right)_{nf}}\nabla^2 T + \dfrac{\vec{\mathrm{J}}.\vec{E}}{\left(\rho C_p\right)_{nf}} - \left(\rho C_p\right)_{nf}^{-1}\dfrac{\partial q_r}{\partial y}, \left[T^4 \cong 4T_c^3 T - 3T_c^4, q_r = -\dfrac{4\sigma_e}{3\beta_R}\dfrac{\partial T^4}{\partial y}\right] \\ \nabla.\vec{V} = 0, \end{cases}, \tag{5}$$

To estimate nanofluid properties, the homogeneous model has been used. This model needs lower time for modeling. The mathematical expressions of $(\rho C_p)_{nf}$, μ_{nf} and ρ_{nf} are [104]

$$\begin{aligned} &\aleph_{nf} = (1-\phi)\aleph_f + \phi\aleph_s, \aleph = \rho C_p \\ &\mu = A_1 + A_2(\Delta\varphi) + A_3(\Delta\varphi)^2 + A_4(\Delta\varphi)^3, \\ &\rho_{nf} = \rho_f(1-\phi) + \rho_s\phi \end{aligned} \tag{6}$$

$$\frac{k_{nf}}{k_f} = \frac{\left(k_p - k_f\right)\phi + mk_f + k_p + k_f - m\left(k_f - k_p\right)\phi}{k_f + mk_f + \left(k_f - k_p\right)\phi + k_p} \tag{7}$$

To gain the properties of iron oxide and base fluid, we utilized the same formulation and properties which were written in ref. [104].

Final forms of equations are:

$$\begin{cases} \nabla.\vec{V} = 0, \\ \dfrac{S_E}{\rho_{nf}/\rho_f} q\vec{E} + \dfrac{1}{\mathrm{Re}} \dfrac{\rho_{nf}/\rho_f}{\mu_{nf}/\mu_f} \nabla^2\vec{V} - \nabla p - \dfrac{1}{\mathrm{Re}\,Da} \dfrac{\mu_{nf}}{\mu_f} \left(\dfrac{\rho_{nf}}{\rho_f}\right)^{-1} \vec{V} = \left(\left(\vec{V}.\nabla\right)\vec{V} + \dfrac{\partial\vec{V}}{\partial t}\right) \\ \left(\left(\vec{V}.\nabla\right)\theta + \dfrac{\partial\theta}{\partial t}\right) = \dfrac{1}{\mathrm{Pr}\,\mathrm{Re}} \dfrac{k_{nf}/k_f}{\left(\rho C_p\right)_{nf}/\left(\rho C_p\right)_f} \nabla^2\theta + Ec\left(\vec{\mathrm{J}}.\vec{E}\right) S_E \dfrac{\left(\rho C_p\right)_f}{\left(\rho C_p\right)_{nf}} + \dfrac{4}{3}\left(\dfrac{k_{nf}}{k_f}\right)^{-1} Rd \dfrac{\partial^2\theta}{\partial Y^2} \\ \vec{E} + \nabla\varphi = 0, \nabla.\vec{\mathrm{J}} + \dfrac{\partial q}{\partial t} = 0, q = \nabla.\varepsilon\vec{E} \end{cases} \tag{8}$$

$$\begin{aligned} &\left(\bar{u},\bar{v}\right) = \frac{(u,v)}{U_{Lid}}, \bar{\varphi} = \frac{\varphi-\varphi_0}{\nabla\varphi}, \theta = \frac{T-T_0}{\nabla \mathrm{T}}, \\ &\bar{t} = \frac{tU_{Lid}}{L}, \bar{p} = \frac{P}{\rho U_{Lid}^{2}} \bar{q} = \frac{q}{q_0}, \bar{E} = \frac{E}{E_0}, \\ &\nabla \mathrm{T} = T_1 - T_0, \nabla\varphi = \varphi_1 - \varphi_0, \left(\bar{y},\bar{x}\right) = \frac{(y,x)}{L}, \end{aligned} \tag{9}$$

To remove pressure terms, below formulation should be applied.

$$v = -\frac{\partial\psi}{\partial x}, \omega = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}, \frac{\partial\psi}{\partial y} = u, \Omega = \frac{\omega}{LU_{Lid}}, \Psi = \frac{\psi L}{U_{Lid}} \tag{10}$$

3.2. CVFEM procedure

There are innumerable ways to study the effects of nanoparticles. However, most of the conventional techniques are infeasible for practical utilization for the reason that they comprise numerous steps, like involve time, material, sources, energy and material-consuming methods. The CVFEM is particularly suitable for heat transfer [105] which collectively benefits to both FEM and FVM. The triangular element via linear interpolation is utilized to calculate scalars and in the last step, the Gauss-Seidel way is engaged to estimate the values of scalars.

The associated Nusselt numbers Nu_{loc} and Nu_{ave} are obtained as:

$$Nu_{loc} = \frac{\partial \Theta}{\partial X}\left(\left(\frac{k_{nf}}{k_f}\right) + \frac{4}{3}Rd\right) \tag{11}$$

$$Nu_{ave} = \frac{1}{L}\int_0^L Nu_{loc}\, dY \tag{12}$$

4. Results and discussion

This unit dedicates to three sub sections namely, mesh analysis, code validation and graphical interpretation by discussing the role of significant physical parameters associated with the proposed study. The reliable outputs always must be independent of mesh size. Consequently, all states must require the step of mesh analysis. For instance, for certain case, the Table1 illustrates the results of different meshes.

For the authentication of FORTRAN code, the existing literature [106] bears witness about its accuracy, as presented in Fig. (3). Fig. 3 presents the comparison of present solutions with previous literature. Strong agreement between the profiles shows the validity of the present numerical solution. In the proposed study the electric filed with ferro-fluid (Fe_3O_4 – $C_2H_6O_2$ nanofluid) like hydrothermal fashion is treated. The characters of voltage supplied ($\Delta\varphi = 0$ to $10\,kV$), Darcy numbers ($Da = 10^2$ to 10^5), shape factors (m=3 to 5.7), radiation parameters ($Rd = 0$ to 0.8), concentration of Fe_3O_4 ($\phi = 0\%$ to 5%) were illustrated in Figs. (4) to (8).

Shape of nanoparticle can change the thermal performance and according to simulation data, platelet shape has maximum efficiency and we used this shape in all outputs except from the last figure. Figs. 4 and 5 illustrate for streamline and temperature field at $\phi = 0.05, Rd = 0.8, \mathrm{Re} = 3000$ in absence of electric field. Flow behavior depicts that some cells near to the heated wall were produced. As permeability augments, cells become merged together and generate stronger cell.

Isotherm becomes more complicate with rise of Da. This is because of favorable impact of permeability on convection flow. So, more heat can be distributed within the tank. Figs. 6 and 7 describe the impacts of Da in appearance of voltage $\Delta\varphi = 10kV$. It can be obvious outputs that both Da and Coulomb force have direct relationship with nanofluid flow and temperature gradient. In comparison of permeability, Coulomb forces have greater impact and isotherm shows greater heat transfer rate. Size of cells enhances with rise of $\Delta\varphi$. Shape of isotherms convert to complex one with rise of both Da and $\Delta\varphi$. In last figure (Fig. 8), influences of all scrutinized parameters were described. Eq. (20) represents a formula which derived from simulation data.

$$\begin{gathered} Nu_{ave} = 6.63 + 0.34m + 4.44\Delta\varphi + 1.66\ln[Da] \\ +3.32Rd + 1.73\Delta\varphi\ln[Da] + 0.99Rdln[Da] - 0.017m^2 \end{gathered} \tag{20}$$

As shape factor enhances, convection becomes stronger. Besides radiation factor is in direct relationship with Nu.

5. Conclusions

Iron oxide transportation within a permeable tank including electric field has been investigated in the current study. To obtain governing formula, homogeneous model was involved and last equations were modeled by involving CVFEM. This model is very powerful for simulating nanomaterial behavior in existence of external forces. Scrutinized variables namely radiation factor, voltage, shape factor and Darcy factor has been simulated. Convection is in direct proportion to permeability and coulomb forces. As Rd enhances stronger cells generates.

Reference

[1] M. M. Bhatti, A. Zeeshan, R. Ellahi, N. Ijaz, Journal of Molecular Liquids 230 (2017): 237-246.

[2] M. Sheikholeslami, Behnoush Rezaeianjouybari, Milad Darzi, Ahmad Shafee, Zhixiong Li, Truong Khang Nguyen, International Journal of Heat and Mass Transfer 141 (2019) 974–980

[3] Mohammadali Hedayat, M. Sheikholeslami, Ahmad Shafee, Trung Nguyen-Thoi, Mouna Ben Henda, I. Tlili, Zhixiong Li, Journal of Molecular Liquids 290 (2019) 111232

[4] Seyyed Ali Farshad, M. Sheikholeslami, International Journal of Mechanical Sciences159 (2019) 126-139

[5] W. Gao, L. Yan, L. Shi, Optoelectronics and Advanced Materials – Rapid Communications, 2017, 11(1-2): 119-124.

[6] Tawfeeq Abdullah Alkanhal, M. Sheikholeslami, Muhammad Usman, Rizwan-ul Haq, Ahmad Shafee, Abdullah Saad Al-Ahmadi, I. Tlili, International Journal of Heat and Mass Transfer 139 (2019) 87–94

[7] M. Sheikholeslami, M. Jafaryar, Jagar A. Ali, Samir Mustafa Hamad, Alireza Divsalar, Ahmad Shafee, Trung Nguyen-Thoi, Zhixiong Li, Journal of Molecular Liquids 291 (2019) 111283

[8] M.M. Rashidi, Z. Yang, M.M. Bhatti, M.A. Abbas, Therm. Sci., 22, 2439-2448.

[9] M. Sheikholeslami, M. Jafaryar, Mohammadali Hedayat, Ahmad Shafee, Zhixiong Li, Truong Khang Nguyen, Mohsen Bakouri, International Journal of Heat and Mass Transfer, 137 (2019) 1290–1300

[10] N. Ijaz, A. Zeeshan, M. M. Bhatti, R. Ellahi, Journal of Molecular Liquids 250 (2018): 80-87.

[11] Seyyed Ali Farshad, M. Sheikholeslami, Renewable Energy, 141 (2019) 246-258

[12] M. Sheikholeslami, R. Ellahi, Int. J Heat Mass Transf; 2015; 89, 799-808

[13] Bhatti, M.M.; Abbas, T.; Rashidi, M.M.; Ali, M.E.-S.; Yang, Z., Entropy 2016, 18, 224.

[14] W. Gao, W. F. Wang, Chaos, Solitons and Fractals, 2016, 89: 290–294.

[15] Jia Qing, M.M. Bhatti, M.A. Abbas, M.M. Rashidi, Entropy, 18(4), p.123.

[16] M. Sheikholeslami, Hadi Keramati, Ahmad Shafee, Zhixiong Li, Omer A. Alawad, I. Tlili, Physica A: Statistical Mechanics and its Applications, 523 (2019) 87–104

[17] M. Sheikholeslami, Houman B. Rokni, Physics of Fluids, Volume 30, Issue 1, (2018), 10.1063/1.5012517, https://doi.org/10.1063/1.5012517

[18] M. Sheikholeslami, Houman B. Rokni, Journal of Molecular Liquids 232 (2017) 390–395

[19] M. Sheikholeslami, M. Shamlooei, International Journal of Hydrogen Energy, 42(9) (2017) 5708–5718

[20] M. Sheikholeslami, Neural Computing and Applications, Volume 30, Issue 4, (2018), pp 1055–1064

[21] M. Sheikholeslami, S. A. M. Mehryan, Ahmad Shafee, Mikhail A. Sheremet, Journal of Molecular Liquids, 277 (2019) 388-396

[22] Wang Y, Zhang M, Wang L, Li W, Zeng J, Xu J, New J Chem 2015; 200-213.

[23] Ghazanfari M, . J Ultrafine Grained Nanostruct Mater 2014; 47(2): 97-103.

[24] S. Yan, F. Wang, Z. Shi, R. Tian, Applied Thermal Engineering 118 (2017) 385-391.

[25] M.H. Al-Rashed, G. Dzido, M. Korpyś, J. Smołka, J. Wójcik, Investigation on the CPU nanofluid cooling, Microelectronics Reliability 63 (2016) 159-165.

[26] Saeed Baghsaz, Saeed Rezanejad, Mahdi Moghimi, J. Mol. Liq. 279 (2019), 327-341.

[27] P. Anil Kumar, Sugata Ray, S. Chakraverty & D.D. Sarma, Journal of Experimental Nanoscience, 9(4), 2014 391-397.

[28] Ching-Chang Cho, Int. J. Mech. Sci. 151 (2019), 703-714.

[29] Y. Qin, J.E. Hiller, Energy and Buildings, 85 (2014) 389-399.

[30] M. Sheikholeslami, Alireza Zareei, M. Jafaryar, Ahmad Shafee, Zhixiong Li, Amor Smida, I. Tlili, Physica A: Statistical Mechanics and its Applications, 525 (2019) 557–565

[31] Dalei Jing, Shankai Yi, Fractals, doi: 10.1142/S0218348X19500956

[32] M. Sheikholeslami, M. Jafaryar, Ahmad Shafee, Zhixiong Li, Rizwan-ul Haq, International Journal of Heat and Mass Transfer 136 (2019) 1233–1240

[33] Y. Qin, J. Liang, H. Yang, Z. Deng, Measurement, 78 (2016) 104-110

[34] Trung Nguyen-Thoi, M.M. Bhatti , Jagar A. Ali, Samir Mustafa Hamad, M. Sheikholeslami, Ahmad Shafee, Rizwan-ul Haq, Journal of Molecular Liquids, 2019, https://doi.org/10.1016/j.molliq.2019.111378

[35] Y. Qin, Energy and Buildings, 96 (2015) 86-9[36] Jing Dalei and Lei He, Entropy 2018, 20, 537.

[37] Y. Qin, M. Zhang, G. Mei, Journal of Hydrology 562 (2018) 725-732

[38] Muhammad Mubashir Bhatti, Mohsen Sheikholeslami, Ahmed Zeeshan, Entropy 2017, 19, 481; doi:10.3390/e19090481

[39] M. M. Bhatti, M. Sheikholeslami, A. Shahid, M. Hassan, T. Abbas, Colloids and Surfaces A: Physicochemical and Engineering Aspects, 570 (2019) 368–376

[40] Qin Y, He Y, Hiller JE, Mei G, Journal of Cleaner Production 199 (2018) 948-956

[41] Yinghong Qin, Jacob E. Hiller and Demiao Meng. Journal of Materials in Civil Engineering, 2019. https://doi.org/10.1061/(ASCE)MT.1943-5533.0002890

[42] Qin Y, Luo J, Chen Z, Mei G, Yan L-E, Solar Energy 171(2018) 971-976

[43] M. Sheikholeslami, Milad Darzi, MK Sadoughi, International Journal of Heat and Mass Transfer 122 (2018) 643–650.

[44] Mohsen Sheikholeslami, Journal of the Taiwan Institute of Chemical Engineers 86 (2018) 25–41

[45] Y. Qin, Renewable and Sustainable Energy Reviews, 52 (2015) 445-459

[46] M. Sheikholeslami, Journal of Molecular Liquids 259 (2018) 424–438

[47] Shi, X., Lu, W., Wang, Z., Pan, L., Cui, G., Xu, J., & LaBean, T. H, Nanotechnology, 25(7) (2014) 075602.

[48] Zehui Shao, Karzan Wakil, Muhammet Usak, Mohammad Amin Heidari, Bo Wang, Rolando Simoes:, Applied Thermal Engineering, 145 (2018) 58-70.

[49] M. Sheikholeslami, , Journal of Molecular Liquids 263 (2018) 303–315

[50] Esmaeil Dehdashti, , Chinese Physics B 25.2 (2015) 024702.

[51] A. Mwesigye, Z. Huan, J.P. Meyer, Applied Energy 156 (2015) 398–412.

[52] V. Esfahanian, E. Dehdashti, A. M. Dehrouyeh-Semnani, Advances in Applied Mathematics and Mechanics 6.3 (2014) 345-358.

[53] M. Sheikholeslami, S.A. Shehzad, Zhixiong Li, Ahmad Shafee, International Journal of Heat and Mass Transfer 127 (2018) 614–622

[54] V. Esfahanian, Esmaeil Dehdashti, Amir Mehdi Dehrouye-Semnani, Chinese Physics B 23.8 (2014): 084702.

[55] M. Sheikholeslami, Journal of Molecular Liquids 263 (2018) 472–488

[56] Amir Mehdi Dehrouyeh-Semnani, HamidZafari-Koloukhi, Esmaeil Dehdashti, Mansour Nikkhah-Bahrami, International Journal of Non-Linear Mechanics 85

(2016): 207-225.

[57] M. Sheikholeslami, Rizwan-ul Haq, Ahmad Shafee, Zhixiong Li, Yassir G. Elaraki, I. Tlili, International Journal of Heat and Mass Transfer 135 (2019) 470–478

[58] W. Gao, W. F. Wang, M. K. Jamil, M. R. Farahani, Journal of Chemistry, Volume 2016, Article ID 1053183, 7 pages, http://dx.doi.org/10.1155/2016/1053183.

[59] M. Sheikholeslami, Ahmad Shafee, Alireza Zareei, Rizwan-ul Haq, Zhixiong Li, Journal of Molecular Liquids 279 (2019) 719–732

[60] Y. Qin, J. Liang, K. Tan, F. Li., Solar Energy, 133 (2016) 172–179

[61] M. Sheikholeslami, Omid Mahian, Journal of Cleaner Production 215 (2019) 963-977

[62] W. Gao, M. R. Farahani, L. Shi, The forgotten topological index of some drug structures, Acta Medica Mediterranea, 2016, 32: 579-585.

[63] Mohsen Sheikholeslami, Houman B. Rokni, International Journal of Heat and Mass Transfer 114 (2017) 517–526

[64] Y. Qin, International Journal of Heat and Mass Transfer, 97 (2016) 391-399

[65] M. Sheikholeslami, Journal of Molecular Liquids 265 (2018) 347–355

[66] Jia-Bao Liu, Xiang-Feng Pan, Applied Mathematics and Computation. 253 (2015) 205-214.

[67] W. Gao, M. K. Siddiqui, M. Imran, M. K. Jamil, M. R. Farahani, Saudi Pharmaceutical Journal, 2016, 24(3): 258-264.

[68] W. Gao, W. F. Wang, M. R. Farahani, Journal of Chemistry, Volume 2016, Article ID 3216327, 8 pages, http://dx.doi.org/10.1155/2016/3216327.

[69] M. Sheikholeslami, Rizwan-ul Haq, Ahmad Shafee, Zhixiong Li, International Journal of Heat and Mass Transfer 130 (2019) 1322–1342

[70] W. Gao, W. F. Wang, Computational and Mathematical Methods in Medicine,

Volume 2015, Article ID 418106, 10 pages, http://dx.doi.org/10.1155/2015/418106.

[71] Jia-Bao Liu, Xiang-Feng Pan, Applied Mathematics and Computation 291 (2016) 84–88.

[72] Y. Qin, Y. He, B. Wu, S. Ma, X. Zhang, Energy and Buildings 156(Supplement C) (2017) 218-224

[73] W. Gao, W. F. Wang, Journal of Chemistry, Volume 2014, Article ID 906254, 8 pages, http://dx.doi.org/10.1155/2014/906254.

[74] W. Gao, W. F. Wang, International Journal of Computer Mathematics, 2018, 95(8): 1527-1547.

[75] W. Gao, M. R. Farahani, The Computer Journal, 2017, 60(9): 1289-1299.

[76] W. Gao, L. Liang, T. W. Xu, J. H. Gan, Open Physics, 2017, 15: 501-508.

[77] W. Gao, Y. Guo, K. Y. Wang, Cluster Computing-The Journal of Networks Software Tools and Applications, 2016, 19(4): 2201–2210.

[78] Y. Qin, H. He, Solar Energy 157(Supplement C) (2017) 1047-1055

[79] W. Gao, L. L. Zhu, K. Y. Wang, Journal of Intelligent & Fuzzy Systems, 2016, 31(4): 2411–2419.

[80] Y. Qin, M. Zhang, J.E. Hiller, Energy, 129 (2017) 138-147

[81] W. Gao, L. L. Zhu, K. Y. Wang, International Journal of Bifurcation and Chaos, 2015, 25(14) , 1540034 (12 pages), DOI: 10.1142/S0218127415400349.

[82] M. Sheikholeslami, M. Barzegar Gerdroodbary, R. Moradi, Ahmad Shafee, Zhixiong Li, Computer Methods in Applied Mechanics and Engineering, 344 (2019) 1–12

[83] M. Sheikholeslami, M. Jafaryar, Ahmad Shafee, Zhixiong Li, Physica A: Statistical Mechanics and its Applications 523 (2019) 544–556

[84] Qin, Y., Zhao, Y., Chen, X., Wang, L., Li, F., Bao, T., Construction and Building

Materials 215(2019) 114-118.

[85] M. Sheikholeslami, A. Ghasemi, International Journal of Heat and Mass Transfer 123 (2018) 418–431

[86] W. Gao, L. L. Zhu, Computational Intelligence and Neuroscience, Volume 2014, Article ID 438291, 12 pages, http://dx.doi.org/10.1155/2014/438291.

[87] M. Sheikholeslami, M. M. Bhatti, International Journal of Heat and Mass Transfer 111 (2017) 1039–1049

[88] M. Sheikholeslami, Computer Methods in Applied Mechanics and Engineering 344 (2019) 319‑333

[89] Tawfeeq Abdullah Alkanhal, M. Sheikholeslami, A. Arabkoohsar, Rizwan-ul Haq, Ahmad Shafee, Zhixiong Li, I. Tlili, International Journal of Heat and Mass Transfer136 (2019) 146–156

[90] M. Sheikholeslami, M. Jafaryar, Ahmad Shafee, Zhixiong Li, Chinese Journal of Physics, 58 (2019) 244-252

[91] M. Sheikholeslami, Computer Methods in Applied Mechanics and Engineering 344 (2019) 306‑318

[92] M. Sheikholeslami, Ilyas Khan, I.Tlili, Scientific Reports, (2018) 8:16881, DOI:10.1038/s41598-018-33079-6

[93] M. Sheikholeslami, K. Vajravelu, Applied Mathematics and Computation, 298 (2017) 272–282

[94] M. Sheikholeslami, S.A. Shehzad, International Journal of Heat and Mass Transfer 115 (2017) 180–191

[95] M. Sheikholeslami, M. M. Bhatti, International Journal of Heat and Mass Transfer 109 (2017) 115–122

[96] Mohsen Sheikholeslami, International Journal of Hydrogen Energy, 42 (2017)

19611-19621

[97] Mohsen Sheikholeslami, Ahmad Arabkoohsar, Ilyas Khan, Ahmad Shafee, Zhixiong Li, Journal of Cleaner Production, 221 (2019) 885-898

[98] M. Sheikholeslami, S.A. Shehzad, International Journal of Heat and Mass Transfer 122 (2018) 1264–1271

[99] M. Sheikholeslami, A. Zeeshan, Computer Methods in Applied Mechanics and Engineering, 320 (2017) 68–81

[100] M. Sheikholeslami, T. Hayat, A. Alsaedi, S. Abelman, International Journal of Heat and Mass Transfer, 108 (2017) 2558–2565.

[101] M. Sheikholeslami, Journal of Molecular Liquids 266 (2018) 495–503

[102] W.H. Azmi, K.V. Sharma, P.K. Sarma, R. Mamat, S. Anuar, International Journal of Thermal Sciences 81 (2014) 84-93.

[103] Mohsen Sheikholeslami, Ali J. Chamkha, Numerical Heat Transfer, Part A, 2016, VOL. 69, NO. 10, 1186–1200, DOI:10.1080/10407782.2015.1125709.

[104] M. Sheikholeslami, Mikhail A. Sheremet, Ahmad Shafee, Zhixiong Li, Journal of Thermal Analysis and Calorimetry, 2019, https://doi.org/10.1007/s10973-019-08235-3

[105] Mohsen Sheikholeslami, Application of Control Volume based Finite Element Method (CVFEM) for Nanofluid Flow and Heat Transfer, Elsevier, (2019), ISBN: 9780128141526.

[106] Khanafer K, Vafai K, Lightstone M., Int. J Heat Mass Transf 2003; 446: 3639–3653.

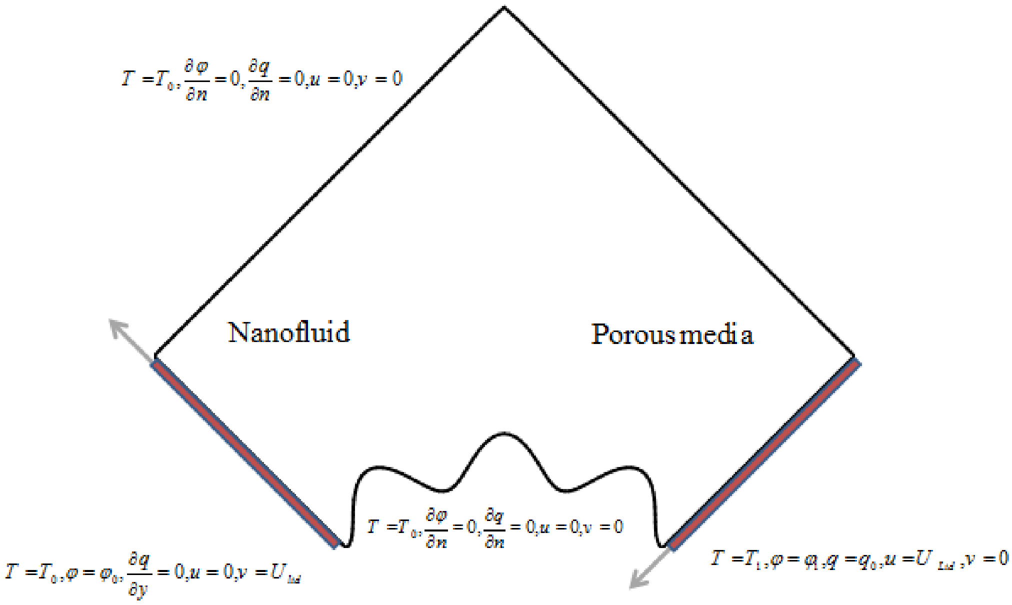


Fig. 1. Present geometry with two lid walls

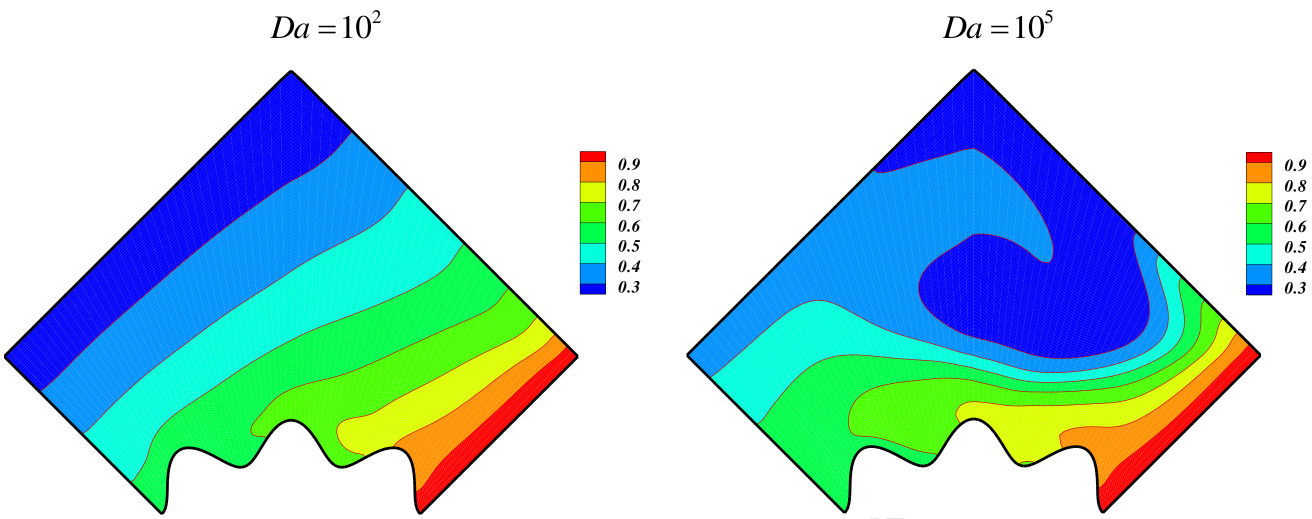


Fig. 2. Electric density distribution injected by the bottom electrode when $\Delta\varphi = 10kV$, $\phi = 0.05, Rd = 0.8, \mathrm{Re} = 3000$

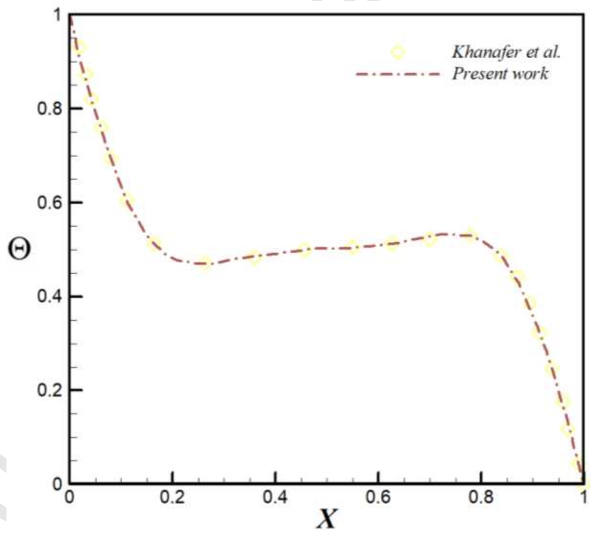


Fig. 3. Verification for nanofluid thermal behavior [106]

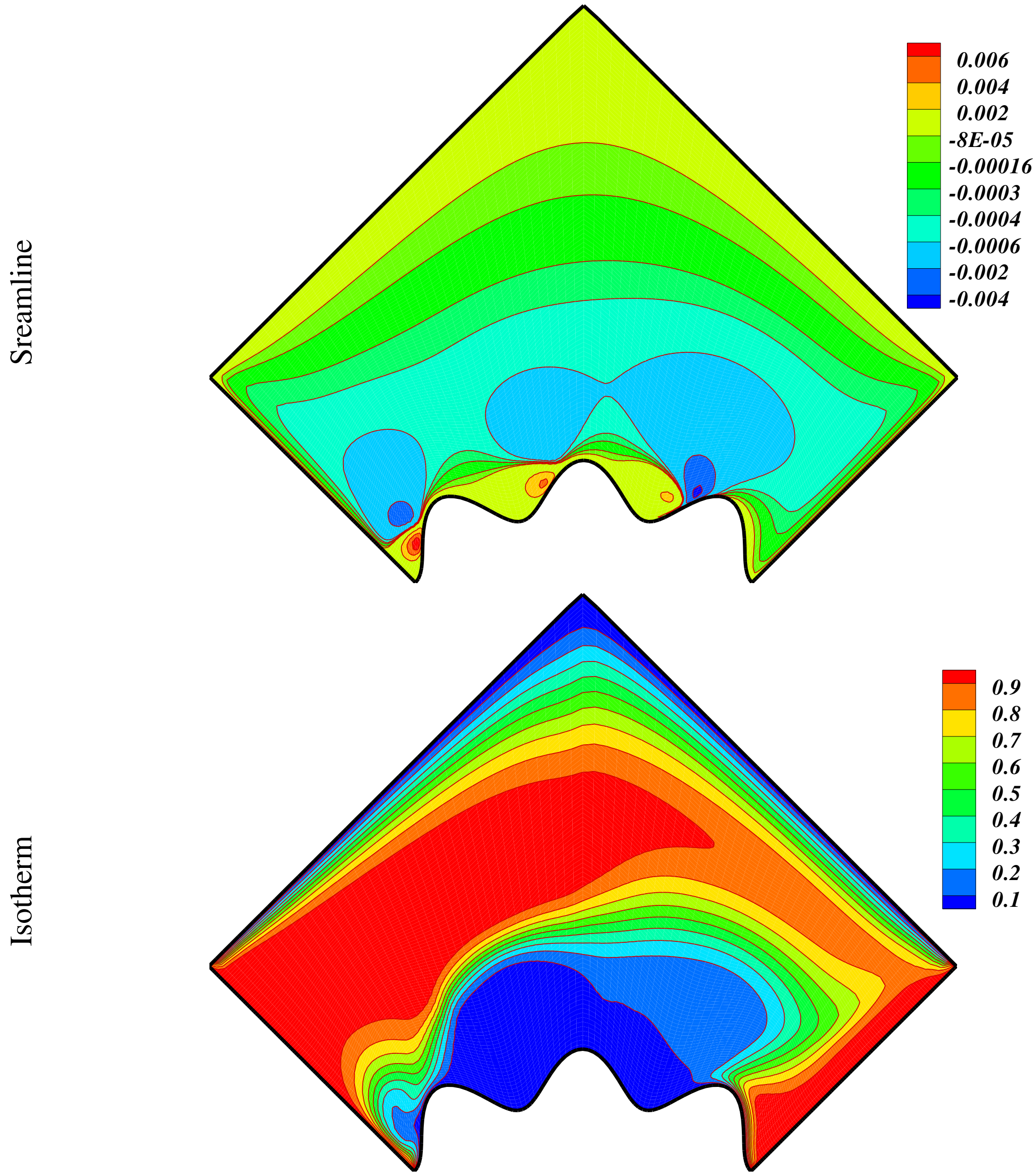


Fig. 4. Results for streamlines and isotherm at
$\Delta\varphi = 0kV$, $\phi = 0.05, \mathrm{Re} = 3000, Rd = 0.8, Da = 10^2$.

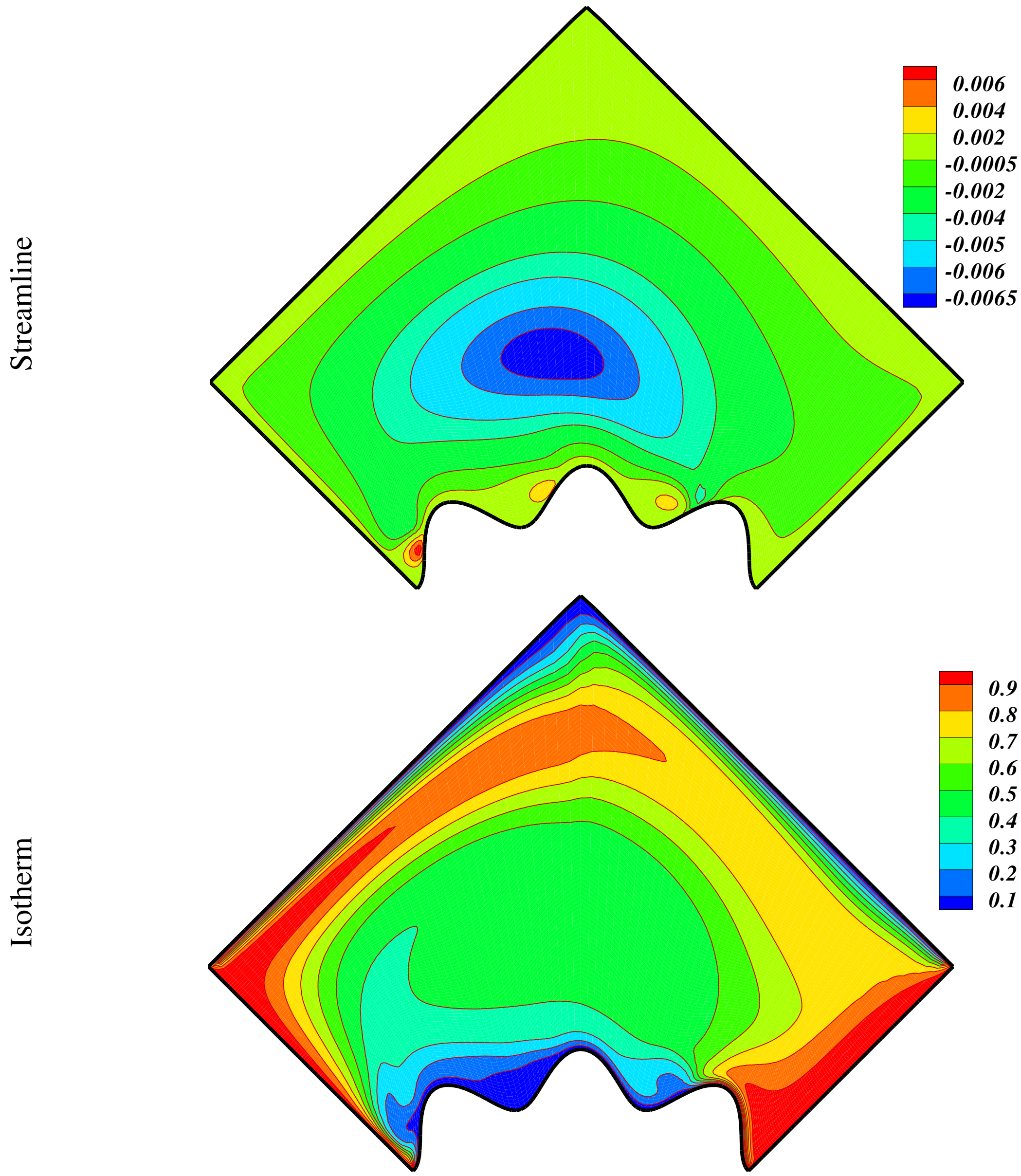


Fig. 5. Results for streamlines and isotherm at
$\phi = 0.05, Rd = 0.8, \mathrm{Re} = 3000, Da = 10^5, \Delta\varphi = 0kV$.

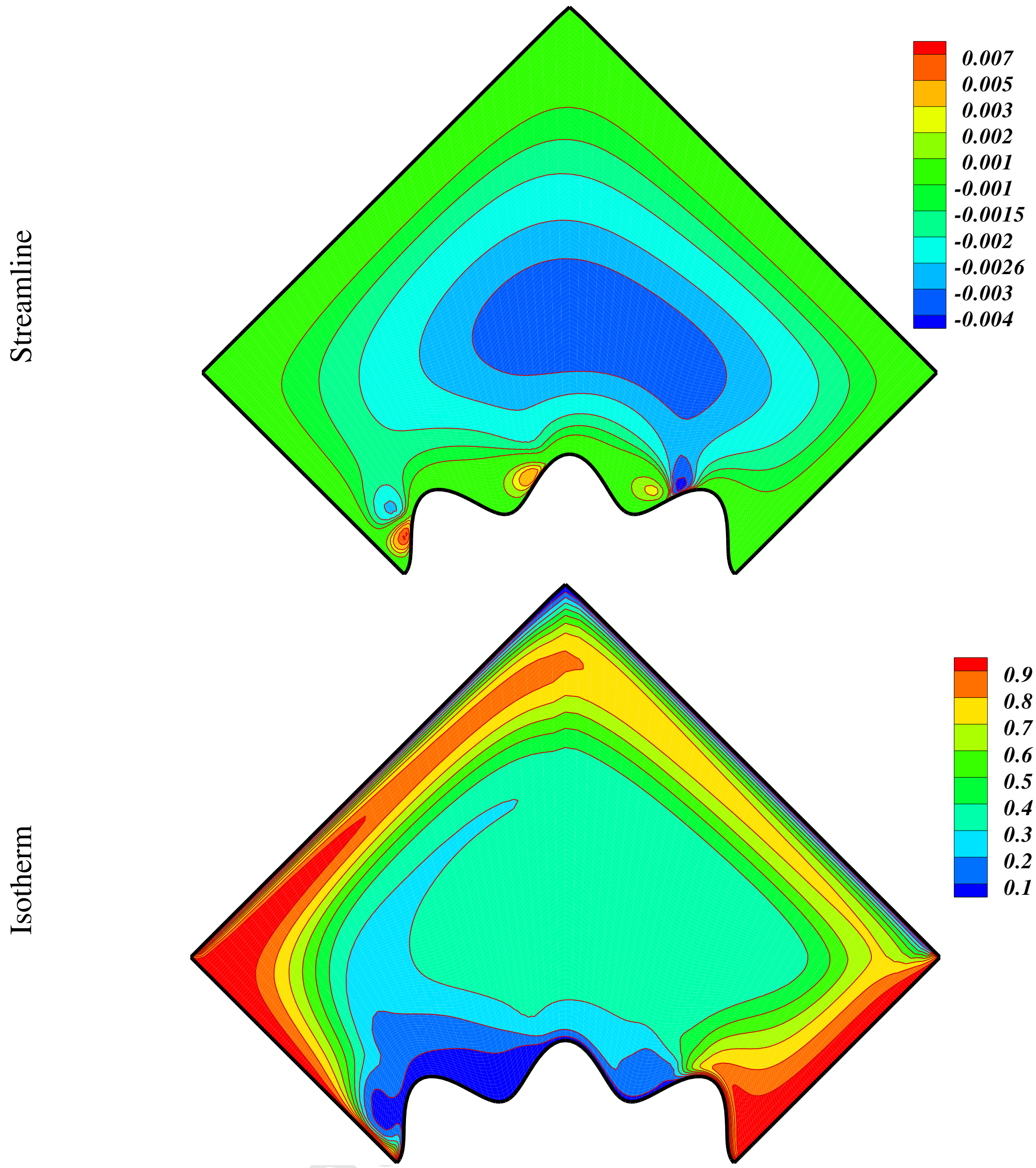


Fig. 6. Results for streamlines and isotherm at
$\mathrm{Re}=3000, Da=10^2, \Delta\varphi=10kV\ , Rd\ =0.8, \phi=0.05$.

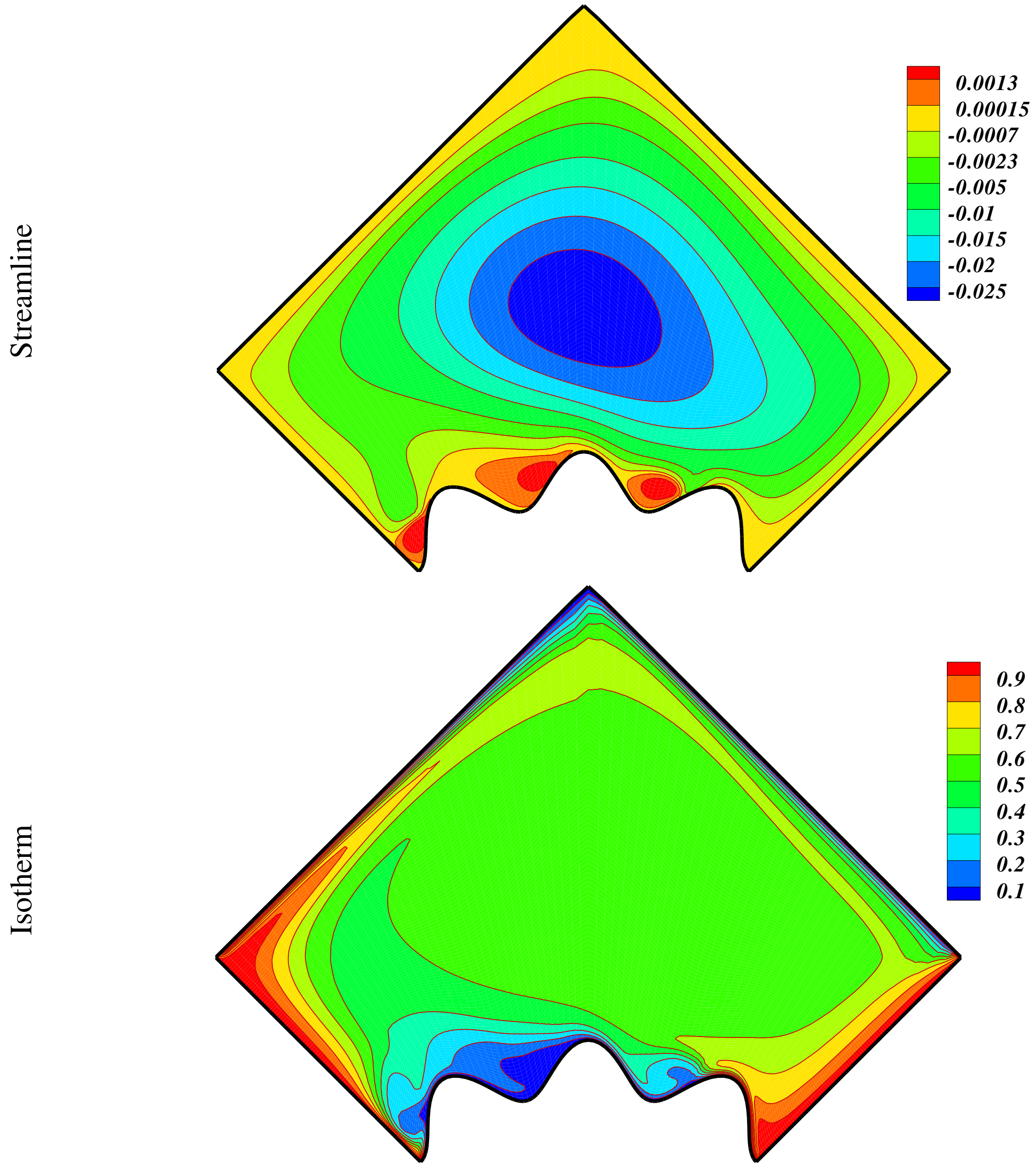
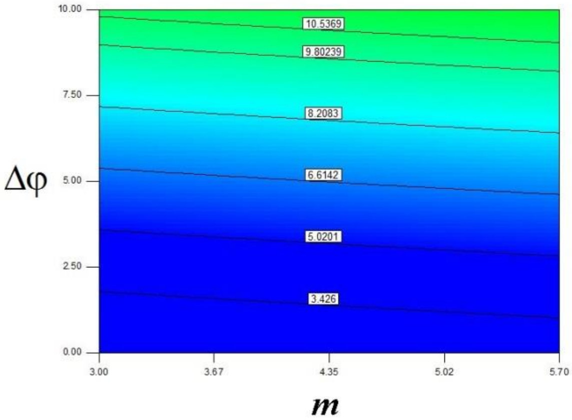
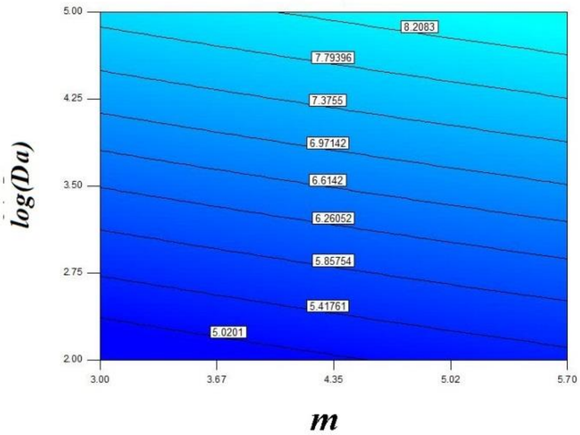


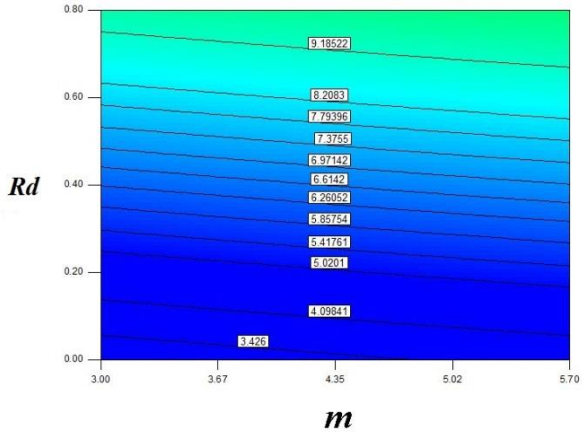
Fig. 7. Results for streamlines and isotherm at $\Delta\varphi = 10kV$, $\mathrm{Re} = 3000, Da = 10^5, Rd = 0.8, \phi = 0.05$.



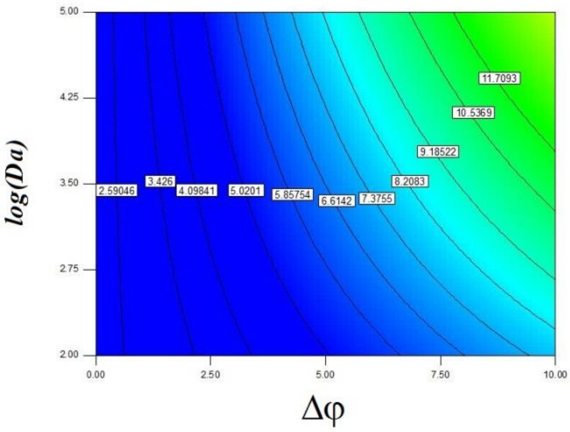
$log\left(Da\right)=3.5\,,Rd\,=0.4\,,\phi=0.05$



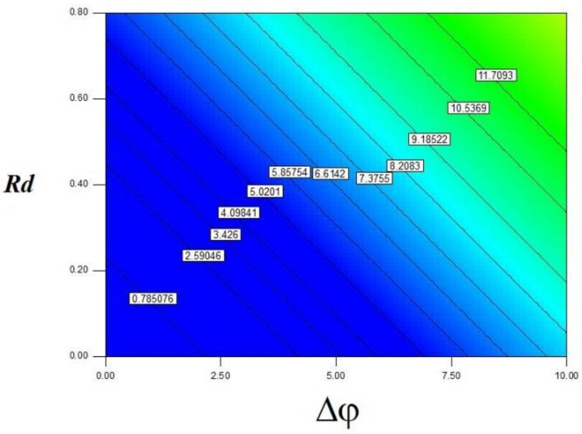
$Rd\,=0.4\,,\Delta\varphi=5\,,\phi=0.05$



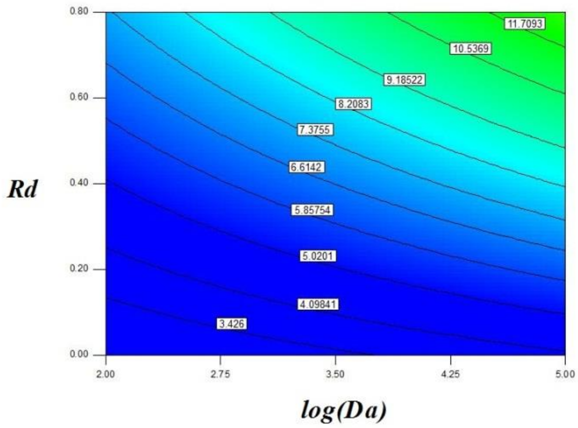
$log\left(Da\right)=3.5\,,\Delta\varphi=5\,,\phi=0.05$



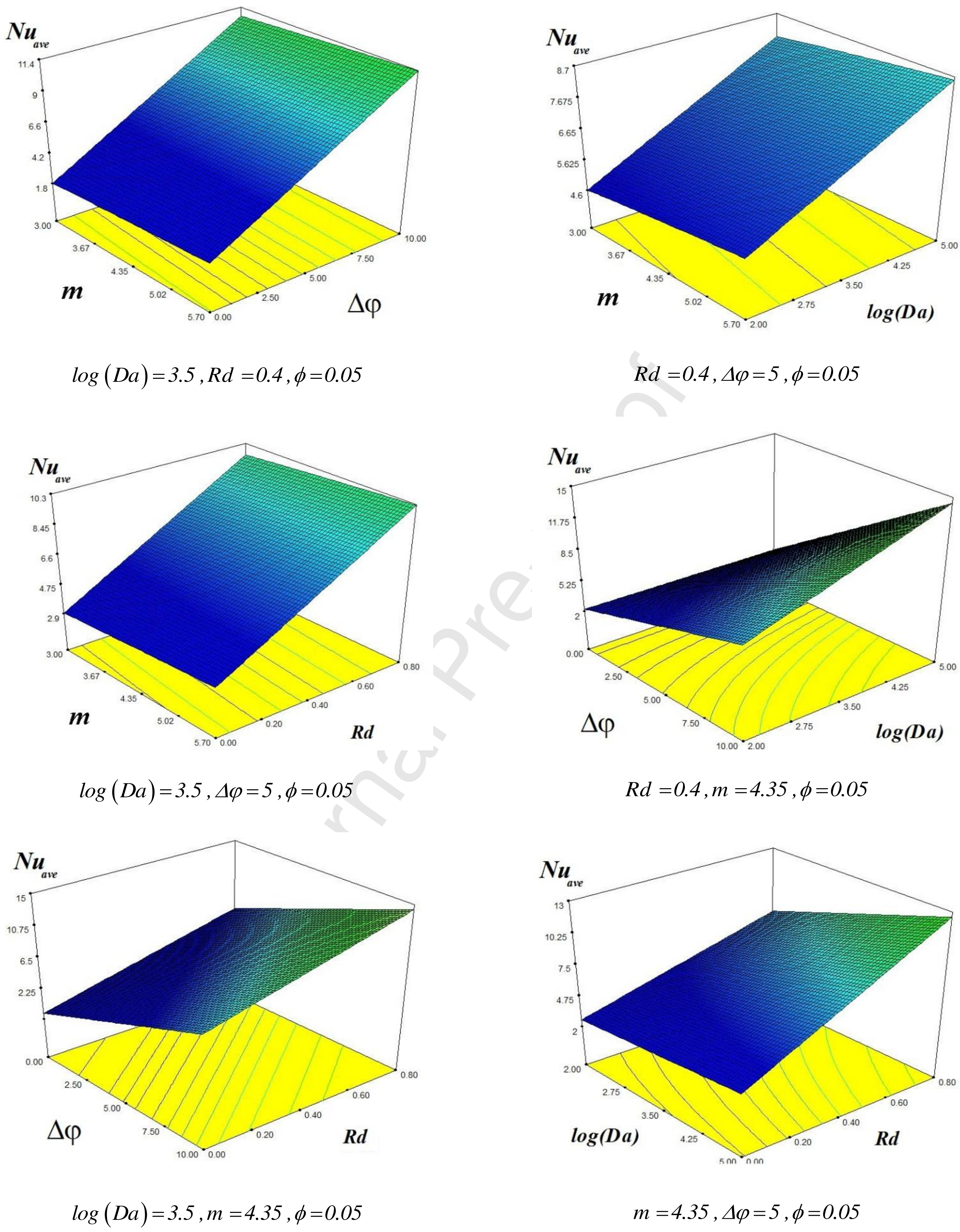
$Rd\,=0.4\,,m\,=4.35\,,\phi=0.05$



$log\left(Da\right)=3.5\,,m\,=4.35\,,\phi=0.05$



$m\,=4.35\,,\Delta\varphi=5\,,\phi=0.05$



$log\left(Da\right)=3.5\,,Rd=0.4\,,\phi=0.05$

$Rd=0.4\,,\Delta\varphi=5\,,\phi=0.05$

$log\left(Da\right)=3.5\,,\Delta\varphi=5\,,\phi=0.05$

$Rd=0.4\,,m=4.35\,,\phi=0.05$

$log\left(Da\right)=3.5\,,m=4.35\,,\phi=0.05$

$m=4.35\,,\Delta\varphi=5\,,\phi=0.05$

Fig. 8. Dependency of Nu_{ave} on $Rd\,,m\,,Da,\,\Delta\varphi$

Table1. Mesh effect on change of Nu_{ave} when $Re = 3000$, $Rd = 0.8$, $Da = 10^{5}$, $\phi = 0.05$, $\Delta\varphi = 10$

81×241	91×271	101×301
19.0857	19.0983	19.0996
51×151	61×181	71×211
19.0639	19.0711	19.0818

Highlights

- Numerical simulation of nanoparticle migration within a porous media was studied.
- Non-Darcy mode was applied to employ porous terms.
- As Da augments, heat transfer augments.
- Nu declines with augment of electric field.