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Mohadeseh Miri, Farhad Vahidinia, Navid Bozorgan

Natural Convection in Special Conditions (Porous media, Magnetic Field) in NanoFluid Flow, A Review in Recent Literature

Natural convection is the fundamental subject in heat transfer. So it is the matter of many theoretical and experimental researches. In recent years, much attention was given to the use of natural convection with nanofluid in reactor design, engineering application, cooling of electronic equipment, aircraft cabin insulation, solar collector etc. and many studies were conducted in this area. In this paper, a review on the influence of parameters of magnetic field, porous media and volume fraction of nanofluid in the natural convection on the heat transfer, Nusselt number, entropy generation and Hartmann number has been investigated. In the end, some suggestions have been given for continue work.

Keywords*: Natural Convection, Porous Media, Magnetic Field, Volume Fraction*

1. Introduction

One way of increasing the heat transfer is adding metal solid particles such as water, oil, and ethylene glycol to the base fluid that is Maxwell's idea [1]. Choi [2] also proposed the addition of the nanoscale solid particles to the base fluid. Since the topic of nanofluid was raised, scientists conducted extensive numerical and experimental studies. Most of the scientists believe that heat transfer improves with the addition of solid nanoparticles (diameter less than 100nm) [3-5].

In general, enhancement techniques can be divided into two groups: a) Passive techniques which require special surface geometries [6], thermal packaging, or fluid additives; and b) Active techniques which require external forces, such as electrical and magnetic fields. The study of magnetic field effects has attracted attentions of engineers and sciences due to its wide industrial applications, such as in the polymer industry (where one deals with stretching of plastic sheets) and in metallurgical process, where hydro-magnetic techniques are being used [7] and many application else such as crystal growth, metal casting and liquid metal cooling blankets for fusion reactors.

In industrial processes, another method for improving the convection heat transfer characteristics is using porous medium (any material which consists of solid matrix with an inter- connected void is called porous media such as rocks and open- cell aluminum foams) and nanofluid [8]

In this paper, investigated and reviewed of the effect the magnetic field, porous media and volume fraction of nanofluid on the rate of enhance natural convection heat transfer of nanofluid in different geometries. In the end, some suggestions have been given for continue work.

2. Volume fraction in natural convection of nanofluid

Increase of heat transfer is the main reason of nanoparticles utilization. Most papers reported that increase of nanoparticles will increases the heat transfer. To understand better the impact of nanoparticles on heat transfer, evaluation of nanoparticles characteristics is effective which includes volume fraction of nanoparticle, nanoparticle size and diameter. Here are some sources which worked on this deal.

Kuppusamy et al. [9] investigated the effect of different volume fraction $(\phi = 0.01 - 0.04)$ and different diameter of nanoparticles $(25 - 80nm)$ at different Reynolds number $(\mathrm{Re} = 0 - 1000)$ on hydro and thermal characteristics of nanofluids with different base fluid (water, ethylene glycol and engine oil) and different nanoparticles (Al2O3, CuO, SiO2, ZnO) in a triangular grooved microchannel heat sink (TGMCHS). The boundary conditions are shown in Figure1 They discovered that the best nanoparticle and base fluid for nanofluid in TGMCHS are Al2O3 and H2O respectively and with the increment of ϕ and reduction of d_{np} the overall performance enhanced. Therefore, $\mathrm{Al}_2O_3 - H_2O\,(\phi = 0.04, d_{np} = 25nm)$ is the most suitable nanofluid for TGMCHS. Mashaei & Shahryari [10] carried out a study on the heat pipe of satellite equipment cooling and examined the effect of particle concentration level $\phi = 0, 2, 4, 8\%$ on the local wall temperature, heat transfer coefficient, thermal resistance, and the size of the heat pipe. They used three fluid including pure water, TiO2-water, and Al2O3-Water and then compared the results. They discovered that the existence of nanoparticles in water can result in weight reduction of heat pipe and satellite under nearly same condition. In addition, with increase of nanoparticle concentration, heat transfer coefficient ratio of heat pipe can be increased which referred to values obtain for base fluid. The effect of nanoparticle type on thermal resistance of heat pipe is actually less than that of particle concentration.

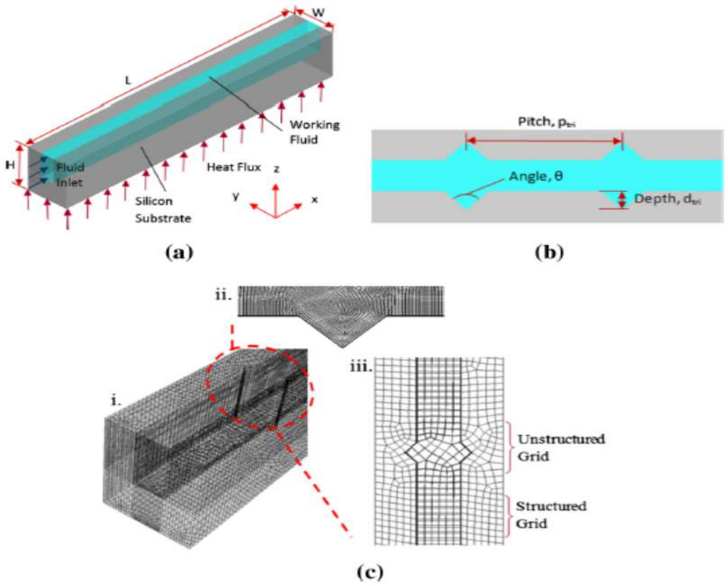

Figure 1. (a) Schematic of the simple MCHS unit cell, (b) groove configuration with its parameters, and (c) (i) computational grid of TGMCHS, (ii) detailed view of grid at the groove area, and (iii) simplified view of grid [9].

Turkyilmazoglu & pop [11] studied heat and mass transfer of unsteady natural convection flow of some nanofluids past a vertical infinite flat plate with radiation effect. They used different nanoparticles including Cu, Ag, CuO, Al2O3, and TiO2 along with water as a base fluid and by changing volume fraction of particles$(0 \le \phi \le 0.2)$, they evaluated parameters such as velocity and temperature profiles, skin friction coefficient and Nusselt number. Regarding uniformly recommended wall temperature, they has been discovered that the least heat transfer takes place for TiO2 and the greatest heat transfer takes place for Cu. They concluded that the least shear stress occurs for TiO2 and the highest occurs for Ag in the PST case, while the order is actually from Al2O3 to Ag in PHF case. The radiation effect is total increasing the skin friction while decreasing the heat transfer rate.

Abdallaoui et al. [12] performed a study on natural convection between a decentered triangular heating cylinder and a square outer cylinder in 2015. Using pure water or water-silver nanofluid, they examined the Nusselt number inside Kuwait by changing volume fraction of nanoparticles ($0 \le \phi \le 0.1$). Their result revealed that inreasing nanoparticles volume fraction has a positive effect on the average Nusselt number for all considered positions of the heating block.

Two different studies were performed numerically and experimentally to investigate the effect of volume fraction and shape of nanoparticle on the thermal characteristics and flow fluid. Paul et al. [13] examined experimentally the effect of volume fraction ($0 \le \phi \le 1.2$) and shape of nanoparticle (spherical and whiskers) in a rectangular enclosure with Ionic liquids. Their results indicated increased density, thermal conductivity, viscosity, and heat capacity of NEILs in comparison with the base IL and they increase with the nanoparticle concentration. However the coefficient of natural convection heat transfer was deteriorated for the NEILs compared to the base IL without regard to the particles shape and aspect ratio of the enclosure and the deterioration enhances with the increase of nanoparticle concentration. In addition, they discovered that, spherical Al2O3 NEILs affected more adversely compared to the whiskers Al2O3 NEILs.

Ooi & Popov [14] investigated numerically the effect of volume fraction $(\phi = 0 - 0.2)$ and shape of Cu-Water nanofluid (spherical and spheroidal nanoparticles (NPs)) in natural convection flow in a square cavity. They found that high values of volume fraction of nanoparticles increases thermal conductivity and viscosity. Also, Sourtiji et al. [15] examined the effect of natural convection and volume fraction of nanoparticle $(\phi = 0 - 0.06)$ on Nusselt number, isothermal lines and flow lines in a horizontal triangular-cylindrical annulus. Their geometry is shown in figure 2. Their results showed that heat transfer is increased by adding the nanoparticles to the base fluid.

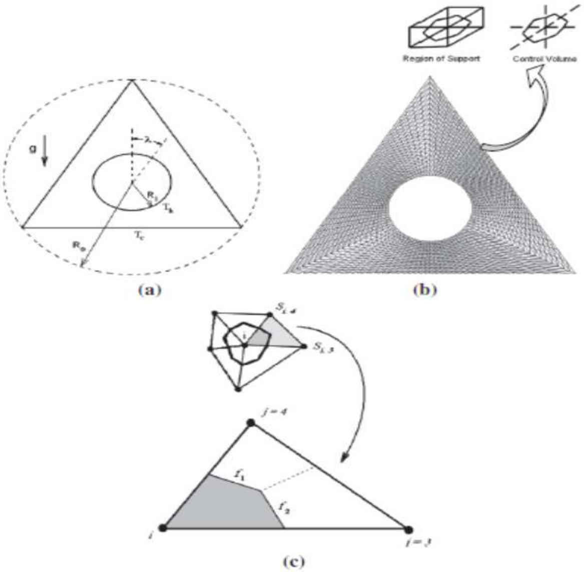

Figure 2. (a) Schematic diagram of the problem, (b) the mesh of enclosure used in this study, and (c) a sample unstructured control volume for node i and its triangular elements [15].

In 2011, Shahi et al. [16] examined numerically the laminar conjugated-natural convection heat transfer in a vertical annular tube formed between an inner heat generating solid circular cylinder and an outer isothermal cylindrical boundary. By changing nanoparticle volume fraction $(\phi = 0 - 0.05)$, Rayleigh number and inclination angle, they plotted the isotherm and flow lines and evaluated changes of average Nusselt number and average temperature on different cross sectional planes.Their results indicated that the average Nusselt number is an increasing function of the solid concentration while the average temperature is a decreasing function. However, as the results revealed increasing the solid concentration has more impact on the average Nusselt number at higher Rayleigh numbers. In addition, the examination of the effect of the inclination angle indicated that the maximum average Nusselt number and the minimum level of fluid temperature are obtained at $\theta = 0^{\circ}$. Table 1 summarizes the results of nanofluids influence on natural convection in special conditions.

Table 1. The influence of nanofluid on natural convection in special condition.

No.	Authors	Experimental or Numerical or Analytical	Type of nanofluid	Volum fraction range	Rayleigh range	Observation/ Result
1	Kuppusamy et al. [9]	Nu.	Al2O3, CuO, SiO2, ZnO	$(\phi = 0.01 - 0.04)$	-	By changing the angle and depth of grooves, they investigated the thermal and hydraulics characteristics of nanofluid. They found that thermal performance of TGMCHS increases with the increase of angle and depth of groove. Also the TGMCHS thermal performance of $\mathrm{Al}_2O_3 - H_2O\ (\phi = 0.04, d_{np} = 25nm)$ was outperformed.
2	Malvandi & Ganji [17]	Nu.	Al2O3	$\phi = 0.02, 0.06, 0.1$	-	They examined the effect of volume fraction of nanoparticles on the non-adherence of the fluid solid interface in the presence of magnetic field and discovered that nanoparticles migrate from the heated walls towards the core region of the microchannel.
3	Turkyilmazoglu & pop [11]	Analytical	Cu, Ag, CuO, TiO2, Al2O3	$0 \le \phi \le 0.2$	-	The effect of different nanoparticles on the vertical infinite flat plate was investigated with change of volume fraction of nanofluid. They discovered that the minimum heat transfer occurs for TiO2 and the maximum heat transfer occurs for CuO.
4	Mashaei & Shahryari [10]	Analytical	Al2O3, TiO2	$\phi = 0, 2, 4, 8\%$	-	They studied the influence of volume fraction and nanoparticles diameter on the wall temperature, heat transfer coefficient and thermal resistance and obtained an optimal size of the heat pipe
5	Sheikholeslami et al. [21]	Nu.	Cu	$\phi = 0 - 0.06$	$Ra = 10^3, 10^4, 10^5$	Considering the effect of magnetic field, they studied the Nusselt number and ratio of heat transfer enhancement
6	Ooi & Popov [14]	Nu.	Cu	$\phi = 0 - 0.2$	$Ra = 10^3, 10^4, 10^5$	They examined the effect of different shapes of nanoparticles (spherical and spheroidal nanoparticles (NPs)) on the heat transfer enhancement and found that the oblate spheroid with aspect ratio of 10 produced the largest enhancement of the overall heat transfer characteristic
7	Paul et al. [13]	Ex.	Al2O3	$0 \le \phi \le 1.2$	$\mathrm{Ra} = 10^6 - 10^9$	Nanoparticles Enhanced Ionic liquids (NEILs) were studied in an enclosure with two different shapes of nanoparticle (spherical and whiskers) and two sizes of nanoparticles. They found that spherical Al2O3 NEILs was observed to affect more adversely compared to the whiskers Al2O3 NEILs.
8	Sourtiji et al. [15]	Nu.	Cu	$\phi = 0 - 0.06$	$Ra = 10^3, 10^4, 10^5, 5$	They investigated the influence of annulus radius ratio along with changes of Rayleigh number on the triangular-cylindrical annulus and found that percentage of heat transfer enhancement caused by the nanofluid is more remarkable at lower Rayleigh numbers
9	Ashorynejad et al. [7]	Nu.	Ag	$\phi = 0.02, 0.04, 0.0$	$Ra = 10^3 - 10^5$	Using Lattice Boltzman method (LBM), they investigated the effect of static radial magnetic field and indicated that the flow oscillations can be suppressed effectively by imposing an external radial magnetic field.

3. Natural convection with presence of Magnetic Field

Enhancing the performance of conventional heat transfer has become a critical challenge for scientists and engineers. In general, enhancement techniques can be divided into two groups: a) Passive techniques which require special surface geometries, thermal packaging, or fluid additives; and b) Active techniques which require external forces, such as electrical and magnetic fields [17]. The effect of magnetic field on natural convection regime was applied in different geometries and most of the papers investigated its effect on heat transfer parameters such as Nusselt number. The effect of magnetic field on increasing or decreasing entropy was also examined in some papers which their results can be more effective to find the optimum conditions (maximum Nusselt number and minimum entropy) for specific application. Aghaei et al. [18] research is among studies which done on the effect of magnetic field in enclosure. In this study, they investigated numerically the effect of entropy in a triangular enclosure filled Al2-O3-Water nanofluid affected by magnetic field considering Brownian motion. They expressed the effect of magnetic fields as Lorentz volume force that is taken into account in momentum equation in term of $\vec{F} = \vec{J} \times \vec{B}$ where $\vec{B}$ is magnitude of magnetic field and $\vec{J}$ is density of electrical flow. They evaluated changes of entropy generation by changing volume fraction of the particle, Hartmann number, and Rayleigh number and found that the increase of volume fraction of the particle increases the Nusselt number and generated entropy. Also, by increasing the Hartmann number at constant Rayleigh number the eyes of the eddies tend toward the bottom vertices of the triangular enclosure which is due to the Lorentz force and magnetic effect. Also, Selimefendigil & Oztop [19] investigated the Nusselt number and entropy generation in a Kuwaiti with obstacles of different shapes along with magnetic effect by changing volume fraction of the particle, Hartmann number, and Rayleigh number. Their results revealed that despite the circular, square, and diamond obstacles the heat transfer reduces 21.35%, 32.58%, and 34.64%, respectively compared to the condition without obstacles.

Skeikholeslami & Ganji [20] worked on a square enclosure filled by Cu-water nanofluid together with the heat source and magnetic effect. They calculated the effective thermal conductivity and viscosity of nanofluid by using KKL (Koo-Kleinstreuer-Li) model and applied parameters such as volume fraction of the particle, Hartmann number and Rayleigh number to calculate heat transfer and Nusselt number. According to their results, by increasing the Rayleigh number and volume fraction of the particles the heat transfer rate increases and it decreases with increase of Hartmann number. Also, with increasing the Rayleigh number and volume fraction of particles the dimensionless entropy generation increases and entropy decreases with the increase of Hartmann number and dimensionless temperature difference. Also, other researchers studied the use of nanofluid with the magnetic field in the natural convention in the geometries such as microchannle and annulus.

Sheikholeslami et al. [21] in accordance with figure 3, studied numerically the natural convection of nanofluid in an enclosure. They used Cu-Water nanofluid in a cold outer circular enclosure containing a hot inner sinusoidal circular cylinder in the presence of horizontal magnetic field and maintained both circular enclosure and inner cylinder at constant temperature. They investigated the effect of effective thermal conductivity and viscosity of nanofluid using Maxwell-Garnetts (MG) and Brinkman model, respectively. They studied various parameters such as Rayleigh number, Hartmann number and volume fraction of nanoparticles on the plotting of flow lines, change of Nusselt number and ratio of heat transfer enhancement.

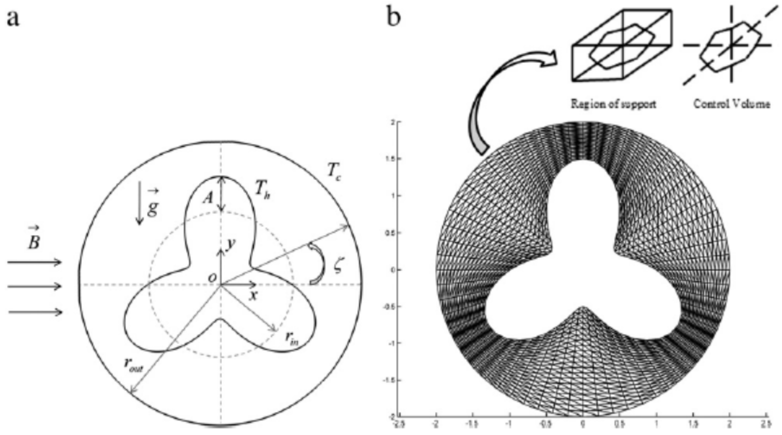

Figure 3. (a) Geometry and the boundary conditions with (b) the mesh of geometry considered in this work [21].

Malvandi & Ganji [17] examined the Brownian motion and thermophoresis effects on a circular microchannle with Al2O3 nanofluid. They heated the microchannels wall using the magnetic field effect and investigated the effects of volume fraction of nanoparticles, the non-adherence of the fluid solid interface in the presence of nanoparticle migration, and the Navier's slip boundary condition with natural convection in the microchannle. The boundary conditions are shown in Figure 4. Their results showed that nanoparticles move from the heated walls (nanoparticles depletion) towards the core region of the microchannel (nanoparticles accumulation) and build a non-niform nanoparticles distribution. The ratio of the Brownian to thermophoretic diffusivities (NBT) has proportionately considerable effects on the nanoparticles distribution and the convective heat transfer coefficient of nanofluids. Using Lattice Boltzman method (LBM), Ashorynejad et al. [7] studied numerically a cylindrical annulus in natural convection flow of a water-Ag nanofluid in the presence of static radial magnetic field effect. The inner and outer cylinder surfaces were kept at different uniform temperature. It is assumed that the walls are insulating with a radial magnetic field. Their results indicated that by imposing an external radial magnetic field the flow oscillations can be suppressed efficiently.

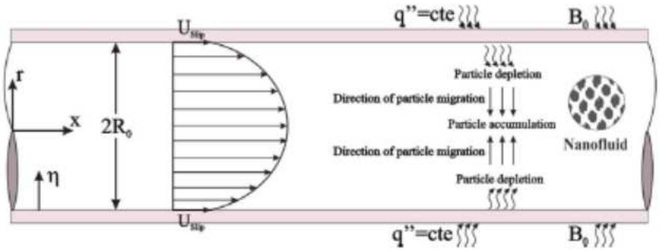

Figure 4. The geometry of physical model and coordinate system [17].

4. Natural convection in Porous Media

There is different ways to improve convective heat transfer characteristics in industrial processes that one of them is the use of porous medium. Any material which consist of solid matrix with an interconnected void is called porous medium such as rocks and open cell aluminium foam. Some authors studied porous media by placing a heat source in the media such as Lam & Pramash [22] who investigated the natural convection in a porous enclosure. As can be seen in figure 5, they considered a two-dimensional problem: Newtonian fluid with buoyancy and Darcy effect. The upper and lower walls have a linear heat source and are adiabatic, while the vertical walls are maintained at constant cold temperature. By changing porosity, Darcy number, and Rayleigh number, they examined the effect of the heat source on the flow pattern, entropy and distribution of temperature. Also, they calculated the Nusselt number with change of Darcy number and porosity in the enclosure of the left, right and top walls and the entire enclosure which were the heat source in in-line and staggered modes. They concluded that strength convection motion increases by increasing the Darcy number and porosity which is due to reducing bulk frictional drag of solid matrix. Also, in terms of both staggered and in-line modes, the distribution of Nusselt number is over the upper and lower heat sources for Darcy numbers and symmetric low porosity; this symmetry deviated by increasing Darcy number and low symmetry. Their results indicated that maximum entropy generation of irreversible heat production occurs near a heat source due to the high temperature gradient.

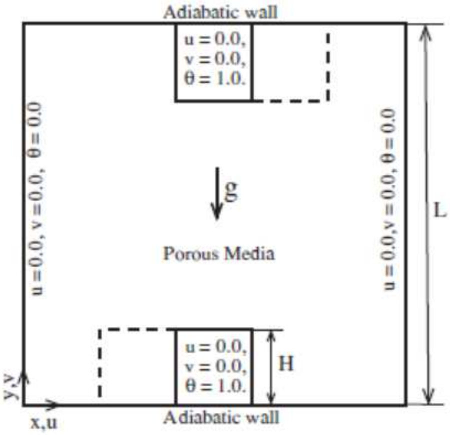

Figure 5. Computational domain with boundary conditions (solid line: in-line arrangement, dashed line: staggered arrangement) [22].

Bourantas et al. [23] also studied in the same field. They used the Darcy-Brinkman and the energy transport equations to analyze the nanofluid flow and the heat transfer process in the porous medium. A heat source was placed in the lower wall of the enclosure and the walls were maintained at constant temperature. They investigated the Nusselt number, isotherms and flow lines for a wide range of Rayleigh and Darcy numbers.They made a conclusion that the average Nusselt number for low Rayleigh number definitely seems to be insensitive to the presence or absence of a porous medium. In the presence of a porous medium and for different values of Rayleigh number, the average Nusselt number increases as the solid volume fraction increases. At last, as the length of heat source increases, the maximum temperature at the heat source surface also increases. Some other studies examined the porous media in a cone. Using drift-flux model, Ghalambaz et al. [24] conducted a study on the vertical cone in Darcy porous media in the natural convection regime. The boundary conditions are shown in Figure 6. It is assumed that the thermal conductivity and the viscosity of the nanofluid be as simultaneous functions of temperature and local volume fraction of nanoparticles. Their results revealed that employing nanoparticles wouldn’t (would) increase the heat transfer from the cone for the situation of a cone with a hot surface (cold surface). Decreasing the nanoparticle size or increasing the volume fraction of nanoparticles bring about a decrease in the heat transfer rate from the cone when the cone surface is hot. Also the results showed that as the size and volume fraction of nanoparticles increase, the drift- flux model tends to the homogeneous model.

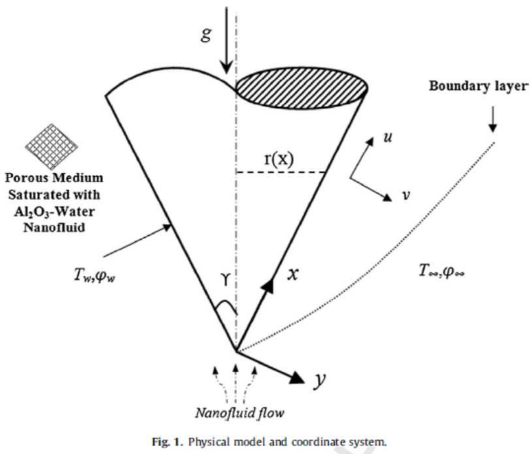

Figure 6. Physical model and coordinate system [24].

Cheng [25] worked on the topic of natural convection boundary layer flow over a truncated cone in a porous medium saturated with nanofluid. He did calculations while the temperature of truncated cone walls was assumed constant. He examined the effects of Brownian motion and thermophoresis on the temperature, nanoparticle volume fraction and velocity profiles. He also investigated the effects of the thermophoresis parameter, Brownian parameter, Lewis number, and buoyancy ratio on the local Nusselt number. Their results indicated that increasing the thermophoresis parameter or the Brownian parameter tends to decrease the local Nusselt number. Furthermore, the local Nusselt number increases with the decrease of the buoyancy ratio or the Lewis number.

Noghreabadi & Behseresht [26] numerically studied natural convection boundary layer flow over a vertical cone in porous media with nanofluid. Unlike two previous authors, they considered the effect of slip of nanoparticle which is due to the Brownian motion and thermophoresis forces and examined the effect of viscosity and thermal conductivity of nanofluid as a function of the local volume fraction of nanoparticles and dynamic effect of nanoparticles, thermophoresis and Brownian motion. They carried out two mathematical processes. The first step was the simplification of the governing partial differential equations making use of appropriate similarity variables. The second step was the numerical solution of the obtained ordinary differential equations. Moreover, they suggested the new definition of the reduced Nusselt and Sherwood numbers with all the specifics based on the Buongiorno's model. Their result indicated that by increasing viscosity parameter, the reduced Nusselt number would increase and by increasing thermal conductivity parameter, it decreases.

Some other studies have also been conducted on the flat plate and annulus in this field such as the following two articles. Sheremet and Pop [27] examined the steady free convection in a porous concentric horizontal cylindrical annulus with a nanofluid using Buongiorno's model in 2015. They examined the effect of Rayleigh number, Lewis number, buoyancy ratio parameter, Brownian motion parameter and thermophoresis parameter on the streamlines, isotherms, isoconcentrations, local and average Nusselt numbers. Their results revealed that nanoparticles insertion result in a transfer from bicellular flow structure to unicellular flow structure for small values of the Rayleigh number. This result describes a displacement of the bifurcation point 2-D unicellular flow to 2-D bicellular flow for R = 2. They also indicated a formation of unicellular and bicellular flows for Ra = 500 at different initial conditions.

In 2012, Aziz et al. [28] studied numerically steady boundary layer natural convection flow past a horizontal flat plate in porous medium filled by nanofluid containing gyrotactic microorganisms. They applied the effect of Boussinesq and investigated the effects of bioconvection parameters on the velocity, temperature, nanoparticle concentration and density of motile microorganisms on Nusselt number, Sherwood number and motile microorganism number. They discovered that the heat, mass, and motile microorganism transport rates were highly affected by bioconvection parameters. They indicated no significant effect of the bioconvection parameters on temperature and nanoparticle concentration distributions in the flow field. In addition, the local Nusselt number, Sherwood number and density number of the motile microorganisms enhanced as the bioconvection parameters, bioconvection Rayleigh number, bioconvection Péclet number and bioconvection Lewis number increase but decreased by increasing the buoyancy parameter Nr.

In 2015, Mahdi et al. [8] conducted a review of the convection heat transfer and fluid flow in porous media with nanofluid. First, they focused on Porous media characteristics including permeability (k) and inertia coefficient (C_f) and effective thermal conductivity (k_{eff}) for porous media, then studied thermophysical properties of nanofluid such as Density, Specific heat capacity, effective heat thermal conductivity and effective viscosity. Finally, they studied convection heat transfer in porous media with nanofluid for Natural, mixed and forced convection.

5. Conclusion

Since the use of porous medias has a considerable impact on the rate of enhance heat transfer in industries such as heat exchangers and also widely used effect of the magnetic field in many cases such as electronics equipment, therefore in the present paper, articles in recent years with regard to the impact of parameters of magnetic field, porous media and volume fraction of nanoparticles using of nanofluid on the heat transfer, Nusselt number, entropy generation and Hartmann number has been investigated and reviewed. Review literature show that the enhance heat transfer in porous medias due to the improvement thermal conductivity that Leading to a significant increase in convection heat transfer coefficient.

Also, most studies considered the water as base fluid and Al2O3 and Cu-Water as nanofluid. Since adding nanofluid increases the heat transfer, the value of volume fraction of nanoparticle should be determined via the experiments by considering the experimental and practical conditions, but the volume of nanofluids must be controlled because of the problems of fouling equipment and ducts.

References

[1] Maxwell J.C., *Electricity and Magnetism*, Clarendon Press, Oxford, 1873.

[2] Choi S.U.S., *Enhancing thermal conductivity of fluid with nanoparticles Developments and Applications of Non-Newtonian flows*, D.A. Siginer and H.P. Wangeds., FED, V.231/MD, Vol. 66, pp. 99-105, 1995.

[3] Akbarinia A., Behzadmehr A., *Numerical study of laminar mixed convection of a nanofluid in horizontal curved tubes*, Applied Thermal Engineering, Vol. 27, pp. 1327-1337, 2007.

[4] Saberia M. Kalbasia A. Alipourzadeb, *Numerical Study of Forced Convective Heat Transfer of Nanofluids inside a Vertical Tube*, International Journal of Thermal Technologies, Vol.3, No.1, 2013.

[5] Wusiman K.B., Chung H.S., Md J.N., Handry A., Eom Y., Kim J., Jeong H., *Heat transfer characteristics of nanofluid through circular tube*, Journal of Central South University, Vol. 20, pp. 142-148, 2013.

[6] Nobari M.R.H., Malvandi A., *Torsion and curvature effects on fluid flow in a helical annulus*, Int. J. Non-Linear Mech. 57 , pp. 90-101, 2013.

[7] Ashorynejad H.R., Mohamad A.A., Sheikholeslami M., *Magnetic field effects on natural convection flow of a nanofluid in a horizontal cylindrical annulus using Lattice Boltzmann method*, International Journal of Thermal Sciences, Vol. 64, pp. 240-250, 2013.

[8] Mahdi R.A., Mohammed H.A., Munisamy K.M., Saeid N.H., *Review of convection heatt ransferand fluid flow in porous media with nanofluid Raed AbedMahdi* , Renewable and Sustainable Energy Reviews , Vol. 41, pp. 715–734, 2015.

[9] Kuppusamy, N.R., Mohammed, H.A., Lim, C.W., *Thermal and hydraulic characteristics of nanofluid in a triangular grooved microchannel heat sink (TGMCHS),* Applied Mathematics and Computation, Vol. 246, pp. 168–183, 2014.

[10] Mashaei P.R., Shahryari M., *effect of nanofluid on thermal performance of heat pipe with two evaporator, Application to satellite equipment cooling*, Acta Astronautica, doi.org/10.1016/j.actaastro. 2015.02.003.

[11] Turkyilmazoglu M., Pop I., *Heat and mass transfer of unsteady natural convection flow of some nanofluids past a vertical infinite flat plate with radiation effect*, International Journal of Heat and Mass Transfer, Vol. 59, pp. 167–171, 2013.

[12] El Abdallaoui M., Hasnaoui M., Amahmid A., *Numerical simulation of natural convection between a decentered triangular heating cylinder and a square outer cylinder filled with a pure fluid or a nanofluid using the Lattice Boltzmann method* , Power Technology, doi: 10.1016/j.powtec. 2015.02.042, 2015.

[13] Paul T.C., Morshed A.K.M.M., Fox E.B., Khan J.A., *Experimental investigation of natural convection heat transfer of Al2O3 Nanoparticle Enhanced Ionic Liquids (NEILs)* , International Journal of Heat and Mass Transfer, Vol. 83, pp. 753–761, 2015.

[14] Ooi E.H., Popov V., *Numerical study of influence of nanoparticle shape on the natural convection in Cu-water nanofluid* , International Journal of Thermal Sciences, Vol. 65, pp. 178-188, 2013.

[15] Sourtiji E., Ganji D.D., Seyyedi S.M., *Free convection heat transfer and fluid flow of Cu–water nanofluids inside a triangular–cylindrical annulus*, Powder Technology, Vol. 277, pp. 1–10, 2015.

[16] Shahi M., Mahmoudi A.H., Talebi F., *A numerical investigation of conjugated-natural convection heat transfer enhancement of a nanofluid in an annular tube driven by inner heat generating solid cylinder*, International Communications in Heat and Mass Transfer, Vol. 38, pp. 533–542, 2011.

[17] Malvandi A., Ganji D.D., *Brownian motion and thermophoresis effects on slip flow of alumina/water nanofluid inside a circular microchannel in the presence of a magnetic field*, International Journal of Thermal Sciences, Vol. 84, pp. 196-206, 2014.

[18] Aghaei A., Sheikhzadeh G.A., Ehteram H.R., Hajiahmadi M., *MHD natural convection and entropy generation of variable properties nanofluid in a triangular enclosure*, Transport Phenomena in Nano and Micro Scale, Vol. 3, pp. 37-45, 2015.

[19] Selimefendigil F., Öztop H.F., *Natural convection and entropy generation of nanofluid filled cavity having different shaped obstacles under the influence of magnetic field and internal heat generation* , Journal of the Taiwan Institute of Chemical Engineers, pp. 1–15, 2015.

[20] Sheikholeslami M., Ganji D.D., *Entropy generation of nanofluid in presence of magnetic field using Lattice Boltzmann Method*, Physica A, doi.org/10.1016/j.physa.2014.09.053.

[21] Sheikholeslami, M., Gorji-Bandpy, M., Ganji, D.D., Soleimani, S., Seyyedi, S.M., *Natural convection of nanofluids in an enclosure between a circular and a sinusoidal cylinder in the presence of magnetic field*, International Communications in Heat and Mass Transfer, Vol. 39, pp. 1435–1443, 2012.

[22] Lam P.A.K, Prakash K.A., *A numerical study on natural convection and entropy generation in a porous enclosure with heat sources*, International Journal of Heat and Mass Transfer, Vol. 69, pp. 390–407, 2014.

[23] Bourantas G.C., Skouras E.D., Loukopoulos V.C., Burganos V.N., *Heat transfer and natural convection of nanofluids in porous media* , European Journal of Mechanics B/Fluids, doi.org/10.1016/ j.euromechflu. 2013.06.013.

[24] Ghalambaz M., Behseresht A., Behseresht J., Chamkha A., *Effects of nanoparticles diameter and concentration on natural convection of the Al2O3–water nanofluids considering variable thermal conductivity around a vertical cone in porous media*, Advanced Powder Technology, doi.org/ 10.1016/j.apt.2014.10.001.

[25] Cheng Ch.Y., *Natural convection boundary layer flow over a truncated cone in a porous medium saturated by a nanofluid*,

International Communications in Heat and Mass Transfer, Vol. 39, pp. 231–235, 2012.

[26] Noghrehabadi A., Behseresht A., *Boundary Layer Flow of Nanofluids with Variable Thermal Conductivity: Natural-Convection Flow over a Vertical Cone in Porous Media*, Computers & Fluids, doi.org/10.1016/ j.compfluid.2013.09.019.

[27] Sheremet M.A., Pop I., *Free convection in a porous horizontal cylindrical annulus with a nanofluid using Buongiorno's model*, Computers & Fluids, Vol. 118, pp. 182–190, 2015.

[28] Aziz A., Khan W.A., Pop I., *Free convection boundary layer flow past a horizontal flat plate embedded in porous medium filled by nanofluid containing gyrotactic microorganisms*, International Journal of Thermal Sciences, Vol. 56, pp. 48-57, 2012.

Addresses:

- Mohadeseh Miri, Department of Mechanical Engineering, University of Zabol, Zabol, Iran, mhdsh.miri@gmail.com
- Farhad Vahidinia, Department of Mechanical Engineering, University of Zabol, Zabol, Iran, f.vahidinia@gmail.com
- Navid Bozorgan, Mechanical Engineering Department, Abadan Branch, Islamic Azad University, Abadan, Iran, n.bozorgan@gmail.com