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A Review on Natural Convection in Nanofluid Flow

The Heat transfer is performed in three forms including conduction, convection and radiation. Convection is one of the major modes which classifies into three categories: natural, mixed or forced convection. In recent years, much attention was given to the use of natural convection with nanofluid in engineering application, satellite, cooling system, solar collector etc. and many studies were conducted in this area. This paper reviews some results of numerical, experimental and theoretical studies in the field of natural convection heat transfer with nanofluid and application of natural convection. Finally, some suggestions are given for future studies in this area.

Keywords: *NanoFluid, Natural Convection, Heat Transfer*

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]. Natural convection is an important heat transfer mechanism induced by density differences. It has received substantial attention in recent years due to its broad range of engineering applications such as domestic heating, solar ponds, solar collectors and food storage to name a few [6].

Engineering application of natural convection requires solving combined problems of heat transfer and fluid mechanics which depend on several parameters among which the geometry and the local values of the thermal and physical properties of the convected fluid. The relative position of active flow sources with respect to the gravity field also plays an important role in determining the nature of the flow. Each application thus requires a specific analysis [7]. Many researchers studied the natural convection [7-12], so far This paper reviews some studies on natural convection with nanofluid. In this paper, a number of parameters are investigated, namely application of natural convection with nanofluid and heat transfer enhancement and Nusslet number. Finally some suggestions are provided for future researches.

2. Natural convection in Enclosure

Natural convection in cavities has many important engineering applications, including electronic cooling devices, heat exchangers, MEMS devices, electric machinery, solar energy collectors, and so on [13]. Enclosures have different shapes. Abdallaoui et al.'s research [14] is one of the studies on the cylinder enclosure in which they carried out a numerical study on natural convection between a decentered triangular heating cylinder and a square outer cylinder with pure water or a water-silver nanofluid using Lattice Boltzmann method. As can be seen in Figure1, the inner heating triangular cylinder is maintained in a constant and uniform temperature, while the vertical / (horizontal) sides of the external cylinder are cooled in a constant temperature / (considered adiabatic). By changing the Rayleigh number, they calculated the effective thermal conductivity and viscosity of nanofluids in a constant Prandtl number (Pr=7) by using Maxwell-Garnetts (MG) and Brinkman models, respectively.

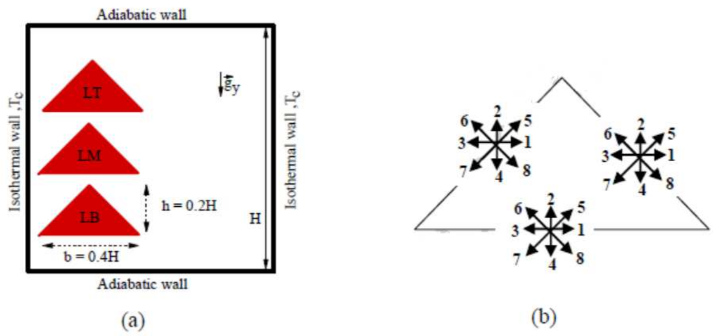

Figure1. (a) Sketch of studied configuration and (b) Lattices positions at the triangle faces for the D2Q9 arrangements [14]

Their results revealed that the heating cylinder position influenced highly on the characteristics of heat transfer and fluid flow. They discovered that the bottom/ (top) position of the block becomes the most/ (least) desirable to heat transfer in dominating natural convection regime. Considering the effect of inclination angle in enclosures on the heat transfer is one of the subjects which has considered in recent year. Moradi et al. [15] studied experimentally the natural convection heat transfer of two Newtonian Al2O3 and TiO2 / water nanofluids in a cylindrical enclosure. They examined changes of Nusselt number by changing the Rayleigh number, concentration of nanofluid, and inclination angles of the enclosure $(\theta = 0, 30, 45, 60, 90^{\circ})$ in different configuration and orientation of the enclosure. Their results indicated that the addition of nanoparticles to water has insignificant or adverse effect on natural convection heat transfer of water: natural convection heat transfer of Al2O3/water is slightly increased, while natural convection heat transfer for TiO2/water nanofluid is inferior to that for the base fluid. Also, their results showed that the probability of increasing natural convection heat transfer at low Ra is more than at high Ra: at low Ra, natural convection heat transfer is more significantly affected by the inclination angle, aspect ratio of the enclosure, and nanoparticles concentration than that in high Ra. Mansour et al. [16] also examined the natural convection in an inclined trapezoidal enclosure or a heat source in the presence of Cu/ water nanofluid. Assuming that Kuwaiti three sides are adiabatic while its smaller side which makes θ angle with the horizon, is at the low temperature T_{cold}. By changing the Rayleigh number parameters, enclosure rotation angle, and Hartmann number, they investigated the changes of flow lines, isotherm lines and average Nusselt number in the heat source of the enclosure larger side. Based on the results, by increasing Hartmann number, diffusive heat transfer increases even with increase of Rayleigh number; and likewise the buoyancy force enhances by increasing inclination angle regardless of the effect of viscous force. Also, in the left inclined surface, once the inclination angle equal 45 the flow invokes the supremacy of convection heat transfer.

Another study on the inclined rectangular enclosure in steady laminar natural convection in enclosure with sinusoidal temperature distribution was carried out by Bouhalleb & Abbasi [17]. In their study, the horizontal walls are thermally insulated and the left vertical side wall is heated by a spatial temperature distribution in the examined enclosure. They studied changes of Nusselt number, flow lines, and isotherm lines by changing the parameters of the inclination angle $\left(\theta = 0^{\circ} - 90^{\circ}\right)$,aspect ratio, while the values of Rayleigh and Prandtl number was constant $(\mathrm{Ra} = 10^{5}, \mathrm{Pr} = 7.02)$. They made a conclusion that first the heat transfer increases and then decreases by increasing the inclination of the enclosure for aspect ratio $Ar \geq 1$ and increases by increasing the inclination angle for $Ar \prec 1$. In addition, by increasing aspect ratio, the Nusselt number decreases and the heat transfer maximum was in $\theta = 90^{\circ}$.

The effect of nanoparticles shape on the heat transfer in different areas has also been the interest of the authors. Ooi & Popov [18] focused on the effect of Cu-Water nanofluid shape (spherical and spheroidal nanoparticles ((NPs) on the natural convection flow in square cavity. To solve the equations, they used radial basis integral equation (RBIE) method and plotted the velocity profile in the geometrical center of the cavity for different naoparticles volume fraction at different Rayleigh numbers. They found that the different nanoparticles shapes and sizes have different effect on the thermal conductivity and viscosity of nanofluid. They proposed that the accumulation of the nanoparticles may result in enhancement of the different levels of heat transfer. Their results revealed that the oblate spheroid with aspect ratio of 10 created the greatest enhancement of the entire heat transfer characteristic. Cho [19] examined the impact of natural convection heat transfer on a square cavity with partially-heated wavy surface which filled with AL2O3 nanofluid. He changed the volume fraction of particles, Rayleigh number, the amplitude and wavelength of the partially-heated wavy surface to check the changes of entropy, Nusselt number, and Bejan number. Based on the results, with increasing the volume fraction of nanoparticles in a given Rayleigh number of fluid, the average Nusselt number increases and the entropy decreases. Also, by increasing Rayleigh number, Nusselt number increases and entropy decreases in a constant volume fraction. Increasing the amplitude and wavelength of a wave surface decreases the average Nusselt number and increases the total entropy.

Cho et al.'s [20] study is one of the studies which carried out on natural convection heat transfer on the wavy wall enclosure. As shown in Figure 2, enclosure has wavy vertical wall and flat upper and lower surface where the left wall is fed by a constant heat source and the right wall has a constant low temperature and the top and bottom walls are insulated. The governing equations are modelled by assuming bosinesq approximation. They examined the Nusselt number by changing wavy-wall geometry parameters, Rayleigh number, and type of nanoparticles. According to the results, by adding the volume fraction of nanoparticles in the overall range of Rayleigh numbers, the Nusselt number increases and the entropy generation decreases. So, Cu-water nanoparticles have the minimum entropy generation among the three nanoparticles including: Cu-water, Al2O3-water, and TiO2-water. They also claimed that wavy-wall geometry can be proposed for certain nanoparticles that have the optimum state (i.e. the Nusselt maximum and the entropy minimum).

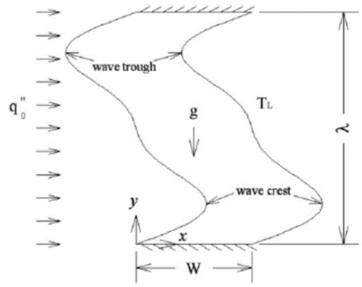

Figure 2. Schematic illustration of wavy-wall enclosure. Note that g indicates the gravitational acceleration [20]

Parvin & Chamkha [21] investigated numerically natural convection, heat transfer, and entropy generation in an odd-shaped cavity which is filled with Cu-water nanofluid. The inner wall temperature is held constant at Th and the outer wall temperature is maintained at the temperature Tc while the other two sides are insulated. The governing equations were solved using penalty finite element method and Galerkins weighted residual technique. In this study, they focused on changes of natural convection, Rayleigh number, and volume fraction of the particles. According to their results, with increasing the Rayleigh number, the Nusselt number and Bejan number increase.

In 2014, Oztop et al. [22] also conducted a review of the natural convection in the enclosures which were under the localized heating with or without nanofluids. They investigated the effect of type and region of the applying local heat on the enclosure and also the effect of Kuwaiti different shapes and boundary conditions on the Kuwaiti fluid flow and heat transfer and evaluated separately the heat transfer in Kuwaitis with one heat source and two or more heat sources. They also brought into account the heat transfer in porous enclosures that were partially heated. In all of the above, they compared the results of experimental studies with two-dimensional and three-dimensional numerical studies and investigated the relationship between the heat transfer and wall heating conditions in the enclosure especially with the use of nanofluids.

3. Natural convection in Microchannle

In recent years, design and fabrication of micro-electromechanical systems (MEMS), such as micro-heat exchangers, micro-reactors and micro-engines, and biomedical applications, such as drug delivery, DNA sequencing, and bio-MEMS, have attracted remarkable research interest on micro-flow in order to understand the fluid flow and heat transfer in micro-geometries [10]. Kuppusamy et al. [23] conducted an interesting study on thermal and hydraulics characteristic of nanofluid in the triangular grooved microchannel heat sink (TGMCHS). By changing grooves characteristics such as angle $(\alpha = 50 - 100^{\circ})$, depth $(\mathrm{d}_{tri} = 10 - 25\mu m)$, and pitch, they evaluated the thermal performance, fluid flow and TGMCHS including Nusselt number, maximum of temperature difference, velocity profile, pressure drop, and increase of overall heat. They used water, ethylene glycol, and engine oil as the base fluid and also utilized Al2O3, CuO, SiO2, ZnO nanofluids. The flow is three-dimensional, laminar, steady state, and incompressible; the channel wall is smooth in terms of hydraulic. The single-phase model is considered for nanofluid and the velocity is zero along all other solid boundaries.

By considering an optimum groove pitch, they found that TGMCHS thermal performance increases with increasing the depth and angle of the groove. The results were the following:

1) The characteristics of nanofluid flow and heat transfer within the TGMCHS principally ascribe to the redeveloping hydraulic and thermal boundary layers, vortices generation, and the enhanced heat transfer surface at the

groove area. This phenomenon increases significantly the heat transfer but it augments the pressure drop.

2) Increment of α and d increases considerably the entire performance as a result of the increment of the surface area as well as larger vortices generation. It is deduced that to supply enough space for the boundary layer redevelopment, an optimum value of p_{tri} is needed. The best geometrical configuration of TGMCHS is $\alpha = 100^{\circ}$, $\mathrm{d}_p = 25\,\mathrm{nm}$ and $p_{tri} = 450\mu m$.

Salman et al. [24] conducted a review of heat transfer and fluid flow on microchannle and micro tube using convectional fluid and nanofluid. They discussed on the parameters of geometrical specifications, boundary conditions, and type of fluids; their main purpose was to provide equations associated with the Nusselt number. They also examined the effect of the techniques using nanofluid, shape and type of nanoparticles, base fluid, thermal conductivity, and the stability of the suspension on the heat transfer ,mechanism of heat conduction ,and rheological behavior of nanofluids.

another review were published regarding the microchannels by Asadi et al. [25]. They worked on single and two-phase flows in the micro-channels. By evaluating heat transfer and pressure drop in the microchannels, they compared used method and equations to predict the heat transfer, pressure drop in the channel based on the geometry and flow regime.

4. Natural convection in Pipe

Today, natural convection in the pipe by using nanofluid has many application in different industry equipment. One of its important use is in solar energy system such as evacuated tube collector; it also uses in satellites. We know that heat pipe as one of the most reliable efficient heat exchanger, is often used to provide suitable thermal conditions for space application. It's another application is in loop heat pipes which used in the server computers and etc.

Mashaei & Shahryari [26] were among those who worked on heat pipe. As can be seen in Figure 3, they investigated the effect of nanofluid on thermal performance of cylindrical heat pipe with two heat sources. The examined heat pipe was a part of satellite equipment cooling. The effect of particle diameter $(d_p = 10, 20, 40nm)$ on the local wall temperature, heat transfer coefficient, thermal resistance, and the size of the heat pipe were also investigated. They discovered that the better wall temperature uniformity can be obtained making use of nanofluid which leads to lower temperature difference between evaporators and condenser sections. Their results showed that applying small nanoparticle increases heat transfer coefficient considerably by reducing thermal resistance.

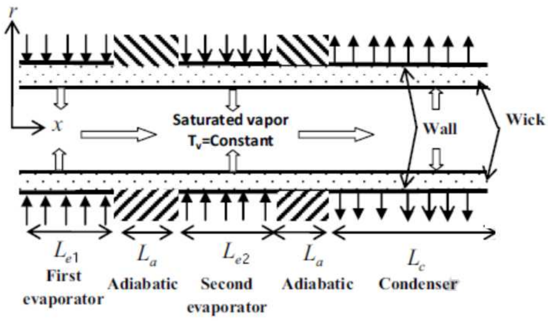

Figure 3. Schematic of a cylindrical heat pipe with two evaporators [26]

Due to the simplicity of geometry, more experimental studies are carried out on the heat pipe. One of those was the study of Wan et al. [27] which was about thermal performance of a miniature loop heat pipe (mLHP) using water. They used Cu-water nanofluid with an average diameter of 50 nm and changed the contact angle, the evaporation rate of nanofluid with deionized water. They also discussed on the thermal performance comparison of the mLHP operating with Cu-Water nanofluid and with deionized water. Their results revealed that the evaporator wall temperature and total thermal resistance reduce 12.8% and 21.7%, respectively, while the evaporator heat transfer coefficient (HTC) enhances 19.5% when replacing the nanofluid with 1.0 wt% of deionized water at a heat load of 100 W. Using the nanofluid, improvement of the mLHP thermal performance results from the reduction of the contact angle, the enhancement of boiling heat transfer, and a deposited nanoparticle coat on the boiling surface.

Another experimental study was conducted by Goudarzi et al. [28] on the thermal efficiency of the cylindrical solar collector along with the helical pipe receiver by changing mass flow rate of fluid, nanoparticle mass concentration, and SDS (sodium dodecyl sulfonate).

Their result showed that the maximum thermal efficiency is enhanced 25.6% for 0.1 wt% nanofluid in 0.0083 kg/s mass flow rate of fluid. Furthermore, by using nanofluid with SDS as surfactant the maximum collector efficiency is increased by 24.2% in comparison with the situation without surfactant. By increasing mass flow rate of fluid, the efficiency is enhanced for low values of decreased temperature differences parameter. And in the case of higher temperature ranges, the efficiency becomes reverse.

Shahi et al. [29] studied numerically the steady natural convection heat transfer in a 3-dimensional single-ended tube with non-uniform heat input. They are assumed that the sealed end of tube to be adiabatic and also the tube opening to be subjected to copper–water nanofluid. They investigated the effect of dimensions and inclination angle of the solar tube, as well as the maximum heat flux $100 \le q_m \le 700$ on the flow patterns and temperature distributions on different cross sectional planes and longitudinal sections, when the tube is positioned at different orientations. Their analysis of the impact of the inclination angle showed that the maximum total average Nusselt number is obtained at $\gamma=35°$ (inclination angle), while the maximum output mass flow rate is enhancing function of the inclination angle. In addition, they obtained that the maximum output mass flow rate as well as the Nusselt number are increasing function of solid concentration, however the existence of nanoparticles is more effective at the smaller inclination angles.

5. Natural convection in Flat Plate

The fluid flow and heat transfer on a flat plate have very important applications in engineering process, including packed-bed catalytic reactors, geothermal reservoirs, drying of porous solids, thermal insulation, packed-bed storage tanks, petroleum resources, gas production, grain storage, etc. [30]. The conducted studies on flat plates have more different circumstances. Considering slip condition which is ignored to simplify the calculation in most studies and also taking non-Newtonian as a fluid for the calculation are among them.

Singh and Kumar [31] studied mass transfer in magneto hydrodynamic (MHD) flow of alumina water nanofluid over a flat plate by taking the slip conditions. They assumed that slip flow an incompressible, electrically conducting, viscous and steady flow of alumina water nanofluid in the presence of magnetic field over a flat plate. To solve the governing equations, they used Runge-Kutta method with shooting technique. They examined the impact of solutal Grashof number as well as Schmidt number on velocity distribution profile, concentration profile, shear stress and concentration gradient. They discovered that by increasing value of solutal Grashof number, the concentration increases and concentration gradient decreases. In addition, the concentration decreases by increasing Schmidt number. Hatami & Ganji [32] studied also natural convection of sodium alginate (SA) non-Newtonian nanofluid flow between two vertical flat plates. They selected Sodium alginate (SA) as the base non-Newtonian fluid and then added copper (Cu) and silver (Ag) as nanoparticles. Least Square Method (LSM), Differential Transformation Method (DTM) and fourth-order Runge-Kutta numerical method (NUM) were employed to solve the problem. They examined the effect of Prandtle number, nanoparticles materials and nanoparticle volume friction on non-dimensional velocity and temperature profiles. As result indicated, Cu as nanoparticles makes larger velocity and temperature values for nanofluid compared to Ag. They concluded that velocity profiles and temperature values increased meaningfully with an increase of Prandtle number.

Khan & Aziz [33] investigated the natural convection flow of a nanofluid by considering uniform surface heat flux over a vertical flat plate. They utilized the transport model which includes the effect of Brownian motion and thermophoresis. The considered boundary conditions can be seen in Figure 4. They plotted the graphs of velocity, temperature and concentration of nanoparticle that are dependent on boundary layers, besides the Prandtl and Lewis numbers, on three additional dimensionless parameters, namely a Brownian motion parameter Nb, a thermophoresis parameter Nt, a buoyancy ratio parameter Nr, respectively. In addition, they obtained an equation for the Nusselt number and Sherwood number with the study of these parameters on the boundary layer flow characteristic which predicted the results of numerical studies with maximum error of 5.5% and 3.2% for reduced Nusselt number and reduced Sherwood number, respectively. Their result revealed that for fixed Lewis number, as the Brownian motion parameter and thermophoresis increases dimensionless skin friction increases but decreases as the buoyancy ratio parameter increases, and, for a fixed Lewis number, by increasing Prandtl number, the reduced Nusselt number increases but it decreases as the Brownian motion parameter, the thermophoresis parameter and the buoyancy ratio parameter increase. In addition, the reduced Sherwood number increases as the Lewis number and the Brownian motion parameter increase for fixed values of Prandtl number and the buoyancy ratio parameter.

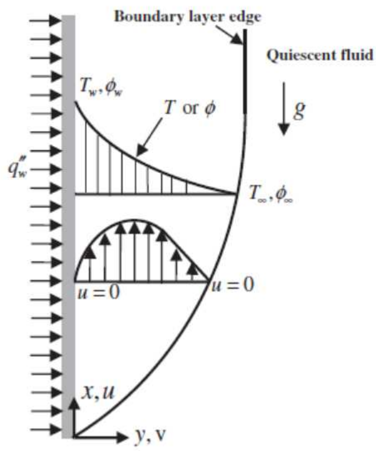

Figure 4. Vertical plate with a constant surface heat flux [33]

6. Natural convection in Annulus

The convection heat transfer within concentric and eccentric annulus have many applications in science and engineering, including completion of an oil source, electrical motor and generator, heat transfer in heat exchanger device, cooling of electrical and electronic components, solar collectors, nuclear reactor, thermal storage system and electrical transmission cables.

In 2015, Dawood et al. [34] conducted a review of heat transfer and fluid / nanofluid flow in annulus. They considered three flow regime, namely natural, mixed and forced convection to study the experimental and numerical literature and analyzed the enhancement of the thermal performance in heat exchanging equipment.They also discussed on how to change the parameters such as the effect of heat lenghth, Darcy, Prandtle, Reynolds, Grashof and Rayleigh numbers on the heat transfer in concentric and eccentric annulus tube in the horizontal, inclined and vertical direction of tube. Considering these two articles, one can compare the two mode in the annulus. The first mode is the concentric annulus and the other is eccentric annulus. Alawi et al. [35] studied natural convection heat transfer in horizontal concentric annulus between outer cylinder and inner flat tube using nanofluid. They regarded a constant heat flux in horizontal flat tube and conducted a numerical study in the range of hydraulic radius ratio (5, 7.5, and 10) at orientation angles from 0° up to 90°. Their results indicated that the average Nusselt number enhances with hydraulic radius ratio, orientation angles and Rayleigh number and also enhancement ratio for Nusselt number is 24.87% at orientation angle 90° and hydraulic radius ratio 7.5.

Matin & Pop [36] investigated the eccentric annulus mode and studied numerically the laminar natural convection flow and heat transfer in an eccentric horizontal annulus filled by CU-Water nanofluid. First they extracted the governing equations in terms of stream function-vorticity formulation in polar coordinate system for eccentric physical domain and then transferred them to the rectangular domain to have better accuracy of the solution near the boundaries. By changing the Rayleigh number, eccentricity, radii ratio, they examined changes of Nusselt number, streamline and isotherm and concluded that with increase of Rayleigh number heat transfer enhances linearly. Furthermore, they discovered that the concentric form of the coaxial cylinder leads to the better condition in transferring the heat from the inner to the outer cylinder for high value of the Rayleigh number ($Ra = 10^6$). Also Sourtiji et al. [37] studied the horizontal triangular-cylindrical annulus which was a combination of two different forms in creating annulus, so annulus radius ratio $(RR = 2.5, 3, 4, 5)$ was one of the important parameters which was examined. They investigated the inner circular cylinder at constant high temperature of T_H while the outer triangular cylinder was maintained at constant low temperature of T_C and also examined the effect of Rayleigh number on fluid flow and temperature. Their results showed that by increasing the radius ratio at higher Rayleigh numbers, the average Nusselt number increases while it decreases at lower Rayleigh numbers. Furthermore, percentage of heat transfer enhancement due to the nanofluid is more considerable at lower Rayleigh numbers. Also, Seyyedi et al. [38] studied natural convection heat transfer under constant heat flux in an annulus filled by Cu-water nanofluid. By changing Rayleigh number, angle of turn for boundary condition, and aspect ratio, they investigated the Nusselt number and stream lines plotting. Their final result showed that increment of the aspect ratio as well as Rayleigh number at high Rayleigh enhances the value of average Nusselt number. Furthermore, while the angle of turn for boundary condition of the inner cylinder enhances, the value of average Nusselt number on the heat source reduces. Soleimani et al. [39] performed a study on natural convection heat transfer in a Cu-Wter nanofluid filled semi-annulus enclosure. As Figure 5 shows, the inner and outer semi-circular walls were maintained at constant temperature while the two other walls were thermally insulated. They used Maxwell-Garnetts and Brinkman models to calculate the thermal conductivity and viscosity of nanofluid. They examined changes of Nusselt number and flow lines by changing the Rayleigh number and angle of turn for the enclosure. Their results indicated that there was an optimum angle of turn in which the average Nusselt number is maximum for each Rayleigh number. Furthermore, the minimum values of local Nusselt number was corresponding to existence of thermal plumes on the top surface of the inner circular wall of the enclosure.

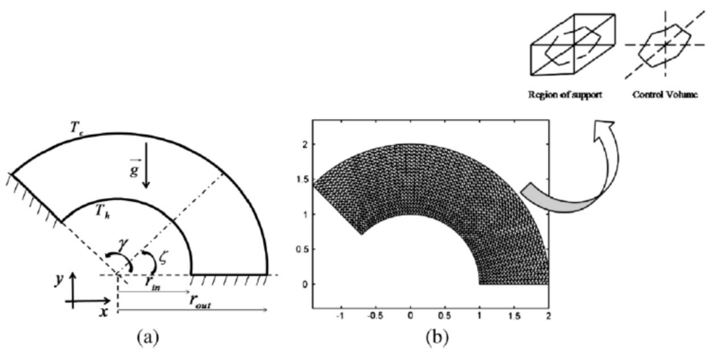

Figure 5. (a) Geometry and the boundary conditions with (b) the mesh of semi-annulus enclosure considered in this work. [39]

7. Conclusion

A review of natural convection heat transfer and flow nanfluid was conducted in various geometry. In this paper, the parameters of the flow, heat transfer, Nusselt number and distribution of flow function in natural convection were studied. Most studies considered the water as base fluid and Al2O3 and Cu-Water as nanofluid. Considering radiation along with natural convection with nanofluid which are applied in solar collectors and satellites can be useful. It also recommended that pay more attention to the study of natural convection heat transfer in microchannles in the future since limited study has been done in this area. Studying natural convection in transient phase at various geometry and considering changes of thermophisical properties temperature will be beneficial to increase the accuracy of the results.

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] Kashani S., Ranjbar A.A., Mastiani M., Mirzaei H., *Entropy generation and natural convection of nanoparticle-water mixture (nanofluid) near water density inversion in an enclosure with various patterns of vertical wavy walls* , Applied Mathematics and Computation, Vol.226, pp.180–193, 2014.
[7] Baïri A., Zarco-Pernia E., García de María J.M., *A review on natural convection in enclosures for engineering applications. The particular case of the parallelogrammic diode cavity*, Applied Thermal Engineering, Vol. 63, pp. 304-322, 2014.
[8] Rahman M.M., Oztop H.F., Mekhilef S., Saidur R., *Unsteady natural convection in Al2O3–water nanoliquid filled in isosceles triangular enclosure with sinusoidal thermal boundary condition on bottom wall*, Superlattices and Microstructures, Vol. 67, pp. 181–196, 2014.
[9] Khan Z.H., Culham J.R., Khan W.A., Pop I., *Triple convective-diffusion boundary layer along a vertical flat plate in a porous medium saturated by a water-based nanofluid* , International Journal of Thermal Sciences, Vol. 90, pp. 53-61, 2015.
[10] Buonomo B., Manca O., *Transient natural convection in a vertical microchannel heated at uniform heat flux*, International Journal of Thermal Sciences, Vol. 56, pp. 35-47, 2012.
[11] Cao Zh.H., Luo K., Yi H.L., Tan H.P., *Energy conservative dissipative particle dynamics simulation of natural convection in eccentric annulus*, International Journal of Heat and Mass Transfer, Vol 65, pp. 409–422, 2013.
[12] Abouei Mehrizi A., Farhadi M., Shayamehr S., *Natural convection flow of Cu–Water nanofluid in horizontal cylindrical annuli with inner triangular cylinder using lattice Boltzmann method*, International Communications in Heat and Mass Transfer, doi.org /10.1016/ j.icheatmasstransfer.2013.03.001, 2013.
[13] Ostrach S., *Natural convection in enclosure, journal of Heat Transfer-Trans*, ASME, Vol. 110, pp. 1175-1190, 1988.

[14] 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.
[15] Moradi H., Bazooyar B., Moheb A., Etemad S.Gh., *Fluid Dynamics and Transport Phenomena Experimental study on natural convection heat transfer of Newtonian nanofluids in a cylindrical enclosure* , Chinese Journal of Chemical Engineering, doi: 10.1016/j.cjche.2015.04.002, 2015.
[16] Mansour M.A., Bakier A.Y., Bakier M.A.Y., *MHD Natural convection in the localized heat sources of an inclined trapezoidal Nanofluid-filled enclosure*, American Journal of Engineering Research (AJER), Vol. 02, Issue-09, pp-140-161, 2013.
[17] Bouhalleb M., Abbassi H., *Natural convection in an inclined rectangular enclosure filled by CuOeH2O nanofluid, with sinusoidal temperature distribution*, international journal of hydrogen energy, doi.org/ 10.1016/j.ijhydene.2015.04.090, 2015.
[18] 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.
[19] Cho Ch.Ch., *Heat transfer and entropy generation of natural convection in nanofluid-filled square cavity with partially-heated wavy surfac*, International Journal of Heat and Mass Transfer, Vol. 77, pp. 818–827, 2014.
[20] Cho Ch.Ch., Chen Ch.L., Chen Ch.K., *Natural convection heat transfer and entropy generation in wavy-wall enclosure containing water-based nanofluid*, International Journal of Heat and Mass Transfer, Vol. 61, pp. 749–758, 2013.
[21] Parvin S., Chamkha A.J., *An analysis on free convection flow, heat transfer and entropy generation in an odd-shaped cavity filled with nanofluid* , International Communications in Heat and Mass Transfer, Vol. 54, pp. 8–17, 2014.
[22] Öztop H.F., Estellé P., Yan W.M., Al-Salem Kh., Orfi J., Mahian O., *A brief review of natural convection in enclosures under localized heating with and without nanofluids* , International Communications in Heat and Mass Transfer, doi.org/10.1016/j.icheatmasstransfer.2014.11.001, 2014.
[23] 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.
[24] Salman B.H., Mohammed H.A., Munisamy K.M., Kherbeet A.Sh., *Characteristics of heat transfer and fluid flow in microtube and micro*

channel using conventional fluids andnanofluids: A review , Renewable and Sustainable Energy Reviews, Vol. 28, pp. 848–880, 2013.
[25] Asadi M., Xie G., Sunden B., *A review of heat transfer and pressure drop characteristics of single and two-phase microchannels*, International Journal of Heat and Mass Transfer, Vol. 79, pp. 34–53, 2014.
[26] 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.
[27] Wan Zh., Deng J., Li B., Xu Y., Wang X., Tang Y., *Thermal performance of a miniature loop heat pipe using water-copper nanofluid*, Applied Thermal Engineering, doi: 10.1016/j.applthermaleng.2014.11.010
[28] Goudarzi K., Shojaeizadeh E., Nejati F., *An experimental investigation on the simultaneous effect of CuOeH2O nanofluid and receiver helical pipe on the thermal efficiency of a cylindrical solar collector* , Applied Thermal Engineering, Vol. 73, pp. 1234-1241, 2014.
[29] Shahi M., Mahmoudi A.H., Talebi F., *Numerical simulation of steady natural convection heat transfer in a 3-dimensional single-ended tube subjected to a nanofluid* , International Communications in Heat and Mass Transfer, Vol. 37, pp. 1535–1545, 2010.
[30] 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.
[31] Singh P., Kumar M., *Mass transfer in MHD flow of alumina water nanofluid over a flat plate under slip conditions*, Alexandria Engineering Journal, doi.org/10.1016/j.aej.2015.04.005
[32] Hatami M., Ganji D.D*., Natural convection of sodium alginate(SA) non-Newtonian nanofluid flow between two vertical flatplates by analytical and numerical methods* , Case Studies in Thermal Engineering, Vol. 2, pp. 14–22, 2014.
[33] Khan W.A., Aziz A., *Natural convection flow of a nanofluid over a vertical plate with uniform surface heat flux*, International Journal of Thermal Sciences, Vol. 50, pp.1207-1214, 2011.
[34] Dawood H.K., Mohammed H.A., Sidik N.A.Ch., Munisamy K.M., Wahid M.A., *Forced, natural and mixed-convection heat transfer and fluid flow in annulus: A review*, International Communications in Heat and Mass Transfer, doi.org/10.1016/j.icheatmasstransfer.2015.01.006.
[35] Alawi O.A., Sidik N.A.Ch., Dawood H.K., *Natural convection heat transfer in horizontal concentric annulus between outer cylinder and inner flat tube using nanofluid* , International Communications in Heat and Mass Transfer, Vol. 57, pp. 65–71, 2014.

[36] Matin M.H., Pop I., *Natural convection flow and heat transfer in an eccentric annulus filled by Copper nanofluid*, International Journal of Heat and Mass Transfer, Vol. 61, pp. 353–364, 2013.
[37] 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.
[38] Seyyedi S.M., Dayyan M., Soleimani S., Ghasemi E., *Natural convection heat transfer under constant heat flux wall in a nanofluid filled annulus enclosure*, Ain Shams Engineering Journal, doi.org/10.1016/ j.asej. 2014.09.003
[39] Soleimani S., Sheikholeslami M., Ganji D.D., Gorji-Bandpay M., *Natural convection heat transfer in a nanofluid filled semi-annulus enclosure* , International Communications in Heat and Mass Transfer, Vol. 39, pp. 565–574, 2012.

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