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Review on Natural Convective Heat Transfer Inside cavities

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ABSTRACT

Heat transfer by natural convection arising from a hot source to its surrounding cavity has important attention in the last two decades because of extensive practical applications. Applications include electronics cooling, solar collectors, thermal storage systems, working fluid systems, reactors and gas insulated electrical transmission systems, renewable energy systems, discharging process, etc. The aim of adding the enclosure is to decrease the heat losses from the hot source to its surrounding or to protect the system from harsh outdoor environment. Different researches were carried out experimentally and theoretically to investigate the effect of different parameters on the natural convection heat transfer inside cavities such as, Rayleigh number, Prandtl number, magnetic effect (Hartmann number), inclination angle, position and location of heat source, changing the length of heat source, etc. Moreover, different enhancement techniques of heat transfer were used such as adding the nanoparticles to the based fluid, using of porous media under different thermal boundary conditions. The present paper includes a review on the natural convection heat transfer inside cavities with different conditions mentioned above.

KEYWORDS

Buoyancy force, natural convective, heat transfer, cavity, enclosure.

INTRODUCTION

Heat transfer by convective mode in cavities has received significant attentions in last two decades because of wide practical applications in industrial and engineering fields such as in heat exchangers, geothermal and geophysical systems [1], reservoirs, building insulations, [2], nuclear reactors design, metal casting, crystal growth, designing and cooling of electronic equipment's, aircraft insulation [3], etc. Many experimental and theoretical literatures were studied to enhance natural heat transfer in the cavities using different active and passive techniques. Some authors added nanoparticles to the based fluid to improve the thermal conductivity of the working fluid [7, 10, 20, 25, 33]. Others used porous medium to obtain the same result [32]. One of the active techniques of heat transfer enhancement was using the corrugated heat source or enclosure due to increasing the heat transfer area which causes improving the thermal performance in the system [1, 20, 33]. Using the active techniques such as magnetic field was presented in many literatures [18, 21]. Moreover, vibration is one of the active techniques which was used in different investigations [6]. There are general parameters affect this phenomenon such as Rayleigh number, aspect ratio, angle of enclosure inclination, etc. [11, 12, 14-16]. To produce more stable thermal system for saving the energy with decreasing the weight, size, and cost; we should look insight into the previous literatures that studied this mode of heat transfer in cavities. So, the present paper focused on the important physical domains considered in the previous works and studying the parameters affected on the behavior of flow field and thermal performance. Many thermal systems have been studied over wide range of effected parameters. Very significant conclusions have been presented in this paper.

LITERATURE REVIEW

Dalal and Kumar (2005), [1] studied the effect of undulations number on natural convection in an inclined cavity with a sinusoidal temperature profile applying on the corrugated wall. It was noticed that increasing the amplitude produced higher heat transfer rate at low Rayleigh number. Ding et al. (2006), [2] concluded that the eccentricities and angular positions of inner hot cylinder had a significant effect on the mechanism of heat transfer in a square enclosure. Mezrhab et al. (2006), [3] proved that the effect of inclination angle of cavity on the heat transfer process depended on the value of Rayleigh number. Ben-Nakhi and Chamkha (2007), [4] found the conjugate natural heat transfer rate in the hot wall of square enclosure depended on length and inclination angle of thin fin attached to it.

Varol et al. (2007), [5] concluded that the changing effect thermal boundary conditions of a solid square body located in a right-triangular cavity controlled the behavior of fluid flow and heat transfer. Alawadhi (2008), [6] concluded that oscillating frequency of the inner cylinder had a positive effect on the flow field and thermal patterns in a horizontal annulus enclosure. Moreover, it increased the heat transfer rate on the inner cylinder. Oztop and Abu-Nada (2008), [7] found that the position and length of heat source affected the flow field and thermal patterns in a rectangular cavity filled with nanofluids. Varol et al. (2009), [8] used porous media to enhance the natural convection in right-angle trapezoidal cavity with vertical hot wall. Xu et al. (2009), [9] discovered that there were significant effects of Rayleigh number, radius ratio, and inclination angle on the natural convection heat transfer around inner triangular cylinder enclosed by circular enclosure. Ogut (2009), [10] used five types of nanoparticles with water as a based fluid to enhance the natural convection in an inclined square enclosure. It was concluded that the heat transfer depended on type of nanofluid, heat source length, Rayleigh number, nanoparticles volume fraction, and inclination angle of enclosure. Varol et al. (2009),[11] found that the inclination angle and length of the corner heater had great effects on heat transfer process inside an inclined square cavity.

Ahmed and Salam (2010), [12] concluded that the hydrodynamic boundary layers at the heated and cooled walls were reduced as the inclination angle of square enclosure increases. Moreover, they [13] studied the natural convection around hot circular cylinder located in a square enclosure. The results showed that the water flow field and thermal patterns depended strongly on Rayleigh number. Xu et al. (2010), [14] proved that at constant radius ratio ratio, both the inclination angle and Rayleigh number had great effects on the thermal and flow patterns in concentric annulus. The annulus consisted of inner circular cylinder and outer triangular cylinder. Yu et al. (2010), [15] studied a wide range of Prandtl numbers for different fluids in horizontal circular enclosure containing a concentric triangular cylinder. The results showed that the fluid fields and thermal patterns were independent of Prandtl number for high $Pr > 0.1$. Tao et al. (2011), [16] showed that the Grashof number, aspect ratio, and inclination angle of the inner triangular cylinder had significant effects on transient free convective heat transfer inside circular enclosure. The natural convection heat transfer emerging from horizontal rectangular cylinder inside circular enclosure was studied by Wang et al. (2011), [17]. It was noticed that the average Nusselt numbers depended on the vortexes generating above the rectangle cylinder for the aspect ratio >1.2. Revnic et al. (2011), [18] investigated the effects of Darcy number, Rayleigh number, Hartmann number and heat generation on transient free convective heat transfer inside square cavity containing a fluid-saturated porous medium. An inclined magnetic field was applied on this enclosure. It was observed that Hartmann number had a significant effect on the heat transfer process for high Rayleigh number. Hojat and Seyed (2012), [19] proved that the average heat transfer by natural convection in concentric annulus with a hot circular inner cylinder and square outer cylinder was better than that in a concentric annulus with square inner and outer cylinders for the same aspect ratio, Rayleigh number, and thermal boundary conditions.

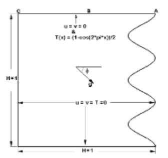
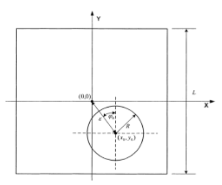
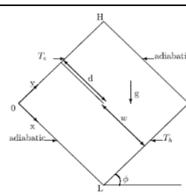
Sheikholeslami et al. (2012), [20] studied the effect of horizontal magnetic field on the natural convection of Cu–H_2O nanofluid around hot inner sinusoidal circular inside a cold outer circular enclosure. It is noticed that the magnetic field played a significant role in the heat transfer enhancement with increasing of Rayleigh number. Moreover, it was observed that the heat transfer process was increased with increasing the Rayleigh number and nanoparticle volume fractions. Shekholeslami et al. (2013), [21] performed another study to examine the effect of magnetic field on heat transfer by free convection inside a curved-shape cavity. It is noticed that the Hartmann number significantly affected the flow field and thermal patterns in the cavity. Salam and Ahmed (2013), [22] proved that the position of hot circular cylinder inside an octagonal enclosure had a significant effect on the flow fields and thermal patterns. Roslan et al. (2014), [23] studied the effect of wall thickness on natural convection in a hot square cavity having a conductive polygon object with different types, sizes, and thermal conductivities. The heat source was applied on the left wall. The heat transfer reached to maximum critical value as the size of the solid polygon increases after which it decreased. Balamurugan and Krishnakanth (2015), [24] proved that the heat transfer rates in a square cavity having square heat source were higher than similar ones in the same enclosure but with triangle heat source for different aspect ratio.

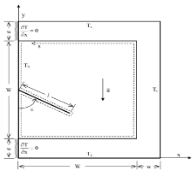
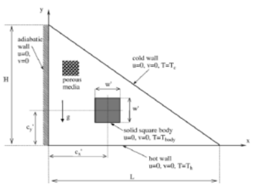
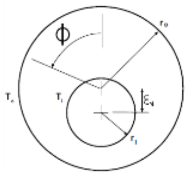
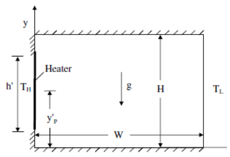
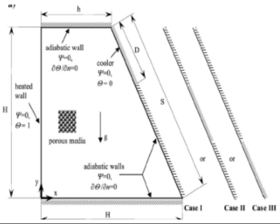
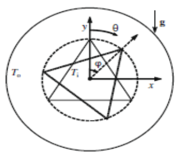
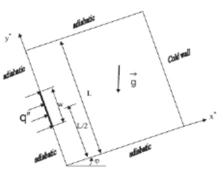
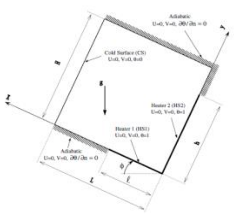
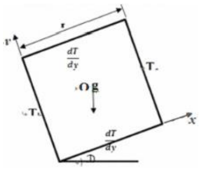
Ravnik and Škerget (2015), [25] examined the free convective heat transfer of H_2O-Al_2O_3, H_2O-Cu and H_2O-TiO_2 nanofluid in an inclined cubic enclosure containing a heated circular and an ellipsoidal cylinder. It was noticed that the dominating conduction heat transfer in the enclosure produced highest heat transfer efficiency. Chowdhury et al. (2015), [26] investigated the effect of heat generation on the buoyancy driven arising from a triangular cavity containing an insulated circular body and filled with a fluid saturated porous medium. The heat source was applied on the bottom wall of the cavity. It was observed that the overall heat transfer rate decreases with increase in heat generation and size of the circular body. The free convection inside rectangular enclosure having a triangular roof and containing an adiabatic solid strip located at a middle of enclosure was studied by Kadhim and Kumar (2015), [27]. All the walls of enclosure were insulated except the vertical left wall which was heated uniformly. The results show that the flow field and thermal patterns depended strongly on the solid strip inside the cavity. Yuan et al. (2015), [28], examined the influences of different shapes of inner cylinder inside circular cavity with or without applying surface radiation. It was concluded that the heat transfer process depended on the surface radiation and presence of corners. Ankit and Saurabh (2017), [29] discussed and presented the streamlines and isotherms resulted in natural convection around semicircular cylinder inside square enclosure. The inner cylinder was placed at different incidences inside the cavity. The results showed that the flow fields depended strongly on the position of semicircular.

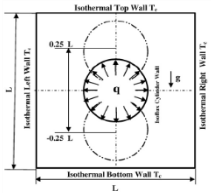
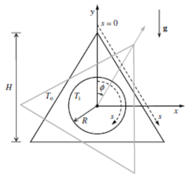
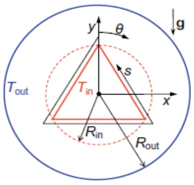
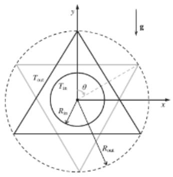
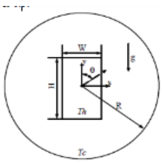
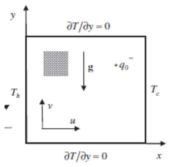
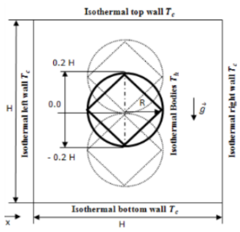
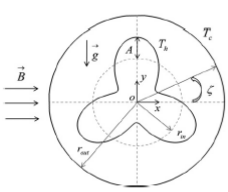
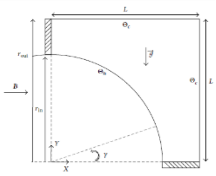
Ho et al. (2017), [30] proved that there were significant influences for location of the circular cylinder inside cubical enclosure on the thermal characteristics of steady and unsteady free convection for different Rayleigh numbers. Gangawane and Manikandan (2017), [31] investigated the heat transfer characteristics around hexagonal block inside square enclosure filled with non-Newtonian power law fluids. It was observed that average heat transfer varied linear function with Grashof and Prandtl numbers. Moreover, uniform heat flux condition for hexagonal body produced higher heat transfer rates than constant wall temperature condition. Akeel et al. [32] studied the influence of thermal conductivity of porous media on the heat transfer and fluid flow characteristics in a square cavity containing concentric circular cylinder. Sattar et al. (2020), [33] studied numerically the heat transfer mechanism by natural convection in eight different corrugated annuli containing water-Al_2O_3 nanofluid. They showed that there is no change in the thermal patterns as the volume fraction increases. [34-57] showed other examples of free convective heat transfer inside enclosures with and without porous media, nanofluids, obstacles, and for different shapes of the domain.

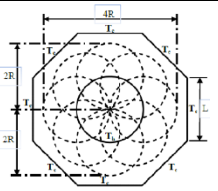
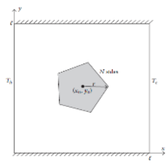
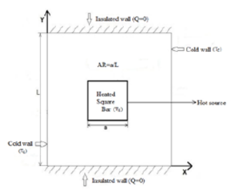
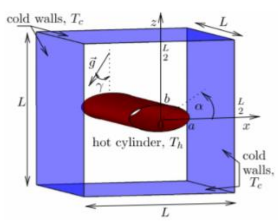
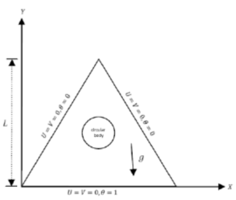
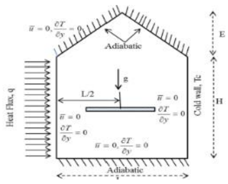
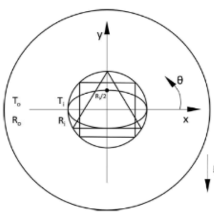
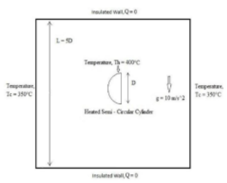
Table 1 shows a summary of some literatures mentioned above.

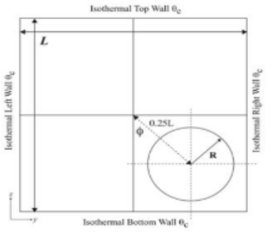
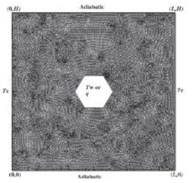
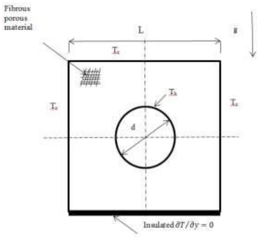
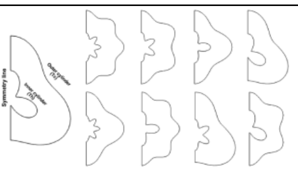
Table 1. Summary of literatures concerning with natural convection inside enclosures.

Authors	Physical domain	Parameters	Conclusions
Dalal and Kumar (2005), [1]		Pr=0.7 (air) $10^3 \leq Ra \leq 10^6$	The increase in the number of undulations more than two leads to decrease in heat transfer rate.
Ding et al. (2006), [2]		Pr=0.7 (air) $10^4 \leq Ra \leq 10^7$	The eccentricities and angular positions of inner hot cylinder had a significant effect on the mechanism of heat transfer.
Mezrhab et al. (2006), [3]		Pr=0.7 (air) $10^3 \leq Ra \leq 10^6$	The heat transfer rate decreased with increasing the number of partitions attached to the cold wall.

Ben-Nakhi and Chamkha (2007), [4]		$Ra=10^4$ and 10^5 $Pr=0.7$ (air)	The thermal conductivity of solid wall had an important effect on overall heat transfer rates of system.
Varol et al., 2007 [5]		$Pr=0.7$ (air) $10^3 \leq Ra \leq 10^6$	Thermal boundary conditions of the square body had a significant effect on the behavior of fluid flow and thermal patterns.
Alawadhi, 2008 [6]		$Ra=10^4$ and 10^5 $Pr=0.7$ (air)	Oscillating eccentricity reduces the average of heat transfer on the outer cylinder.
Oztop and Abu-Nada (2008), [7]		$Ra=10^3-5\times10^5$ Volume fraction ($0\leq \varphi \leq 0.2$) nanofluids	Increasing the heat transfer rate with increase in the nanoparticles volume fraction.
Varol et al. (2009), [8]		$100 \leq Ra \leq 1000$ Porous media	Significant changes occurred in the flow fields and thermal patterns with using the porous media.
Xu et al., 2009 [9]		$10^3 \leq Ra \leq 10^6$ $Pr=0.71$	There is no effect of the inclination angle of the inner triangular cylinder on the average heat transfer rate.
Ogut (2009), [10]		$10^4 \leq Ra \leq 10^6$ H_2O-Cu, H_2O-Ag, H_2O-CuO, H_2O-Al_2O_3, and H_2O-TiO_2, nanofluids $\varphi = 0 - 0.2$	The heat transfer decreases for a small inclination angle with increase in the heater length.
Varol et al. (2009), [11]		$10^3 \leq Ra \leq 10^6$ $0.07 \leq Pr \leq 70$ Inclination angle ($0^o \leq \theta \leq 270^o$)	There is a significant effect of Prandtl number on average heat transfer for Prandtl less than one.
Ahmed and Salam (2010), [12]		$Ra= 10^3 – 10^8$ $Pr=6$ (water) ($0^o \leq \theta \leq 360^o$)	Increasing the thermal boundary layer with increase in the internal heat source.

Salam and Ahmed (2010), [13]		$10^3 \leq Ra \leq 10^6$ Pr=0.71 (air)	The overall average heat transfer rate had nonlinearly behavior with inner cylinder locations.
Xu et al., 2010 [14]		$10^3 \leq Ra \leq 10^7$ Pr=0.71 (air)	The inclination angle of outer cylinder had a slight effect on overall heat transfer rate.
Yu et al, 2010 [15]		$10^3 \leq Ra \leq 10^6$ $10^{-2} < Pr < 10^3$	The fluid field and thermal patterns for Pr = 0.03 are unique.
Tao et al. (2011), [16]		$10^5 \leq Gr \leq 10^7$ Pr=0.71 (air)	Different behaviors of flow development were identified.
Wang et al., 2011 [17]		$Ra=10^3-10^6$ $Pr = 0.71$	The intensity of Vortex generated above the inner cylinder increases with increase in Rayleigh number.
Revnic et al. (2011), [18]		$Ra=10^3 - 10^5$ Ha=Hartmann number=1 & 1000 fluid-saturated porous medium	Increasing Hartmann number affected the diffusive heat transfer for high Rayleigh number
Hojat and Seyed (2012), [19]		$Ra=10^3$ to 10^5 Pr=0.7	The circular inner cylinder produced higher heat transfer rates than square cylinder.
Sheikholeslami et al., 2012 [20]		$Ra=10^3$ to 10^5 Cu-water nano fluid.	With presence of magnetic field, enhancement ratio is increased with decrease in Rayleigh number.
Shekholeslami et al. (2013), [21]		$Ra=10^3$ to 10^5 Pr=0.025 Ha=0, 10, and 100.	The overall heat transfer rate is reduced with increase in Hartmann number.

Salam and Ahmed (2013), [22]		$10^3 \leq Ra \leq 10^7$ Pr=0.707 (air)	The streamlines and isotherms in the enclosure depended significantly on the location of inner cylinder.
Roslan et al. (2014), [23]		$10^3 \leq Ra \leq 10^6$ Pr=0.71 (air)	The heat transfer is enhanced with increase in the size of the solid polygon.
Balamurugan and Krishnakanth (2015), [24]		Heat input=Q=25-61 W Pr=0.7	The average heat transfer depended strongly on the shape of inner heat source for the same aspect ratio.
Ravnik and Škerget (2015), [25]		$10^3 \leq Ra \leq 10^6$ H_2O-Al_2O_3, H_2O-Cu and H_2O-TiO_2 nanofluids	When convection heat transfer is the dominant mode, adding the nanoparticles produced small increase in heat transfer efficiency.
Chowdhury et al. (2015), [26]		$Ra=10^5$ Pr=0.71	There is no effect of heat generation on the heat transfer for large circular body.
Kadhim and Kumar (2015), [27]		$10^3 \leq Ra \leq 10^6$ Pr=0.7 (air)	The flow patterns and thermal performance depended strongly on the solid strip inside the cavity.
Yuan et al., 2015 [28]		$10^3 \leq Ra \leq 10^5$ Pr=0.7 (air)	Surface radiation had a significant role in the behavior of heat transfer only when the reference temperature increases.
Ankit and Saurabh (2017), [29]		$Ra=10^4$ Pr=0.7 (air)	The heat transfer rate is enhanced for all incidences of semicircular cylinder.

Ho et al. (2017), [30]		$10^4 \le Ra \le 10^6$ Pr=0.7 (air)	The influences of the boundary wall on thermal patterns and fluid field inside the enclosure depended on the location of the circular cylinder.
Gangawane and Manikandan (2017), [31]		$10^3 \le Gr \le 10^6$, $1 \le Pr \le 100$, power law index ($0.5 \le n \le 1.5$).	The heat transfer rate is reduced for power law index value.
Akeel et al. (2020), [32]		Pr=0.71, Da=0.01, Gr= $5\times10^6 - 5\times10^7$ porosity (ε) = 1.0. thermal conductivity ratio $(kr) = 0.1 - 10$.	The temperatures reduces with increase in the thermal conductivity of porous media .
Sattar et al. (2020), [33]		$10^4 \le Ra \le 10^6$ H_2O-Al_2O_3 $\varphi = 0 - 0.25$	Decreasing the heat transfer rate with increase in the number of undulations.

CONCLUSIONS

This paper has included review on the available literatures dealing with the natural convection heat transfer inside cavities. Theoretical assumptions in these literatures were miscellaneous. Different physical domains, geometries and thermal boundary conditions were used. The shape, dimensions, and position of heat source were changed from paper to other. Some of these literatures studied the combined natural convection and conduction or radiation heat transfer. Others studied the effect of vibration and magnetic field on the natural convective heat transfer process. Different parameters play important rule in the mechanism of thermal patterns and fluid fields such as Rayleigh number, Prandtl number, Darcy number for porous media, Hartmann number for magnetic field, etc. Table 1 shows the important conclusions extracted from this paper.

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