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Review on Combined of Forced-Natural Convection in Lid-Driven Cavities

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Abstract

In last years, many researchers have investigated forced and mixed convection in an enclosure with moving one wall or two parallel walls under a different thermal boundary conditions and different geometries of cavity. Many researchers studied different enhancement techniques for the mixed convection heat transfer in lid-driven cavities. The present paper comprises the available theoretical studies related to this field of heat transfer and enhancement techniques.

1. Introduction

Mixed convection heat transfer in lid-driven enclosures with different geometries, boundary conditions, and enhancement techniques has received great attention by authors because of its importance in the industrial applications. Examples of applications can be found in domains affected by electromagnetic fieldsو nuclear reactors, cooling of electronic equipment's, furnace engineering, solidification of casting, chemical vapor deposition instruments, separation processes in chemical industries, solar energy, non-Newtonian chemical processes and technology of lubrication [5-8].

2. Heat Transfer Enhancement Using Nanofluids

Nemati et al. (2010), [1] used Lattice Boltzmann Method to solve the problem of the mixed convection heat transfer in a lid-driven cavity filled with H_2O- Cu, CuO or Al_2O_3 nanofluids. The results indicated that the effects of solid volume fraction grow stronger sequentially for Al_2O_3, Cuo and Cu. Additionally, the increase in Reynolds number leads to decrease in the solid concentration effect.

Rahman et al. (2011), [2] studied the convective recirculation and flow processes induced by a Cu–H_2O nanofluid in an inclined lid-driven triangular enclosure. The nanoparticles volume fraction φ is varied as 0%, 4%, 8% and 10%. It was observed that solid volume fraction strongly influenced the fluid flow and heat transfer in the enclosure at the three convective regimes.

Sheikhzadeh et al. (2012), [3] studied the mixed convection heat transfer characteristics in a lid-driven enclosure filled with H_2O- Al_2O_3 nanofluids using variable thermal conductivity and variable viscosity. The variable viscosity and thermal conductivity of both the Brinkman and the Maxwell–Garnett model were compared. Significant differences were found between the magnitudes of heat transfer enhancement in the enclosure for two employed models.

Hassan El Harfi et al. (2013) [4] solved the mixed convection problem, in a shallow lid-driven rectangular cavity filled with water-based nanofluids. It was found that the addition of Cu-nanoparticles, into the pure water, leads to an enhancement or a degradation of heat transfer depending on the values of Re and Ri.

Hassanzadeh and Farhadi (2013), [5] used Lattice Boltzmann method to solve the governing equations of the mixed convection in a square lid-driven cavity in presence of cubic obstacle. The Richardson number had more effect on Nusselt number when obstacle was located at the bottom section of enclosure.

Said et al. (2013), [6] used different nanofluids to enhance the combined forced-free convection heat transfer in a lid driven square cavity with moving the top wall. Al_2O_3, CuO, SiO_2 and TiO_2 nanoparticles were used with diameters 25nm, 40nm and 60nm. The based fluid was the water. The results show that Al_2O_3-H_2O produced the highest heat transfer rate, followed by TiO_2-H_2O, SiO_2- H_2O and lastly CuO-H_2O.

Rehena et al. (2014), [7] modeled the problem of mixed convective heat transfer in a vertical triangular wavy enclosure with double lid-driven. The cavity was filled with water-CuO nanofluid in in the presence of internal heat generation. It was shown that Richardson number has a significant effect on the behavior of heat transfer and fluid field inside cavity.

Kourosh et al. (2014), [8] studied the mixed convection flow in a lid-driven triangular enclosure with triangular heat source filled with water-TiO_2 nanofluid. The vertical walls of the enclosure were kept at constant temperatures and the top moving wall moving was insulated. The results show that considerable heat transfer enhancement can be obtained due to the presence of nanoparticles at small, moderate and large Richardson numbers.

Billah et al. (2014), [9] studied the heat transfer performance of Cu-H_2O nanofluids with volume fraction ranged from 0 to 0.2 inside inclined lid-driven triangular enclosure. It was obtained that the heat transfer increased by 28% as volume fraction φ increases from 0 to 0.2 at $Gr = 10^5$. Moreover, the variation of the average Nusselt number and average fluid temperature in the cavity is linear with the solid volume fraction.

Kalteh et al. (2014), [46] used in his study a triangular heat source located in a lid-driven square cavity filled with H_2O–Al_2O_3 nanofluid. The left vertical and bottom horizontal walls of the cavity were adiabatically insulated. The moving top wall and the right wall were isothermally cooled. The results show that adding the nanoparticles in base fluid produced a significant heat transfer increase.

Anirban et al. (2017), [10] used Brinkman-extended Darcy model to analyze the mixed convection in a lid-driven porous cavity filled with H_2O-Al_2O_3 nanofluid. The effects of Grashof number (Gr), Darcy number (Da), and solid volume fraction (φ) on streamline patterns and isotherm were performed in both the cases of uniform and nonuniform wall heating. Increase the heat transfer rate was occurred by the increase in Gr number for a fixed Da.

Abdelkader et al. (2015), [11] studied the phenomena of combined convection in a square enclosure, filled with a mixture of Cu and Ag- H_2O nanofluid with volume fraction $\varphi = 0 - 0.1$. It was shown that the heat transfer rate enhances as Richardson number and nanoparticles volume fraction decrease. Also, Using of Ag-water nanofluid produced higher heat transfer rate than Cu-water nanofluid.

Mahmudul Hasan et al. (2015), [12] studied the influence of inclination angle of the cavity on combined convection heat transfer inside two different lid-driven trapezoidal enclosures filled with water-Al_2O_3 nanofluid ($\varphi = 0.1$). The variation of average Nusselt number of the hot wall and average fluid temperature of the enclosure were analysed for different tilt angles.

Abdelkader Boutra et al. (2015), [13] studied the mixed convection heat transfer in a square enclosure, filed with a mixture of water and Cu (or Ag) nanoparticles. The side walls moved at constant velocities and both horizontal walls were adiabatically insulated. The results were presented through streamlines and isotherm contours, with analyzing the behavior of the Nusselt number.

Habib Salahi et al. (2015), [14] studied the combined convection heat transfer in a shallow inclined lid-driven enclosure with aspect ratio equaled to 10. The results show that, at any s φ, the heat transfer rate enhances slightly as the cavity inclination increases for Ri=0.1 (dominated forced convection). Additionally, this increasing was much more rapidly for Ri=10 (dominated natural convection).

Zoubair Boulahia et al. (2016), [15] studied the influences of size and number of the heated triangular cylinders on the flow and Nusselt number in a lid driven square cavity having several heated triangular cylinders. It is found that increasing size and number of the heated triangular cylinders leads to increase the heat transfer rate.

They (2016), [16] submitted another study of mixed convection heat transfer of **H_2O-Cu** nanofluid in a lid driven square cavity with three triangular heating blocks. The ranges of parameters were taken as the same as their previous study. It is seen that, there is an optimal position of triangular heating blocks where the heat transfer rate is maximized.

Alireza Hossein et al. (2016), [17] used a new approach for numerical solution of the sole effects of nanoparticles volume fraction of Cu-water nanofluid on laminar force, mixed, and natural convection heat transfer in a square cavity. The results show that the average Nusselt number by the mentioned approach increases with increase in nanoparticles volume fraction, temperature difference, and walls velocity.

Ahmad Reza et al. (2016), [18] used constant and variable properties models to calculate the thermal conductivity coefficient of H_2O-Cu nanofluid in a double lid-driven cavity. It was seen that in high Richardson numbers, the influence of the thermal phase deviation changes on the flow pattern was obvious, whereas and in low Richardson numbers, the phase deviation changes did not affect the flow pattern.

Elif and Kamil (2016), [19] used Al_2O_3 as nanoparticle and ethylene glycol-water mixture as the base fluid to study the mixed convection heat transfer in a lid-driven square enclosure. Four different volume ratios of ethylene glycol to water were considered: 0:100%, 40:60%, 60:40% and 100:0%. It was concluded that for all the thermal conductivity models taken in this work, the average heat transfer coefficient increases linearly with increase in the nanoparticle volume fraction.

Zhimeng Guo et al. (2016), [20] studied the influences of number and amplitude of sinusoidal roughness elements at the bottom wall of a lid-driven square cavity on the heat transfer and fluid flow. The enclosure was filled with H_2O-Al_2O_3 and H_2O-CuO nanofluids at different volume concentrations. The flow patterns, thermal fields, and heat transfer rate were discussed for different Rayleigh and Reynolds numbers.

Mastiani et al. (2017), [21] solved the governing equations based on the Boussinesq and non-Boussinesq homogenous models using finite volume method. The physical domain consisted of square lid-driven cavity filled with Cu-water nanofluid. It was shown that the density inversion phenomenon produced a lower heat transfer rate under the non-Boussinesq approximation compared to the Boussinesq approximation.

Ilhem and Rachid (2017), [22] used four types of nanoparticles (Cu, Ag, Al_2O_3 and TiO_2) with the water as a base fluid in a lid-driven square cavity heated simultaneously at a uniform heat flux q" by two heat sources placed on the two side walls. The results show that the heat transfer rates improve with the increase in Rayleigh number and solid volume fraction of nanofluids.

Selimefendigil et al. (2017), [23] examined the combined convection heat transfer in a lid-driven 3D flexible walled trapezoidal cavity with nanofluids. The increase and decrease in the space which were provided by the flexible side walls produced heat transfer enhancement and deterioration for side wall inclination angle of 0° and 10°. Heat transfer rate increases by about 9.80% as the value of the elastic modulus was increased from 1000 to 10^5 for side wall tilt angle of 0°.

Bijan et al. (2018), [24] investigated the mixed convection heat transfer in a lid-driven cavity filled with H_2O-Al_2O_3 nanofluid. The cavity contained a hot elliptical centric cylinder. The results show that the Nusselt number decreases with increase in Richardson number at a constant volume fraction and cavity angle.

Haque et al. (2019), [25] studied the influences of Darcy number, Grashof number, Reynolds number, and volume fraction of Cu on the mixed convection heat transfer of H_2O-Cu nanofluid in a lid-driven porous medium square cavity with several pairs of heat source-sinks. The results were presented in the form of streamlines, isotherms contours, velocity and dimensional temperature as well as Nusselt number and average Nusselt number along the several pairs of heat source-sinks considered.

Ishrat Zahan (2019), [26] studied the effects of magnetohydrodynamic (MHD) and Joule heating on mixed convection heat transfer in a lid driven triangular cavity filled with Cu+ TiO_2 -H_2O hybrid nanofluid. The sinusoidal bottom wall of the cavity was cooled isothermally while the left vertical wall was heated. The inclined side was insulated. The results show that increasing wave number from 0 to 3 produces higher heat transfer rate by 16.89%.

Rahman et al. (2019), [27] investigated the forced-mixed-natural convections in a lid-driven square cavity, filled H_2O-Cu nanofluid with a volume fraction of 2%. The side moving walls produced a temperature difference driving the convection, when both the top and bottom walls were isothermally insulated. Moreover, the heat and mass transfer rate increase approximately 6% for water with the increase in Richardson number from 0.1 to 10, whereas this increase about 34% for nanofluid.

Shajedul et al. (2019), [28] examined the combined effect of the buoyancy force due to temperature gradient and forced flow due to the top moving wall of lid-driven square cavity filled with in a Cu-water nanofluid and containing a concentric hot cylinderIt is concluded that augmentation of heat transfer occurs significantly with continuously changing of Reynolds number and solid volume fraction.

Kekl et al. (2020), [29] studied the combined convective heat transfer in a square cavity filled with Al_2O_3-water nanofluid $\varphi = 0 - 0.05$. Different viscosity and thermal conductivity models were used to find heat transfer enhancement. The Grashof and Reynolds numbers were (Gr=10^3 and 10^5), (Re = 10, 100, and 1000); respectively.

Mostafa et al. (2020), [30] The influences of Richardson number and volume fractions of nanoparticles on the fluid field and thermal patterns in a lid-driven enclosure filled with Cu-water nanofluid. The results show that decreasing frequency of the wall oscillation produced high heat transfer rate.

Al-Rashed et al. (2020), [31] studied the flow field and heat transfer of a H_2O–Cu nanofluid in a trapezoidal cavity saturated with porous media. The results show that the average heat transfer rate enhances with increase in volume fraction of nanoparticles for all taken Darcy numbers. The convection and motion of the nanofluid reduce by decreasing the Darcy number which produced a reduction in the velocity and local Nusselt number.

3. Heat Transfer Enhancement Using Porous Media

The down literatures used a porous media as enhancement method of heat transfer in lid-driven cavity. In addition to using other methods such as adding nano particles to the base fluid, vibration, inclination angle of cavity, etc.

Hakan (2006), [32] performed a numerical study for the combined primary and secondary flows and heat transfer in a porous cavity with moving the top wall at constant velocity and constant cold temperature. The left wall is partially heated while the other walls were insulated. In this study different parameters effected on streamlines and isotherms which are Darcy number, Richardson number, position and length of heater on the left wall.

Hakan et al. (2008), [34] analyzed the conjugate conduction-mixed convection heat transfer in lid-driven cavities having thick bottom hot wall. It was shown that the heat transfer improves with increase in the thermal conductivity of wall relative to the thermal conductivity of fluid k_w/k_f, and decrease in Richardson number.

Wang (2009), [35] used in his work a porous Darcy–Brinkman medium in rectangular cavity with moving of top wall. The results show that adding the porous materials into the medium reduces the number of recirculating eddies leading to decrease in its strength, especially for deep cavities.

Stephen and Kambiz (2010), [36] used two combined methods to enhance the mixed convection heat transfer in open ended cavity: vibration and porous media. The vibration was applied on the left wall of cavity. The results show that with increase Darcy and Reynolds numbers, the vibrational effects were pronounced.

Mohd et al. (2010), [37] investigated the heat transfer and fluid flow characteristics in a lid driven square cavity filled with porous media. The objective was investigating the influence of porosity on the thermal and fluid fields. The results show that the velocity, vortex strength and hydrodynamic boundary layer are highly affected porosity of field.

Waheed et al. (2011), [38] studied the combined convection heat transfer in rectangular enclosure filled with a fluid-saturated porous medium. The horizontal wall of cavity moved at constant velocity. It was noticed that the governing parameters (Richardson number, Darcy number, Peclet number, and aspect ratio) had important effect on the flow field and temperature patterns inside the enclosure.

Wael et al. (2012), [39] studied this phenomenon in a square lid-driven cavity filled with fluid-saturated porous material. The top wall was moved at constant velocity. The horizontal walls of cavity were insulated. Sinusoidal temperatures were applied on the vertical walls to improve the heat transfer. The results show that Darcy number (Da) and the amplitude ratio of sinusoidal temperature (ε) had significant effects on the flow and thermal patterns.

Abdalla AlAmiri (2013), [40] studied the combined inertia and buoyancy effects in a square cavity containing a porous block with moving the top wall at constant speed. It was concluded that the increase in Richardson number enhances flow mixing and heat-transfer rate.

Anirban et al. (2014), [41] studied the mixed convection (Ri=1) in lid-driven square cavity saturated with a porous medium. The left wall was heated isothermally while the right wall was cold. The horizontal walls were insulated. The results show that the heat transfer behavior depended strongly on the direction of moving wall.

Mojumder et al. (2016), [42] studied the effect of Grashof number, Reynolds umber, Darcy number on the fluid flow and thermal fields in a lid-driven *L*-shaped enclosure filled with a porous medium. The results show that the heat transfer reduces up to 63% in the bottom wall at high value of Reynolds number (Re = 100).

Ahmad Ababaei et al. (2018), [43] studied the entropy generation of double-diffusive combined convection in a right-angled trapezoidal enclosure with a partially heated and salted bottom wall. It was obvious that, the average heat transfer rate decreases with increase in Lewis number and the total entropy generation.

4. Heat Transfer Enhancement Using Magnetic Field and Vibration with or without Nanofluid

The following literatures studied and discussed the enhancing of heat transfer process in lid-driven cavity using magnetic field and vibration. It may be including the other enhancement methods such as nanofluid, porous media, etc.

Salma and Rehena (2010), [44] investigated the mixed convection heat transfer and fluid flow characteristics in a lid-driven cavity. The sinusoidal wavy bottom wall was heated isothermally. It was concluded that the pattern of the local heat transfer is a wavy trend. Additionally, the rates of heat transfer enhance as the number of waves increases and Hartmann number decreases.

Khaled et al. [45], analyzed the influences of wall movement direction on MHD combined convection in a lid driven cavity with linearly heated bottom wall. The results show that direction of wall movement was more effective on the behavior of thermal patterns and streamlines in combined convection case than that in forced convection case.

Ziafat and Tabish (2016), [47] analyzed the problem of mixed convection heat transfer in a lid driven trapezoidal cavity in the presence of uniform magnetic field. The results show that the local Nusselt number along bottom wall was noticed to be maximum at edges and it decreases towards center from edges to attain minimum value.

Bakar et al. (2016), [48] studied the influence of applying **t**he magnetic field on mixed convection heat transfer and fluid field characteristics in square cavity. The vertical parallel walls were kept adiabatic; the top and bottom walls were cooled and heated at constant temperature, respectively. The results show that the magnetic field affected strongly the heat transfer and fluid flow characteristics.

Borhan et al (2016), [49] used the magnetic field to enhance the double diffusive mixed convection heat transfer process in a trapezoidal cavity. In this study, the uniform and non-uniform heat and mass were applied at the bottom wall. While at the moving top wall, the heat and mass were absorbed uniformly. The results show that the mass transfer strongly depended on Lewis number.

Rashad et al. (2017), [50] studied the magneto-hydrodynamic combined convection and partial slip in a square lid-driven enclosure filled with a Darcian nanofluid saturated porous medium. The remainder enclosure walls were insulated. The heat transfer and fluid flow results was presented and discussed to show interesting features of the study.

Sameh (2018), [51] applied in his study the magnetohydrodynamic at different orientation angles on the left side wall of trapezoidal cavity filled with water-based micropolar nanofluids with different types of nanoparticles (Cu, Ag, Al_2O_3, and TiO_2). The results show that the average heat transfer rate increases with decrease in Richardson number and the heat source length, and increase in the solid volume fraction.

Kefayati and Tang (2018), [52] investigated the combined convection in a different aspect ratios of cavity in the presence of a uniform magnetic field. The cavity was filled with a viscoplastic fluid. It was shown that increasing the Reynolds number enhances the heat transfer rate. The angle of the magnetic field affects the heat transfer in the cavity.

Humaun et al. (2019), [53] studied MHD combined convection heat transfer in a lid-driven porous rectangular cavity filled with H_2O-Cu nanofluid and equipped with three square heating blocks. The vertical walls were insulated adiabatically. It was noticed that the average Nusselt number increases with increase in Darcy number and Richardson number.

Al-Asada et al. (2019), [54] studied the effect of magnetic field on combined free-forced convection heat transfer in a lid-driven square enclosure with single vertical fin attached to its hot wall. It was concluded that the average Nusselt number increases with the increase in Richardson number. Moreover, Hartmann number is a good control parameter for heat transfer process in the lid-driven cavity having vertical fin in a lid-driven square cavity.

Monda and Mahapatra (2020), [55] studied the heat and mass transfer with entropy generation due to the effects of fluid flow, heat flow, mass flow and magnetic field in a trapezoidal cavity. Parametric studies were performed for helping to construct the perfect shape of cavity in different engineering applications to produce minimum entropy and get the maximum efficiency of engineering system.

5 Heat Transfer Enhancement in Lid-Driven Cavity Using Other Parameters

Many authors studied heat transfer enhancement in lid-driven cavity using other different parameters. Other enhancement methods of heat transfer process may be included the following: using wavy wall or wavy cavity, different values of Prandtl number, inclination angle of cavity, etc.

Chen and Cheng (2004), [56] used new geometry in their study. They studied experimentally and numerically the free, forced, and mixed convection heat transfer inside a lid-driven arc-shape enclosure Thermal patterns, streamlines, pressure drop, and average heat transfer rates (average Nusselt number) were studied and discussed in tail in this study. Results show that close strong convergence between the predicted and the visualized flow patterns.

Sharif (2007), [57] studied numerically the effect of inclination angle of shallow rectangular lid-driven cavity with constant aspect ratio of 10 on the heat transfer and fluid flow characteristics in this cavity. It was concluded that the average heat transfer rate increases with increase in cavity inclination angle.

Bhattachary et al. (2013), [58] studied the effect of Prandtl number combined free-forced convection inside a lid-driven trapezoidal cavity. The moving top wall was cooled isothermally. While, the bottom wall was heated for two different cases: isothermal (case 1) and non-isothermal (case 2). In convection dominated heat transport regime $Re.Pr > 1$, the results show that $(case\ 2)$ produced multiple steady states in either dominating natural convection region ($Ri \gg 1$) or mixed convection region ($Ri \sim O(1)$).

Chen and Chung (2015), [59] studied the effect of inclination angle, Reynolds number, and Grashof number on mixed convection heat transfer in a triangular lid-driven enclosure. The moving flat wall was cooled isothermally. t was noticed that there are three kinds of flow regime in a triangular lid-driven enclosure inclined from 0° to 360°: dominating natural convection, dominating forced convection, and mixed convection flow.

Krunal and Siddharth (2018), [60] studied the influences of the aspect ratio, the direction of moving vertical wall, and Prandtl number on the flow field and thermal patterns on mixed convection in the rectangular lid-driven cavity. The elliptical block heat source was located centrally in the cavity. The results show that the direction of moving lid is more predominantly affected the thermal characteristics than the aspect ratio of the elliptical cylinder.

Saha et al. (2013), [61] used wavy bottom wall of square lid-driven cavity to study the mixed convection flow and heat transfer in this cavity. The moving top wall is heated at constant temperature, and the cavity vertical walls were insulated adiabatically. The wavy bottom wall was cold. It is found that Reynolds and Grashof numbers have important effect on the thermal fields; streamlines and average Nusselt number in the cavity.

Rosdzimin et al. (2010), [62] studied the combined (forced–natural) convection heat transfer around a hot square cylinder located concentrically inside a lid driven square enclosure. The results of streamline and isotherm patterns as well as the local and average Nusselt number at the top surface of the inner cylinder were presented and discussed. Moreover, these results were influenced strongly by the Reynolds number and Richardson number.

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