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A Review about Mixed Convection Resulted From Buoyancy Forces and Moving Wall in Cavities

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Abstract: Over the past few years, a considerable number of scholars have been diligently investigating forced and mixed convection in containers, irrespective of whether the walls were stationary or mobile. Therefore, they have experimented with several thermal boundary conditions and geometries in order to achieve the best possible outcomes utilizing sophisticated analytical techniques. Many researchers have employed various methods to promote the transfer of heat via mixed convection in lid-driven cavities.

Keywords: Mixed convection, lid-driven, heat transfer.

1. Introduction

The phenomena of the transfer of heat and fluid fields within a hollow structure under the influence of a moving wall are of great significance in industrial applications and have been the focus of research for the last two decades. Some applications of these machines include electromagnetic field analysis, thermal control of electronic devices, furnace technology, casting solidification, chemically vaporized depositing tools, nuclear-powered plants, chemical industry separation processes, solar energy, and lubrication technology.

2. Heat Transfer Enhancement Using Nanofluids and Hybrid Nanofluids

Nemati et al. (2010), [1] Utilized the Lattice Boltzmann Method to tackle the problem of combined thermal convection transfer in a cavity with a lid in motion, which contains nanofluids consisting of H_2O - Cu, CuO or Al_2O_3. The results exhibited a gradual rise in the intensity of the effects of solid volume fraction for Al_2O_3, CuO, and Cu.

Rahman et al. (2011), [2] Analyzed the convective circulation and stream phenomena resulting from the presence of a combination of copper and water nanoparticles in a triangular enclosure. The enclosure is equipped with a lid that is manipulated using an angled motion. The solid volume fraction was shown to have a substantial influence on the fluid dynamics and heat transfer within the enclosure under all three convective conditions.

Sheikhzadeh et al. (2012), [3] employed Al_2O_3-water nanofluid in a different form of enclosure to explore the impacts of mixed convection thermal transfer, with distinct features of fluid resistance and thermal conductivity. Results demonstrated that the Nusselt number rises with larger nanoparticle concentrations in a general trend and the choice of model greatly affects the accuracy, particularly at low Richardson numbers.

Hassan El Harfi et al. (2013) [4] investigated the mixed convection heat transfer in a square cavity with a lid-driven motion, where the cavity was filled with nanofluids consisting of Cu-water. The research illustrated the combined effects of shearing forces from mixed convection and buoyancy, and also highlighted the influence of nanofluid properties on the efficiency of heat transfer.

Hassanzadeh and Farhadi (2013), [5] investigated the heat transfer caused by natural convection in a square enclosure with a sliding lid. The enclosure contains a nanofluid made of copper and water, and the Lattice Boltzmann Method was used for analysis. The outcomes indicate that an increased concentration of nanoparticles leads to a larger average Nusselt number, which in turn enhances the heat transfer process.

Said et al. (2013), [6] utilized a water-based nanofluid containing copper in a cavity driven by a lid. To ensure consistency in the analysis, the study focused on a specific Rayleigh number of 10. The results demonstrated how different concentrations of solid particles and Richardson numbers affected heat transfer in the system under investigation.

Rehena et al. (2014), [7] examined the mixed convection heat transfer occurring in a trapezoidal cavity under the influence of double-lid-driven motion. The cavity was filled with a mixture of water and CuO particles, known as a nanofluid. The conclusions suggest that the inclusion of nanoparticles can enhance the heat transfer process, with CuO nanoparticles proving to be more effective than the base fluid in increasing the rate of heat transfer.

Kourosh et al. (2014), [8] Investigated a hybrid convection flow in a triangular enclosure with a lid, featuring a triangular heat source and filled with a nanofluid consisting of water and TiO_2 particles. The conclusions demonstrated that including nanoparticles at different Richardson numbers can result in substantial enhancement in heat transfer.

Kalteh et al. (2014), [9] investigated the mixed convection in a square cavity that is lid-driven and has a triangular heat source. The working fluid is a water-based nanofluid, and the left- and lower-walls were insulated. It was demonstrated that the heat transfer performance was significantly enhanced when the nanoparticles were suspended in a pure fluid.

Anirban et al. (2017), [10] Examined the mixed convective heat transfer that occurs when water - Al_2O_3 nanofluid are mixed within a porous cavity. The results were verified by comparing them with other studies, and it was observed that the increase in the Gr number led to an increase in heat transfer.

Abdelkader et al. (2015), [11] Analyzed the presence of combined convection in a cubic receptacle containing a mixture of Cu and Ag - H_2O nanofluid with a volume ratio of $\varphi = 0 - 0.1$. The results showed that the heat transfer increases as the Richardson value and the volume fraction of nanoparticles increase. In addition, the use of Ag-water nanofluid led to a higher heat transfer value in comparison to Cu-water nanofluid.

Mahmudul Hasan et al. (2015), [12] This study investigated the impact of the inclination angle of the cavity on convection heat transfer in two trapezoidal enclosures filled with water containing Al_2O_3 nanofluid at a concentration of 0.1 (φ=0.1). The changes in the mean Nusselt number of the heated wall and the temperature of the fluid inside the enclosure at different tilt angles were analyzed.

Abdelkader Boutra et al. (2015), [13] examined the effects of Richardson numbers, nanoparticles volume fraction, and tilting angle of a square cavity on the flow patterns and temperature field within the cavity. The results demonstrate that the inclusion of nanoparticles in the base fluid improves heat transfer. Specifically, the addition of Ag nanoparticles produces the highest average Nusselt number values.

Habib Salahi et al. (2015), [14] Examined the convection heat transfer in a shallow inclined enclosure with a lid that is influenced by external forces, taking into account an aspect ratio of 10. Conclusions suggest that, regardless of the nanoparticles volume percentage, the heat transfer rate shows a slight increase when the cavity inclination increases in the scenario of Ri = 0.1, where forced convection is dominant. Furthermore, the rate of growth was notably greater when Ri = 10, in which natural convection had a predominant role.

Zoubair Boulahia et al. (2016), [15] employed numerical modeling techniques to investigate the impact of heated triangular cylinders on the transfer of heat in a lid-driven cavity using nanofluids. It was demonstrated that increasing the dimensions, as well as incorporating more heated triangular cylinders, improves the rate of heat transfer.

Cimpean, D., M. Sheremet, et al. (2020), [16] Enhanced the mixed convection heat transfer mechanism in a porous trapezoidal chamber filled with a hybrid nanofluid consisting of Cu-Al_2O_3 / water, by employing suitable algorithms. It was shown that the ability to control the required thermal transfer rate can be achieved by manipulating a variety of nanoparticles in a hybrid nanofluid.

Ali, I., et al. (2020), [17] Utilized a hybrid nanofluid to enhance the transfer of heat through mixed convection in enclosed spaces. It has been noted that a high Reynolds number and specific solid body sizes might enhance heat transfer within the cavity above the usual level, potentially impacting the overall efficiency of the system.

3. Heat Transfer Enhancement Using Porous Media

The main parameters, boundaries, and geometries for improving the transfer of heat in lid-driven cavities utilizing porous media are covered in these studies. These investigations used this method and others, such as adding hybrid nanoparticles to the main fluid, vibrating, and tilting the cavity.

Hakan (2006), [18] performed a numerical simulation to calculate the heat transfer and combined primary and secondary flows in a porous cavity, where the upper wall moved at a consistent low temperature and velocity. This study investigated the influence of many elements on the flow patterns and temperature contours, such as the Darcy number, Richardson number, and the position and size of the heater on the left side.

Hakan et al. (2008), [19] analyzed the thermal transfer in cavities with a thick bottom hot wall that is in motion, taking into account both conduction and mixed convection. Conclusions indicate that heat transfer improves when the thermal conductivity of the wall (k_w) is higher than the thermal conductivity of the fluid (k_f), and when the Richardson number is lowered.

Wang (2009), [20] investigated the application of a permeable Darcy-Brinkman medium in a rectangular container, where the upper wall is in motion. The inclusion of porous materials in the medium has been observed to minimize the occurrence of recirculating swirls, leading to a decrease in their intensity, especially in the case of deep cavities.

Stephen and Kambiz (2010), [21] utilized vibration and porous material to improve the mixed convection of heat transfer in an open chamber. Conclusions suggest that when the Darcy and Reynolds numbers increase, the vibrational impacts become more prominent.

Mohd et al. (2010), [22] analyzed the characteristics of fluid flow and heat transfer in a square enclosure with a porous material, when the lid is in motion. The study demonstrated that the porosity of the field exerts a substantial influence on the velocity, vortex intensity, and boundary layer.

Waheed et al. (2011), [23] analyzed the concurrent convective heat transfer phenomenon that arises when a rectangular container is filled with a porous material saturated with fluid. The flow and temperature distributions inside the enclosure were significantly affected by the controlling variables, specifically the Richardson number, Darcy number, and geometric proportion.

Wael et al. (2012), [24] examined the phenomenon taking place within a square enclosure with a lid that moves, which contains a porous substance saturated with fluid. The Darcy number (Da) and the magnitude proportion of varying temperature (ε) were discovered to have a significant impact on the flow and thermal properties.

Abdalla AlAmiri (2013), [25] examined the combined impact of inertia and buoyancy within a square container containing a porous structure, while keeping the top wall's speed constant. The study revealed that an increase in the Richardson number enhances the phenomenon of flow mixing and increases the rate of heat transfer.

Anirban et al. (2014), [26] investigated the mixed convection heat transfer in a square container with a movable lid, filled with a permeable substance. The study focused on combined convection, with the right wall maintained at a low temperature and the left wall uniformly heated. Conclusions indicate that the heat transfer rates were significantly influenced by the direction of motion of the driven wall.

Mojumder et al. (2016), [27] examined the influence of Grashof number, Reynolds number, and Darcy number on temperature distribution and fluid flow characteristics in a lid-driven L-shaped cavity containing a porous medium. Conclusions revealed a significant decrease of up to 63% in the transfer of heat in the lower wall as the Reynolds number reaches a high value of 100.

4. Heat Transfer Enhancement Using Magnetic Field and Vibration

The following literature provides a concise overview of the research activities focused on improving the transfer of heat in hollow structures and enclosures by the use of magnetic field &/or vibration. This may require the integration of further boosting methods, such as nanofluid hybrids and porous media.

Billah et al. (2014), [28] conducted a numerical investigation on the heat transfer occurring in a two-dimensional inclined lid-driven equilateral triangular enclosure that was filled with nanofluids consisting of copper and water. Conclusions indicated that there was a 28% increase in heat transfer as the solid volume percentage increased.

Raizah, Z., et al. (2021), [29] examined how magnetic fields affected the flow of mixed convection in a wavy container containing permeable medium and hybrid nanofluids. Results indicate that the length and positioning of the heater enhance the flow of nanofluids and the transfer of heat in cavities with a wavy shape.

Salma and Rehena (2010), [30] explored the properties of heat transfer in a lid-driven cavity with a heated base bottom wall that is sinusoidal and wavy. The investigation concluded that the localized heat transfer has a sinusoidal shape. Moreover, the heat transfer coefficients increase as the wave value increases and decrease as the Hartmann number decreases.

Khaled et al. (2012), [31] explored the impact of wall motion direction on MHD mixed convection within a lid-driven enclosure. Conclusions indicate that in mixed convection scenarios, wall movement direction has a greater impact on the influence of streamlines and thermal patterns than in forced convection circumstances.

Ziafat and Tabish (2016), [32] examined the heat transfer occurring in a trapezoidal cavity with a mobile upper wall, while considering the influence of a steady magnetic field. Conclusions indicate that the Nusselt number, which measures the rate of heat transfer, is highest at the borders of the wall and steadily declines towards the center, where it reaches its minimum value.

Bakar et al. (2016), [33] examined the effects of applying a magnetic field on the combined heat transfer and fluid flow characteristics within a rectangular container. Conclusions suggest that the magnetic field had a substantial impact on the parameters of thermal transfer and fluid dynamics.

Borhan et al (2016), [34] applied the electromagnetic field to enhance the process of twin molecular diffusion coupled convection heat transfer in a quadrilateral enclosure. The study determined that the mass transfer was greatly affected by the Lewis value.

Rashad et al. (2017), [35] investigated the effects of partial slip and MHD convection in a square cavity with lid-driven motion, as well as mixed and natural convection. An analysis was conducted on the physical phenomena associated with the transfer of heat and fluid movement under these constraints, and the intriguing outcomes of this study were reported.

Sameh (2018), [36] conducted experiments on MHD effects by applying them to different alignment directions on the left sidewall of a trapezoid-shaped enclosure. The enclosure was filled with water micro polar nanofluids containing several types of nanoparticles, including Cu, Ag, Al_2O_3, and TiO_2. Conclusions demonstrate a direct relationship between the average heat transfer coefficient and the decrease in Richardson number and thermal source magnitude, as well as a rise in particle concentration.

Kefayati and Tang (2018), [37] investigated the mixed convection phenomena occurring in an enclosure with different aspect ratios, taking into account the impact of a uniform magnetic field. Results have shown that increasing the Reynolds number enhances the coefficient of heat transfer. As the Bingham number increases, the rate of heat transfer decreases.

Humaun et al. (2019), [38] explored the phenomenon of MHD mixed convection heat transfer in a porous rectangular enclosure including three square heating components and a lid that is actively propelled. The chamber was filled with a nanofluid consisting of H_2O - Cu. The results showed a positive relationship between the average Nusselt number and both the Darcy parameter and the Richardson parameter.

Al-Asada et al. (2019), [39] examined the impact of a magnetic field on the mixed convection heat transfer in a square enclosure with a lid and a vertical fin attached to the hot wall. Conclusions demonstrate a positive relationship between the average Nusselt number and the Richardson number. Moreover, the Hartmann number plays a critical role in enhancing the heat transfer mechanism within the lid-driven cavity.

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

Multiple authors have undertaken investigations on enhancing heat transfer within a moving-lid cavities by optimizing different parameters. Further strategies to enhance the heat transfer process may include employing a wavy wall or cavity, manipulating the Prandtl number, fine-tuning the slope angle of the cavities, etc.

Chen and Cheng (2004), [40] investigated the heat transfer taking place in a moving-lid arc-shaped container using both numerical and experimental methods, taking into account mixed, forced, and free convection. The mixed heat transfer outcomes are utilized to construct thermal maps, stream vectors, and ensemble mean Nusselt numbers employing more intricate numerical methodologies. This outcome demonstrates an exceptional alignment between the predicted flows and the observed patterns of flow.

Sharif (2007), [41] carried out a numerical analysis to examine how the tilt angle affected the fluid flow characteristics and thermal transfer within a shallow rectangular chamber with a set aspect ratio of 10. It was found that the mean thermal transfer rate increases as the cavity's tilt inclination rises.

Bhattachary et al. (2013), [42] investigated the impact of Prandtl number on the combined free-forced convection occurring within a lid-driven trapezoidal cavity. The bottom wall was heated in two different cases: isothermal and non-isothermal. In the domain of heat transfer dominated by convection, where $Re.Pr > 1$, results indicate that in case 2, numerous steady states were seen in either the region where natural convection dominates ($Ri \gg 1$) or the region of mixed convection ($Ri \sim O(1)$). The non-isothermal bottom wall exhibited higher mean Nusselt values.

Chen and Chung (2015), [43] investigated the impact of tilt angle, Reynolds number, and Grashof number on mixed convection heat transfer in a triangular lid-driven cavity. Three distinct flow regimes were discovered in a triangle-shaped chamber with a lid that may move at angles ranging from 0° to 360°. These regimes include mixed convection flow, dominating forced convection, and dominating natural convection.

Krunal and Siddharth (2018), [44] examined the flow characteristics in rectangular enclosures with a lid that is driven by motion, focusing on the effects of the Prandtl number and the direction of the moving vertical wall. Explored the relationship between these factors and the distribution of heat within the enclosure. Conclusions suggest that the primary element influencing heat dispersion is the direction in which the sliding lid moves, rather than the aspect ratio of the circular cylinder.

Saha et al. (2013), [45] used an irregular square lid-driven cavity with a wavy bottom wall to investigate the related dynamics of convection flow and thermal transfer. Conclusions demonstrate that the interaction between Reynolds and Grashof numbers had a significant influence on the thermal trends, flow lines, and the average Nusselt number detected inside the enclosure.

Rosdzimin et al. (2010), [46] examined the phenomena of combined convection transfer of heat around a hot square cylinder placed inside a square enclosure activated by a lid. This work presented and analyzed the flow and isotherm profiles, as well as the regional and average Nusselt number, at the upper limit of the internal cylinder. Moreover, the Reynolds number and Richardson number exerted a substantial influence on these outcomes.

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