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A Theoretical Study of Natural Convection Heat Transfer in A Partially Opened Square Cavity with an Internal Heat Source

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Abstract

Many engineering and industrial applications are always seeking ways to dissolve heat from the heated surfaces in these industries. It is entering into the cooling of electronic parts and electrical transformers as well as the design of solar complexes as well as a thermal exchange process between hot and liquid surfaces. A theoretical study of convective heat transfer in a partially open square cavity with internal heat sources presented. This topic is of great interest in the engineering field, particularly in applications involving the development of heat exchangers and systems for cooling or heating objects by means of a natural convection mechanism. Free or natural convection occurs when fluid flow motions (currents and paths) result from buoyant forces resulting from density changes that in turn arise from temperature changes in the fluid. Partially open cavities are found in various engineering systems, such as open cavity solar heat receivers, flat panel solar collectors with rows of vertical strips, electronic cooling devices, buildings, etc. Natural convection that develops in a closed cavity is finding applications in many fields, citing the thermal power, petrochemical, aerospace and construction industries. Several studies have been conducted to understand this phenomenon. It is also noted from earlier studies that many strong secondary cycles are formed for fluids with small rays while these features are absent in higher rays. The comprehensive analysis was completed with horizontal air velocities and orifice temperatures.

Keywords: Heat Transfer, Natural Convection, Square Cavity, Finite Element Method, Internal Heat Source.

1. Introduction

At present, the search for natural convection in cavities has been the subject of numerous studies. Natural convection in open cavities and slots is encountered in many engineering applications, such as solar thermal receivers, convection from extended surfaces in heat exchangers, and insulated ribbon solar collectors. Side-slit cavities and an internal heat source can be seen in many electronic devices, as the slots facilitate cooling of the device's internal components. Moreover, the study of this case is relevant to many other applications, among them: construction and operation of nuclear reactors, solar collectors, energy storage systems, design and construction of indoor environments, and grain storage (Supraja & Raju, 2021).

Several studies have been reported in the literature, assessing the behavior of fluids within cavities, and we mention a number of them below. Natural convection in cavities caused by temperature difference between vertical (or horizontal) walls is a case that has been extensively studied (Mezrhab, 2006). In those studies, the authors evaluated the effect of a thermal gradient (Kaluri, 2009), partial opening and elimination of the thermal properties of the cavity (Mezrhab, 2006).

A numerical study on heat distribution and thermal mixing during static natural laminar heat flow within liquid-saturated porous square cavities for three different states: a uniformly heated bottom wall, separate heat sources on the walls, and uniformly heated left and bottom walls was considered in Kaluri et al. (2009). Deng and Chang (2008) numerically study the stratified and constant two-dimensional natural convection in an air-filled rectangular enclosure in which the horizontal walls are thermally insulated and the vertical side walls have two varying spatial distributions of sinusoidal temperatures of different amplitudes and phases (Deng & Chang, 2008).

Michalek (2005) performed experiments to measure the flow of water inside a cubic cavity with isothermal vertical walls and adiabatic horizontal walls for values of Ra greater than 109. The transition from constant flow to non-constant flow was less than the theoretical value of the critical Rayleigh number (Michalek, 2005).

Bilgen and Oztop performed a numerical study of natural convective heat transfer in an inclined, partially open two-dimensional cavity. A parametric study of Ra values between 103 and 106 concluded that the Nusselt number was maximized for angles between 30 and 60 for low values of Ra, while at high values of Ra the Nusselt number was maximized for angles between 60 and 90 (Bilgen & Oztop, 2005). Kuznik et al. used the Lattice–Boltzmann method with an irregular grid was used to simulate natural convection in a square cavity (Kuznik, 2007). Hence, this paper investigates natural convection in a partially open square cavity with an internal heat source.

2. Heat transfer in partially open cavities

2.1 Natural convection

Convection (or convective heat transfer) is the transfer of heat from one place to another due to the movement of a fluid. Although often discussed as a distinct method of heat transfer, convection heat transfer includes the processes of co-conduction (heat diffusion) and delay (heat transfer by bulk fluid flow). Convection is usually the dominant form of heat transfer in liquids and gases (Supraja & Raju, 2021).

Convective heat transfer occurs if an object is placed in a fluid at a temperature higher or lower than the object (Kaluri, 2009). As a result of the temperature difference, heat will flow between the fluid and the body and cause a change in the density of the fluid adjacent to the surface (Grosan & Ingham, 2009). See figure (1) below;

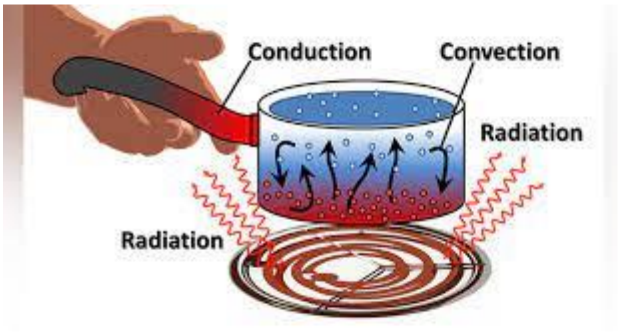

Figure (1): Example of Convective heat transfer

Heat transfer by convection is the transfer of heat from one place to another through the movement of fluids, a process that mainly represents the transfer of heat through the transfer of mass. Fluid flow improves heat transfer in many physical states, for example, between a solid surface and a fluid. Convection is usually the dominant form of heat transfer in liquids and gases (Taylor, 2012). Although it is sometimes discussed as a third form of heat transfer, convection is often used to describe the combined effect of heat conduction within the fluid (diffusion) and heat transfer by flow paths of the fluid's flow. The process of translational movement through fluid currents is known as transport, but net transport is a term usually associated with the transfer of mass only in fluids, such as the movement of gravel in a river. In the case of heat transfer in fluids, where transfer in fluid is always accompanied by thermal diffusion (also known as thermal conduction), convection is understood to refer to the sum of heat transfer by transfer and diffusion/conduction (Çengel, 2003).

Heat transfer by convection occurs when a flowing stream of fluid (liquid or gas) carries heat with the flow of matter in the fluid. The fluid flow may be driven by external processes, or in some cases (in gravitational fields) by buoyant forces caused by the expansion of the fluid's thermal energy (as in plumes of smoke), affecting its own transmission—thermal energy. The last process is often called a 'natural convection'. All convective processes move heat partly by diffusion (conduction) as well. Another form of convection is forced convection. In this case the fluid is forced to flow using a pump, fan, or other mechanical means (Lienhard, 2019).

Free or natural convection occurs when fluid flow motions (currents and paths) result from buoyant forces resulting from density changes that in turn arise from temperature changes in the fluid (Faghri, 2010). Forced convection is a term used when paths and currents in the fluid are induced by external media, such as fans, stirrers, and pumps, creating an artificially induced load current (Supraja & Raju, 2021).

Convection can be "forced" by the movement of a fluid by means other than buoyant forces (for example, a water pump in a car engine). Thermal expansion of fluids may also force convection. In other cases, only natural buoyant forces are entirely responsible for the fluid movement when the fluid is heated, and this process is called "natural convection." In natural convection, an increase in temperature leads to a decrease in density, which in turn leads to fluid movement due to stresses and forces when fluids of different densities are affected by gravity (or any force g). For example, when water is heated on a stove, hot water rises from the bottom of the pan, displacing the cooler liquid that falls. After the heating stops, mixing and conduction from this natural convection eventually leads to a nearly homogeneous density, even temperature. Without the presence of gravity (or conditions that cause an acceleration force of any kind), natural convection does not occur, and only forced convection patterns operate (Deng & Chang, 2008).

Heat transfer by convection is a mechanism for heat transfer as a result of the mass movement (observed movement) of fluids. Heat is the studied entity that is transferred (carried) and diffused (distributed). This is in contrast with heat transfer by conduction, which is the transfer of energy by vibrations at the molecular level through a solid or fluid, and with heat transfer by radiation, which is the transfer of energy through electromagnetic waves (Lienhard, 2019). A convective heat transfer occurs through the movement of a fluid that can be a gas or a liquid. As the density decreases with increasing temperature, the masses of the warmer liquid rise, while the cooler parts decrease. In this way there is a mass movement of fluids, through which heat is transmitted from one side to the other. This is the property that distinguishes convection from conduction and radiation, because in convection there is always a net displacement of masses. On the other hand, radiation does not require a physical medium for propagation and as far as transport by conduction is concerned, it is caused by successive collisions between atoms and molecules, without a net movement of matter (Çengel, 2003).

Heat is transferred by convection in various examples of natural fluid flow, such as winds, ocean currents, and movements within the Earth's mantle. The load is also used in home engineering, industrial processes, equipment cooling, etc. The rate of convective heat transfer can be improved by using a heat sink, often in combination with the use of a fan. For example, a conventional CPU has a dedicated fan to ensure that the temperature is kept within permissible limits while working (Taylor, 2012).

The convective heat transfer mode includes one mechanism. In addition to the transfer of energy due to specific molecular motion (diffusion), energy is transferred by mass, or the macroscopic motion of a fluid. This motion is related to the fact that, at any given moment, large numbers of molecules are moving collectively or as agglomerations. This movement, in the presence of a temperature gradient, contributes to heat transfer. Since the molecules in the aggregate retain their random motion, the total heat transfer is due to the superposition of energy transfer by the random motion of the molecules and the overall motion of the fluid. It is usual to use the term convection when referring to this cumulative transport and the term advection when referring to transport due to the movement of bulk fluids (Hinojosa, 2012).

Convection Currents is the method of simultaneous transfer of heat and mass in fluids (liquids and gases); As a result of the difference in the temperature of the material, and thus its density, and a well-known example of convection currents is what happens when water is heated in a bowl on the stove. Some water molecules down, and the process is repeated until all the water is heated, There is a type of convection called natural convective heat transfer: it are convection currents that arise from the buoyant force of fluids as a result of their temperature and density differences without the intervention of external forces (Massinissa, 2017).

Natural or free convection: when the movement of fluids is the result of buoyant forces that result from changes in density due to changes in the thermal temperature in the fluid. In the absence of an internal source, when a liquid comes into contact with a hot surface, its molecules separate and disperse, making the liquid less dense, as a result, the fluid is displaced while the cooler fluid becomes denser and the fluid sinks. Thus, the hotter volume transfers heat towards the cooler volume of that fluid. Familiar examples are the upward flow of air due to a fire or a hot object and the circulation of water in a vessel heated from below. Which happens without human intervention? For example: air carries heat from a hot place to a cold place during its movement due to the density difference, the hot gases decrease in density and therefore rise to the top and are replaced by cold gases (Hinojosa, 2012).

Natural convection is a very important topic “due to its many applications in many areas of nature, and although there is no forced velocity to generate this type of convection, natural convection currents are generated within the fluid that urge it to flow as a result of” the effects of buoyancy force or so-called With the power of flotation. As we see in many devices that include multiple methods of heat transfer through which the rates of heat transfer or operating cost are affected, the natural load plays an important role in the design or performance of the device, which is much preferred over forced load. Also, natural convection also occurs in a partially open square cavity, and as with any scientific and technical issue, the treatment of heat transfer and fluid flow in a partially open square cavity with an internal heat source has become studied in two ways: practical and theoretical. Therefore, in this paper, heat transfer by natural convection will be studied in a partially open square cavity with an internal heat source (Ibrahim, 2011).

Many engineering and industrial applications are always seeking ways to dispel heat from the heated surfaces in these industries. It is entering into the cooling of electronic parts and electrical transformers as well as the design of solar complexes as well as a thermal exchange process between hot and liquid surfaces. Most electronic organs or their parts are cooled by removing heat generated inside using air as a heat carrier and natural convection, and the heat transmission by natural convection occurs in many areas so there were many studies that have been shown (Ibrahim, 2011).

The natural convection is generated through the buoyant force, as a result of the difference in the density of the fluid adjacent to the heated surface due to the difference in temperatures between the fluid and the surface. The stratigraphic flow along the surfaces has been studied [Phase 2, 3, Analytical] And in the horizontal, inclined and vertical cases, whether by the stability of the thermal flux or the stability of the surface temperature, as well as there are many experimental studies of the transfer of heat by natural convection from surfaces with horizontal and vertical surfaces, [7, inclined, 6] Some experimental studies have also been conducted on heat transfer by natural convection from heated surfaces in the form of a ring (ring), and the outcome of these studies was the extraction of an exponential mathematical relationship between the averages of multiples and the averages of multiples. For the following formula NU = C (RA): n is one of the most appropriate formulas for heat transmission of free natural and various forms and extensive of the number of rally. All these studies have not addressed the impact of the impact of the cavity rate on heat transmission Square-shaped surfaces, which is the shape that is more applied in electronic devices (Supraja & Raju, 2021).

2.2 Partially open cavities

Partially open cavities are common in a wide range of engineering applications such as open cavity solar thermal receivers, flat-panel solar collectors containing vertical strip rows, electronic chips, room heating, etc. Thus, cavity heating researchers have become increasingly interested in analyzing fluid flow and heat transfer in these cases. There are many studies in the literature on the problems of natural convection in rectangular and square cavities exposed to heat flow and temperature. Costa (2002) examined natural convection in differentially heated rectangular packages with diffused vertical walls. The proposed procedure was examined, by comparing the results obtained with those obtained from the full 2D numerical simulation of the conjugate heat transfer problem, which occurs in the complete enclosure, with diffuse walls (Doğan, 2009).

Aydın et al. (1999) investigated natural convection numerically in rectangular packages heated on one side and cooled from the ceiling. They analyzed the static natural convection of air in a two-dimensional container using a vortex-functional stream formula. Experiments and numerical calculations of natural turbulent convection in a large air-filled cavity were performed by Salat et al. (2004), they made numerical simulations of both adiabatic conditions, and experimentally measured temperature on horizontal walls. Another study was performed by Di Piazza and Ciofalo (2000), who made a direct two-dimensional numerical simulation of the free heat flow for a low Brantel number (0.0321), for a thin cavity of AR = 4.

Arcidiacono et al (2001) studied a square cavity (AR = 1), which has isothermal side walls and adiabatic upper and lower walls. Chang and Tsay (2001) examined normal convection in a container caused by a hot retrograde step. The influence of Rayleigh number, Prantel number, and shell geometry on the flow structure and heat transfer properties has been studied in detail.

Leong and Tan (2001) carried out an experimental investigation of freezing an n-paraffin solution in a rectangular container with an isothermal vertical side wall and other isothermal walls. Nithyadevi et al. (2007) studied the effect of the aspect ratio on the natural convection of a fluid contained in a rectangular cavity with partially thermally active sidewalls. The active part of the left lateral wall was selected at a temperature higher than that of the right lateral wall. The upper and lower part of the cavity and the inactive part of the side walls are thermally insulated.

Another study was carried out experimentally and numerically by Poujol (2000), who examined transient natural convection in a square cavity heated by a time-dependent convection over one vertical wall, and cooled by keeping the opposite wall, at a constant temperature. Başak et al. (2006) conducted a study on the effect of thermal boundary conditions on natural convective flows within a square cavity. They examined normal, static laminar heat flow in a square cavity with a uniformly and non-uniformly heated lower wall, and an adiabatic upper wall that maintains a constant temperature at the cold vertical wall. The numerical procedure adopted in this study was used on a wide range of parameters (Rayleigh Ra number, 103 ≤Ra≤105 and Prandtl Pr number, 0.7≤Pr≤10) in relation to the continuous and discontinuous Drechlet boundary conditions. Mr. Elsayed & Chakroun (1999) studied the effect of orifice geometry on heat transfer in oblique and partially open cavities. They conducted experiments to study the effect of orifice geometry on heat transfer between the cavity and ambient air. They examined different geometric arrangements, different opening ratios, and tilt angles.

Polat and Bilgen (2002) numerically investigated natural laminar convection in shallow and open inclined cavities for Rayleigh numbers 103 to 107, and cavity aspect ratio from 1 to 0.125. Bilgen and Oztop (2005) studied natural convection heat transfer numerically in partially open inclined square cavities. They numerically studied the steady-state thermal transfer by natural laminar convection in a partially open two-dimensional cavity. Kasayapan (2007) investigated the numerical modeling of the effect of an electric field on natural convection in partially open square cavities, using a computational fluid dynamics technique (Doğan, 2009).

2.3 Heat transfer in open cavities

Heat transfer in open cavities is closely related to many applications of thermal engineering, for example in the cooling of electronic devices and the design of solar condenser receivers, among others. In a parabolic dish solar thermal system with a Stirling heat engine used to produce electricity, the solar concentrator contains a tracking system to keep its optical axis pointed directly toward the sun. During tracking, the receiver (open bore) located at the focal point of the capacitor operates at different angles of inclination. The circulation modifies the air movement pattern and the heat field and, as a consequence, the heat loss in the open cavity. A better understanding of how heat is transferred from the receiver will help improve thermal design and improve the thermal performance of the solar thermal system (Hinojosa, 2012).

A large number of numerical studies describing heat transfer in open cavities have been reported in the literature. Some studies have analyzed natural convection heat transfer, considering the effects of Rayleigh number, aspect ratio, and cavity inclination angle on flow patterns, temperature ranges, and heat transfer behavior within the open cavity (Polat & Belgen, 2002; Bilgen and Oztop, 2005).

Other authors have focused on the analysis of flow instability (Hinojosa et al., 2005), and the definition of approximate orifice-plane boundary conditions (Khanafer and Vafai, 2000, Khanafer and Vafai , 2002), mixed convection (Khanver et al., 2002), the presence of conjugated heat transfer (Polat and Bilgen, 2003; Koca, 2008), three-dimensional flow systems (Hinojosa et al., 2006; Hinojosa and Cervantes , 2010) and combined natural convection and radiative heat transfer in the cavity (Singh and Venkateshan, 2004; Hinojosa et al. 2005; Nouaneguea et al., 2008).

There have been many investigations on convective heat transfer in partially open cavities, Bilgen and Oztop (2005) made a numerical study of inclined and partially open square cavities, which consist of adiabatic and partially open walls. A parametric study was performed using the following parameters: Rayleigh number from 103 to 106, dimensionless aperture size from 0.25 to 0.75, aperture position at high, middle and low and aperture inclination from 0° (facing up) to 120° (facing 30° down). He found that the Nusselt number is an increasing function of Rayleigh's number, aperture size and overall aperture position. Koka (2008) also solved natural convection and conduction in a partially open square cavity with a vertical heat source. The bore has a hole at the top in several different lengths and three different positions. The heat source is located on the lower wall of the cavity. The results were recorded for several governing parameters such as Rayleigh number. It was found that the ventilation position has a significant effect on heat transfer.

Nevertheless, the Rayleigh numbers studied by Bilgen and Oztop (2005) correspond to cavities that are smaller in size than those typically used as receptors in Stirling dish thermal systems; Moreover, the considered angles of inclination do not cover the complete rotation of the thermal receiver during its operation (Hinojosa, 2012).

The development of the governing equations is one part but the second and important part is to solve these equations in order to predict the various parameters of interest in the porous medium. There are many numerical methods available to achieve the solution of these equations, but the most popular numerical methods are the finite differences method, the finite volume method, and the finite element method. The choice of these numerical methods is an important decision, as it is influenced by a variety of factors among which field geometry plays a vital role. Other factors include the ease with which these PDEs can be converted into simple forms, the computational time required and the flexibility in developing computer code to solve these equations. In the current study, we mostly used the finite element method (FEM) (Supraja & Raju, 2021).

The finite element method is a deservedly popular method among the scientific community. This method was originally developed to study mechanical stresses in complex airframe structure popularized by Zienkiewicz and Cheung by applying it to continuum mechanics. Since then, the application of the finite element method has been exploited to solve numerous problems in various engineering disciplines. The great thing about the finite element method is how easy it is to generalize to a myriad of engineering problems made of different materials. Another impressive advantage of the finite element method (FEM) is that it can be applied to a wide range of geometric shapes with irregular boundaries, which is difficult to achieve with other contemporary methods (Supraja & Raju, 2021).

3. Numerical modeling of the convective heat transfer

In recent years, numerical modeling of the convective heat transfer problem has been an area of great interest due to its wide applications in engineering. Compared to the experimental method, numerical analysis provides a more direct method to effectively enhance/reduce heat transfer in order to improve performance or improve the structure of the thermal device. Natural convection in enclosures has been studied experimentally and numerically, due to great interest in its many engineering applications, such as building insulation, solar energy harvesting, cooling of heat-generating components in the electrical and nuclear industries, and flows in rooms due to thermal energy sources (Mariani, 2007). Numerical studies of natural convection heat transfer and flux in closed packages without a local heat source have been reported in the literature; the work of Corcione (2003), and Ben-Nakhi and Chamkha (2006).

Other authors have studied natural convection. Chan and Tien, 1985 have made several studies on natural convection induced only by external heating in partially open packages; Polat & Belgen, 2002; Bilgen & Oztop, 2005; Lauriat and Desrayaud, 2006. Nevertheless, few results of natural convection have been reported simultaneously from both external heating in partially open enclosures and internal local heat sources although problems of this type are often important and their study is necessary to understand the performance of complex natural convective flow and heat transfer.

Indirectly related to the current study, Xia and Zhou (1992) studied a square, partially open container with an internal heat source. These authors changed position on the lower wall or left vertical wall for only three R ratios. They found that the hole was beneficial for the flow and transfer of heat into the cavity. In this case, the flow and heat transfer characteristics change depending on the location of the heat source, the outer and inner Rayleigh number, and the opening size. Reinehr et al. (2002) examined natural convection using an aspect ratio H/W = 2, with an internal heat source whose position varies only on the lower wall. In this work, no results of heat transfer were recorded and a limited number of Rae and R ratios were also studied (Mariani, 2007).

4. Natural convection heat transfers in partially open square cavities

Partially open cavities are found in various engineering systems, such as open cavity solar thermal receivers, flat-panel solar collectors with rows of vertical strips, electronic cooling devices, buildings, etc. open cavity. With the exception of a series of experimental studies in a select number of Rayleigh, most of these studies were with fully open horizontal cavities with all three isothermal walls or the wall facing the isothermal opening with two other isothermal. Since fully open cavities are a special case of the more general case considered in this study, we will provide a brief review including fully open cavities. Various authors have studied open cavities experimentally (Kaluri, 2009).

The first two works were with a fully open horizontal bore. The last three were fully and partially open cavities. A dimensionless aperture size of 0.5 and was centrally located in a square bore. They used laser Doppler velocity and flow visualization techniques to study flow characteristics and determine the local Nusselt number at different scales covering Rayleigh number from 107 to 1011 in laminar and turbulent systems (Bilgen & Oztop, 2005).

Chakroun et al. (1997) fully and partially open oblique cavities were studied with an aperture size of 0.25 to 1, the aperture is located in the middle. Grashof's number was $5.5 * 10^8$ and fixed. Later using the same experimental setup, they studied the effect of size location in an inclined square cavity with an isothermal heated wall with the same Grashof number. Others theoretically studied heat transfer by natural stratified convection in fully open cavities (Elsayed, W. Chakroun, 1999).

Le Quere et al., investigated thermally driven natural stratified convection were examined in containers on all three isothermal sides, one of which is facing the hatch. Its Grashof range was from 104 to 107.

Pinot studied a similar problem using the vortex formula - the flow function. His Grashof range was 103-105. Chan and Ten numerically studied a fully open square cavity, which has a heated vertical side facing the hole and two horizontal sides connected to the thermocouple. In these studies, the calculation was done using an extended field. Despite the difficulties due to unknown boundary conditions at the opening level, the other studies mentioned above were conducted using a computational field limited to the cavity (Bilgen & Oztop, 2005).

Chan and Ten studied shallow fully open cavities numerically and also performed a comparative study using square cavities in an extended arithmetic field. They found that for an open square cavity with an isothermal vertical side facing the hole and two adjacent horizontal sides, satisfactory heat transfer results can be obtained, especially at high Rayleigh numbers.

In a similar way, Muhammad studied fully inclined open square cavities, by considering a restricted arithmetic field. Different from those of Chan and Ten, the gradients for both velocity components are set to zero at the opening level. It was found that the heat transfer was not sensitive to the tilt angle and that the flow was unstable at high Rayleigh numbers and small tilt angles.

Polat and Bilgen (2002) studied shallow, numerically inclined, fully open cavities in which the side facing the hole was heated by a constant heat flow, two adjacent walls insulated and the hole was in contact with a tank at constant temperature and pressure. The arithmetic domain was limited to the cavity.

Miyamoto et al., studied a partially and fully open square cavity numerically with all three isothermal walls and different angles of inclination. In the case of a partially open bore, the dimensionless size size was 0.5 and was centrally located. Their Rayleigh number was from 0.7 to

$7 * 10^5$ for the horizontal bore and from $7 * 10^3$ to $7 * 10^4$ for the inclined bore. They used an extended arithmetic range. A review of the literature shows that in experimental studies with partially open cavities, either the Rayleigh number remained constant, or it was very high. In the numerical study of the same problem, the three walls were heated (Miyamoto, 1989). After the applications encountered in thermal systems, the wall facing the opening is isothermal and in contact with the air of the open case. All other walls are insulated. Ambient air circulates at a characteristic temperature through the heat dissipating the opening from the hot wall by natural convection (Bilgen & Oztop, 2005).

Natural convection that develops in a closed cavity finds applications in many fields, quoting the thermal power, petrochemical, aerospace and construction industries. Several studies have been conducted to understand this phenomenon. A numerical study of natural stratified convection in a rectangular and square cavity was made by De Vahl Davies (Massinissa, 2017).

The sensitivity of fluid properties and specifically the effect of the Brantel number, on normal load have been extensively documented by Bejan, Gorgadis (1992). Yoo (1999) investigated the transmission of free convective fluxes in a wide-gap horizontal ring. They find that the bifurcation points are functions of the Prandtl number. Poujol, Rojas and Ramos (2000) analyze the problem of natural convection in a square cavity for a Prandtl spike. It happens that natural convection depends quantitatively and qualitatively on the set of boundary conditions imposed on the walls, as well as the position of the cavity with respect to the center of gravity (Cianfrini, Corcione, and Dell'Omo (2005); Huelez, Rechtman (2013).

Buoyancy forces inherent in temperature gradients tend to increase heat transfer and normal convection appears increasingly with increasing temperature gradient (Mahmoudi (2011). Al- Sadaoui et al, (2015) performed numerical studies on natural convection in square cavities in the presence of a thin plate exposed to elevated temperature inside the enclosure. They examined the effect of the plate on heat transfer and flow field. Heat transfer depends mainly on the geometry and location of the plate. Thus, heat transfer is more pronounced with increasing Rayleigh number.

Aminossadati et al. (2014) studied natural stratified convection in a thin-finned square cavity under the influence of a uniform magnetic field. The results indicate that at higher Rayleigh numbers, the fields of flux, temperature, and rate of heat transfer of the cavity are all affected by the magnetic field.

Oztop et al. (2011) performed a numerical study of fluid flow and heat transfer due to buoyant forces in a tube inserted into a fluid-filled square cavity. The results indicate that the heat transfer and flow field depend on the position of the inserted tube and are affected by the change in Rayleigh number.

With regard to the numerical studies accompanying experimental studies, the heat transfer by natural convection and thermal radiation on a cubic-type solar receiver, studied by Montiel et al. (2015), shows that the comparison of experimental and theoretical results is better when Using a model with variable thermophysical properties compared to the Boussinesq approximation. Nardini and Paroncini (2012) investigate the effects of different sizes and positions of heat sources on convective heat transfer. Comparison of empirical data with numerical data provides a good level of agreement for Rayleigh numbers ranging from 104 to 105.

The evolution of convective heat increases with increasing Rayleigh numbers and the velocity range is affected by the size and location of heat sources. Other studies focus on trigonometric geometry. Al-Mahmoudi et al. (2013) made a numerical study of the natural convection in an inclined triangle cavity for different thermal boundary conditions, and noted that the heat transfer mainly depends on the angle of inclination. Koca et al. (2007) performed a numerical study of natural convection in triangular packages. The results showed that both the flow field and temperature are affected by the variation of Prandtl number, heater location and length as well as Rayleigh number. For the cylindrical bore, the natural convection heat transfer from a heated horizontal semicircular cylinder was investigated by Chandra and Chhabra (2012). They developed predictive correlations to estimate the value of the Nusselt number based on Prandtl and Grashof numbers in a new application.

The cavity heated through the side walls at low Prandtl numbers with large density differences was investigated numerically and theoretically by Pesso and Piva (2009). The analysis indicates that heat transfer increases with Prandtl number, in particular, for very high Rayleigh numbers. Finally, a 3D numerical study of natural convection in an isothermal open cavity was presented by Hinojosa and Cervantes-de Gortari (2010). All these works illustrate a range of physical phenomena observed in natural convection in cavities (Massinissa, 2017).

The authors identified Rayleigh numbers for the transition region between 103 and 109, and note good agreement with those reported in the literature. The same method was used by Mezrhab et al. (2006), in which the effect of the slope of the cavity and the presence of an internal spacer were evaluated. There was a maximum decrease in heat transfer for the range of Rayleigh numbers between 6 103 and 2 104.

Some studies combine the effect of radiation with natural convection in differentially heated cavities (Bahlaoui, 2007). When there is an internal heat source in the cavities, significant changes in the internal flow characteristics occur. Studies of natural convection can be found in the cavities containing an internal heat source in Kuznetsov and Sheremet, Oztop et al. (2006), or with internal barriers in Fontana et al. [24]. In many cases, the cavity represents a partial opening, facilitating mass flow and thus the cooling process. Mariani and Silva performed a numerical study of the thermal behavior and fluid dynamics of air in partially open 2D containers based on two sides of the radius, H/W = 1 and 2 (Mariani & Silva, 2007). The container had an opening on the right wall and a small heat source located on the lower or left wall It operates in three different modes. Numerical simulations of Ra were performed in the range of 103 and 106 and it was found that changes in this parameter have significant effects on the average local Nusselt numbers (Nu) for the containers (Supraja & Raju, 2021).

Another study was performed by Mariani and Coelho to investigate static heat transfer and flow phenomena for natural convection of air in enclosures, with three aspect ratios (H/W = 1, 2, and 4), within which there is a local position of the heat source on the wall Bottom in three different modes (Mariani, 2007). A similar study was performed by Kandaswamy et al, in which the effect of the location and size of the heat source was evaluated. This study was conducted for Grashof numbers between 103 and 105 (Kandaswamy, 2007).

Hence, this study investigates natural convection in a partially open square cavity with an opening in the right wall of three different sizes H/4, H/2 and 3H/4, where H is the height of the cavity. The cavity was subjected to temperature differences between the left and right vertical walls and had an internal heat conduction source. The effect of an internal heat source with intensities of R = 400, 1000 and 2000, on the thermodynamics and fluid dynamics of air within the cavity and the mass flow rate upon opening, was investigated.

The finite element method is used to convert the nonlinear coupled partial differential equations of the flow field and temperature into a matrix form of equations, which can be solved iteratively with the help of computer code. The Galerkin Finite Element method consisting of three overlapping trigonometric elements is used to divide the material sphere into smaller parts, which is a prerequisite for the finite element method.

Numerical results are presented in terms of current functions, isotherms, temperature profiles and Nusselt numbers. This study investigates natural convection in a partially open square cavity with an opening in the right wall of three different sizes H/4, H/2 and 3H/4, where H is the height of the cavity. The cavity was subjected to temperature differences between the left and right vertical walls and had an internal heat conduction source. The effect of an internal heat source with intensities of R = 400, 1000 and 2000, on the thermodynamics and fluid dynamics of air within the cavity and the mass flow rate upon opening, was investigated (Supraja & Raju, 2021).

5. Conclusion

Natural convection that develops in a closed cavity is finding applications in many fields, citing the thermal power, petrochemical, aerospace and construction industries. Several studies have been conducted to understand this phenomenon. The research in previous studies clarified a set of physical phenomena observed in natural convection in cavities. In natural convection, an increase in temperature leads to a decrease in density, which in turn leads to fluid movement due to stresses and forces when fluids of different densities are affected by gravity.

This study investigated the differences in rheology and isometrics in a partially open square cavity with an internal heat source. The results in the previous studies showed that the thermodynamics and fluid dynamics of the fluid are greatly affected by the presence of the heat source, the size of the opening and the temperature difference between the vertical walls. When the flow is primarily controlled by the heat source (high values of R and low values of Rae), there are large secondary cycles within the cavity and the isotherms exhibit equivalent behaviour, causing an increase (in modulus) in the local Nusselt number values. When convection is controlled by the temperature difference between the walls (low values of R and high values of Rae), the volume of the secondary circulation is negligible compared to the main circulation and is more horizontal isotherms. The contribution of convection to the local Nusselt number is increased in the lower region near the hot wall and in the upper region near the cold wall, except for the smaller size H/4 when the air temperature increases in the higher region of the cavity near the hot wall for larger Rayleigh numbers and R values Larger. At the same time, the air temperature in the lower region to the right of the cavity near the cold wall decreases, resulting in lower local Nusselt numbers in these regions only if the R values are lower.

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