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Natural Convection in Closed Enclosures

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Abstract: Convection is one of heat transfer modes, there are many factors effect on the convection heat transfer coefficient like surface temperature, fluid properties, and other parameters, free or natural convection in closed region or enclosuresis important case for many applications like ovens. In this paper theboundary effects on the convection are studied, the designed setup consists of insulated rectangular cross section box, it is made from wood, the box inner surface is coated by steel sheets. The heat source consists of two heaters, the heater shape is cylindrical, the measured data are temperature with time for different cases, the main case is studying the effect of box cover also the temperature profile measured from the heater surface.

Keywords: Natural Convection, Temperature, Convection Coefficient, Enclosure.

INTRODUCTION

Convection is classified to free and forced¹, forced convection depends on the fluid velocity, mass flow rate, and density. Natural or Free convection is very important heat transfer mechanism that is operative in a variety of environments from cooling electronic circuit boards in computers to causing large scale circulation in the atmosphere as well as in lakes and oceans that influences the weather².

Natural convection is caused by the action of density variations in conjunction with a gravitational field. There are two cases in the context of natural convection as shown in Figure (1). Fluid is located between cold and hot surfaces; the location of hot and cold surface shows the gradient of temperature and system stability³. In the first case the fluid is located in the middle, the hot surface is located above the fluid and the cold surface down this case shows stable system and increasing in temperature

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gradient. The second case shows that the fluid is located in the middle, the cold surface is located above the fluid and the cold surface above this case shows unstable system and increasing in temperature gradient.



Figure 1: Natural convection behaviour, A- stable case, B- unstable case.

The thermal region around the surface is called thermal boundary layer; it shows the relation between fluid temperature and distance from the surface. **Figure (2)** shows thermal boundary layer for different cases.



Figure 2: Thermal boundary layer for different cases. A- Vertical plate, B- Hot pipe, and C- Horizontal plate.

THEORTICAL UNDERPINNING

Natural convection in closed region has many engineering applications like electronics; the concept of heat transfer in closed region like cooling of electronics or processors depends on the natural convection conditions. Rectangular cavity was studied numerically⁴ for natural convection, the cavity was heated on one side and cooled on the opposite side, the heat transfer and Rayleigh number of the cavity was studied based on different aspect ratios, CFD was used to simulate the case. Natural

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convection in two-dimensional rectangular enclosure was studied numerically using a finite element method⁵, the studied case was rectangular cavity with the following constraints, the top wall was considered adiabatic, two vertical walls were maintained at constant low temperature, the bottom wall was maintained at constant high temperature and the non-heated parts of the bottom wall were considered adiabatic, the study was created to demonstrate the capabilities of this numerical methodology for handling such Problems, during study Grashof number were varied from 1000 to 1000,000 and Prandtl number was taken as 0.71.⁶A numerical program is used to simulate the natural convection in a rectangular cavity affected by a magnetic field, the cavity was filled with mercury with a Prandtl number equal to 0.024, and flow was induced by a vertical temperature gradient. The governing equations were mass, momentum and energy, adopting the Boussinesq approximation, was solved numerically using the finite-volume method in conjunction with the SIMPLER algorithm the flow under consideration wassteady, laminar and two-dimensional. The temperature gradients were assumed to be weak. The results showed that the dynamic and temperature fields were strongly affected by variations of the magnetic field intensity and the angle of inclination. Numerical simulations were carried out considering different combinations of Grashof and Hartmann numbersto show their effects on the streamlines, the isotherms and the Nusselt number.Natural convection heat transfer with two-dimensional in a rectangular enclosure was studied numerically⁷, the model was an enclosure object with heated left side wall, while the right side was cold, the top and bottom walls was adiabatic. The theoretical study involved the numerical solution of the Navier-Stokes and energy equations by using finite difference method. The stream function formula was used in the mathematical model, the numerical solution was capable of calculating the velocity, stream function, and vortices and temperature fields of the computational domain. A FORTRAN 90computer program was used to carry out the numerical solution. Problem has been analysed and the non-dimensional governing equations are solved using finite difference method. Enclosure was assumed to be filled with an air with a Prandtl number of 0.71. The problem is analysed for different values of the Rayleigh number in the range from 1000 to 100000, aspect ratio parameter (AR: 1, 3, and 5). It was found that for small Reynolds number (Ra), the heat transfer was dominated by conduction and begins to be dominated by convection with increasing Ra, and the Nusselt number Nu decreases with increasing AR due to decreasing the volume of the enclosure. In order to validate the numerical model, the results of variation local Nusselt number and a relation between average Nusselt number and Ra number⁸. The Computational Predictability of natural Convection Flows in Enclosures is studied based on deferentially heated cavity with Ra= $3:4 \times 10^5$ and Pr=0:71, ADINA system was used to simulate the case, 9-node quadrilateral element in ADINA was used with various meshes. Periodic solutions witha period of 3.42–3.43 were obtained. The simulation results were the boundary layers, vortices, etc. A rectangular enclosure bounded with solid wall was tested⁹, the obtained result was the temperature profile in the closed enclosure, the studied parameters were solar sky radiation and environmental convection heat transfer, internal conduction heat transfer, and internal wall radiation. The collected data from experiment had been collected every 5 minutes 24 hours a day for 1 week. The square enclosure filled with a water-Al₂O₃nan fluid and subjected to a magnetic field is examined¹⁰, the cavity side walls had spatially varying sinusoidal temperature distributions and the horizontalwalls were adiabatic, mathematical model was done based on Boltzmann method (LBM) and thegoverning equations were solved for fluid velocity and temperature, the simulation parameters were Rayleigh number of the base fluid, from Ra=10³ to 10⁶, Hartmann number from Ha=0 to 90, phase deviation (g=0, p/4, p/2, 3p/4 and p) and solid volume fraction of the nanoparticles between f=0 and 6%. There sults showed that the heat transfer rate increased with an increasing in the Rayleighnumber but it decreased with an increase in the Hartmann number. Natural convection of a single circuit board in asealed electronic equipment enclosure is modelled¹¹ in this study, the circuit card was modeled as a

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vertical isothermalplate located at the center of an isothermalcuboid shaped enclosure, a compositemodel was developed based on asymptotic solutions, the simulation was designed for three cases: pure conduction, laminar boundary layer convection, and transition flow convection. Steady laminar natural convection heat transfer in 3-D horizontal narrow rectangular enclosure, with heated finnedbase plate was studied numerically¹² using FLUENT 6.3, the variableparameters were fin andfin height (L/H=0.25-0.75). spacing (S/H=0.875-1.75) Heaterwas located in the enclosurebottomwall and the opposite top wall was cooled while the other wallsof the enclosure were assumed to be adiabatic. 3-D steady statecontinuity, Navier-Stokes and energy equations using Boussinesq approximation are solved, Rayleigh number range Was 10^4 to $3x10^5$, the study showed the effect of fin height and fin spacing on the fin effectiveness and heattransfer in enclosure.

EXPERIMENTAL SETUP

Wooden insulated box 60x47.5x20cm is used for the rectangular cavity as shown in **figure (3)**, the box and its cover are made from wood because wood is good insulation material.



Figure 3: Rectangular Cavity

double heaters each one has 54.4Ω resistance are used to heat the cavity, they connected together by using wood frame shown in **figure** (4), each heater has separate switch.



Figure 4: Electrical heater and its frame (all dimensions in cm).

Thermocouples are fixed inside the box using another wooden frame, the frame has three legs each one on 15 cm apart, each leg hold four thermocouples 5cm apart, so there are 12 thermocouples in the box, **figure (5)** shows a cross section in the box.



Figure 5: Thermocouples arrangements inside the box (dimensions in cm).

RESULTS AND DISCUSSION

The experimental results are plotted to show temperature distribution inside the rectangular cavity for open and closed top cases. The temperature is measured continuously using data collection system attached to twelve thermocouples.

The heater surface temperature is 150C°, heater has two locations horizontal and vertical, and for horizontal heater position all temperature measuring points are located above the heater while in vertical heater position the measuring points are located on the heater opposite wall. Cover is also used as parameter, open cavity without cover and closed cavity with cover. **Figure (6)** shows temperature profile inside the cavity for closed cavity case and different heater locations, the horizontal heater has higher effect in the cavity than vertical heater this effect is shown by the temperature gap between curves with time.





Cover effect is shown in **figure** (7), the temperature was increased in closed cavity case (with cover) so convection heat transfer coefficient in closed cavity is higher than open cavity case.



Figure 7: Temperature profile with and without cover.

For horizontal heater case Nusselt number is found based on Rayleigh number for three positions above the heater, the selected position were attached to thermocouples, they locations above the heater surface are 2,6, and 10cm. the relation between Nu and Ra is shown in **figure (8)**.

For horizontal heater Rayleigh number is plotted with air temperature [T] for three positions above the heater, the selected position were attached to thermocouples, they locations above the heater surface are 2,6, and 10cm. the relation between Nu and Ra is shown in **figure (9)**, the plot shows that Rayleigh number is increased with distance above the heater is increased.







Figure 9: Rayleigh number [Ra] vs. Air temperature [T] for horizontal heater case.

CONCLUSIONS

Natural convection in closed cavity is important case for many engineering applications; the study of free or natural convection in closed cavity depends on cavity shape, heater orientation, and fluid parameters.

In this study arectangular cavity is tested for horizontal and vertical heater arrangements, experimental results show the temperature profile for many points located at 2, 6, 10, and 14cm above the heater, based on experimental data Rayleigh number is plotted with temperature for the selected positions.

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