Numerical Investigation of Forced Convection Heat Transfer with Heat Source inside an Enclosure

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ABSTRACT

For the purpose of analysis of several electronic package, cooling systems are essential to remove the waste heat. The components inside the package should be maintained at a permissible operating limit to prevent malfunctioning of system or even it leads to permanent failure. Different methods are available for effective cooling. Among these forced convection heat transfer is the most common and effective. In this work forced convection heat transfer inside a ventilated enclosure is numerically investigated. A discrete heat source is mounted on one of the vertical walls and vents are provided at the top and bottom. Our aim is to obtain an optimum correlation for Nu as a function of Re and AR(L/H) of the enclosure. 2D model for numerical simulation is considered. The work is being initiated at a Re of laminar range and aspect ratio between 1 and 2. It is found that increase in aspect ratio increases the Nu number, i.e. heat transfer rate is increased as the aspect ratio is increased. Therefore designing a better model, it is inevitable to design the model for higher Re number and higher aspect ratio. Radiation is also considered. The radiation parameter under consideration is optical thickness. It is found that increase in optical thickness reduces the value of Nu number, which means heat transfer rate is decreased as the value of optical thickness is increased. So a final correlation for Nu is derived as a function of Re, AR and OT.

Keywords- Re-Reynolds number, Nu-Nusselt number, AR-Aspect Ratio, OT-Optical Thickness.

1. INTRODUCTION

As electronic and power components are designed into denser, smaller packages, it becomes increasingly important to consider how well the equipment dissipates heat. These components has specific operating temperature ranges, when put inside cabinets and enclosures, as temperature can become a big issue. Excessive waste heat generated by equipment within a cabinet is one of the most important factor affecting equipment performance, reliability and failure. Cooling should be considered early in the design process. Having an effective cooling strategy can help in adequately dealing with heat dissipation. Different methods are available for effective cooling of these components. Vapour

compression refrigeration based systems, liquid cooling systems, heat pipes, thermoelectric cooling, fin with natural and forced heat convection etc are some examples. Each system has their own advantages and disadvantages. Among these, methods utilizing fins with natural and forced convection heat transfer are most common. Even though currently available cooling systems are easy to construct and economical, each of them have their own disadvantages and advantages. Low-power electronic systems are commonly cooled by natural convection and radiation. Where natural convection is inadequate, forced convection via fans and blowers can be used. The main difference between fans and blowers is in their flow and pressure characteristics. Fans provide airflow parallel to the fan blade axis and can deliver high

airflow rates. However, they are suitable for low to moderate backpressure only where there is little resistance to airflow by equipment inside the cabinet. Blowers normally deliver air in a direction perpendicular to the blower axis. They are suitable for moderate to high airflow against high backpressure. A combination of a blower and an exhaust fan sometimes works best in densely packed cabinets.

Forced convection within a lid-driven sealed cavity and buoyancy-driven convection within differentially heated cavities have provided excellent opportunities for researchers. Forced convection heat transfer inside an enclosure with inlet vents and exit vents placed parallel on the same wall is studied numerically. From the heat transfer point of view, the vents should be as large as possible to minimize the flow resistance and should be located at the bottom of the case for air entering and at the top for air leaving. But equipment and human safety requirements indicate that the vents should be quite narrow to discourage unintended entry into the box.

2 PROPOSED WORK

Fig. 1 Schematic of the proposed work

In this work forced convection heat transfer inside a vertical vented enclosure is numerically investigated. A discrete heat source is mounted on one of the vertical wall and vents are provided at the top and bottom of the same wall. The aim is to observe the variation of various parameters involved in the heat transfer problem and to obtain a correlation for

Nusselt number as a function of Reynolds Number (Re) and aspect ratio (AR), defined as the ratio of width of enclosure to the length of the heater (L/H_s) in the enclosure. The numerical simulations are conducted using a commercial CFD package ANSYS FLUENT. For the present study, a two dimensional model is considered. The geometry constitutes a rectangular enclosure having length L and width H . A discrete heat source is mounted on the inner vertical wall and the opposite wall is kept isothermal. The remaining walls are considered adiabatic. The simulations are conducted for Re ranging from 1×10^5 to 5×10^5 and AR varying between 1.0 and 2.0. Finite volume method is used for solving the problem. Radiation effects are also observed for an optical thickness ranges from 0 to 100. Discrete transfer method (DTRM) is used to solve the radiation model. Effect of radiation on the convection problem is observed. Also a correlation for Nusselt number as a function of Reynolds number (Re), aspect ratio (AR) and optical thickness (OT) is derived

3 LITERATURE REVIEW

A lot of scientists have did some works in this field and obtained their valuable conclusion. Here are some related works performed from different parts of the world. S.M.Saeidi conducted a study on "Forced Convection in a square cavity with inlet and outlet ports". A finite-volume-based computational study of steady laminar forced convection inside a square cavity with inlet and outlet ports is done. For design purposes, inlet and outlet ports should be parallel to each other in order to minimize pressure drop, even if they are designed to be placed on the same wall. For high Re and with the shortest distance between the inlet and outlet ports along the top wall, a primary CW rotating vortex that covers about 75–88% of the cavity is observed. The temperature fields are directly related to the presence of multiple vortices in the cavity. Suman Saha conducted a study on 'Combined free and forced convection inside a two-dimensional multiple vented rectangular enclosure'. A uniform heat source on the bottom of a horizontal

rectangular enclosure with side openings is studied numerically. The inlet opening allows an externally induced air stream at the ambient temperature to flow through the cavity and exits from another two openings placed top of the both side walls. Two-dimensional forms of Navier-Stokes equations are solved by using control volume based finite element technique. Three typical values of the Reynolds numbers, based on the enclosure height, are chosen as $Re = 50, 100$ and 200 , and steady, laminar results are obtained in the range of Richardson number as $0 \leq Ri \leq 10$ and a fixed Prandtl number of 0.71 . The numerical solution indicates that the increasing value of Re and Gr leads to higher heat transfer coefficient, higher heat source temperature, and higher intensity of recirculation. Mayor.T.Bhoite and M.V.Krishna Murthy had studied "Mixed convection in a shallow enclosure with a series of heat generating components". The important parameter they taken under consideration were Archimedes number (Gr/Re^2) to find which convection is dominating. This study was conducted to obtain the velocity and temperature field inside the enclosure to find whether the heat source works within the safe limit. Zero global pressure drop assumption is taken for realistic situations in natural convection. They used power law scheme for approximating combined diffusive and convective flux in fluid energy equation. Pressure and velocity coupling is handled by using implicit version of SMAC (Simplified Marker And Cell). It found out that block surface temperature decrease with Reynolds's number for a " Gr " less than or equal to 5×10^5 . Laith Jaafer Habeeb studied "Free and Forced Convection Heat Transfer Characteristics in an Opened Box with Parallel Heated Plates". The experiments include a study of the effect of forced and free convection heat transfer and the effect of the position of the two parallel heated plates in an enclosure. This experimental work represents the study of heat transfer characteristics by forced convection for the exit air from the top circular hole for Reynolds number range at all power range. The results show that the average Nusselt number increases with increase of the power. The maximum

temperature is noticed to be in between the heaters for both horizontal and vertical conditions and for the two cases. Therefore it is required a good location when choosing the fan location and the configuration of its exit. And also the average Nusselt number is begins to increase with the increase of air velocity until ($V=2.6$ m/s) and then the average Nusselt number value decreases. Norma Alejandra investigated on "Numerical Study of Heat Transfer by Free and Forced Convection in a Ventilated Cavity,". The heat transfer by free and forced convection in a ventilated cavity was studied. The cavity is used to model a room, where a wall in receiving a uniform heat flux (like the one supplied by sun). In order to obtain the numerical results, the CFD's software Fluent 6.3 was used. When the inlet velocity increases the temperature values reduce and for $U_{inlet} = 0.5$ m/s a thermal stratification in the top of cavity is formed. The Nusselt number on the heated wall increases with the Rayleigh and Reynolds numbers. G.Lauriat and G.Desrayaud studied the "Effect of surface radiation on conjugate natural convection in partially open enclosure". They focused on the conjugate problem of natural convection and wall conduction for various thermal resistances of cold wall. Radiation exchanges are also considered and its effect on decreasing the temperature of hot wall. It is investigated that, the temperature outside the wall increases when surface radiation is accounted while average temperature between the vertical walls decreases. Radiative contributions of heat transfer along facing surfaces are dominant in all cases they are considered

4 RESULTS AND DISCUSSIONS

Forced Convection heat transfer is considered as one of the main methods of useful heat transfer as significant amounts of heat energy can be transported very efficiently. Convection heat transfer is complicated since it involves fluid motion as well as heat conduction. The fluid motion enhances heat transfer (the higher the velocity the higher the heat transfer rate).

4.1 Forced Convection Heat Transfer

The velocity, non-dimensional temperature as well as Nusselt number varies with aspect ratios as well as Reynolds number. A total of 30 cases are studied for the variation of various parameters. Velocity and non-dimensional temperature variations are observed along the mid plane of the enclosure and Nusselt number variation is observed along the length of the heater. Temperature is non-dimensionalised by a factor $(T-T_a) / (qH/k)$.

Fig. 2 Plots of velocity along the mid plane of the enclosure for various AR .

The plot showing the mid plane velocity along the enclosure width. It is found that velocity of fluid is increasing with increase in Reynolds number as well as increase in aspect ratio. Higher velocity is observed near heater location, then velocity is decreasing to a minimum of zero and then again the velocity is increasing with maximum velocity at the opposite end.

Fig. 3: Non dimensional temperature profiles at the mid plane of the enclosure for various Reynolds number and same aspect ratio (AR=1.8).

From the plot it is evident that maximum non dimensional temperature is occurred at minimum Reynolds number and minimum aspect ratio. As Re number as well as aspect ratio increases, heat transfer rate is increased and net temperature inside the enclosure will be minimized. It is found that maximum temperature is found to be at the heater position and as along the enclosure width, temperature is decreasing.

After the numerical simulation of all the 30 cases, a table is generated includes all the Reynolds numbers, aspect ratios and Nusselt numbers over the heater as shown in Appendix, a correlation is generated for Nu as a function of Re number and aspect ratio (AR) with the help of a correlation generating software AXUM-5.0

$$Nu = 175.32 Re^{0.21} AR^{0.8}$$

The above correlation is capable of finding out the average Nu number inside a vertical vented enclosure where Re number ranges from 1×10^5 to 5×10^5 and AR ranges from 1.0 to 2.0.

4.2 Forced Convection Heat Transfer With Radiation

While considering a convection heat transfer problem, radiation effects cannot be neglected. So along with the convection heat transfer, radiation effects are also studied for various optical thicknesses (OT). A total of 150 cases are performed for finding out a correlation for Nu number as a function Reynolds number, aspect ratio (AR) and optical thickness (OT). Radiation effects are studied for an optical thickness value ranging from 0 to 100. Discrete Transfer method (DTRM) for solving the radiation problem. All the parameters are selected for atmospheric conditions.

Fig. 4 Velocity plot along the mid plane for same Aspect ratio (AR=1) and different Reynolds number

It is clear that as in the before case, maximum velocity is achieved for minimum aspect ratio and maximum Re number. Here also high velocity is achieved near the location of heater and decreases to zero and then increases to maximum velocity at the other end.

Fig. 5 Velocity profiles inside the enclosure for a $Re = 1 \times 10^5$ and $AR = 1.0$ with optical thickness vary 0 to 100 respectively.

Fig. 6 Temperature profiles inside the enclosure for a $Re = 1 \times 10^5$ and $AR = 1.0$ with optical thickness vary 0 to 100 respectively

After performing a total of 150 cases includes Re number ranging from 10^5 to 5×10^5 , AR ranges from 1.0 to 2.0 and OT ranges from 0 to 100, a correlation is derived for Nu number as a function of Ra number, AR and OT by means of a correlation generating software AXUM-5.0. A table is prepared for tabulating the values of Nu number obtained from all the 130 cases against Re number, AR and OT shown in Appendix.

$$Nu = 432 Re^{0.16} OT^{-0.0023} AR^{0.53}$$

From the above correlation average Nusselt number of a vertical vented enclosure can be calculated, where its Re ranges from 1×10^5 to 5×10^5 , OT ranges from 0 to 100 and AR ranges from 1.0 to 2.0.

5 CONCLUSIONS

In the present work, variation of various heat transfer parameters is observed. In the forced convection heat transfer problem, it is found that increase in Re increases heat transfer rate, thereby net heat content inside the enclosure will be minimum. Also it is found that increase in aspect ratio increases the Nu number, i.e. heat transfer rate is increased as the aspect ratio is increased. Therefore designing a better model, it is inevitable to design the model for higher Re number and higher aspect ratio. A correlation for average Nusselt number inside the enclosure is obtained. For the effective usage of velocity, partitioned heat sources can be placed at either ends of the mid plane as velocity reaches maximum at both the ends. Effect of radiation also studied in this natural convection heat transfer problem. Optical thickness is the radiation parameter considered for study. It is found that increase in optical thickness reduces the value of Nu number, which means heat transfer rate is decreased as the value of optical thickness is increased. But radiation is not predominant from the results as the heat transfer rate is negligible by the change in optical thickness. So for a better model, it is better to design the model for maximum Re number, maximum aspect ratio and minimum optical thickness. A correlation is also derived for Nu as a function of Re, AR and OT.

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