Experimental Thermal and Fluid Science 68 (2015) 402–411

Contents lists available at ScienceDirect

Experimental Thermal and Fluid Science

journal homepage: www.elsevier.com/locate/etfs

Experimental investigation of mixed convection in multiple ventilated enclosure with discrete heat sources

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ARTICLE INFO

Article history:
Received 4 October 2014
Received in revised form 28 May 2015
Accepted 30 May 2015
Available online 12 June 2015

Keywords:
Experimental
Mixed convection
Multiple ventilated enclosure
Discrete heat sources
Electronics cooling

ABSTRACT

Mixed convection heat transfer in multiple ventilated enclosure with three numbers of discrete heat sources at bottom is investigated experimentally. Each of the three heat sources has been flush mounted at the enclosure bottom and subjected to uniform heat flux. All the walls of enclosure are insulated adequately and the enclosure can be considered as adiabatic. The enclosure is having inlet at bottom of left side wall and outlet at both the left and right sides of the roof of enclosure. The flow velocity and applied heat flux are varied. The experimental investigations were executed for AR (L/H) = 1, range of Reynolds number and Grashof number considered are $270 \leqslant Re \leqslant 6274$ and $7.2 \times 10^6 \leqslant Gr \leqslant 5.5 \times 10^7$ and as a consequence, the Richardson number obtained in the range 0.201–571. The experimental results stipulate that the heater nearest to enclosure inlet (heater-1) subjected lowest surface temperatures at all Reynolds numbers while the surface temperatures of heater-2 and heater-3 are almost same until Grashof number attains a critical value. Different correlations are proposed for Nusselt number within the range of parameters considered in the study.

1. Introduction

The analysis of heat transfer in the free, forced and mixed convection flow for enclosures and channels constitutes a very important problem in the field of heat transfer and has received substantial engrossment. The prediction of heat transfer for such equipments covers a wide range of technical applications, such as the cooling problems in electronic devices, food processing, turbine blades, silencers and among others. The combination of forced and buoyancy driven flow can impart complexity in flow phenomena and a careful study of the same is essential. Several researchers have done substantial work in this field both numerically and experimentally.

Hsu and Wang [1] performed a numerical study on mixed convection in a rectangular enclosure with discrete heat sources. The cooling medium considered was air and two openings were made on the opposite vertical walls of the enclosure to allow for flow of air. The heat source was embedded on a board in vertical orientation on different sides and it was investigated that when the heat source is on the right surface of the board, the value of Nu_{conv} is independent of the variation of both the locations of the heat source on the board and the location of board while on the contrary, the left side placement of heat source affects strongly Nu_{conv} for the variation of the two elements locations. Radhakrishnan et al. [2] presented both experimental and numerical investigation of mixed convection in a ventilated cavity by considering two different size heaters at different positions. The outcome of their study revealed that position of heater in the parallelepiped affects its cooling greatly and the right side of the enclosure is the optimum place where 10–50% reduction in temperatures was observed. The heater orientation was also referred and it was deduced that inclining the heaters lower the heat transfer rates in comparison to the horizontal orientation. Bilgen and Muftuoglu [3] numerically observed that the optimum position of eccentrically placed discrete heat source in a square enclosure with ventilation ports is not depending on ventilation ports arrangement and the value of Nusselt number decreases and increases with Richardson number at its low and high values respectively. Zhao et al. [4] developed an algorithm which is capable of predicting the heat flux values from the temperatures measured experimentally for problems involving direct and inverse mixed convection in slot-ventilated enclosures and also revealed that for the laminar region of $50 \leqslant Re \leqslant 500$ and the Richardson number range of 0.0–6.0, heat transfer characteristics are less affected by the heat flux profiles. Venkatachalapathy and

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http://dx.doi.org/10.1016/j.expthermflusci.2015.05.012
0894-1777/

Nomenclature

A_s	heat source surface area (m^2)
AR	aspect ratio
D	enclosure depth (m or mm)
Fo	Fourier number
g	gravitational acceleration (m/s^2)
Gr	Grashof number
$Gr_{critical}$	Critical Grashof number
h	convective heat transfer coefficient (W/m^2 K)
h_{savg}	local heat transfer coefficient at the surface of the heat source (W/m^2 K)
H	enclosure height (m or mm)
k	thermal conductivity (W/m K)
L	width of enclosure (m or mm)
l	characteristic length (m)
Nu	Nusselt number
Pr	Prandtl number
q	heat flux (W/m^2)
Q_r	radiation heat (W)
Ra	Rayleigh number
Re	Reynolds number
T	temperature (°C or °K)
T_{in}	inlet temperature (°C or °K)
T_{bavg}	average bulk fluid temperature (°C or °K)
T_{savg}	average heater surface temperature (°C or °K)
v_{in}	fluid average velocity at enclosure inlet (m/s)

Greek symbols

β	thermal expansion coefficient (K^{-1})
σ	Stefan–Boltzmann constant (W/m^2 K^4)
Δ	increment
μ	dynamic viscosity (kg/m s)
ν	kinematics viscosity of fluid (m^2/s)
ρ	fluid density (kg/m^3)
ε	heater surface emissivity

Subscripts

Air	–
b	bulk fluid quantity
Critical	critical quantity
in	inlet
ref	reference quantity
r	radiation
s	surface quantity

Udayakumar [5] investigated experimentally and numerically the heat transfer from a 5 × 4 array of protruding heat sources in the bottom wall of an adiabatic enclosure with fixed inlet and different outlet conditions for Reynolds number values of 900, 1800 and 3600 and shown that the first row of array is the coolest for all outlets and flow velocities and for the lower Reynolds numbers the first and last rows are the coolest in comparison to others. They also concluded that the opposite outlet configuration gives better heat transfer results. Abhinav et al. [6] computationally studied effect of vent locations on natural convection in enclosures with partial openings having an internal heat source. They considered an enclosure of different aspect ratios (H/W = 1, 2 and 3) and lower Rayleigh numbers ($Ra_h = 10^3$, 10^4 and 10^5) with four different configurations based on the number and position of vents - same side (SS), diagonal side (DS), one inlet two outlets and two inlets one outlet and found that the two inlets one outlet configuration yielded better heat transfer rates of the four considered and the mass flow rates and Nu increased with increase in Ra_h and decrease in the aspect ratio.

The aforementioned studies disclose that despite a reasonable work performed in the field of mixed convection in enclosures both experimentally and numerically, ample apertures are still unexplored. One of its kind is experimental analysis of the enclosures with discrete heat sources and with multiple ventilation ports. However, apart from the enclosures, a lot of work has been performed on different other geometries and most popular among those are horizontal and vertical channels. Apart from channels flow, attention was also given at some non regular fields like triangular cylinder, variety of open cavities flow, channels with open cavity, etc. as mentioned beneath.

Bhoite et al. [7] considered a shallow enclosure with block-like heat generating components and inlet and outlet openings, executed a computational study of laminar mixed convection and found that higher Reynolds numbers tend to create a recirculation region of increasing strength at the core region and the effect of buoyancy becomes insignificant beyond a Reynolds number of typically 600. Aminossadati and Ghasemi [8] contemplated the case of horizontal channel with a discrete heat source in an open cavity and investigated numerically the mixed convection and the results showed that when the heat source is located on the right wall, the cavity with an aspect ratio of two has the highest heat transfer rate and when the heat source is located on the bottom wall, the flow field in the cavity with an aspect ratio of two experiences a fluctuating behaviour for Richardson number of 10. Their results also showed that at a fixed value of Richardson number, all three different heating modes show noticeable improvements in the heat transfer mechanism as the cavity aspect ratio increases. Hassab et al. [9] experimentally investigated the laminar mixed convection heat transfer from an isothermal horizontal triangular cylinder. They investigated equilateral triangular cylinders in the study with side length of 37, 50 and 70 mm respectively and the mixed convection experiments were established for Grashof numbers ranging from 26.32×10^4 to 213.46×10^4, Reynolds number ranging from 75.3 to 1251.6, and the attack angles from 0° to 180° and proposed that by increasing triangular side length, the average Nusselt number increases at the same Reynolds and Richardson number and for the same Reynolds number, as the attack angle of the air flow increases the Nusselt number decreases.

Substantial studies were executed for flows inside channels both experimentally and numerically and various heat transfer strategies were proposed by distinguished researchers. Mentioned below are a few of those.

Elpidorou et al. [10] studied numerically convection in a vertical channel with a finite wall heat source and observed that the strength and extent of the convective cell depend strongly on Grashof and Reynolds numbers and show the possibility of flow entrainment at the exit end if the channel is short. Ozsunar et al. [11] investigated numerically that the onset of instability move upstream for increasing Grashof number and it is delayed for increasing Reynolds number and increasing inclination angle in rectangular channels for range of inclination angles $0° \leqslant \theta \leqslant 90°$, Reynolds numbers $50 \leqslant Re \leqslant 1000$ and modified Grashof numbers $7 \times 10^5 \leqslant Gr \leqslant 4.0 \times 10^6$. Bhowmik and Tou [12] performed the experimental study of transient natural convection heat transfer from simulated electronic chips for the heat flux ranges from 1 kW/m^2 to 6 kW/m^2 and their results indicate that Nusselt number improves with increase in Peclet number and the heat transfer coefficient is affected strongly by the number of chips. They