International Communications in Heat and Mass Transfer 56 (2014) 121–132

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

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

Buoyancy enhanced natural convection inside the ventilated square enclosure with a partition and an overhanging transverse baffle ☆

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ARTICLE INFO

Available online 14 June 2014

Keywords:
Natural convection
Protrusion
Nusselt number
Velocity

ABSTRACT

Finite difference based numerical studies of steady laminar natural convection inside the open square enclosure with protrusions are presented. The fluid considered is air with a Prandtl number of 0.71. The buoyancy enabled cold air flows from bottom-left vertical wall to the diagonally opposite top-right vertical wall crossing the obstacles in the form of a partition and transverse baffles. All the external peripheral walls are considered as hot and the interior cross walls are assumed as cold. The effect of obstacles on the heat transfer is numerically investigated. The convective heat transfer mechanism is enhanced further through the Rayleigh number by varying Ra as 10^3, 10^4 and 10^5. The subtle variation in buoyancy, momentum, hydrodynamic blockage and protrusions influences the formation, size and geometry of the vortices and also influences the heat transfer intensities inside the enclosure. The intriguing physics is elucidated with streamlines, isotherms, Local Nusselt number and velocity profiles. The study reveals that the introduction of cold baffle intensifies the heat transfer inside the enclosure irrespective of its position and length. The hydrodynamic blockage effect is dominant when the transverse baffle is positioned on the right side of the partition.

1. Introduction

Natural convection inside the enclosure has been the attraction for many researches in the past. The applications include crystal growth in fluids, nuclear reactor, cooling of micro-processors and energy conservation. Natural convection is the most economical mode of convection when comparing with other modes of convection. The heat transfer intensities inside the enclosure have been modified either by considering difference in temperature among the walls [1] or by constructing the obstacles. The obstacles have been considered either in the form of blocks [2] or by fins [3] or by partition walls [4]. The protrusions were oriented either horizontally or vertically or angularly. The enclosures were considered as closed one [5] or as ventilated [6]. Some authors have studied the effect of aspect ratios of the cavity [7]. Also the type of investigation was numerical or experimental [8] or a combination of both [9]. Even though the natural convective heat transfer is considered as economical, the physics behind the natural convection is complex in nature. The prime reason is the coupling of flow and thermal parameters. Due to the coupling of the vorticity and energy equations, the convection pace is very slow and consumes more computational time. One of the simple ways to alter the flow physics and heat transfer intensity is the construction of obstacles.

Ahmet Koca et al. [10] studied the natural convection with partition of varying width and concluded that thickness is important for high value of Ra. Bennet and Hsueh [11] presented the benchmark solutions and concluded that local Nusselt number is identical for both 2-dimensional and 3-dimensional analyses when $Ra \leq 10^5$. Cianfrini et al. [12] found that the heat transfer rate decreases when aspect ratio of cavity increases. Alam et al. [13] highlighted that the heat transfer was maximum when the aspect ratio is one with $Pr = 100$ and $Ra = 10^3$ to 10^6. Arefmanesh et al. [14] performed the study on the square cavity containing air with baffle and indicated that the heat transfer contribution by the baffle was higher than the hot wall itself. Recently, Aklouche Benouague et al. [15] made a research on the effect of Rayleigh number on transient laminar natural convection and concluded that when $Ra \geq 5 \times 10^5$, the flow becomes fully chaotic. Kandaswamy et al. [16] studied the effect of baffle-cavity ratios on convection with orthogonal heated baffles and highlighted that increasing the height of vertical wall increases

☆ Communicated by W.J. Minkowycz

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http://dx.doi.org/10.1016/j.icheatmasstransfer.2014.06.007
0735-1933/

Nomenclature

L	Length of enclosure in m
H	Height of enclosure in m
CW	Clock wise direction
CCW	Counter clock wise direction
L_b	Percentage length of horizontal baffle

Greek symbols

ω	Dimensionless vorticity
ψ	Dimensionless stream function
θ	Dimensionless temperature $= \frac{(T-T_{in})}{(T_w-T_{in})}$

the heat transfer irrespective of its location. The horizontal baffle has great impact if placed below the center of the cavity.

Bilgen and Balkaya [17] investigated the heat transfer inside the ventilated cavity with discrete heaters on the vertical wall and reported that convection is predominant when Ra > 10^3. Xaman et al. [18] performed the turbulent model study with single inlet and different positions of outlet and recommended to construct the outlet at top-right of vertical wall. Eliton Fontana et al. [19] performed a 3-dimensional analysis with a single vent on the right wall for a range of Pr number and concluded that Nusselt number on the cold wall may be neglected.

Literature study reveals that buoyancy assisted natural convection inside the square enclosure has a great potential in industrial and day to day applications. The specific applications include modeling solar collectors, cooling of electronic chips [20] and lofts inside the building. The mid-vertical partition obstructs the through flow and improves the heat transfer on the left side of the enclosure. The mid-opening on the vertical partition reduces the momentum, diverts the flow, and creates the flow separation and re-circulation which subsequently alters the vortices' formation. The transverse baffle increases the hydrodynamic blockage and modifies the flow physics. When the inlet port is located at the bottom and the outlet port is fixed diagonally on opposite wall, the buoyancy force accelerates the fluid towards the exit port [20]. Also, such geometry enables the longest travel distance for the fluid. The combined effect of horizontal baffle and vertical partition on the complex physics related with heat transfer and ventilation is the focus of the current study.

2. Problem formulations

The schematic diagrams of the present study illustrating the protrusion with co-ordinates system are shown in Fig. 1. In this study, square enclosure with aspect ratio of 1 is considered. The depth of the enclosure perpendicular to the plane of the diagram is assumed as too long and hence the problem can be assumed as two-dimensional [14]. All the peripheral walls are assumed as hot with a dimensionless temperature of 1 like Saeidi and Khodadadi [21]. All the interior walls are considered thin and cold with a dimensionless temperature of zero. The width of the partition wall and baffle is equal to 4% of the width of the enclosure. A vertical opening of 30% of the height of the enclosure is provided at the mid-height of the partition. To acquire maximum heat transfer, the inlet is located at the bottom of the left vertical wall and outlet port is provided at the top of the right vertical wall as indicated by Suman Saha et al. [22] and present authors [23]. The cold air with a dimensionless temperature $\theta = 0$ enters the enclosure through the inlet port with a horizontal velocity component of unity. During the flow, the fluid crosses the protrusions in the form of vertical partial partition and horizontal baffle. The orientation of the baffle is shifted from left to right and then placed combined together. To modify the flow physics, the length of the transverse baffle is varied as 10%, 20% and 30% of the length of the enclosure. The chosen fluid is air with Pr = 0.71. The buoyancy is enhanced further by increasing the Rayleigh number from 10^3 to 10^5 similar to Da Silva and Gosselin [24] and Eliton Fontana et al. [19]. The corresponding values of Re are 38, 119 and 375 respectively. Numerical simulation has been performed with different positions and lengths of baffle along with a range of Rayleigh number.

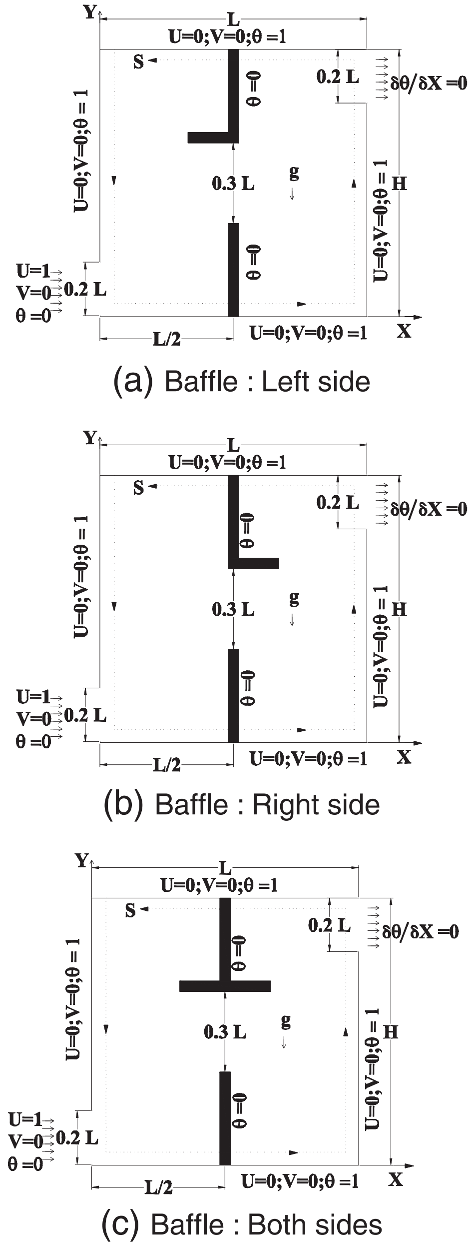

Fig. 1. Schematic diagram illustrating the boundary conditions and co-ordinate system.

2.1. Governing equations

Dimensionless form of the governing equations is obtained by using dimensionless variables. These are defined as follows:

$$u = \bar{u}\,L/\alpha;\ v = \bar{v}L/\alpha;\ \theta = \frac{(T-T_{in})}{(T_w-T_{in})}.$$

The governing equations for the problem are the continuity, momentum and energy equations. The advantage of the stream