International Journal of Heat and Mass Transfer 124 (2018) 860–875

Contents lists available at ScienceDirect

International Journal of Heat and Mass Transfer

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

Mixed convection characteristic in a lid-driven cavity containing heated triangular block: Effect of location and size of block

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ARTICLE INFO

Article history:
Received 6 February 2018
Received in revised form 21 March 2018
Accepted 23 March 2018

Keywords:
Mixed convection
Triangular block
Lid-driven cavity
Richardson number
Nusselt number
Reynolds number
Finite volume method

ABSTRACT

The present work examines the influence of location of the heated triangular block along the vertical centerline of cavity on mixed convection characteristics. The flow is assumed to be 2D, steady, laminar and for incompressible and Newtonian. The physical domain of study is top lid-driven square cavity. The top and bottom walls of cavity are thermally insulated; while the both vertical walls are exposed to ambient (T_c). The cavity contains equilateral triangular block (size of edge, b), maintained at isothermal temperature condition ($T_H(> T_c)$) along its geometric horizontal centerline. The change in the position of block is permitted along the vertical centerline ($x = 0.5, y$) of cavity. Flow pertaining equations are solved by using finite volume method (FVM) and *SIMPLE* algorithm. The dependence of various relevant dimensionless parameter, such as, Reynolds number ($Re = 1$—1000), Richardson number ($Ri = 0.01, 1, 10$), blockage ($\overline{B} = 0.1, 0.2, 0.3$) and location ($L_y = 0.25, 0.5, 0.75$) of triangular block on convection characteristics have been elucidated. Flow and thermal patterns in the cavity are analyzed by systematic evaluation of streamline and temperature contours. Followed by heat transfer characteristics are presented by studying variation of local as well as average Nusselt number. Average Nu values are presented in the form of tables for different values of *Ri*. Higher heat transfer rates can be achieved for centered block position ($L_y = 0.5$) than remaining two ($L_y = 0.25, 0.75$).

1. Introduction

Recent years have witnessed a tremendous growth in the heat transfer enhancement methodologies. One of such topic of great pragmatic as well as theoretical importance is combined free-forced convection heat transfer and fluid flow in the complex shaped geometry. It is widely acknowledged that the fundamentals of convective fluid flow and heat transfer are quite essentially involved in the most of the energy associated applications. Therefore, the effective use of the energy for such fields is an important requirement. Moreover, the problem of lid-driven flow in a cavity has always attracted substantial focus among the researchers on the account of its extensive variety of practical findings, such as growth of crystals, cooling system of electronic devices, solar heat collectors, heat exchangers, multi-screen objects utilized for nuclear reactors and food processing. Analysis of flow inside the lid-driven cavity (internal flow) is very significant in the field of fluid dynamics (as it helps to clear some of the key fundamentals of fluid mechanics, such as flow transition to turbulent, flow bifurcation, multiple steady states, location of primary/corner eddies, etc.) [1]. All-inclusive research has been contained on the lid-driven cavity problem owing to its idealized rectangular geometry with relevant simple boundary conditions. Even though for isothermal condition, the resulting flow (purely shear driven) is quite complex. Imposing temperature gradient, resulting in combination of shear and buoyancy force, greatly enhances the flow complexity further [2]. Practical applications of such systems can be seen in broad range of fields, such as, refrigerators and oven, cooling devices in different electronic devices, polymer and material processing, food processing, heat exchangers, production of float glass, solar heat collectors [3], etc. Moreover, the presence of heated obstacle (of varying cross-sections) inside the lid-driven cavity makes the interaction of flow very complex from moving lid and heated obstacle to ambient wall, which requires a comprehensive study to interpret underlying physics. Therefore, due to its simple geometry and the strong theoretical foundation, large number of studies have been conducted in the past on mixed

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https://doi.org/10.1016/j.ijheatmasstransfer.2018.03.079
0017-9310/

Nomenclature

b	size of triangular block, m
$\overline{B}$	blockage (b/H), dimensionless
c_p	specific heat capacity, J/(kg K)
g_y	acceleration due to gravity, m/s^2
H	height of cavity, m
k	thermal conductivity, W/(m K)
L	length of cavity, m
L_y	location of triangular block, dimensionless
Nu	local Nusselt number, dimensionless
$\overline{Nu}$	average Nusselt number, dimensionless
P	pressure, N/m^2
P^*	pressure, dimensionless
AR	aspect ratio (=L/H), dimensionless
T	temperature, K
T^*	temperature, dimensionless
u_{lid}	characteristic velocity, m/s
u_y, u_y	velocity component, m/s
u_y^*, u_y^*	velocity component, dimensionless

Greek letters

α	thermal diffusivity, m^2/s
β	coefficient of thermal expansion, K^{-1}
μ	dynamic viscosity, N s/m^2
ν	kinematic viscosity, m^2/s
ρ	density, kg/m^3
$\overline{\rho}$	reference density, kg/m^3

Dimensionless groups

Gr	Grashof number, $\frac{g\beta\Delta TH^3}{\nu^2}$
Pr	Prandtl number, $\frac{\nu}{\alpha}$
Re	Reynolds number, $\frac{Hu_{lid}\rho}{\mu}$
Ri	Richardson number, $=\frac{Gr}{Re^2} = \frac{g\beta\Delta TH}{u_{lid}^2}$

Subscripts and superscripts

*	dimensionless variable

Abbreviations

SIMPLE	semi-implicit method for pressure linked equation method
FVM	finite volume method
QUICK	quadratic upstream interpolation for convective kinematics

convection in lid-driven cavity; While, the research covering lid-driven flow containing heated obstacle/block is still modest.

Some of the recent development in the field of lid-driven cavity flow along with mixed convection are briefed herein. Billah et al. [4] explored the mixed convection in a lid-driven cavity containing heated hollow-circular cylinder by using finite element analysis for different diameters of cylinder (0.2–0.5) and Richardson number ($0 \leqslant Ri \leqslant 5$). They reported significant impact of diameter of cylinder on overall convection characteristics in cavity. Sivasankaran et al. [5] studied the influence of non-uniform heating on side-walls on the fluid flow and thermal patterns due to mixed convection. Numerical study was carried out for different Richardson numbers ($0.01 \leqslant Ri \leqslant 100$). Authors shown the formation of multi-cellular and uni-cellular flow patterns in natural and forced convection dominant regions, respectively. Sun et al. [6] examined the presence of conductive triangular fins inside the lid-driven cavity to control the flow. Numerical experimentations were based on the variation of location fins and Richardson number ($Ri = 0.1, 1, 10$). On the other hand, the effect of heated square block on mixed convection flow patterns inside a lid-driven cavity was given by Islam et al. [7]. Authors studied influence of parameters, such as, location of block, Richardson number ($0.01 \leqslant Ri \leqslant 100$) for $Re = 100, Pr = 0.71$. Bhattacharya et al. [8] analyzed the multiple solutions for the mixed convection inside the trapezoidal lid-driven cavity for different Gr, Re and Pr. More steady states are observed for the natural convection dominant region and $Re = 1$. Chatterjee et al. [9] explored the fluid flow and heat transfer due to combined natural and forced convection in lid-driven cavity containing rotating circular cylinder for $Cu - H_2O$ nanofluid. Physical insights of the cavity were analyzed for $Ri = 1$—10, rotational speed (0–5) and nano-particles volume fraction (0–0.2) for $Gr = 10^4$. Similar study was performed by [10,11] for Al_2O_3 nanofluid in the lid-driven cavity containing heated square block. Distinct improvement in the heat transfer rate can be achieved by using nanofluid. Sheremet and Pop [12] used Buongiorno's mathematical model for the interpretation of mixed convection in a lid-driven cavity for water based nanofluids. Subsequently, Chamkha et al. [13] numerically analyzed the effect of inner rotating circular cylinder placed inside porous cavity on convection behavior. Whereas, the effect of heat conducting solid backward step in lid-driven cavity on flow physics was examined by [14,15]. Factors such as, heat conductivity and size of backward step found to enhance heat transfer. Another mixed convection study delineating the flow physics and heat transfer characteristics of lid-driven cavity with horizontal porous layer filled with ferrofluid is shown by Gibanov et al. [16]. Gangawane and Manikandan [17] explored the result of various Re, Gr and Pr on the mixed convection flow and thermal patterns inside lid-driven cavity containing heated triangular cylinder (either with constant Temperature or constant heat flux). Hammami et al. [18] presented a numerical study based on two sided lid-driven cavity containing

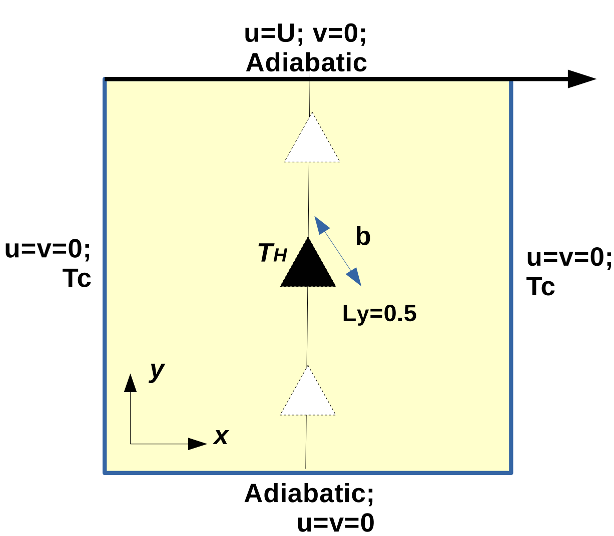

Fig. 1. Schematic representation of the computational domain along with boundary condition.