Investigation of Heat Transfer Due To Isothermal Heater in Irregular Porous Cavity: Part III

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Abstract. Heat transfer in porous medium is one of the intense filed of research for many years. This paper investigates the heat transfer in a porous cavity due to an isothermal block placed at top of left vertical wall. The right vertical wall of cavity is maintained at isothermal cold temperature. The governing partial differential equations are solved by employing finite element method. Results are discussed with respect to physical parameters in terms of contour plots of isothermal and streamlines. It is found that the heat transfer due to block at top of vertical surface makes the heat to be concentrated at upper side of porous domain.

Keywords. Isothermal block, Irregular square cavity, Finite element method, Porous medium.

INTRODUCTION

Heat transfer along with its allied areas is one of the intense topics that have motivated plenty of researchers across the globe for many decades. In particular, last two to three decades have seen huge number of publications in this area [1-36] which probably gained its first attention during nineteenth century when Henry Darcy formulated the simple laws governing the flow through porous medium. The literature has been well summarized in some of the books [1, 3, 4, 5, and 7]. The current work is focused to investigate the heat transfer in an irregular porous cavity due to presence of a step shaped heater at top left corner of the domain. This is an extension of the work where the heater is placed at bottom or center of cavity. The authors could not find the information about the heat transfer in porous cavity due to step sized heater placed at various locations. Thus, the current work tries to investigate the effect of size of step shaped heater inside the porous region.

MODEL DEVELOPMENT

An irregular porous cavity having a heater of step shape placed at the top left corner of cavity is considered. The height of the heater is maintained at 20% of cavity height whereas its length is varied. Heat is supplied by one horizontal and a vertical edge of the heater which are maintained at isothermal temperature T_h , to porous medium. The right vertical surface of porous cavity is maintained at lowest temperature T_c in the medium. The horizontal top and bottom surfaces along with the portion of left vertical surface which is not the part of heater are maintained adiabatically. The physical domain is depicted in Fig. 1. The fluid flow is modeled using Darcy law and density variations of fluid created by supplied heat from heater are assumed to follow Boussinesq approximation. There is no discrepancy in temperature of fluid and solid phase thus making the mathematical model a thermal equilibrium model. The mathematical equations governing the heat and flow can be given as:

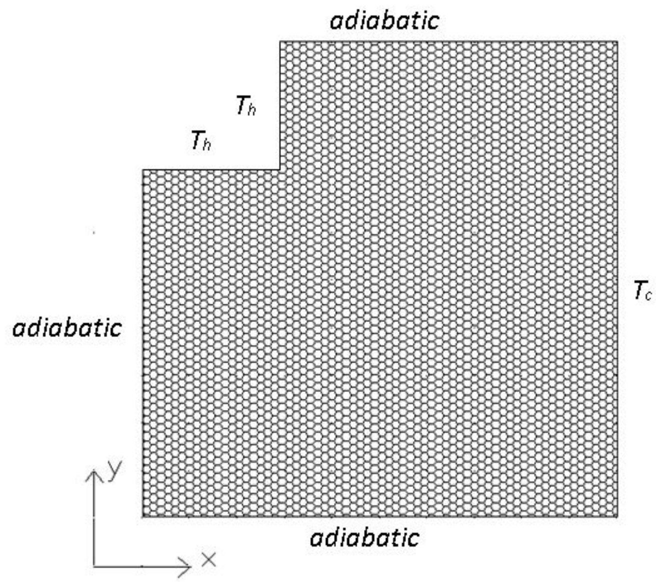

FIGURE 1. Porous domain

$$\frac{\partial \mathrm{v}}{\partial x}-\frac{\partial \mathrm{u}}{\partial y}=\frac{gK\beta}{\nu}\frac{\partial T}{\partial x} \tag{1}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)-\frac{1}{\rho C_p}\frac{\partial q_r}{\partial x} \tag{2}$$

After introducing the Rosseland hypothesis [6] to approximate the radiation q_r parameter,

$$q_r=-\frac{4n^2\sigma}{3\beta_R}\frac{\partial T^4}{\partial x} \tag{3}$$

The equation (2) becomes:

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha\left(\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right)+\frac{1}{\rho C_p}\frac{4n^2\sigma}{3\beta_R}\frac{\partial^2 T^4}{\partial x^2} \tag{4}$$

Taking stream function as

$$u=\frac{\partial \psi}{\partial y} \tag{5a}$$

$$\mathrm{v}=-\frac{\partial \psi}{\partial x} \tag{5b}$$

The boundary conditions are

$$0 \le x \le L_s \quad , \quad y = 0.8 \quad , \quad v = 0 \quad , T = T_h \tag{6a}$$

$$x = L_{,} \quad u = 0 \quad T = T_c \tag{6b}$$

$$x = L_s, 0.8 \le y \le L \quad , \quad T = T_h \quad u = 0 \tag{6c}$$

$$x = 0, \quad 0 \le y \le 0.8 \quad u = 0 \tag{6d}$$

RESULTS AND DISCUSSION

This section discusses the results of current study. The governing equations are converted into algebraic equations as a result of application of finite element method. Triangular element with three nodes is chosen to divide the domain into smaller segments. Each of the element stiffness matrix resulting from every element is transferred into global stiffness matrix and then solved iteratively after incorporating the boundary conditions as given by equation 6. It is worth mentioning that all the equations are converted into non-dimensional form before solving them. Figure 3 shows the results of varying size of step shaped heater into 3 stages that is 20%, 37.5% and 50% of the total length of the porous cavity but keeping its height at constant value of 20% of cavity height. These results corresponds to Ra=100 and Rd=0.5. It is interesting to note that the isothermal lines of vertical edge of heater are spread out to greater extent as compared to its horizontal hot surface. This is opposite trend as compared to the cases when step shaped heater is placed at bottom or center of left vertical surface of cavity. The spreading of isotherms decreases the thermal gradient at the hot surface that in turn should decrease the heat transfer rate from hot surface to the porous region. Thus the heat transfer from horizontal and vertical surface of heater in case of heater at top corner is quite opposite to the case of heater at bottom or mid of left vertical surface of cavity. The magnitude of stream function is lowest in current case as compared to the other two cases as mentioned above. This indicates that the fluid velocity is weakest in current case. Fig. 3 shows the effect of Rayleigh number on heat transfer characteristics which is obtained at Rd=0.5 and Ls=0.2L. The stream function magnitude increased with increase in Rayleigh number but still it is lower than the cases of heater at bottom or center of left surface.

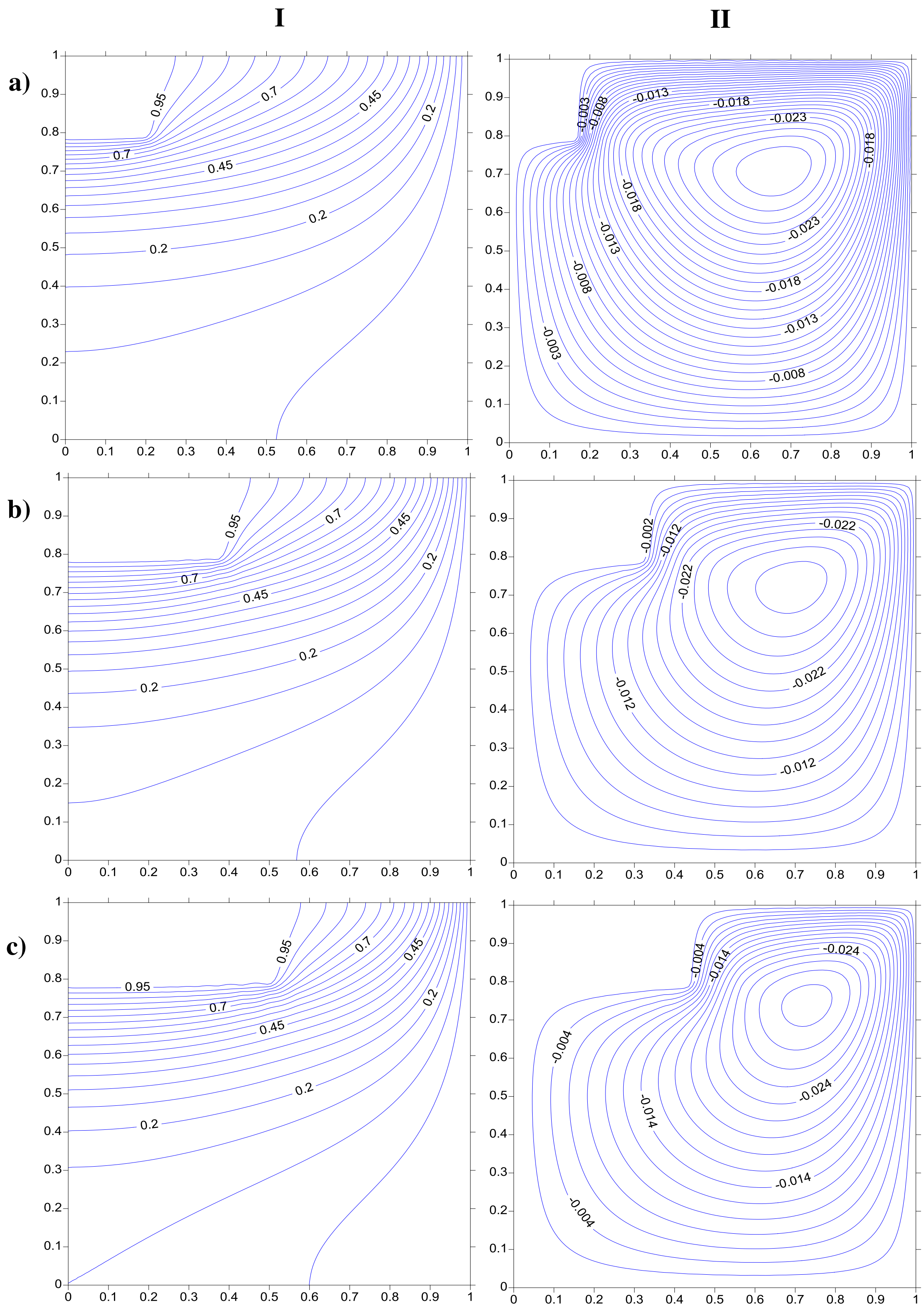

FIGURE 2. I) Isotherms II) Streamlines a) L_s=0.2L b) L_s=0.375L c) L_s=0.5L *at* R_d = 0.1 *and* Ra = 100

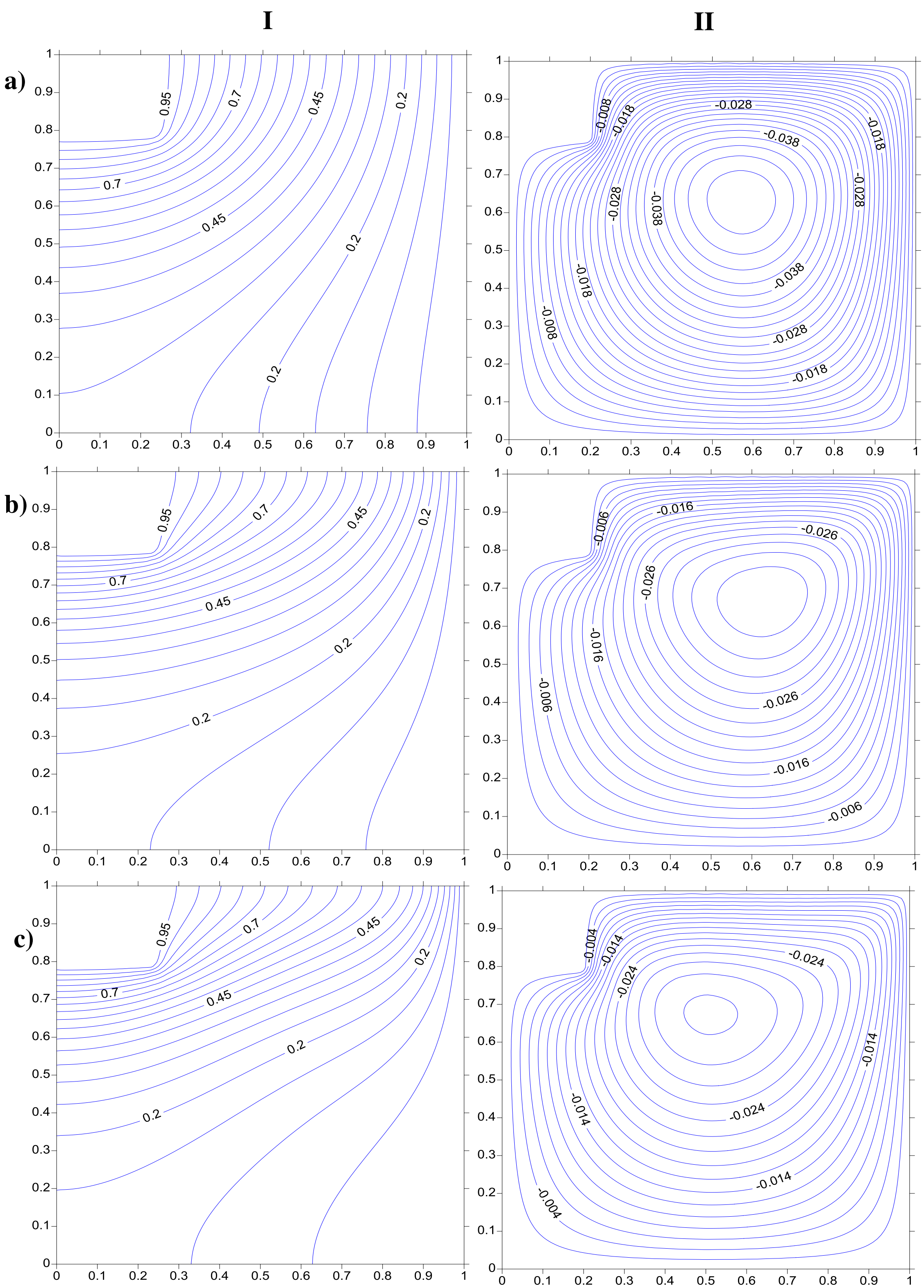

FIGURE 3. I) Isotherms II) Streamlines a) $Ra = 10$ b) $Ra = 50$ c) $Ra = 100$ *at* $R_d = 0.5$ *and* $L_s = 0.2L$

CONCLUSION

The current work is carried out to investigate the effect of heater placed at top of left surface of cavity. It is found that the thermal energy transfer from hot surface to porous medium is completely different from the cases when heater is placed at bottom or center of left vertical surface of cavity. The fluid velocity is found to be weakest in this particular case.

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