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

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Abstract. The present work is undertaken to investigate the effect of isothermal block placed at center of left vertical surface of porous cavity. The block is heated with isothermal temperature and right vertical surface of cavity is maintained at lowest temperature in domain. Finite element method is used to convert the governing equations into a simpler form. It is found that the heat transfer behavior for present case is different from that of the case when isothermal block is placed at bottom or top of the cavity.

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

INTRODUCTION

It is well known that the flow through a medium containing pores has significant importance in many of the applications which has relevance in industry. The flow of thermal energy is a result of combined effect of conduction, convection and radiation if the medium has radiative properties. The fluid inside the porous medium is heated due to applied heat that reduces its density thus allowing the fluid to move inside the medium. This leads to transfer of energy in the form of convection. There are various studies being conducted to understand the heat transfer in porous medium [1-37]. The majority of studies in the porous medium has been considered by taking the regular geometry of porous domain such as square cavity [9,20,31,36], annulus [12,13,14,16,17,21,23,37] etc. The current work is motivated to study the porous medium in irregular geometry formed due to heat source applied in the form of a step at the center of left vertical wall.

MODEL DEVELOPMENT

This study is an extension of the case where the step sized heater is placed at the bottom of cavity. In this particular study, the step size heater is placed at the mid of the left vertical wall that turns the geometry into irregular shape. The step creates an opportunity for the heater to supply heat at three surface i.e. two horizontal surfaces and one vertical surface as shown in Fig.1. The right vertical surface of cavity is cooled to isothermal temperature T_c. and the top and bottom surfaces of cavity are maintained adiabatically. The governing equations of this particular phenomenon in its dimensional form are given in the Part I of this paper. The following non dimensional parameters are used to convert the dimensional equations into non-dimensional form.

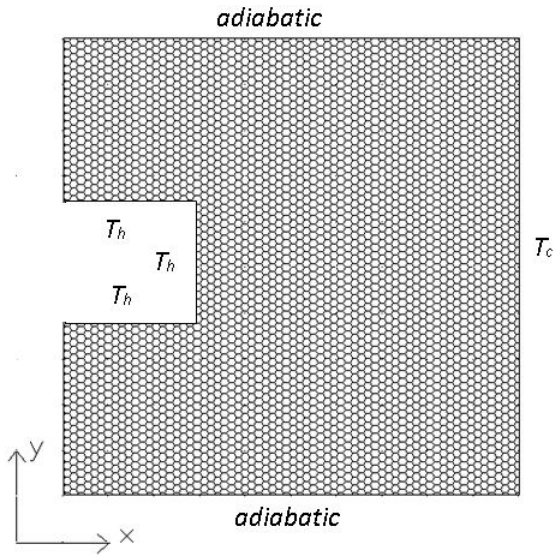

FIGURE 1. Porous domain

$$\bar{x} = \frac{x}{L}\ ,\ \bar{y} = \frac{y}{L}\ ,\ \bar{\psi} = \frac{\psi}{\alpha}\ ,\ \bar{T} = \frac{(T - T_c)}{(T_h - T_c)}\ ,\ Rd = \frac{4n^2\sigma T_c^{\ 3}}{\beta_r k}\ ,\ Ra = \frac{g\beta\ \Delta TKL}{\nu\alpha} \tag{1}$$

T^4 can be expanded according to Taylor series about T_c as: [13,14,37,38]

$$T^4 \approx 4TT_\infty^{\ 3} - 3T_\infty^{\ 4} \tag{2}$$

With the help of above mentioned parameters, the non-dimensional governing equations can be given as:

$$\frac{\partial^2\bar{\psi}}{\partial\bar{x}^2} + \frac{\partial^2\bar{\psi}}{\partial\bar{y}^2} = -Ra\frac{\partial\bar{T}}{\partial\bar{x}} \tag{3}$$

$$\left[\frac{\partial\bar{\psi}}{\partial\bar{y}}\frac{\partial\bar{T}}{\partial\bar{x}} - \frac{\partial\bar{\psi}}{\partial\bar{x}}\frac{\partial\bar{T}}{\partial\bar{y}}\right] = \left(\left(1 + \frac{4R_d}{3}\right)\frac{\partial^2\bar{T}}{\partial\bar{x}^2} + \frac{\partial^2\bar{T}}{\partial\bar{y}^2}\right) \tag{4}$$

The corresponding boundary conditions are

$$0 \le \bar{x} \le \bar{L}_s \quad and \quad \bar{y} = 0.4\ and\ \bar{y} = 0.6 \qquad \bar{\psi} = 0\ ,\quad \bar{T} = 1 \tag{5a}$$

$$0 \le \bar{y} \le \bar{L}_h \quad and \quad \bar{x} = \bar{L}_s \qquad \bar{\psi} = 0\ ,\quad \bar{T} = 1$$

$$\bar{x} = 1 \qquad \bar{\psi} = 0 \qquad \bar{T} = 0 \tag{5b}$$

$$\bar{y} = 0\ \ and\ \ \bar{y} = 1, \qquad \bar{\psi} = 0\ , \qquad \frac{\partial\bar{T}}{\partial\bar{y}} = 0 \tag{5c}$$

RESULTS AND DISCUSSION

The above mentioned equation 3 describes the fluid transport whereas equation 4 simulates the energy transport inside the porous medium. These equations are converted into a much simpler form by applying finite element method. The solution of equations 3 and 4 yields the value of non-dimensional temperature as well as stream functions at all the nodes of domain that can be further processed to plot the isotherms and streamlines. The effect of step sized heater at center of left surface is illustrated in Fig. 2 that shows the variation in step size and its corresponding influence on isotherms and streamlines. The length of heater is 20%, 37.5% and 50% of the length of the cavity and its height is maintained at 20% of cavity height. The heater supplies heat at three of its edges i.e. bottom and top horizontal edges and one of the vertical edge. It can be inferred from Fig. 2 that the temperature gradient is highest along the vertical edge of heater followed by bottom and then by top edge. This clearly indicates that the heat transfer is maximum along the vertical edge then followed by bottom and top edges respectively of the heater. The overall temperature of cavity increases with increase in the size of the heater as obvious from Fig. 2 that shows that the temperature line corresponding to 0.95 moved deep into porous region due to increase in the size of heater. The increase in the Rayleigh number leads to much more distortion of temperature lines as indicated by figure 3 which is obtained at constant heater size of 0.2L where L is the length of cavity. As expected the magnitude of stream function increases with increase in Rayleigh number.

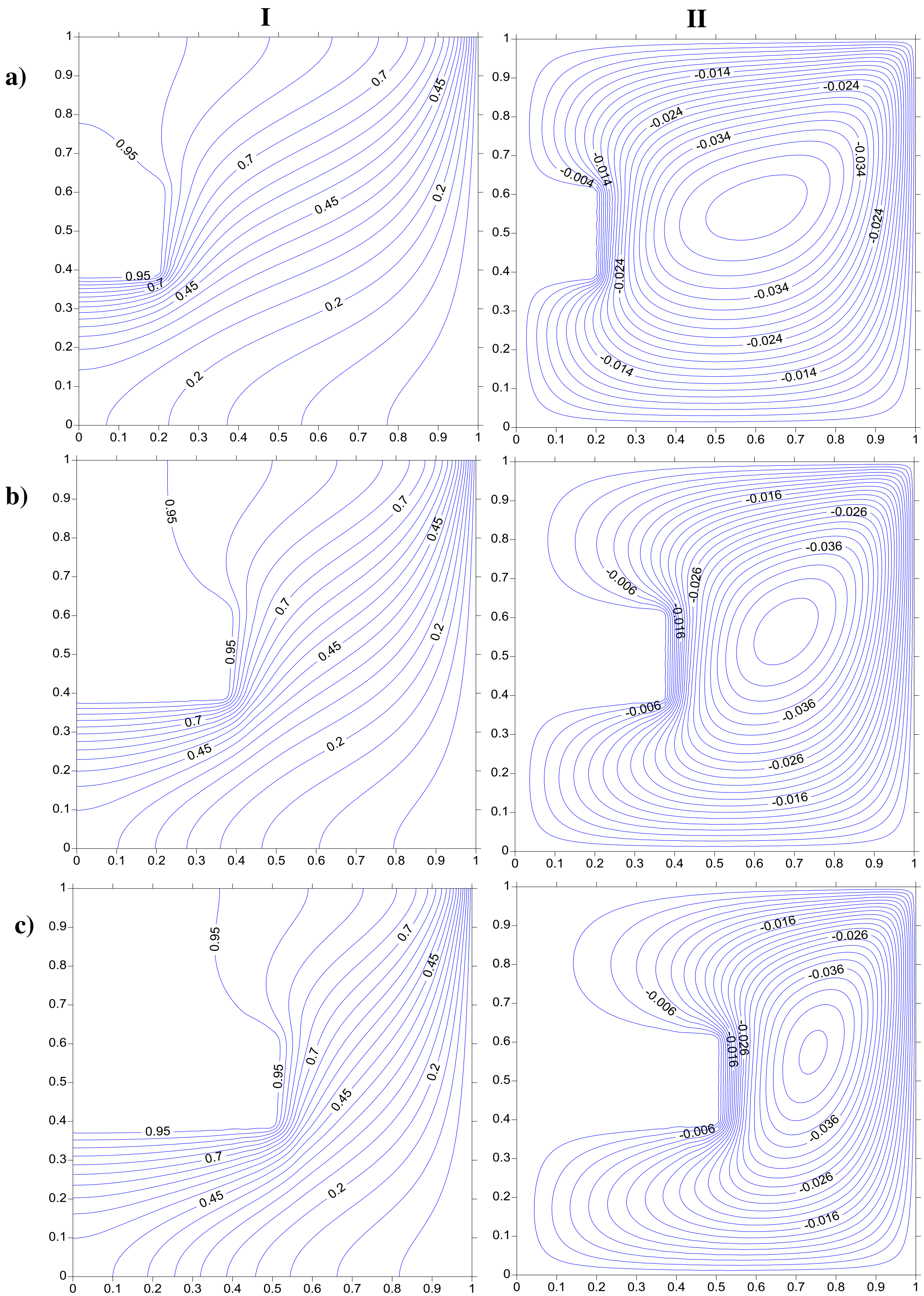

FIGURE 2. I) Isotherms II) Streamlines a) $L_s=0.2L$ b) $L_s=0.375L$ c) $L_s=0.5L$ *at* $R_d = 0.2$ *and* $Ra = 100$

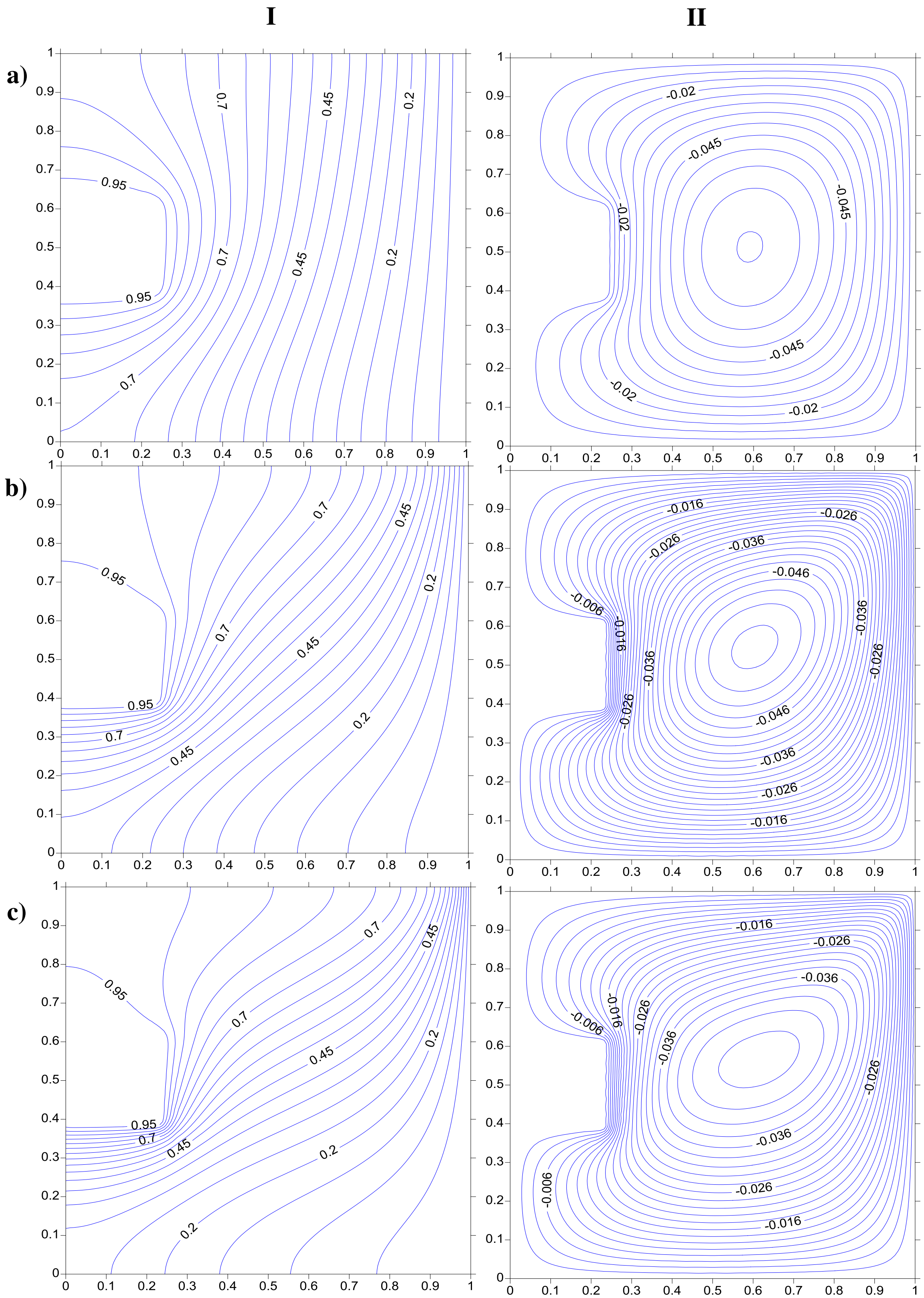

FIGURE 3. I) Isotherms II) Streamlines a) $Ra = 10$ b) $Ra = 50$ c) $Ra = 100$ at $R_d = 0.1$ and $L_s=0.2L$

CONCLUSION

An investigation of heat transfer in a square porous cavity turned into irregular shape due to introduction of step size heater at center of cavity is carried out. Finite element method is used to solve the governing equations. It is found that the thermal energy distribution is uneven across horizontal central line of cavity even though the heater is placed at center of cavity. The increased size of heater increases the thermal energy level of cavity.

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