Convective heat transfer in the Channel having Multiple Heated Entities

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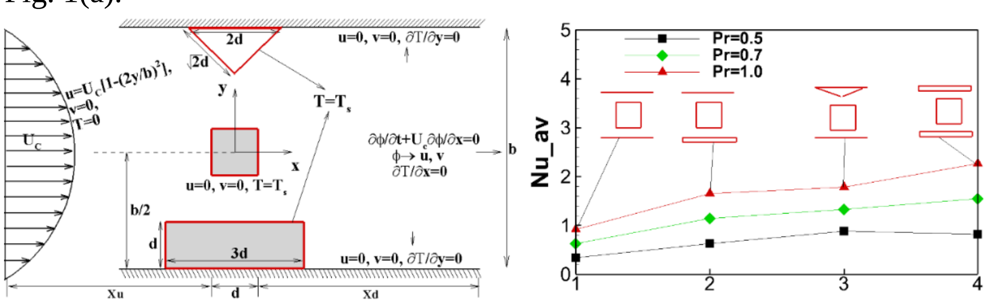
1. ABSTRACT

Convective heat transfer in a channel heaving heated square, triangular and plane shaped entities is analyzed in this paper. Multiple heated entities are placed in a staggered arrangement on the walls of the channel. The problem is studied for fixed Reynolds number (Re) as 100 and Prandtl number (Pr) in the range 0.5-1.0, by using a Higher Order Compact (HOC) finite difference scheme. The effect of Pr is considered on the heat convection phenomenon. The isotherm contours in the vicinity of heated entities in the channel are presented and heat transfer evaluated in terms of Nusselt number, average Nusselt number. The results show that the temperature distribution is strongly dependent on flow structure and varies with any change of flow pattern in different shaped entities. The significant effect of Pr has been concluded over heat transfer rate.

Keywords: HOC scheme; Heated entities; Navier-Stokes equations.

2. PROBLEM INTRODUCTION

Heat transfer in channels having heated entities is one of the applied problems in different engineering fields. The major applications of this problem are flow in heat exchangers, cooling of electronic components, and computation of heat losses at exterior building walls by atmospheric airflow, especially at power plant buildings. Hence, the study of heat transfer in this configuration attracts the researchers as an appropriate model suitable for above mentioned real examples. There are so many numerical and experimental studies have been announced in the literature with new observations. However, most of the studies concentrated on heat transfer characteristics of square entities placed on either wall of the channel ([1-4]). The main characteristic of the flow in this configuration is the vortex formation between the different shaped entities. The vertices generated from each entity closely interact and some vortices merge to each other because of crossing over the center line which further leads to complex heat transfer as every vortex carries certain of heat. The entity in the centerline of the flow creates an adverse pressure gradient, which cause flow separation in upstream of the entity. The schematic diagram of the problem shown in Fig. 1(a).



(a) **(b)**

Fig. 1-**(a)**Schematics diagram of flow configuration,**(b)**Time average Nusselt variation with Pr for all configurations

The two-dimensional governing equations of flow motion and energy in stream function-vorticity (ψ−ω) form (x, y) are given as

$$\frac{\partial^2 \omega}{\partial x^2} + \frac{\partial^2 \omega}{\partial y^2} = Re\left\{u\frac{\partial \omega}{\partial x} + v\frac{\partial \omega}{\partial y} + \frac{\partial \omega}{\partial t}\right\} \qquad (1)$$

$$\frac{\partial^2\psi}{\partial x^2}+\frac{\partial^2\psi}{\partial y^2}=-\omega \qquad (2)$$

$$\frac{\partial^2\theta}{\partial x^2}+\frac{\partial^2\theta}{\partial y^2}=Re\,Pr\left\{u\frac{\partial\theta}{\partial x}+v\frac{\partial\theta}{\partial y}+\frac{\partial\theta}{\partial t}\right\} \qquad (3)$$

Where $Re=\frac{U_c d}{\nu}$ is the Reynolds number and $Pr=\frac{\nu}{\beta}$ is the Prandtl number. The velocity components in terms of stream function is written as $u=\frac{\partial\psi}{\partial y},\ \ v=-\frac{\partial\psi}{\partial x}$ and vorticity $\omega=\frac{\partial v}{\partial x}-\frac{\partial u}{\partial y}$.

3. RESULTS COMPUTATION AND DISCUSSION

The discretization of the governing equations of flow motion and energy is done by a higher order compact (HOC) finite difference scheme on Cartesian grids ([5]). The HOC discretization of equations $(\mathbf{1})$ and $(\mathbf{2})$ is same as discussed in Kumar and Ray ([5-6]). Further, the discretization of the energy equation $(\mathbf{3})$ at $(\boldsymbol{i},\boldsymbol{j})^{\boldsymbol{th}}$ mesh point of the computational domain is given by

$$\begin{aligned}&[\boldsymbol{Re\,Pr}+\boldsymbol{\beta 11_{ij}\delta_x}^2+\boldsymbol{\beta 12_{ij}\delta_y}^2+\boldsymbol{\beta 13_{ij}\delta_x}+\boldsymbol{\beta 14_{ij}\delta_y}+\boldsymbol{\beta 15_{ij}\delta_x\delta_y}+\boldsymbol{\beta 16_{ij}\delta_x\delta_y}^2\\&\quad+\boldsymbol{\beta 17_{ij}\delta_x}^2\boldsymbol{\delta_y}+\boldsymbol{\beta 18_{ij}\delta_x}^2\boldsymbol{\delta_y}^2]\boldsymbol{\theta_{ij}}^{\boldsymbol{n+1}}\\&=[\boldsymbol{Re\,Pr}+\boldsymbol{\beta 21_{ij}\delta_x}^2+\boldsymbol{\beta 22_{ij}\delta_y}^2+\boldsymbol{\beta 23_{ij}\delta_x}+\boldsymbol{\beta 24_{ij}\delta_y}+\boldsymbol{\beta 25_{ij}\delta_x\delta_y}+\boldsymbol{\beta 26_{ij}\delta_x\delta_y}^2\\&\quad+\boldsymbol{\beta 27_{ij}\delta_x}^2\boldsymbol{\delta_y}+\boldsymbol{\beta 28_{ij}\delta_x}^2\boldsymbol{\delta_y}^2]\boldsymbol{\theta_{ij}}^{\boldsymbol{n}}\end{aligned}$$

Where the coefficients $\boldsymbol{\beta 11_{ij}},\boldsymbol{\beta 12_{ij}}\ldots\boldsymbol{\beta 18_{ij}}$ and $\boldsymbol{\beta 21_{ij}},\boldsymbol{\beta 22_{ij}}\ldots\boldsymbol{\beta 28_{ij}}$ are functions of $\boldsymbol{x}$ and $\boldsymbol{y}$. The computation of heat convection is analyzed in terms of isotherm contours, Nusselt number and Average Nusselt number variation. Fig. 1(b) showing the time average Nusselt number plot with Pr for all considered configurations. It is observed that heat convection is increases with increasing Pr irrespective of the configuration of heated entities considered in this study.

4. CONCLUSION

The HOC finite difference simulation of convective heat transfer in a channel in the presence of multiple heated entities at *Re* = 100 for Pr from 0.5 – 1.0 is presented here. It is observed that the amount of heat transfer is significantly depends on the Prandtl number. The different configurations of multiple heated entities also play significant role in heat convection. We have studied the effect of Prandtl number, Reynolds number on the heat transfer process for a wide range of parameter values but full work is not in the scope of the conference.

REFERENCES

1. Paulraj, M.P., Byon, C., Vallati, A. and Parthasarathy, R.K., 2020. A numerical investigation of flow and heat transfer of laminar multiple slot jets impinging on multiple protruding heat sources. *Heat Transfer Engineering*, *41*(1), pp.65-83.
2. Mandal, S. K., Arnab Deb, and Dipak Sen. "Mixed convective heat transfer with surface radiation in a rectangular channel with heat sources in presence of heat spreader." *Thermal Science and Engineering Progress* 14 (2019): 100423.
3. Sekrani, Ghofrane, Sébastien Poncet, and Pierre Proulx. "Conjugated heat transfer and entropy generation of Al 2 O 3–water nanofluid flows over a heated wall-mounted obstacle." *Journal of Thermal Analysis and Calorimetry* 135 (2019): 963-979.
4. Imani, Gholamreza, Mehdi Maerefat, and Kamel Hooman. "Lattice Boltzmann simulation of conjugate heat transfer from multiple heated obstacles mounted in a walled parallel plate channel." *Numerical Heat Transfer, Part A: Applications* 62, no. 10 (2012): 798-821.
5. Kumar, Atendra, and Rajendra K. Ray. "Theoretical understanding of unsteady flow separation for shear flow past three square cylinders in vee shape using structural bifurcation analysis." Computational and Applied Mathematics 39, no. 3 (2020): 177.
6. Kumar, Atendra, and Rajendra K. Ray. "Higher order compact numerical simulation of shear flow past inclined square cylinder." In Advanced Computing and Communication Technologies: Proceedings of the 9th ICACCT, 2015, pp. 305-313. Springer Singapore, 2016.