Numerical Analysis of Secondary Flow Strength Induced by Electrohydrodynamic Actuator Through a Smooth Channel

H. Moayedi[1], N. Amanifard[1]*, H. Mohaddes Deylami[2]

[1] Thermo-Fluids Department, Faculty of Mechanical Engineering, University of Guilan, Guilan, Iran

[2] Faculty of Technology and Engineering East of Guilan, University of Guilan, Rudsar, Iran

ABSTRACT: In this paper, the effect of the secondary flow induced by the electrohydrodynamic actuator is numerically investigated in the vorticity flux, as a criterion for the secondary flow strength, and the electrohydrodynamic vortices through a smooth channel. In this study, the influence of effectiveness parameters of the electrohydrodynamic as the Reynolds number, applied voltage and the arrangement of the emitting electrode on the vorticity flux, and also relationship between flow and heat transfer characteristics with the vorticity flux are evaluated. The results indicated that in presence of electric field, by increasing the Reynolds number, dimension of the upstream electrohydrodynamic-induced vortices and the vorticity flux are decreased. Also, it is obvious that by increasing the applied voltage, the dimension of the electrohydrodynamic-induced vortices and the vorticity flux are increased. According to numerical results, the heat transfer enhancement is completely depending on the vorticity flux. Also, by changing of the emitter arrangements, the non-dimension average vorticity flux and the average heat transfer enhancement are changed. It is shown that with decrease of the distance between emitter electrode and inlet of channel, the non-dimension average vorticity flux and the average heat transfer enhancement are increased 27.9% and 17.9%, respectively.

1. Introduction

The geothermal energies are stable, reliable, and unlimited souVortex-generating technique as a powerful tool has always been subjected to deep scrutiny by researchers. Along with the improvements of vortex-generation techniques, the ElectroHydroDynamic (EHD) induced vortex method has been deeply concerned during the last decade, because of their easy implementation. In this method, a high voltage is applied to the discharge electrode to induce a secondary air flow which is known as corona wind [1]. Deylami et al. [2] numerically investigated the influence of using various arrangements of the emitter on the heat transfer augmentation through a smooth channel. Moreover, Wang et al. [3] proposed an effective electrode pair arrangement in a rectangular double-wall-heated channel, where one electrode impinged on the top wall, and the other impinged on the bottom wall. On the other hand, in some studies, the analogy between the heat transfer and the vorticity flux have been investigated [4,5]. Chang et al. [4] and Song and Wang [5] suggested the spanwise averaged vorticity flux to analysis the strength of the generated secondary. They showed that a similar trend is occurred between the longitudinal variation of the spanwise averaged vorticity flux and the spanwise averaged Nusselt number. In the present study, the averaged absolute vorticity flux for EHD-induced flow is introduced, and is used for the discussion on the relationship between the vorticity flux with the heat transfer and the flow structure. The case studies are conducted for a 2Dimensional smooth channel with variation of substantial parameters; Reynolds number, applied voltages, size of collector plate and the arrangements of emitter, affecting the vorticity flux.

2. Geometry

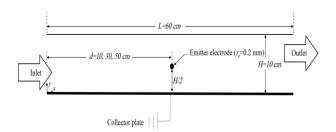Fig. 1 represents a schematic view of the computational domain used for the present study.

Fig. 1. Schematic view of the computational domain.

3. Governing Equations

The governing equations of the flow, thermal, and species fields including continuity, momentum energy equations are as follows.

*Corresponding author's email: namanif@guilan.ac.ir

$$\nabla \cdot u = 0 \tag{1}$$

$$\rho(u \cdot \nabla)u = -\nabla P + (\mu + \mu_t)\nabla^2 u + F_{ei} \tag{2}$$

$$u \cdot \nabla T = \nabla \cdot ((\alpha + \alpha_t)\nabla T) \tag{3}$$

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon} \tag{4}$$

In order to quantify the strength of the secondary flow, Song and Wang [5] referred to the averaged absolute vorticity flux J as follows:

$$J = \frac{\iint_S |\omega_z| \, dz \, dy}{\iint_S dz \, dy} \tag{5}$$

Also, a dimensionless value of the averaged absolute vorticity flux can be given by the following relation:

$$\sigma = \frac{JS}{UH} \tag{6}$$

The governing equations for the electric field as following:

$$\nabla^2 V = -\frac{\rho_c}{\varepsilon_e} \tag{7}$$

$$\frac{\partial \rho_c}{\partial t} + \nabla \cdot (-\rho_c \beta \nabla V) = 0 \tag{8}$$

4. Results and Discussion

Evaluation of the averaged absolute streamwise vorticity flux for EHD-induced flow, as a main factor of the EHD phenomenon, is computed, and is used for the discussion on the relationship between the vorticity fluxes with the heat transfer. The vorticity contour based on different applied voltage are presented in Fig. 2. Based on this figure, it is clear that by increasing the applied voltage, the intensity of the vorticity in the recirculation zones in the vicinity of emitter is increased.

Moreover, the longitudinal evolution of the dimensionless absolute vorticity flux for different applied voltage is shown in Fig. 10.

According to Fig. 4, it can be argued that the behavior of $\sigma_{EHD}/\sigma_{non-EHD}$ and hEHD/hnon-EHD are nearly same for the EHD phenomenon. In addition, the maxima of both profiles of the $\sigma_{EHD}/\sigma_{non-EHD}$ and $h_{EHD}/h_{non-EHD}$ take place in the vicinity of emitter position ($x \approx 0.3$m).

To investigate the effect of longitudinal position of the emitter on the secondary flow strength, three longitudinal positions are set to be considered and results of these cases are presented in Table 1. It is clear that the and hEHD/hnon-EHD are significantly sensitive to the emitter arrangements.

5. Conclusions

A numerical investigation on the strength of EHD-induced secondary flow through a smooth channel is conducted by using the vorticity flux framework. The effects of effectiveness parameters of the EHD as: Reynolds number, applied voltages and obviously arrangements of emitters were studied for evaluation the behavior of the vorticity flux. The results indicated that the behavior of the axial direction profiles of dimensionless vorticity flux and normalized heat transfer coefficient are nearly the same for the EHD-induced flow.
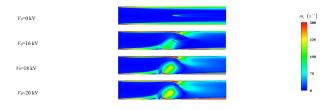

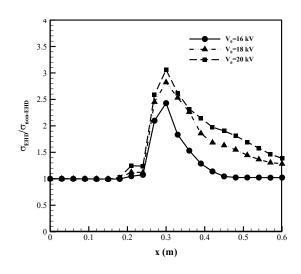**Fig. 2. Distribution of vorticity based on applied voltage (Re=3000, d=30 cm).**

Fig. 3. Longitudinal evaluation of dimensionless vorticity flux based on different applied voltage (Re=3000, d=30 cm).
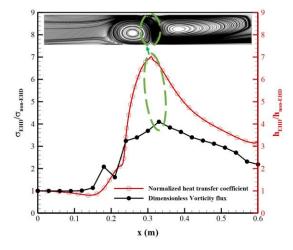

Fig. 4. Longitudinal evaluation of dimensionless vorticity flux and normalized heat transfer coefficient (Re=1000, V0=18 kV, d=30 cm).

References

[1] H. Moayedi, N. Amanifard, H.M. Deylami, Evaluation of using micropolar fluid approach for the EHD-enhanced forced convection through a rectangular channel using multiple electrode arrangements, Applied Thermal Engineering, (2019) 113857.

[2] H.M. Deylami, N. Amanifard, F. Dolati, R. Kouhikamali, K. Mostajiri, Numerical investigation of using various electrode arrangements for amplifying the EHD enhanced heat transfer in a smooth channel, Journal of Electrostatics, 71(4) (2013) 656-665.

[3] T.-H. Wang, M. Peng, X.-D. Wang, W.-M. Yan, Investigation of heat transfer enhancement by electrohydrodynamics in a double-wall-heated channel, International Journal of Heat and Mass Transfer, 113 (2017) 373-383.

[4] Chang, L.M., Wang, L.B., Song, K.W., Sun, D.L. L.-M. Chang, L.-B. Wang, K.-W. Song, D.-L. Sun, J.-F. Fan, Numerical study of the relationship between heat transfer enhancement and absolute vorticity flux along main flow direction in a channel formed by a flat tube bank fin with vortex generators, International Journal of Heat and Mass Transfer, 52(7-8) (2009) 1794-1801.

[5] K.-W. Song, L.-B. Wang, The effectiveness of secondary flow produced by vortex generators mounted on both surfaces of the fin to enhance heat transfer in a flat tube bank fin heat exchanger, Journal of Heat Transfer, 135(4) (2013) 041902.