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The Numerical Simulation of the Effect of the Location of Impinging Jets on the Convective Heat Transfer from a Cylindrical Concave Surface

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1- Introduction

In today's industry, one of the relatively modern and effective methods for cooling hot parts is impingement heat transfer. Impinging jets have attracted a great deal of attention from researchers due to having a high heat transfer rate.

In this method, by applying a considerable momentum to a fluid exiting from a nozzle and then forming a thin hydrodynamic and thermal layer on the impinging surface, considerable improvement was obtained in the increase of mass, heat, and momentum transfer.

The main application of impinging jets to concave surfaces is related to cooling of inferior front surface of turbine blade, which is heavily influenced by hot gasses and its need for cooling. Extensive studies have been conducted on the effective parameters for flow and heat transfer in single jets or an array of jets.

2- Geometry and Boundary Conditions

Fig. 1 shows the computational domain and boundary condition of the present study. The impinging surface was in a semi-cylindrical shape with the diameter of 100 mm and length of 28 times of the jet diameter, which was extended in the direction of z-axis by two flat plates with the width of 50 mm and the length of 28mm.

The tube length of the jets was considered so long that the flow exiting from the jets could be completely developed.

In the experimental study, a supporting plate was placed in the outlet of the jets, which prevented their vibration (due to high velocity of the outlet fluid) and impingement of the returning flow towards the wall of the jets. In this study, this supporting plate was considered with the same length as a concave surface and width of 30 mm.

Velocity boundary condition was considered at the inlet of jets. Inlet air temperature of jets and turbulence intensity at their inlet were 298 K and 5%, respectively.

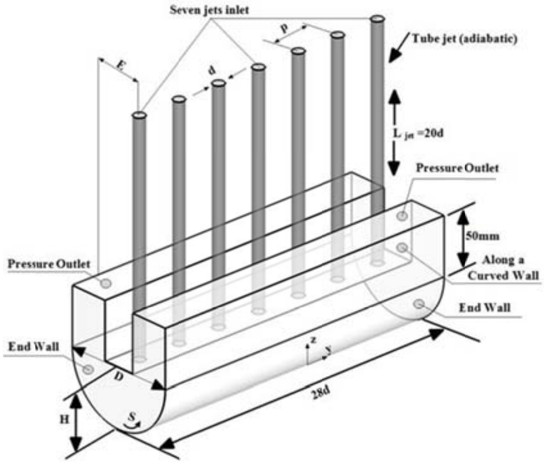

Fig. 1. Geometry and boundary conditions of the present study

3- Discussion of Results

In order to investigate the validity of the numerical solution, the Nusselt number distribution in the Reynolds number 23000 obtained in this study was compared with the experimental results. The SST k-ω model predicts the turbulence kinematic energy and intensity lower than those of other models, and it seems that this is the best option for investigating the behavior of impinging jets on the concave surface due to its 11.47% error in the Nusselt number prediction in the impinging point and acceptable prediction of the Nusselt number distribution behavior along the curve.

The decrease in the distance among the center of jets and the outer edge of the concave surface (E/d) resulted in the increase in the kinematic energy of the impinging point. Therefore, it caused that by decreasing E/d from 5 to 2 in the Reynolds number 40000, the Nusselt number in the impinging point increases to 21%. It should be noted that according to Fig. 2, the averaged Nusselt number of the whole concave surface decreases to 6.49% as E/d decreases.

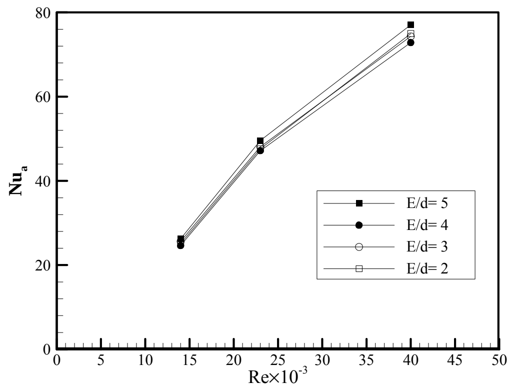

Fig.2. Average Nusselt Number on the concave surface, $C_r = 0.1$

The results also show that by increasing the relative curvature from 0.1 to 0.15, no significant change occurs quantitatively and qualitatively in the Nusselt number distribution in the impinging point and along the curve.

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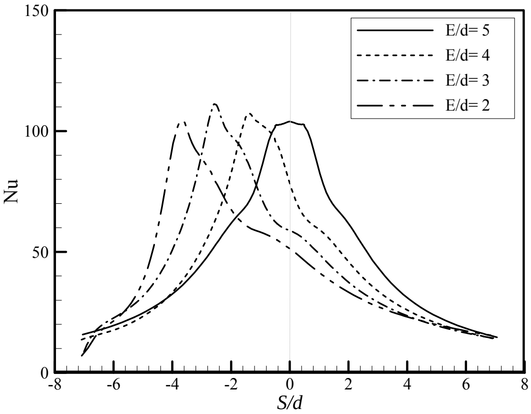
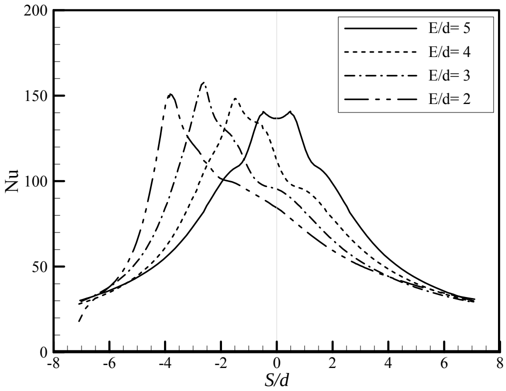
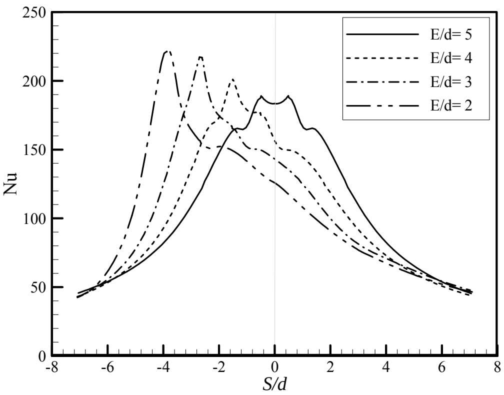
Fig. 3 shows the effect of Reynolds number on the local Nusselt number distribution along S-axis.



(a) Re= 14000



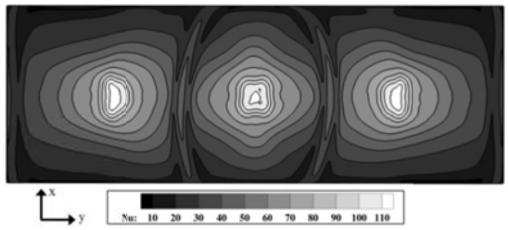
(b) Re= 23000



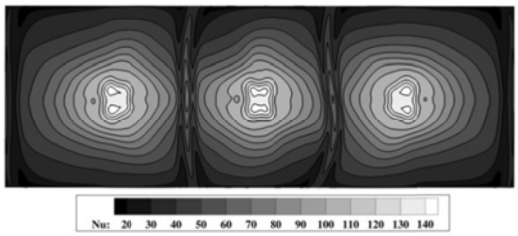
(c) Re= 40000

Fig. 3. Nusselt number distribution on the concave surface for different E/d

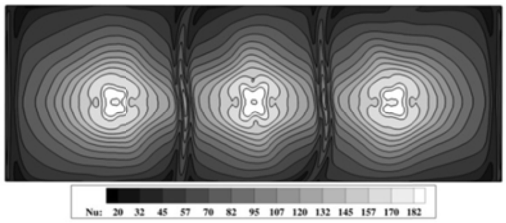
The results demonstrated that, for the case where E/d=5.0, distribution of the Nusselt number along s-axis was completely symmetrical and, at Reynolds of 23,000 and 40,000, the maximum Nusselt number occurred further away from the impinging point. By decreasing E/d ratio, the maximum value of the Nusselt number occurring at the impinging point deviated to the upstream direction. In Fig. 4, the distribution of the Nusselt number is compared for different Reynolds numbers.



(a) Re= 14000



(a) Re= 23000



(a) Re= 40000

Fig. 4. Nusselt number contours on the concave surface

4- Discussion of Results

In this study, we discuss the effect of the horizontal movement of impinging jets on the convective heat transfer from a cylindrical concave surface. The results of the present study show that the decrease in the distance of the jets' center to the outlet edge of the concave surface lead to the transfer of the maximum amount of the Nusselt number to the upstream flow. And the approach of the main flow of the jet to the recirculation region formed in the upstream flow results in increase in the turbulent kinetic energy of this area and the Nusselt number in the stagnation point so that for the Reynolds number 40000, with decreasing the distance of the center of the jets to the outlet edge of the concave surface, the 21 % increase in the Nusselt number was achieved with respect to the reference state. This is while by increasing the relative curvature of 0.1 to 0.15, no significant increase has been observed for the Nusselt number at the impinging point.