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Numerical Simulation on Heat Transfer Enhancement in Channel by Triangular Ribs

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***Abstract*—**Turbulent heat transfer to fluid flow through channel with triangular ribs of different angles are presented in this paper. Ansys 14 ICEM and Ansys 14 Fluent are used for meshing process and solving Navier stokes equations respectively. In this investigation three angles of triangular ribs with the range of Reynolds number varied from 20000 to 60000 at constant surface temperature are considered. The results show that the Nusselt number increases with the increase of Reynolds number for all cases at constant surface temperature. According to the profile of local Nusselt number on ribs walled of channel, the peak is at the midpoint between the two ribs. The maximum value of average Nusselt number is obtained for triangular ribs of angel 60° and at Reynolds number of 60000 compared to the Nusselt number for the ribs of angel 90° and 45° and at same Reynolds number. The recirculation regions generated by the ribs corresponding to the velocity streamline show the largest recirculation region at triangular ribs of angle 60° which also provides the highest enhancement of heat transfer.

***Keywords*—**Ribs channel, Turbulent flow, Heat transfer enhancement, Recirculation flow.

I. Introduction

REQUIRMENT of enhancement of heat transfer in thermal systems is very important for saving energy therefore, there are many investigations with different technique are presented. Reconfiguration of geometry is one of the methods to increase efficiency of heat exchangers and saving costs and energy. There are many investigations have been performed to study the influence of ribs in the channel on improvement of heat transfer. Perry et al. [1] can be considered as the pioneer researchers studied the effect of rib roughness on turbulent boundary layer flow where different pitch-to-height ratios of square ribs were used in their investigations. The results indicated that the separation flow is mixed with the reattachment flow at the large rib pitch. Durst et al. [2] presented experimental and computational study of turbulent flow in channel with two ribs by using laser-Doppler velocimeter. They observe that the increase in Reynolds number and blockage ratio of ribs leads to increase of separation flow before and after the ribs. Turbulent heat transfer augmentation and friction factors through a rectangular channel with square, triangular and semi-circular ribs were experimentally studied by Liou and Hwang [3], [4]. The higher augmentation of heat transfer was observed for square ribs compared to the triangular and semi-circular ribs. The effects of space between the ribs on heat transfer and friction factors have been experimentally investigated by Zhang et al. [5]. They have used two opposite ribbed walls channel with pitch to height ratios varied from 8 to 30. It can be seen that the increase ratio of pitch to height caused a decrease in heat transfer and friction factor. Murata and Mochizuki [6] have used large eddy simulation to study the enhancement of heat transfer in a square duct with different positions of rib on the wall and have noticed higher heat transfer coefficient occurred at the midpoint of ribs due to recirculation flow at that point. Ahn et al. [7] have numerically studied the heat transfer and flow in a channel with square and semicircle ribs by large eddy simulation method. They obtained results of augmentation of heat transfer due to vortices created by ribs. Tanda [8] had performed a study on heat transfer in rectangular channels with transverse and v-shaped broken ribs. They found that the higher augmentation of heat transfer was at v- broken ribs compared to the continuous ribs. Also, Sri Harsha et al. [9], Promvonge [10], and Gupta et al. [11] observed that the maximum enhancement of heat transfer occurred with V-broken ribs compared to other ribs used in their investigations. Thianpong et al. [12] have experimentally studied the turbulent heat transfer and friction factor for air flow in channels with triangular ribs. Different aspect ratios between the heights of channel and ribs are used with Reynolds number range from 5000 to 22,000. They obtained higher of Nusselt number and fraction factor for in-line rib arrangement compared to staggered ribs.

Caliskan and Baskaya [13] used triangular ribs with different orientations (convergent-divergent) to study heat transfer from impinging jet array. They have noticed increase in average Nusselt number from 4% to 26.6% at V-SR arrangement compared to the smooth plate.

The aim of this paper is to study enhancement of heat transfer and turbulent water flow in channels with triangular ribs placed at different angles.

II. Geometry Model and Mathematical Description

Fig. 1 shows the geometry which has been considered in this simulation to study effect of ribs on heat transfer and friction factor. The total length of channel is 250mm and 10

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mm height, the space between the ribs is 20mm, the bottom and the top of the channel is heated at 313 K. Three shapes of triangular ribs according to the angles and aspect ratio are presented with Reynolds number range varied from 20000 to 60000.

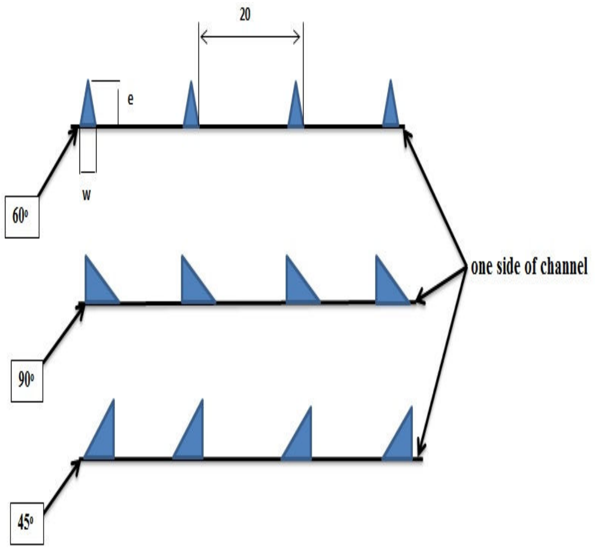


Fig. 1 Geometry domain

The numerical simulation was conducted by the Ansys14 ICEM for meshing process and Ansys 14 Fluent for solving the equations. The continuity, momentum, and energy equations are solved with the assumptions of two dimensional, steady state, and turbulent flow, and the working fluid is water. The general form of Navier stokes equations used in this simulation are presented by (1)-(5).

$$\frac{\partial}{\partial x_i}(\rho u_i) = 0 \quad (1)$$

$$\frac{\partial}{\partial x_j}(\rho u_i u_j) = -\frac{\partial P}{\partial x_i} + \frac{\partial}{\partial x_i}\left[\mu\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_i}{\partial x_j}\right)\right] + \frac{\partial}{\partial x_j}\left(-\rho\overline{u_i' u_j'}\right) \quad (2)$$

$$\frac{\partial}{\partial x_i}[u_i(\rho E + P)] = \frac{\partial}{\partial x_j}\left[\left(\lambda + \frac{c p \mu_t}{Pr_t}\right)\frac{\partial T}{\partial x_j} + u_i(\tau_{ij})_{eff}\right] \quad (3)$$

where

$$-\rho\overline{u_i' u_j'} = \mu_t\left(\frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j}\right) - \frac{2}{3}k\delta_{ij} \quad (4)$$

The k-ω Model for shear stress transport (SST) is employed in the simulation where the transport equations in this model are presented by (5), (6).

$$\frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left(\Gamma_k \frac{\partial k}{\partial x_j}\right) + G_k - Y_k \quad (5)$$

$$\frac{\partial}{\partial x_i}(\rho\omega k u_i) = \frac{\partial}{\partial x_j}\left(\Gamma_\omega \frac{\partial \omega}{\partial x_j}\right) + G_\omega - Y_\omega + D_\omega \quad (6)$$

where, G_k is defined as the generation of turbulent kinetic energy by mean velocity gradients, G_ω is defined as the generation of ω, Y_k, and Y_ω which represents the dissipation of k and ω by turbulence, D_ω refers the diffusion term.

The Reynolds number is calculated based on hydraulic diameter (D_h) as equal to 2H of the step height of channel

$$Re = \frac{u_{av} D_h}{v} \quad (7)$$

and the Nusselt number is determined by (8)

$$Nu_{av} = \frac{h_{av} D_h}{k} \quad (8)$$

III. Numerical Simulation and Grid Independent

A second order upwind scheme for momentum and energy equations were considered with SIMPLE coupling for couple velocity and pressure drop. In order to increase the accuracy of results the residual for the energy and velocity components were adjusted to 10-11 and 10-8, respectively. Grid independent investigation was achieved at the Reynolds number 20000 for case 2 by increasing number of elements through the meshing process. The grid number 2 was adopted because the difference in calculated values of average Nusselt numbers between grid 2 and 3 is less than 1% therefore, the Grid number 2 can be considering in calculations following grid independent study as shown in Table I.

TABLE I
Grid Independent at Re=20000 for Case 2

Grid	Number of grid nodes	Nuav
1	19000	2681.58276
2	37616	2683.802931
3	42688	2684.446277

IV. Results and Discussions

A. Effect of Reynolds Number

Figs. 2-4 show variation of local Nusselt number with the axial distance for triangular ribs of 90°, 60°, and 45°angles and Reynolds number s of 20000, 30000, 40000, 50000, and 60000 at the surface temperature of 313 K. It can be seen that the Nusselt number increases with the increase of Reynolds number along the whole channel and that increment was occurred for all the rib types used in the present study.

B. Effect of Ribs

Effect of angles and aspect ratios of ribs on variation of local Nusselt number at the Reynolds number of 60000 are presented in Fig. 5. The result shows increase of Nusselt number before and after ribs where the peak of Nusselt number observed at the midpoint between the ribs. Due to pressure drop and recirculation flow created by the ribs the heat transfer performance was improved compared to the smooth channel.

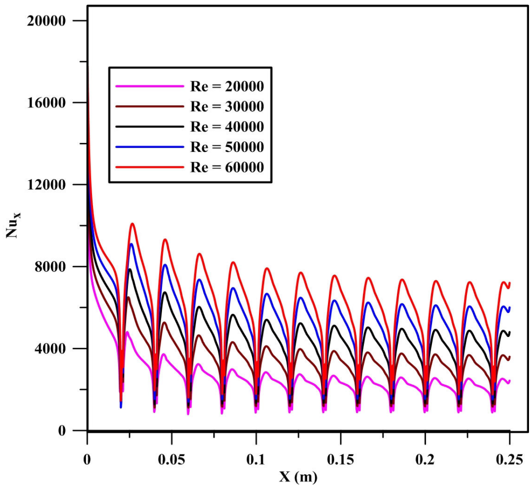


Fig. 2 Variation of local Nusselt number with different Reynolds number at ribs angle 60°

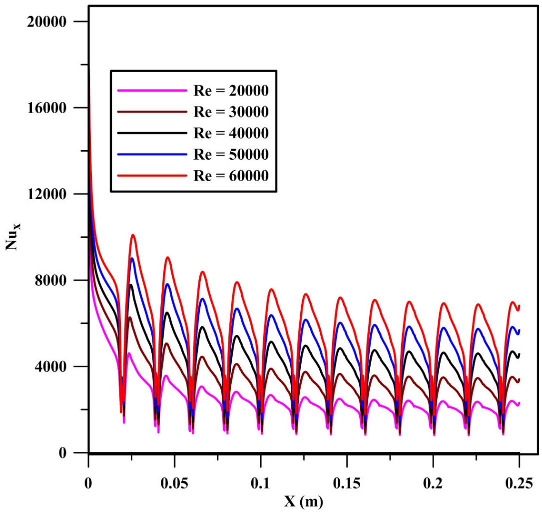


Fig. 3 Variation of local Nusselt number with different Reynolds number at ribs angle 45°

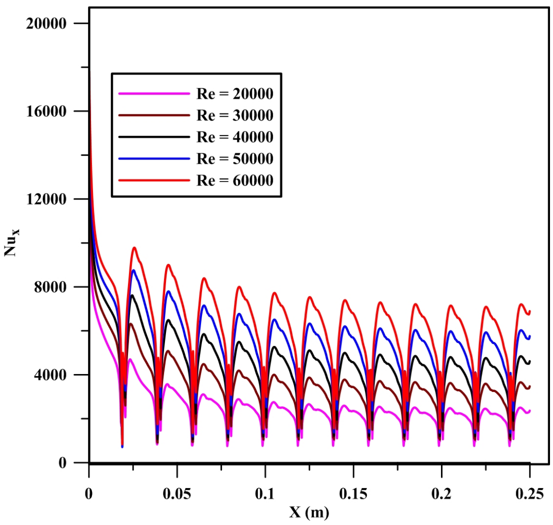


Fig. 4 Variation of local Nusselt number with different Reynolds number at ribs angle 90°

C. Average Nusselt Number

Fig. 6 shows the comparison of average Nusselt number between smooth and ribbed channel for all the Reynolds numbers. The general trend indicates that the average Nusselt number increases with the use of ribs and increase of the Reynolds number. Higher enhancement of heat transfer was obtained for the triangular ribs of 60° angle compared to other types of ribs at the Reynolds number of 60000.

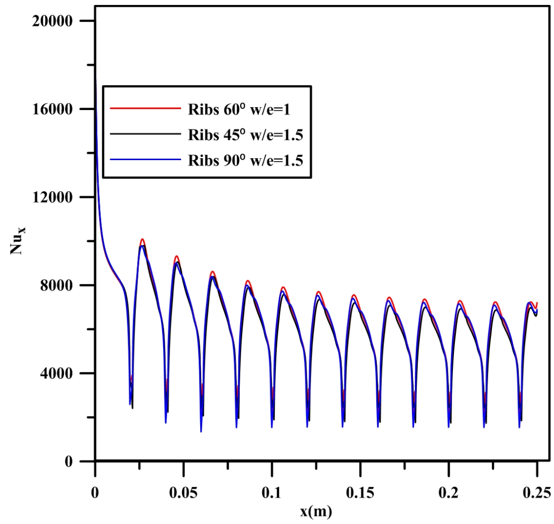


Fig. 5 Effect of angles and aspect ratio of ribs on variation of local Nusselt number for Reynolds number of 60000

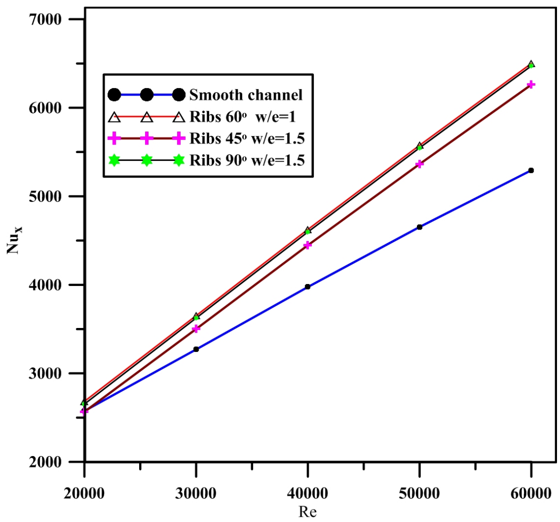
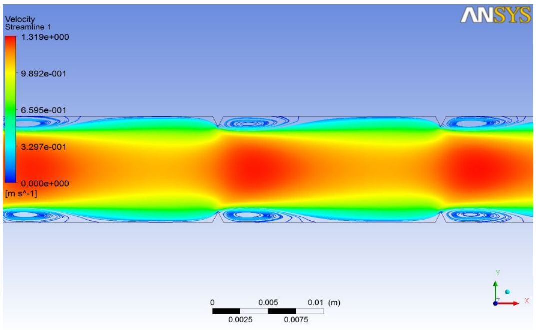


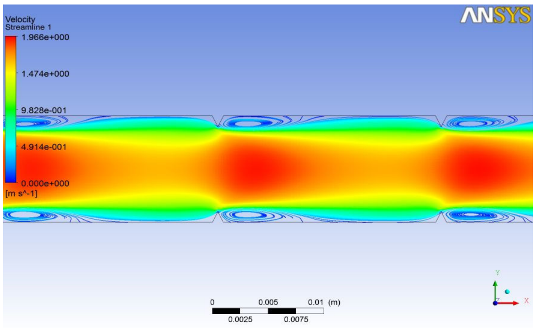
Fig. 6 Comparison of average Nusselt number

D. Velocity Streamline

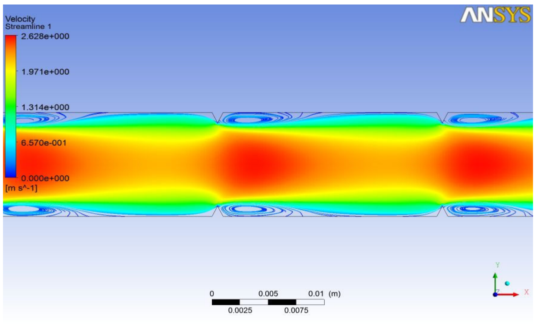
Streamline of velocities for triangular ribs of angle 60°at different Reynolds numbers are illustrated in Figs. 7 (A)-(E). It can be seen that the recirculation regions developed by the ribs are increased with the increasing of the Reynolds number. Fig. 8 represents the compression between the velocity streamlines for the ribs 90°, 60°, and 45° angles at the Reynolds number of 60000 and observed the biggest recirculation regions at the rib angle of 60°which leads to the highest augmentation of heat transfer rate.



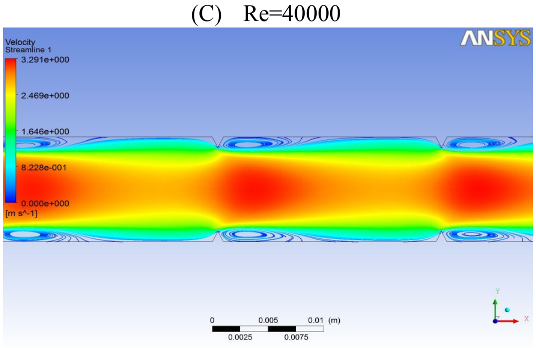
(A) Re=20000



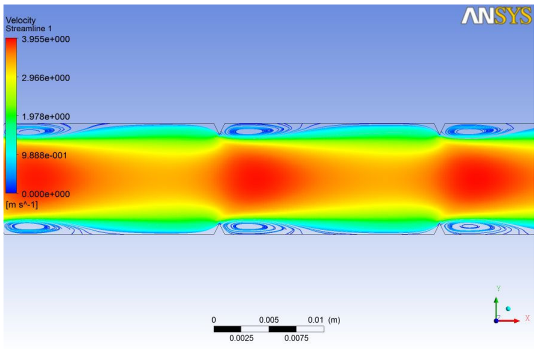
(B) Re=30000



(C) Re=40000



(D) Re=50000



(E) Re=60000

Fig. 7 Velocity of streamline with different Reynolds number for Triangular ribs angle 60°

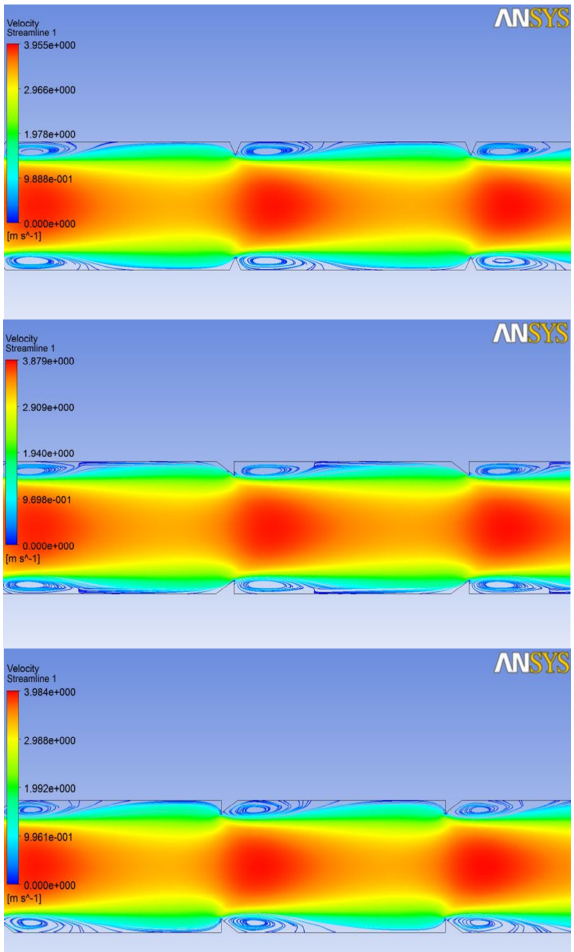


Fig. 8 Compression between velocity streamline for ribs 90°, 60°, and 45° angles at Reynolds number 60000

V. Conclusion

Simulation study on heat transfer to water flow in ribbed channel with different angles is conducted in the present study. Generally, the Nusselt number increases with the use of ribs on wall of the channel compared to the smooth channel. The results indicate that the Nusselt number increases with the increase of Reynolds number for all the rib angles and greatest improvement of heat transfer is observed at the Reynolds number of 60000 for the ribs angle 60° compared to other types of rib. Recirculation flow created between the ribs is significant to improve the Nusselt number.

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NOMENCLATURE

Cp	Specific heat, J/kg k
e	Rib height, m
Nu	Nusselt number
P	Pressure, Pa
Pr	Prandtl number
Re	Reynolds number
T	Temperature, K
u, v	Axial velocity
w	Rib width, m
x, y	Cartesian coordinates, m
Greek symbols	
δ	Kronecher delta function
μ	Dynamic viscosity. Pa s
ρ	Density, kg/m^3
σ	Turbulent Prandtl number
τ	Wall shear stress, kg/m^2
ω	Rate of dissipated turbulent kinetic energy

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