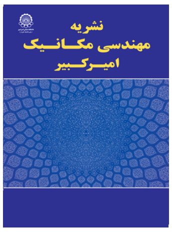

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Experimental investigation of heat transfer and pressure drop in perforated ribs in the solar air heater channel

F. Mirali, E. Mohammadi, M. Ansari, M. Bazargan*

Mechanical Engineering Department, K.N. Toosi University of Technology, Tehran, Iran

ABSTRACT: In the present study, heat transfer and pressure drop inside the square channel are investigated experimentally with perforated ribs. The Reynolds range was between 15000 and 50,000. The ratio of ribs height to channel hydraulic diameter was 0.1 and 0.13 and ribs pitch to height ratio was 20, 25, and 30, respectively. The ratio of hole diameter to rib height was 0.3 and 0.5, respectively. The results obtained from the experimental setup developed in the laboratory compared with the results of previous studies, which confirmed the accuracy of the experimental results. The results show that the use of ribs in the channel surfaces results in a significant improvement in the heat transfer rate in the canal as well as an increase in the pressure drop. The perforated ribs resulted in less pressure drop, however, the Nusselt decreased. As well The effect of perforation on the indentation was more evident in the smaller pitch ratio. The results show that in applications where there is a need to lower the wall temperature or increase the heat transfer and the blower energy consumption is less important, using holes in the ribs, the performance of the relevant system such as gas turbine or heaters can be improved.

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1- Introduction

Enhancing heat transfer is being extensively applied in the applications like cooling turbine blades and solar air heaters. There are two general methods to attain such objectives, active and passive. One of the most effective passive ways is putting ribs on the heated surfaces. In spite of the mechanism of using fins which is extending the heat transfer surface, ribs improve the heat transfer coefficient with the mechanism of breaking down the boundary layer which acts as thermal resistance and redeveloping it through the channel and making the near-the-wall flow regime more turbulent which promotes heat transfer dissipation from near the wall to the mainstream of the flow. Using the ribs usually has two opposite effects. Although the presence of the ribs enhances heat transfer significantly, which is preferable, it also leads to a higher pressure drop.

Han et al. [1] investigated different angles of attack and pitch to height aspect ratios in a Reynold range between 7000 to 90000. They found out that the best thermal performance is achieved using ribs with an angle of attack of 30, and 45 degrees. Jin et al. [2] numerically investigated heat transfer on the absorber plate of a solar air heater duct with multi V-shaped ribs. They claimed that increasing the pitch ratio results in declining the Nusselt number, friction factor, and thermal performance. Increasing the height of the ribs improves the average Nusselt number and friction factor, however, thermal performance decreases. The maximum Nusselt number and thermal performance is achieved in the angle of attack of 45 degrees and the maximum pressure drop happens in the angle of attack of 60 degrees. Liou et al. [3] investigated the effect of the relative roughness pitch and relative roughness height in a Reynold range between 5000 to 5400. They observed that increasing relative roughness height, in a fixed Reynolds number, results in a reduction of the Nusselt number and friction factor. These parameters also decreased in higher relative roughness pitch within fixed relative roughness height. Tanda et al. [4] experimentally investigated the effect of rib spacing on heat transfer and friction factor in a rectangular channel by installing the ribs on one and two surfaces of the channel, in a Reynolds range between 9000 to 35500. The experiments indicated, when the gap between the ribs is large, the Nusselt number behind each rib is starting to increase to a maximum at one point. The maximum heat transfer performance was carried out at the relative roughness pitch for the one and two sides ribbed wall channel. Chang et al. [5] studied the effect of relative roughness height. They fixed the height of the ribs as well as the width of the duct, varying the height of it. They did their investigations in fixed Reynolds number and fixed mass flow rate. They concluded that in a fixed mass flow rate, reducing the height of the channel results in better heat transfer and a fixed Reynolds number. Desrues et al. [6] numerically studied heat transfer and pressure drop in a channel with alternated opposed ribs in a Reynolds number ranging from

*Corresponding author's email: : bazargan@kntu.ac.ir

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Fig. 1. The elements of the test rig and the perforated rib

75 to 2000. They found that although the friction factor rises monotonically with the increase of the Reynolds number, this happens about the heat transfer only for Reynolds numbers greater than a critical value. Ansari and Bazargan [7] investigated the effect of ribs in improving the performance of solar air heaters and optimizing geometric parameters of the ribs. They developed a mathematical model of a solar air heater using the genetic algorithm to optimize geometry and the layout of the ribs. They could improve thermal efficiency by 9%. They validated their result with the semi-empirical correlation given by Han and Park [8].

2- Methodology

The present research is based on experimental measurements. In order to analyze the experimental observations, the effective physical parameters and processes influencing heat transfer and pressure drop have been analyzed and described.

An experimental setup has been designed and constructed at the K. N. Toosi University of Technology so that heat transfer and pressure drop could be studied experimentally.

In order to do the data reduction process and comparing the different conditions based on significant values, after measuring the surface temperature along the channel and the rate of pressure drop at the beginning and end of the channel, the average Nusselt number and friction factor were calculated using Eqs (1) and (2), respectively:

$$\bar{f} = \frac{\Delta p}{4\left(\frac{L}{D}\right)\left(\frac{G^2}{\rho g}\right)} \quad (1)$$

$$Nu = \left(\frac{q''}{\bar{T}_w - \bar{T}_b}\right)\left(\frac{D}{k}\right) \quad (2)$$

In the presented equations Δp is the pressure difference in the inlet and outlet which is the pressure drop of the channel, L and D are the length of the channel and the hydraulic diameter of the channel respectively, G and ρ are the inlet mass flow rate and the density of the air, q'' is the heat flux per unit area, $\bar{T}_w$ and $\bar{T}_b$ are the average wall temperature and average bulk temperature respectively, and k is the conduction heat transfer coefficient, lastly f and Nu are pressure drop coefficient and Nusselt number respectively.

3- Results and Discussion

The present study consists of an experimental investigation on the effect of perforation on the ribs. The ribs were studied with a height of 10 and 8mm. In each case, three different pitches of ribs layout with single perforated rib and three-perforated ribs considered, besides the ratio of diameter perforation to the height of ribs 0.3 and 0.5 was investigated in Reynolds range between 15000 and 50000. It was concluded that in ribs with higher height, perforation makes pressure drop decrease significantly. Using three perforations on the ribs with perforation diameter to height of rib ratio of 0.5 makes frication factor a reduction of 30%. On the other hand, the Nusselt number is reduced by 20%. The interesting point is that the maximum decrease of friction factor belongs to the ribs with a height of 10 mm and three perforations with the ratio of perforation diameter to rib height of 0.5, however, the Nusselt number is reduced approximately by 10%. This point shows the positive effect of perforation on the ribs with higher height. It was observed that the rate of decrease of friction factor is almost independent of the ribs pitch. Hence, at shorter pitches, the application of the perforated ribs will be more justified.

4- Conclusions

The solar air heater performance would increase significantly, using perforated ribs with higher height. Also, a reduction in pressure drop factor would lead to a decrease in power usage of the air handling system. Although creating perforation on ribs, compared to simple ribs, would decrease the rate of heat transfer to some extent, but the pressure drop decreases notably. In order to apply such a method, the system on which the ribs will be assembled should be modeled and investigated in terms of technical and economic justification, otherwise, especially in the case of shorter ribs, it won't have any advantage compared to simple ribs.

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