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A REVIEW- ENHANCEMENT OF HEAT TRANSFER IN A SOLAR AIR HEATER HAVING RIB ROUGHNESS

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ABSTRACT

Artificial roughness in the form of repeated ribs is one of the effective way of improving the performance of a solar air heater ducts. Various studies have been carried out to determine the effect of different artificial roughness geometries on heat transfer and friction characteristics in solar air heater ducts. The objective of this paper is to review various studies, in which different artificial roughness elements are used to enhance the heat transfer coefficient with little penalty of friction factor. The present paper is a review of research work on heat transfer enhancement in a rectangular duct with rib turbulators. Detailed information about the heat transfer and flow characteristics in ribbed ducts is very important in proper designing of rectangular ducts, heat exchangers and cooling systems of gas turbine engines. The application of rib turbulator in the form of fine wires of different shapes has been recommended to enhance the heat transfer coefficient by several investigators. It has been found that the main thermal resistance to the convective heat transfer is due to the presence of laminar sub layer on the heat-transferring surface. The ribs break the laminar sub layer and create local wall turbulence due to flow separation and reattachment between consecutive ribs, which reduce the thermal resistance and greatly enhance the heat transfer. However, the use of rib turbulator results in higher friction and hence higher pumping power requirements.

Keywords: Solar air heart, Heat transfer enhancement, pressure drop, rib.

1. INTRODUCTION

In our environment, we are using various types of energy resources which have direct impact on our environment and global development. In recent years, it has been found that fossil fuel like coal, oil and natural gas causes more harm to the ecosystem in terms of air and water pollution, damage to public health, wildlife and in terms of global warming. Also, these fossil fuels are depleting and hence renewable energy emerges as clean and alternative energy source to meet the energy demands and a prime agent in economic development. Solar energy is available in ample amount on the surface of the earth in the form of the radiations. Solar energy can be used as a non-polluting reservoir of fuel and should be converted into thermal energy to make use of it in various heating applications. When the absorbing surface is perpendicular to the sun radiations, the average value of solar radiation evaluated as 1000 W/m^2. Among several existing methods of converting solar radiations into useful thermal energy, flat plate solar collectors are the most common types of solar collectors which are used in many applications such as solar water heater and solar air heater.

Solar air heaters are cheap because of their inherent simplicity and are widely applicable for many applications at low and moderate temperatures. The solar air heater is generally used in applications like drying of agricultural, textile and marine products, heating of building's space heating and in industrial HVAC systems.

A conventional solar air heater consists of;

- A flat-plate absorber which absorbs the solar energy.
- A transparent cover(s) which allows solar radiations to pass through and hence reduces heat losses from absorber plate.
- A heat-transport fluid (air) flowing through the collector to remove heat from the absorber.
- A heat insulating backing over the surrounding walls of the air heater. [1-2].

2. HEAT TRANSFER ENHANCEMENT BY RIBS

Efforts for improving the heat transfer rate have been directed towards artificially destroying or disturbing the viscous sub-layer by providing the artificial roughness on heated surface. Many experimental investigations have been carried out to study the flow field and characteristics of heat transfer and friction factor of roughened tubes, annuli and. The present paper contributes for review of rib turbulators for heat transfer enhancement. The main objective of this paper is to review the work carried on rectangular duct having different types of rib turbulators. Heat transfer enhancement by inserting ribs is commonly used application in tubes and ducts. Ribs improve the heat transfer by interrupting the wall sub layer. This yields flow turbulence, separation and reattachment leading to higher heat transfer rates. Due to the existence of ribs effective heat transfer surface increases. Many researchers have been carried out on heat transfer enhancement achieved by different ribs.

Webb et al. [3] covering a wide range of e/Dh ratio with P/e values of more than 10 was used in his experiments in flow through pipes where the ribs were aligned normal to the main stream direction. Firth and Mayer [4] investigated heat transfer and friction factor performance of four different types of artificially roughened surfaces with square transverse rib, helical rib, trapezoidal transverse ribs and three, dimensional surfaces in gas cooled reactor. The experiments conducted with roughness in one wall of absorber plate, two walls and four walls. The roughness element in one wall is favored by most of the investigators as discussed below in the range of Re=3000 to 30000. Different correlations for heat transfer and friction factor were developed based on the experiments done by different investigators.

Bhargava and Rizzi [5] demonstrated that the efficiency of solar air heaters can be increased by increasing the channel depth along length. Hegazy [6] optimized the channel height of different types of solar air heater. Han and Park [7] investigated the effects of rib shape, angle of attack and pitch to height ratio on friction factor and heat-transfer on symmetric and staggered ribs. They found that the ribs at 45^0 of attack angle have better performance than at 90^0 attack angle and sand grain roughness. Hsieh et al. [8] investigated on the combined effects of the rib, angle-of-attack ($\alpha = 90^0$, 60^0, 45^0 and 30^0) and the channel aspect ratio (W/H = 1, 2 and 4) on the heat transfer coefficient in short rectangular channels (L/D = 10 and 15) with two opposite rib-roughened walls. They concluded that the highest heat transfer and the highest pressure drop can be obtained at α = 60' in the square channel; the highest heat transfer and pressure drop occur at $\alpha = 90^0$ with W/H = 4 in the rectangular channel and the values of highest heat transfer and pressure drop differs marginally at $\alpha = 60^0$ for W/H = 2. The Heat transfer and friction correlations were also obtained for the surface. Hong and Hseish [9] investigated effects of aspect ratio (W/H) = 1, 2, Reynolds number (Nu) 63.5 < Re < 254 and the initial boundary layer thickness on low speed forced convective heat transfer near two dimensional transverse ribs. They also derived the correlation for average Nusselt number. Hwang and Liou [10] investigated for turbulent flow on staggered ribs in a square duct with two opposite rib-roughened walls using the parameters e/D_H = 0.19; p/e = 5.31 and Re= 13000 to 130000.The temperature distribution and correlations between Nusselt number and Reynolds number was established. The heat transfer rate was calculated to be 2.02-4.60 times higher than fully developed turbulent flow in smooth duct for Re = 13000. Gao and Sunden [11] investigated the heat transfer and pressure drop in a rectangular duct with staggered ribs of parameters aspect ratio (W/H) = 1 to 8; relative roughness height (e/D_H) = 0.06; angle of attack (α) = 60^0; Reynolds number (Re) = 1000 to 6000. They observed that secondary flow causes span wise variation of heat transfer coefficient along the rib length and reattachment occurs between two ribs. They concluded that the V downstream ribs induce highest friction factor then V upstream and then parallel ribs with least friction factor. Also V downstream has stronger secondary flow and gives higher heat transfer when compared to V upstream and parallel ribs and parallel ribs has better performance at higher Reynolds number than V upstream. Murata and Mochizuki [12] investigated on laminar and turbulent flow with transverse or angled rib turbulators of 60^0 or 90^0 in a square channel. They concluded that heat transfer is highest in front of the rib and laminar flow has lesser effect on flow field with ribs than turbulent flow as a result the velocity and temperature profiles have lesser differences than turbulent case. Ahn [13] investigated on five different types of roughness element in rectangular duct with e/D_H =0.0476, P/e=8, and W/H=2.33, to understand the comparative thermo-hydraulic performance due to these elements.They concluded that the triangular rib has the highest heat transfer capacity and Nusselt number is higher in the case of square and triangular ribs when compared to semicircular ribs. The square ribs have the highest friction factor.

Chandra et al. [14] investigated the effect with varying number of with transverse ribbed walls with the parameters Re = 10,000 to 80,000; P/e = 8; e/D_H = 0.0625; L/D_h = 20 for fully turbulent flow in square channel. They concluded that one ribbed wall has the heat transfer increase of 2.43–1.78 (40% improvement) for Re = 12,000 to 75000, with two opposite ribbed walls the increment was 2.64 to1.92 (6% improvement), three ribbed walls has the increment of 2.81to 2.01 (5% improvement) and with four ribbed walls, an increment of 2.99 to 2.12 (7% improvement).The maximum increase in the friction factor was found to be 9.50 with four sided ribbed walls and minimum with one ribbed wall of 3.14.They also compared the performance factor $\{(St_r/St_{ss})/(f_r/f_{ss})\}$of four cases and concluded that ,it is highest at 1.78–1.17 for one wall ribbed surface. Tanda [15] investigated for heat transfer coefficient distribution in rectangular channel with transverse continuous, transverse broken and V-shaped broken ribs with the parameters W/H = 5;α = 45^0 or 60^0. Liquid crystal thermography was applied to the study of heat transfer from the ribbed surface. He found the maximum performance of continuous transverse ribs, 45^0 V-shaped ribs and 60^0 V-shaped ribs at the optimum value of P/e = 13.3, transverse broken ribs with P/e = 4 and 8 give the higher heat transfer augmentation. Transverse broken ribs with P/e = 4 and 13.3 gives best thermal performance and transverse continuous ribs again with P/e = 4 and 8 gives lesser heat transfer increment.Tariq et al. [16] investigated the heat transfer and flow characteristics in the entrance section of a rectangular channel with one and two solid ribs at the bottom surface. They used hot wire anemometry (HWA) and resistance thermometry (RTD) for measuring the velocity and temperature and Liquid crystal thermography (LCT) to trace temperature profiles , heat transfer coefficient evaluation and Nusselt number calculation. The various parameters used are Re = 2.09 x 10^4; P/e = 10.They compared the results of experimentation and theoretical energy balance and found similar performance under the given range of data selected. Won and Ligrani [17] compared the thermo-physical characteristics in channels with parallel and cross rib turbulators on two opposite surfaces with the parameters Reynolds number based on channel height (Re_H)= 480 to 18300; W/H = 4; $\alpha = 45^0$; $e/D_H = 0.078$; P/e = 10.They found that Nusselt number is almost same for crossed and parallel-ribs, local. Nusselt numbers for parallel-rib are significantly higher than crossed-rib and pressure loss is higher in central part of the channel. Wang and Sunden [18] performed investigation of heat transfer and fluid flow in rectangular channel with broken V-shaped up ribs using crystal thermography (LCT) and particle image Velocimetry (PIV) teqniques using the parameters $e/D_h$of 0.06; P/e was kept to 10; $\alpha = 60^0$; W/H = 1/8. They concluded that the performance in heat transfer is higher than the continuous ribs bur with more friction loss.

Bopche and Tandale [19] used artificial roughness in the form of specially prepared inverted U-shaped turbulators on the absorber surface of an air heater duct. As compared to the smooth duct, the turbulator roughened duct enhanced the heat transfer and friction factor by 2.82 and 3.72 times, respectively. At low Reynolds number too (Re < 5000) where ribs were inefficient. At Reynolds number, Re = 3800, the maximum enhancement in Nusselt number and friction factor were of the order of 2.388 and 2.50, respectively.

Hans et al. [20] carried out an experimental investigation to study the effect of multiple v-rib roughness on heat transfer coefficient and friction factor in an artificially roughened solar air heater duct. The experiment encompassed Reynolds number (Re) from 2000 to 20000, relative roughness height (e/D) values of 0.019–0.043, relative roughness pitch (P/e) range of 6–12, angle of attack (α) range of 30^o–75^o and relative roughness width (W/w) range of 1–10. Correlations for Nusselt number and friction factor in terms of roughness geometry and flow parameters were developed. A maximum enhancement of Nusselt number and friction factor due to presence of such an artificial roughness was found to be 6 and 5 times, respectively, in comparison to the smooth duct for the range of parameters considered. Lanjewar et al.

[21] carried out an experimental investigation of heat transfer and friction factor characteristics of rectangular duct roughened with W-shaped ribs on its underside on one broad wall arranged at an inclination with respect to flow direction. Maximum enhancement of Nusselt number and friction factor as a result of providing artificial roughness was found to be respectively 2.36 and 2.01 times that of smooth duct for an angle of attack of 60^o. Maximum thermo-hydraulic performance occurred at an angle of attack of 60^o. Correlations were developed for heat transfer coefficient and friction factor for roughened duct. Chaudhary et al.

[22] carried out an experimental investigation of heat transfer and friction factor characteristics of a solar air heater duct having M-shaped geometry as roughness elements on absorber plate. The range of parameters were; Reynolds number range from 3000-22000, relative roughness height (e/D) of 0.037-0.0776, relative roughness pitch (P/e) of 12.5-75 and angle of attack (α) of 30-60°. It was found that providing the artificial roughness of M shape increased heat transfer upto 1.7-1.8 times over the smooth duct. The maximum value of Nusselt number attained corresponding to e/D, P/e and α were 0.0777, 25 and 60 respectively. Sharma and Thakur [23] conducted a CFD study to investigate the heat transfer and friction loss characteristics in a solar air heater having attachments of V-shaped ribs roughness at 60^o relative to flow direction pointing downstream on underside of the absorber plate. The computations based on the finite volume method with the SIMPLE algorithm were conducted for the air flow in terms of Reynolds numbers ranging from 5000-15000.

Prasad et al. [24] carried out experimental work and optimal thermo hydraulic performance of three sides artificially roughened solar air heater of high aspect ratio has been analyzed. For a particular set of values of roughness and flow parameters the optimal thermo hydraulic performance condition always corresponds to an optimal value of roughness Reynolds number.

3. CONCLUSION

In the present paper an attempt has been made to review heat transfer and friction characteristics of artificially roughened duct of solar air heaters. The concept of performance enhancement of roughened ducts has also been discussed. Based on the literature review following conclusions are drawn;

1. It has been found that roughness geometries being used in solar air heaters are of many types depending upon shapes, size, arrangement and orientations of roughness elements on the absorber plate.
2. General arrangement of different types of roughness geometries reported by the various investigators are fixing wires, rib formation by machining process, expanded metal mesh ribs, and creating Dimple shaped geometries.

3. Transverse rib roughness enhances the heat transfer coefficient by flow separation and generation of vortices on the upstream and downstream of rib and reattachment of flow in the inte-rrib spaces.
4. Angling of transverse rib further enhances the heat transfer on account of the movement of vortices along the rib and formation of a secondary flow cell which results in high heat flow region near the leading end. V-shaping of a long, angled rib helps in the formation of two secondary flow cells as compared to one in case of an angled rib resulting in still higher heat transfer rate.

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