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Heat Transfer Enhancement in a Rectangular Duct with Rib Turbulators

Research Article

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Abstract: The present paper is a review of research work on heat transfer enhancement in a rectangular duct withrib turbulators. In the present paper emphasis is given to works dealing with rib turbulators because according to the recent studies, these are known to be economic tool in the field of heat transfer enhancement. The use of rib turbulator has been found to be an efficient method of enhancing the heat transfer to fluid flowing in the rectangular duct. 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. The thermo-hydraulicperformance of rectangular duct withrib turbulatorsdepends on the various factorssuch as flow conditions, geometry of rib and different configurations.

Keywords: Heat transfer enhancement,pressure drop, rib turbulators.

1. Introduction

Nowadays, the high cost of energy and material has resulted in an increased effort aimed at producing efficient heat transfer equipments. The heat transfer rate can be enhanced by introducing the disturbance in the fluid flow (making and breaking thermal boundary layers) but in process industries pumping power may increase significantly and ultimately the pumping cost becomes high .Therefore to achieve the desired heat transfer rate in an existing heat exchange equipments at an economic pumping power, several techniques have been proposed in recent years and are discussed in further sections. Heat transfer augmentation techniques refer to different method used to increase rate of heat transfer without affecting much the overall performance of the system. These techniques are used in heat exchangers. Some of the applications of heat exchangers are in process industries, thermal power plant, air conditioning equipment, refrigerators, radars for space vehicles, automobiles etc. The Heat transfer enhancement in duct flow by inserts such as twisted tape, coil inserts/spirals, ribs and dimples is mainly due to flow blockages, partitioning of the flow and secondary flow. The flow blockages increase the pressure drop and leads to increased viscous effect because of reduced fluid flow area. The blockages also increase flow velocity and in some situations it leads to a significant secondary flow. The secondary flow further provides a better thermal

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contact between surface and fluid as secondary flow creates swirl and thisresultsin mixing of fluid that enhances the thermal gradient which ultimately enhances the heat transfer coefficient. In the past decade, several studies on the passive techniques of heat transfer augmentation have reported. The present paper review mainly focus on the rib turbulatorsheat transfer enhancement and its design modification towards the enhancement of heat transfer and saving pumping power. Adecrease in heat transfer surface area, size, and henceweight of heat exchanger for a given heat duty and pressuredrop. The heat transfer can be increased by the followingdifferent augmentation techniques. They are classified as (i) Passive Techniques (ii) Active Techniques (iii) Compound Techniques.

(i) Passive Techniques: These techniques generally usesurface or geometrical modifications to the flow channel byIncorporating inserts or additional devices. Thesetechniques do not require any direct input of externalpower; rather they use it from the system itself whichultimately leads to an increase in fluid pressure drop. They promote higher heat transfer coefficient bydisturbing or altering the existing flow behavior except forextended surfaces. Following methods are used generallyused, Treated surfaces: Such surfaces have a fine scalealteration to their finish or coating which may becontinuous or discontinuous Rough surfaces: These are the surface modificationsthat promote turbulence in the flow field in the wall region,primarily in single phase flows, without increase in heattransfer surface area. Extended surfaces: They provide effective heattransfer enlargement. The newer developments have led tomodified finned surfaces that also tend to improve the heattransfer coefficients by disturbing the flow field in additionincrease the surface area. Inserts: Inserts refer to the additional arrangements madeas on obstacle to fluid flow so as to augment heat transfer.Such as twisted tapes, wire coils, ribs, baffles, plates etc. Additives for gases: These include liquid droplets orsolid particles, which are introduced in single-phase gasflows either as dilute phase or as dense phase. Additives for liquids: These include the addition ofsolid particles, soluble trace additives and gas bubbles insingle phase flows and trace additives which usuallydepress the surface tension of the liquid for boilingsystems.

(ii) Active techniques: This technique involves someexternal power input for the enhancement of heat transfer;examples are mechanical aids, surface vibration, fluidvibration, electrostatic fields, suction and jet impingement.

(iii) Compound techniques: When any two or moretechniques employed simultaneously to obtainenhancement in heat transfer that is greater than thatproduced by either of them when used individually, istermed as compound enhancement.In the present paper, a review of heat transfer augmentationtool i.e.rib turbulatorsis discussed, for laminar and turbulent flow. Rib turbulatorsaremost commonly used as enhancement tool [1-2].

2. Literature Review on RIB Turbulators For Heat Transfer Enhancement

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.

The phenomenon of heat transfer enhancement:

- Breaking of laminar sub layer
- Creation of local wall turbulence
- Decrease in the thermal resistance.

But Drawbacks are higher friction and hence higher pumping power requirements. Method of producing surface roughness:

- Sand blasting
- Machining
- Casting
- Forming
- Welding ribs
- Fixing thin wires of different cross-sectioned along the surface

The initial efforts on using artificial roughness for improving heat transfer characteristics were confided with the areas of nuclear reactors, gas turbines blades, pipes carrying fluids and compact heat exchangers. Several types of artificial roughness elements were used extensively to improve the heat transfer characteristics in this equipment. The roughness elements of two dimensions, three dimensions and of irregular shapes were used by investigators like Nikuradse, Nunner and Dippery. 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 as shown in Fig.1 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.

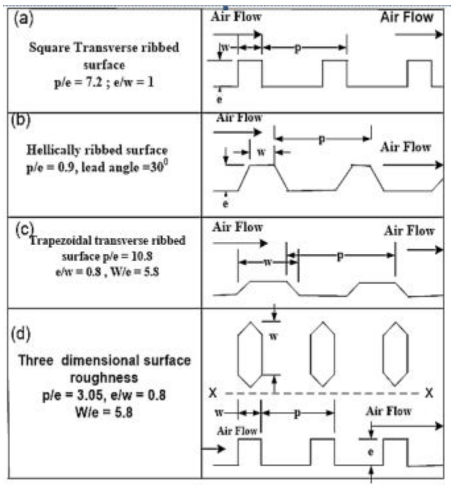

Figure 1. **Firth & Mayers rib geometry**

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° of attack angle have better performance than at 90° attack angle and sand grain roughness. Hsieh et al. [8] investigated on the combined effects of the rib, angle-of-attack ($\alpha = 90°, 60°, 45°$ 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 highestpressure drop can be obtained at $\alpha = 60'$ in the square channel; the highest heat transfer and pressure drop occur at $\alpha = 90°$ with W/H =4 in the rectangular channel and the values of highest heat transfer and pressure drop differs marginally at $\alpha = 60°$ 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. Hwangand 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 $(\alpha) = 60°$; 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° or 90° 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 as shown in Figure (2) 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.

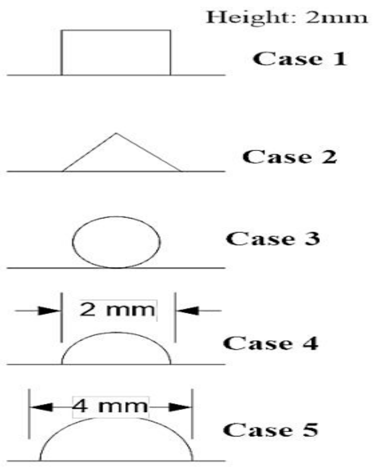

Figure 2. **Different geometries**

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° 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° V-shaped ribs and 60° 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 = 2.09×10^4; 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; α = 45°; e/D_H = 0.078; P/e = 10.They found that Nusselt number is almost same for crossed and parallel-ribs, local. Nusseltnumbers 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; α = 60°; 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 Figure (3). 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.

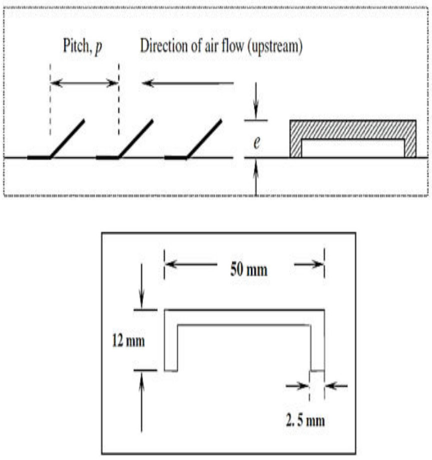

Figure 3. **Turbulator geometry**

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°–75° 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 Figure (4). 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°. Maximum thermo-hydraulic performance occurred at an angle of attack of 60°. Correlations were developed for heat transfer coefficient and friction factor for roughened duct.

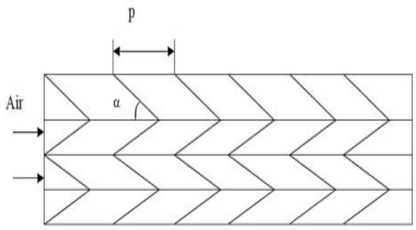

Figure 4. **W-shaped Turbulator geometry**

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° 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 sidesartificially roughened solar air heater of high aspectratio has been analyzed. For a particular set of values of roughness and flowparameters the optimal thermo hydraulic performancecondition always corresponds to an optimal value ofroughness Reynolds number.

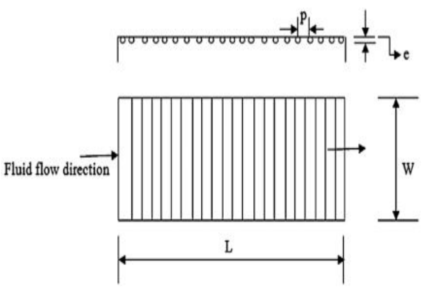

Figure 5. **Absorber plate with artificial roughness**

3. Conclusion

This review is based on the different investigations in duct flow with rib turbulence promoters. It can be concluded that there is definite increase in heat transfer in duct when its surface is roughened. However the different investigators find different values of increment in heat transfer with increase in friction factor for each experiment. We can see that the increase in heat transfer is achieved but the friction factor is also increasing simultaneously. The various correlations developed for the Nusselt number and friction factor for the range of parameters considered will give insight to the designers and other investigators in their work for finding out the optimum values. These correlations and heat transfer values can help the beginners of this field will help to know about the various geometries used till now and encourage them for investigating new roughness elements or even combinations of already existing elements for their work.

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