Review of Forced Convection Heat Transfer through a Non Circular Duct Provided with Different Types of Inserts

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Abstract— Among most of the conventional methods used to enhance the efficiency of a gas turbine, the one method which is commonly used is to increase the temperature at the inlet; thereby improving the power output and the efficiency. The internal cooling passages of blades are artificially roughened to improve the heat transfer performance. Modern gas turbines employ the application of inserts to enhance heat transfer through ducts. The reason behind the use of inserts is that they improves the turbulence in the fluid flow near the surface of the duct and creates obstruction to the laminar boundary layer to improve the heat transfer rate. The other reason is that the inserts also enhance the heat transfer rate by increasing the heat transfer area. The thermo hydraulic performance of the ribs is governed by many parameters such as the shape, size, angle and spacing. The present paper focuses on review of research work already done related to forced convection heat transfer through non circular ducts provided with different kind of inserts.

Key words: Duct, Inserts, Forced Convection, Nusselt number, Reynolds number, Friction factor, Heat transfer coefficient, Thermo hydraulic performance

I. INTRODUCTION

Now a day's the focus is on using different active and passive methods of heat transfer enhancement in non circular ducts which are used in gas turbine cooling systems, compact heat exchangers, HVAC applications, combustion chamber cooling channels and in electronic chipsets, etc. Achieving higher heat transfer rates through result in substantial energy savings, more compact and cheap equipment with enhancement in the heat transfer rate. One of the methods to enhance the heat transfer in a non circular duct is to create the artificial roughness on the surfaces of the duct by using the inserts which is commonly used in the design of internal cooling passage of gas turbine blades. The surfaces roughened with the inserts leads resistance to the fluid flow.

The thermal performance of the non-circular duct provided with inserts depends greatly on the parameters of the flow structure, such as reattachment length of the separated streamline and turbulence intensities, flow area and velocity of flow. The inserts increase the level of mixing by turbulence and disturb the laminar sub-layer, also increase the surface area for convective heat transfer, thereby enhance the cooling capacity of the passage. In general, mixing the main flow, reducing the flow boundary layer, raising the turbulent intensity, creating rotating and secondary flows are the main reasons for the increase of the heat transfer.

Heat transfer enhancement technology is the process of improving the performance of a heat transfer by increasing the convection heat transfer coefficient. Generally the main objective is to reduce the size and costs of heat exchangers. The heat transfer can be increased by the following different augmentation techniques. They are classified as (a) Passive Techniques (b) Active Techniques (c) Compound Techniques.

A. *Passive Techniques:*

These techniques generally use surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. These techniques do not require any direct input of external power; rather they use it from the system itself which ultimately leads to an increase in fluid pressure drop. They promote higher heat transfer coefficient by disturbing or altering the existing flow behavior except for extended surfaces. Following methods are used generally used.

Treated surfaces: Such surfaces have fine scale alteration to their finish or coating which may be continuous or discontinuous.

- Rough surfaces: These are the surface modifications that promote turbulence in the flow field in the wall region, primarily in single phase flows, without increase in heat transfer surface area.
- Extended surfaces: They provide effective heat transfer enlargement. The newer developments have led to modified finned surfaces that also tend to improve the heat transfer coefficients by disturbing the flow field in addition increase the surface area.
- Inserts: Inserts refer to the additional arrangements made as 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 or solid particles, which are introduced in single-phase gas flows either as dilute phase or as dense phase.
- Additives for liquids: These include the addition of solid particles, soluble trace additives and gas bubbles in single phase flows and trace additives which usually depress the surface tension of the liquid for boiling systems.

B. *Active Techniques:*

This technique involves some external power input for the enhancement of heat transfer; examples are mechanical aids, surface vibration, fluid vibration, electrostatic fields, suction and jet impingement.

C. *Compound Techniques:*

When any two or more techniques employed simultaneously to obtain enhancement in heat transfer that is greater than that produced by either of them when used individually, is termed as compound enhancement.

II. LITERATURE REVIEW

The heat transfer enhancement and friction factor characteristics in a non circular duct provided with various inserts having different arrangements and configurations have been investigated by many researchers. The work that has been carried out related to study of forced convection heat transfer from non circular duct provided with different types of inserts is reviewed as follows:-

Sahu et al. [01] reported the effect on heat transfer coefficient and thermal Efficiency of solar air heater by providing 90^0 broken transverse ribs on absorber plate. Integral rib roughened absorber plate were prepared by fixing wire of 1.5 mm diameter over one side of absorber plate as depicted in fig. 1, with the roughness geometry having pitch (p) range from 10-30mm, height of rib of 1.5mm, duct aspect ratio was 8 and Reynolds number of 3000-12000.

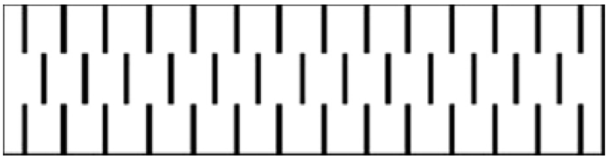

Fig. 1: Transverse Broken Ribs

It was also reported that, heat transfer coefficient and maximum thermal efficiency obtained as 1.25 to 1.4 times and 83.5% than that of smooth duct respectively. The maximum enhancement of heat transfer coefficient occurs at pitch of about 20 mm.

Karmare et al. [02] carried out an experimental investigation of heat transfer in the rectangular duct of an aspect ratio 10:1. The top wall surface is made rough with metal ribs of circular cross section in staggered manner to form defined grid as shown in fig. 2. The roughened wall is uniformly heated and the other walls are insulated. The broad wall is subjected to uniform heat flux.

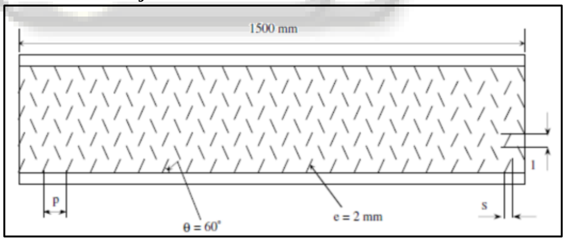

Fig. 2: Geometry of roughened surface collector

The effect of relative length, height and pitch of metal grid ribs on the heat transfer and friction factor studied for the flow range of Reynolds numbers 4000–17,000.

Wei et al. [03] studied convection heat transfer in a channel with 90° ribs and V-shaped ribs experimentally and numerically. The results showed that both the 90° ribs and V-shaped ribs enhance the convection heat transfer compared with a flat wall without ribs, but the pressure drop also increases. The overall thermal/hydraulic performance of the V-shaped ribs is better than that of the 90° ribs. The rib layout and wall temperature distribution is as shown in fig. 3.

Felipe et al. [04] carried out a numerical analysis of forced convection heat transfer from 3D protruding heaters mounted on an adiabatic substrate of a horizontal rectangular channel using the ANSYS software as shown in fig. 4.

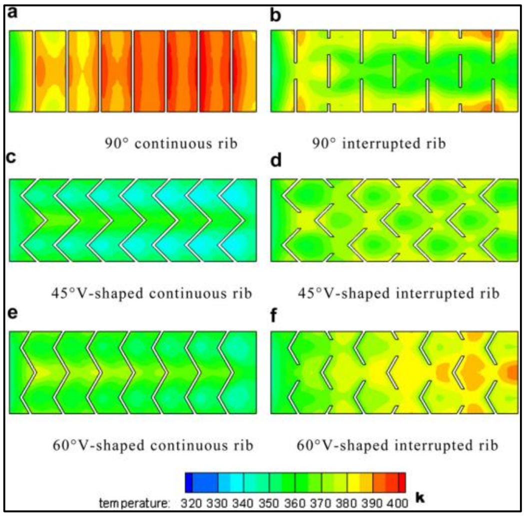

Fig. 3: Rib layouts and wall temperature distributions

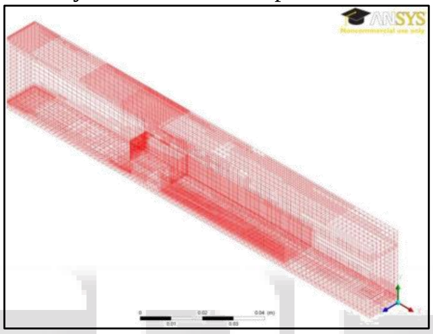

Fig. 4: 3D non-uniform mesh

It was found that the fluid flow development around the 3D protruding heaters lateral surfaces does not freely happen due to the small space between the protruding heaters. The fluid dynamic symmetry conditions of the blocks were dominant and the corresponding flow and the thermal wake were different than a single 3D protruding heater with free domain in the transversal direction to the flow.

Abhilash et al. [05] carried out numerical analysis of heat transfer characteristics of a square channel roughened with plain, rectangular perforated ribs of rounded corners and elliptical perforated ribs in the flow direction on two opposite walls for Reynolds numbers ranging from 8500 to 14500. The geometric model was created using GAMBIT software as shown in fig.-5, 6 and 7. Numerical simulations were performed using the CFD software package ANSYS FLUENT. Turbulence closure was achieved using the shear-stress transport (SST) *k*-*ω* model. From this, the heat transfer characteristics of plain, rectangular perforated ribs of rounded corners and elliptical perforated ribs were plotted.

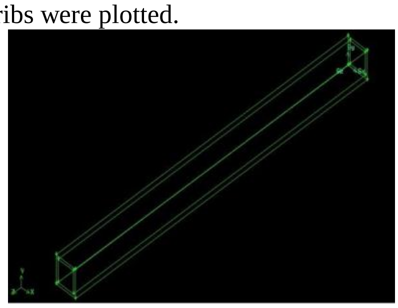

Fig. 5: Plain channel without ribs

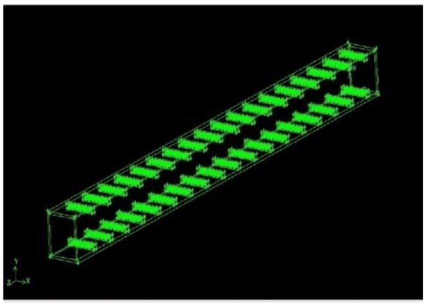

Fig. 6: Periodically arranged ribs

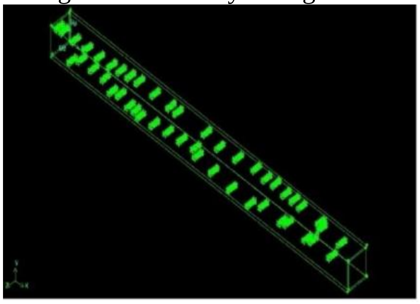

Fig. 7: Randomly arranged ribs

It was found that for the various range of Reynolds number studied, the rectangular perforation with rounded corner exhibits best results than others as in case of rectangular with rounded corners there is no sharp corners and so no accumulation of heat at corners. Similarly, for the various range of Reynolds number studied, the periodically arranged ribs onto the channel gives good result compared with randomly arranged ribs because it creates more turbulence than the randomly arranged ribs. Thus, the local heat transfer is dependent on the ribs perforation.

Anand et al. [06] investigated the convective heat transfer and friction factor characteristics of a rib-roughened square duct. The test section of the duct is roughened on its top and bottom wall with V and ʌ- shaped square ribs as shown in fig. 8 and 9. In the study, the Reynolds number varied from 10,000 to 40,000, the relative roughness height (e/D_h) is 0.060, relative roughness pitch (p/e) is 10 and rib attack angle (α) is taken as 45^0 and 60^0.

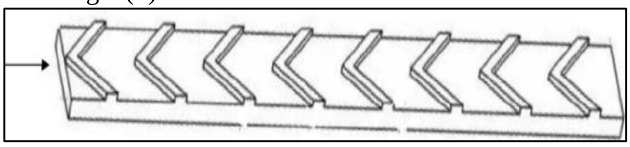

Fig. 8: V-shaped Rib

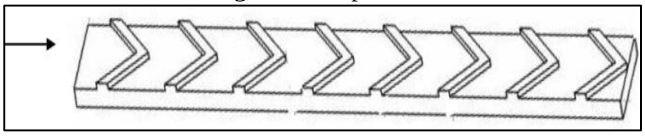

Fig. 9: ʌ-shaped Rib

The comparison of heat transfer and pressure drop for V and ʌ- shaped ribs is presented in the form of Nusselt Number and friction factor. The results show that the Nusselt number enhancement decreases when the Reynolds number increases. The friction factor ratio is found to increases as Reynolds number increases. The thermal performance decreases when the Reynolds number increases. It seems that the ribs disturb the main flow resulting in the recirculation and secondary flow near the ribbed wall. The heat transfer coefficient and friction factor for all the cases are higher than that of the smooth duct. The V-shaped ribs have higher Nusselt number and friction factor than the ʌ- shaped ribs. It is also concluded that the V -shaped ribs perform better than the ʌ- shaped ribs.

Bharatbhai et al. [07] carried study to find out the heat transfer coefficients for copper, aluminium and steel. He also found out the heat transfer coefficients for same surface area (i.e. $A_s = 0.0056\ m^2$) and different cross section like circular, rectangular and trapezoidal of same material copper as shown in fig. 10.

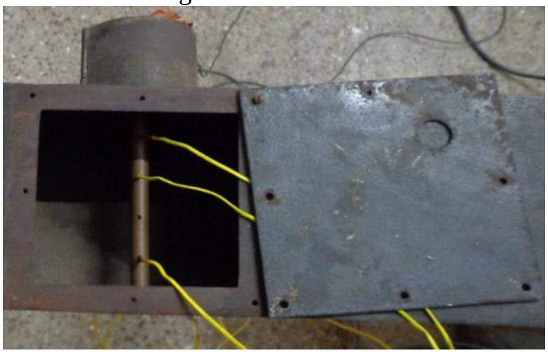

Fig. 10: Test Section of Experimental set-up

The heat transfer coefficients are also compared on the basis of different air flow rate. After performing this experiment he observed that heat transfer rate is higher in copper rod than aluminium and steel rod. For different cross section trapezoidal rod has high heat transfer than that of circular and rectangular rod as it has more surface area near the base where the difference in temperature is high.

III. Conclusion

1) Inserts installed at an acute angle provide better heat transfer performance than orthogonally installed ribs.
2) Parallel ribs installed on opposite channel surfaces generate a rotational flow, which promotes mixing of the fluid.
3) The heat transfer characteristics are mainly dominated by turbulent transport and secondary flow induced by geometrical features.
4) Heat transfer rate is increased by using non circular ducts provided with different kinds of inserts, because inserts increase the turbulence of the flow.
5) Angled ribs generate strong secondary vortices adjacent to the channel surface as the flow moves in the direction of the ribs. The vortices sweep the surface, and locally intensified heat transfer occurs in these regions.

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