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Jet Impingement on Ribbed Surfaces

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ABSTRACT

Jet impingement is a technique for enhancing the heat transfer rate from the surface. Research is currently going on extensively in the area of jet impingement. It has been proven experimentally that, Heat transfer rate increases if the surface (which needs to be cooled) is provided with the ribs. Till now the extensive study and experimentation have been conducted on smooth surface and surface having V-shaped ribs. It shows that, by jet impingement on V-shaped ribs enhance the heat transfer rate of surface to great extent because of increased heat transfer area and turbulence created. The aim of this thesis is to compare the heat transfer performance of smooth surface, V-shaped ribbed surface with surface having X-shaped ribs and surface having continuous projections. X-shaped ribs provide more heat transfer area as well as more turbulence as compared to V-shaped ribs because of which the rise in heat transfer is expected. The experimentation will be conducted on ribbed surfaces with –V-shaped projections, X-shaped projections and with continuous V-shaped projections. Theoretical analysis will be also conducted on all geometries with the help of CFD. The effect of varying pitch, Reynolds number on heat transfer rate will be analyzed and compared for different geometries.

Keywords— **CFD, Heat transfer rate, Jet impingement, ribbed surface**

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I. INTRODUCTION

Jet impingement is a technique for enhancing the heat transfer rate from the surface. In this technique, a high velocity cold liquid is directed from a vertical hole onto the component surface which is to be cooled. As the cooling liquid jet hits the surface it is diverted in all directions parallel to the impingement surface. The cooling effect is high but decreases continuously as the distance from the impingement point increases. To ensure efficient impingement cooling of larger areas a great number of such holes must be arranged in a row or several rows.

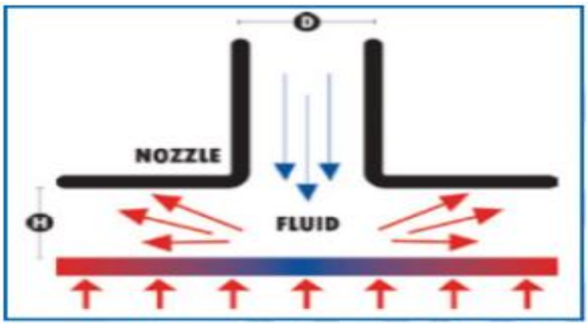


Fig 1: Jet impingement

S. Caliskan , S. Baskaya[1] have studied detailed heat transfer over a surface with V-shaped ribs (V-SR) and convergent-divergent shaped ribs (CD-SR) by a circular impinging jet array was investigated using thermal infrared camera.Both V-SR and CD-SR configurations are considered. In-line jet arrays with different exit flow orientations were also considered. The range of parameters for the analysis has been decided on the basis of practical considerations of the system and operating conditions. The effects of different rib heights on the heat transfer along the wall are studied. Five different ribbed surfaces with different rib height and shapes were selected. The rib pitch (p) to rib height (e) ratio is 6. During the experiments, the Reynolds number was varied from 2000 to 10,000, the jet diameter-to-rib height ratio from 0.6 to 1.2, and jet-to-plate spacing from 2 to 12. The heat transfer results of the rib-roughened plate are compared with those of a smooth plate. The heat transfer from the rib-roughened wall may be enhanced or retarded. Best heat transfer performance was obtained with the V-SR arrangements.The presence of rib turbulators on the target plate produces higher heat transfer coefficients than the smooth plate. The average Nusselt number values for the V-SR plate showed an increase ranging from 4% to 26.6% over those for the smooth plate. Correlations have been developed for the average Nusselt number for the rib-roughened surfaces. Rib-roughened surface looks as shown in the below given figure:

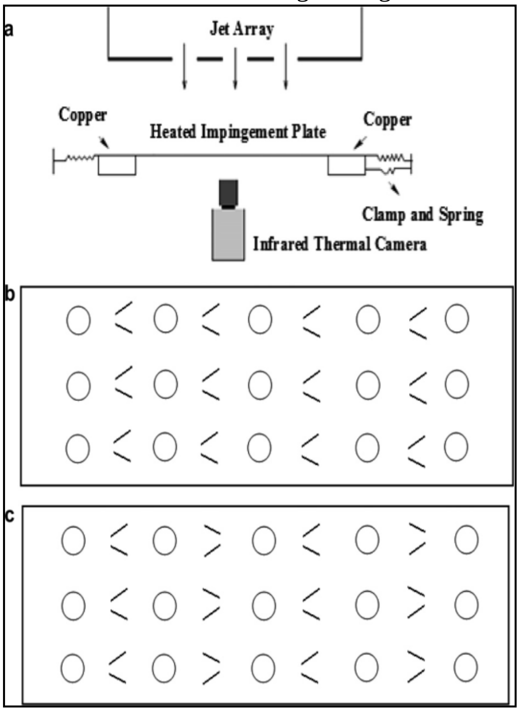
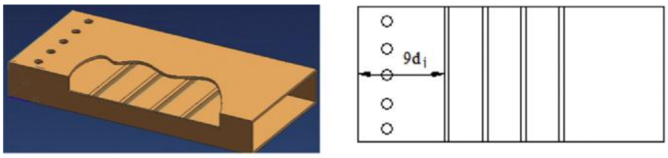


Fig:2 (a) Target plate assembly with infrared thermal camera and jet array plate (b) V-SR and nozzle arrangement (c) CD-SR and nozzle arrangement.

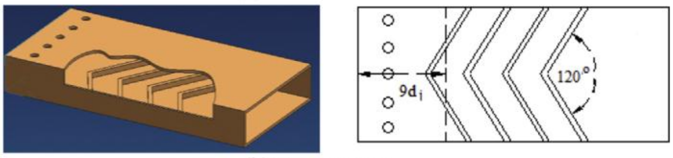
In Second paper by Lei Tan , Jing-Zhou Zhang , Hua-Sheng Xu [2], Convective heat transfer on the rib-roughened wall impinged by a row of air jets inside semi-confined channel was experimentally investigated. Four rows of transverse ribs were arranged in the wall-jet zone downstream from the impinging jet stagnation to enhance heat transfer. Three typical rib configurations, including orthogonal ribs, V-shaped ribs and inverted V-shaped ribs, were considered under different non-dimensional jet-to-target distances ranging from 1 to 3 diameters and impinging jet Reynolds numbers ranging from 6000 to 30,000.The results show that the rib-roughened wall enhances the convective heat transfer up to 30% in the ribbed region by comparison with the smooth wall under the same jet Reynolds number. Among three rib configurations, the inverted V-shaped rib seems to be advantageous on the convective heat transfer enhancement, especially at lower jet-to-target spacing. The ribs on the impinging target do provide stronger convective heat transfer in the wall-jet region, but at greater expense of pressure drop inside the channel.

At the jet-to-target spacing ratio of 1, the flow coefficient of the rib-roughened channel is decreased 5%-10% in related to the smooth channel.

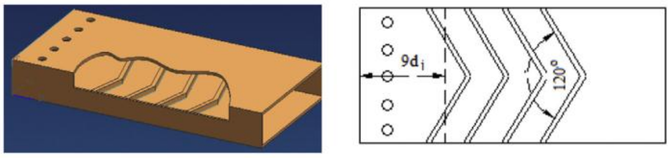
Different types of ribbed surfaces are shown in figure:



(a) orthogonal ribs



(b) V-shaped ribs



(c) inverted V-shaped ribs

Fig 3: Physical model of jet impingement in rib-roughed channel

In third paper by C. Gau[3], I.C. Lee, Experiments are performed to study slot air jet impingement cooling flow and the heat transfer along triangular rib-roughened walls. Both flow visualization and local heat transfer measurements along the ribbed wall are made. The effect of different rib protrusions (heights) on the impinging flow and heat transfer along the wall is studied, which is achieved by using different sizes of nozzles.

Two different ribbed walls with different rib pitches are selected which have a rib pitch-to-height ratio of 2 and 4, respectively. The widely opened cavity between neighboring ribs make more intense transport of momentum between the wall jet and cavity flow so that recirculation cell in the cavity is hardly observed. This leads to a higher heat transfer around the cavity wall than in the case with rectangular ribs. However, in the region of laminar wall jet, a number of air bubbles enclosing the cavities are formed which prevent penetration of the wall jet into the cavities. This leads to a significant reduction in the heat transfer. The geometric shape of the triangular ribs is more effective in rebounding the wall jet away from the wall than in the case with rectangular ribs. The rebound of the jet away from the wall causes a significant reduction in the heat transfer.A comparison and correlations of the stagnating point Nusselt number under different conditions are presented and discussed. During the experiments, the Reynolds number varies from 2500 to 11,000, the slot width-to-rib height ratio from 1.17 to 6.67, and nozzle-to-plate spacing from 2 to 16.

In another paper by S. Caliskan , S. Baskaya the flow field of smooth surfaces and surfaces with V-shaped ribs (V-SR) was studied experimentally. Heat transfer characteristics were also experimentally investigated. Heat transfer results from these surfaces under impingement of a circular jet array (5 X 3) using an infrared thermal imaging technique are presented. The velocity profiles were measured at Reynolds number of 10,000 and at H/d equal to 3 and 12.

For each H/d position, profiles were collected from x/d = 0 to 6 axial locations. The heat transfer data were obtained at Reynolds numbers equal to 2000, 6000, and 10,000. Different boundary layer profiles were obtained for smooth and V-SR plates at H/d = 3 and 12. Positions of maximum radial and axial velocities and turbulence intensities have been determined for smooth and V-SR plates. For low jet-to-plate spacings, the production of turbulence kinetic energy is higher for the V-SR surfaces as compared to smooth surfaces. For H/d = 3, the radial velocities are higher for the V-SR surfaces as compared to smooth surfaces but for H/d = 12, the radial velocities are not nearly changed all x/d locations. The heat transfer results have also been compared with those of a smooth surface under the same flow conditions to determine the enhancement in the heat transfer coefficient. In these locations, the Nusselt numbers are higher for the V-SR surfaces as compared to smooth surfaces. The locations of the peaks and the minima are influenced by cross flow velocities which in turn depend on jet-to-plate spacing and V-SR arrangements. For all results, the Nusselt numbers at the stagnation points decrease with increase in H/d.

From the experimentation, it has been proven that,heat transfer rate increases if the surface(which needs to be cooled) is provided with the ribs. Till now the extensive study and experimentation have been conducted on smooth surface, surface having V-shaped ribs. It shows that, by impinging jet on surface with V-shaped ribs heat transfer rate of surface increases to the great extent. Ribs enhance the heat transfer rate because of increased heat transfer area and turbulence created.The aim of this thesis is to compare the heat transfer performance of smooth surface, V-shaped ribbed surfacewith surface having X-shaped ribs and surface having continuous projections. X-shaped ribs provide more heat transfer area as compared to V-shaped ribs because of which the rise in heat
transfer is expected. The effect of varying pitch, Re number on heat transfer rate will be analysed.

II. SCOPE

Experimentation:

Heat transfer rate on smooth surface will be compared with the surfaces with ribs having V-shape, X-shape, continuous projections over the surface. Following parameters will be varied for each type of surfaces: pitch, Reynolds number, Jet height to diameter ratio.

The experimental setup will be as shown in the figure below.The blower will be used to pull the air into the circuit and use it for impinging it onto the test surface. The pulled air will be provided to air-box and from there, through the arrangement of multiple nozzle system, air is impinged onto the test surface. A schematic diagram of the experimental set up is shown in Fig.2 It is an Air flow bench, which provides controlled and measurable flow of air through nozzles or jet plate directed towards the target plate. It consists of a 0.5 HP blower, air straightener (air box), contraction section, and structure and Data Acquisition System (DAQ) to measure temperature, pressure. The blower draws air from the atmosphere and delivers it along a pipe to an air box, which is above the test area. There is honeycomb structure inside the air box in order to provide streamlined flow prior to impinging on the heat sink and a butterfly valve used in order to regulate the discharge from the centrifugal blower. The air flow bench structure is made to incorporate other devices such as DAQ system, Power supply, pressure measurement devices and various controls. Micro-manometer is used to measure the static pressure of air at the outlet of the jet at different locations. K-type thermocouples are used to measure the temperature. Average of all the readings is taken and jet velocity is calculated. Different test surfaces will be used for comparison purpose. Different parameters which are mentioned in the scope will be varied and their effect on Nusselt number will be observed.

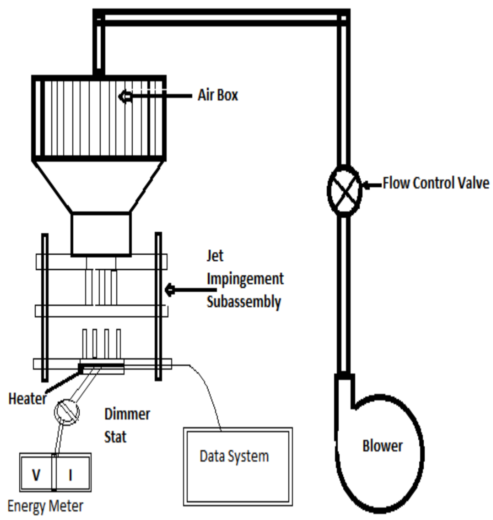


Fig 4: Experimental set-up

CFD:

The heat transfer rate will be analysed by simulation method also. CFD will be used to validate the results obtained by experimentation. The numerical approach will involve the following steps:

1. Modelling of test piece: Test pieces will be modelled on 3D modelling software such as Pro-E.
2. Meshing of test piece: Meshing will be done in Ansys. Size of the mesh depends on the accuracy of results required.
3. Analysis: Analysis will be done by CFD using Ansys Fluent software.

III.CONCLUSION

From the literature survey, it shows that, the heat transfer rate increases because of ribs. Ribs increase the heat transfer area and turbulence which helps to enhance the heat transfer rate significantly. Papers show that, V-shaped ribs increase the rate of heat transfer V-shaped ribs as compared to any other geometries. It has been estimated that, X-shaped ribs will enhance the heat transfer rate as compared to V-shaped ribs because of the more heat transfer area and turbulence created by V-shaped ribs. Experimentation and analysis are required to support the estimations made.

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