NUMERICAL INVESTIGATION ON JET IMPINGEMENT COOLING AIDED WITH CROSS FLOW AND RIBS ON TARGET PLATE

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***Abstract**:-The aim of this work was to do a numerical investigation to determine the heat transfer characteristics of multiple impinging circular jets in a rib-roughened channel in the presence of cross-flow. Modifications such as perforations in the ribs are also suggested in this work. The present problem is analyzed at steady state condition. The steady state analysis deals with mainly 3 cases without ribs, with rib and rib with perforations and also study conducted by variation of the pitch and no perforated holes in the ribs. The variation of Nusselt number and temperature studied for all cases. The model used for solving the problem is standard k-ε turbulent model, while the Reynolds numbers of jet and the channel inlet are fixed at 6,000 and 14,000, respectively. The ribs will increase the turbulence intensity which enhance the heat transfer. The height to diameter of jet choose as 4 for maximum heat transfer got from previous journal. The square rib of same width and height used. From these studies it is found that the local Nusselt number is increasedwith the increase in the number of perforations through the ribs.*

Index Terms:- cross flow, turbine blade cooling, steady, element based study,meshing.

INTRODUCTION

Impingement heat transfer is considered as a promising heat transfer enhancement technique. Among all convection heat transfer enhancement methods, it provides significantly high local heat transfer coefficient. Jet impingement produces a rapid cooling or heating of the surface where it impinges. Jet impingement can be used for cooling, heating and drying. Jet impingement cooling (or heating as well) is a very effective heat transfer mechanism. The main reason is that jet impingement flow forms a very thin boundary layer. 'Impingement' means 'collision' that the coolant flow collides into the target surface and guarantees a thin stagnant boundary layer at the stagnant core for cold coolant contacting the hot surface without damping.In the present study, heat transfer of multiple impinging circular -jets along a rib roughened channel is considered. This can be regarded as a combination of multiple impingement jets cooling and turbulent cooling in a rib-roughened channel. Such heat transfer processes occur in combustor wall cooling, electronic cooling andleading edge cooling of gas turbine blades.

Taslim et al. [1]studied impingement cooling on the gas turbine blade leading edge with ribs and conical bumps. They have found that the roughened surface and conical bumps are the best for heat transfer enhancement.

Gardon and Akfirat [2]studied the effect of turbulence on the heat transfer between two dimensional jet and flat plate. They also studied effect of multiple two-dimensional jets onthe heat transfer distribution. Yan et al. [3]investigated heat transfer characteristics along rib-roughened walls for circular and elliptic impinging jet arrays by using transient liquid crystal technique. They determined that the heat transfer over the rib surface may be enhanced or retarded depending on the orientation of the ribs and the highest heat transfer rate was obtained with 45^{o}V-shape ribs.Miyake et al. [4] investigated the impinging jet heat transfer from rib-roughened flat surfaces and presented some optimum conditions (i.e. rib height, shape, pitch, jet-to-plate distance, etc.) for the maximum heat transfer.

Tan et al. [5] have reported that the convective heat transfer rate can be increased up to 30% in the ribbed regions for Reynolds numbers ranging from 6,000 to 30,000.Caliskan et al. [6] reported that the average Nusselt number values for the V-shaped rib-roughened plate can be increased by 4% to 26.6% over those for the smooth plate as the Reynolds number varied from 2,000 to 10,000 and the perforated rib surface produced higher heat transfer coefficients compared with the smooth and solid rib surfaces.

However, Sagot B et al. reported thatthe rough target plates would reduce the heat transfer from the target plate to the impinging fluid in the laminar region [7]. On the other hand for turbulent impinging jets, the heat transfer coefficient can be enhanced significantly for a rough impinging surface.Jet impingement heat transfer has been studied extensively in the past, especially for steady jet impingement on a smooth target by Al Mubarak, A.A., et al [8]. However, the high heat transfer coefficient of a single jet on the target decays rapidly with distance downstream of impingement surface. Further enhancement in the convective heat transfer coefficient for jet impingement is to "roughen" the impinging target using fins or extended surfaces.The combination of

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air jet impingement and finned heat target surface has potential in heat transfer enhancement as the heat sink exhibits smaller thermal resistance over the range of Reynolds number of interest. The effect of “patterned” surface with ribs on heat transfer in impingement systems has been examined by several researchers. Katti, V., Prabhu, S.V shown that properly arranged ribs can enhance the heat transfer coefficient for turbulent impinging jet [9].

Xing et al. [11] presented experimental and numerical results on heat transfer characteristics of jet arrays impinging on micro-rib roughened surfaces. They have shown that the overall heat transfer performance on the micro-rib roughened plate is always best for minimum cross-flow case, and that the heat transfer enhancement ratio increases with increasing Reynolds numbers.Sanyal et al. [10] numerically investigated the heat transfer characteristics of confined slot jet impingement on a pin-fin heat sink. Their results indicated that the effective heat transfer coefficient increases with fin height for the steady jet impingement on a pin-fin heat sink.

From these research details absorbing the advantages of these studies apply some useful technics to this project.The objective of this work was to do a numerical investigation to determine the heat transfer characteristics of multiple impinging circular jets in a rib-roughened channel in the presence of cross-flow. Modifications such as perforations in the ribs are also suggested in this work. The present problem is analyzed at steady state condition. The steady state analysis deals with mainly 3 cases without ribs, with rib and rib with perforations and also study conducted by variation of the pitch and no perforated holes in the ribs.

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NUMERICAL PROCEDURE

The jet impingement with cross flow and ribs on the target plate heat transfer problems is numerically computed with the commercial finite-volume code FLUENT 15 using the time-averaged Navier-Stokes and energy equations with the standard k-ε turbulent model. The k-ε model is chosen due to its simplicity, computational economy and wide acceptability. The circular air jet is assumed to have constant thermo- physical properties such as density, specific heat and thermal conductivity. The 3-D model is created using some modeling tools the two walls are confined there is no flow occurs through that wall. The cross flow comes perpendicular to the jet and it causes deviation to the jet and resultant flow occurs through only one direction. The gravitational effect during the impinging jet are neglected. The finite-volume code FLUENT 15 is used to solve the thermal and flow fields using the standard turbulence model. Diffusion terms of all the governing equations are discretized using the central difference scheme. Convective terms of the momentumandenergyequationsarediscretizedusingt he third order QUICK interpolation scheme and convective terms of the turbulent kinetic energy and turbulent dissipation rate equations are discretized using a second-order upwind differencing scheme. Pressure-velocity coupling is handled using the SIMPLEC algorithm.. The computational domain is given below.

COMPUTATIONAL DOMAIN

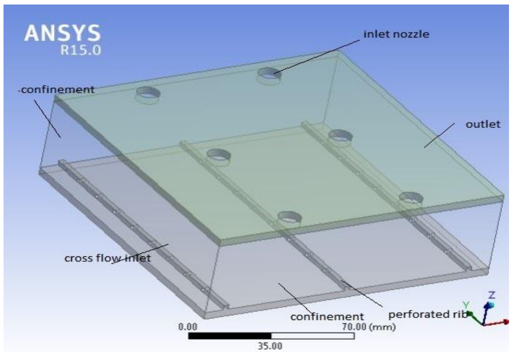

Figure 6.1: computational domain

6.1 Design parameters

- Size of nozzle plate - 140mm*140mm
- Size of target plate - 140mm*140mm
- Diameter of jet -10mm
- Thickness of plate - 4mm
- Height between plates -40mm (h/d =4)
- Pitch of jet=pitch of rib -60mm(p/d=6)
- Diameter of perforation - 2mm
- Cross flow Reynolds no - 14000
- Jet flow Reynolds no - 6000
- Heat flux -6000 W /m2
- Size of ribs - 2.5 mm*2.5mm
- Air inlet temperature- 300 k

6.2 Boundary conditions

The SIMPLEC (Semi-Implicit Method for Pressure-Linked EquationsConsistant) algorithm is used as the solution method. This algorithm is essentially a guess-and-correct procedure for the

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calculation of pressure on the staggered grid arrangement.

Pressure= 0.3

Momentum=0.7

Energy=1

Turbulent kinetic energy=0.8

Turbulent Dissipation rate=0.8

For the analysis, the flow is assumed to be at steady state, the fluid physical properties are constant and the effect of gravity is neglected. For this numerical simulation flow is assumed to be incompressible, turbulent with constant fluid properties. The heat flux of 6000 W/m^2 is given at the bottom of the target plate of thickness 4 mm. Cross flow has Reynolds number of 14000 and the jet has 6000, in terms of velocity it is 5.92 m/s and 10.18m/s respectively. The height of the channel is around 40mm according to the design parameter H/D = 4. The square ribs arranged perpendicular to the direction of the cross flow. The two walls are confined there is no flow and heat transfer occurs through the confined wall. The wall opposite to the cross flow inlet is given as pressure outlet and turbulent intensity is given as 8%. The nozzle plate and target plate are taken as copper plate

6.4Meshing

The computational domain is associated with fine meshing and smoothening is given as high for high accurate results. The relevance of 40 is selected because after this relevance there is no noticeable change in temperature and also at this relevance there is average number of elements. Computational domain contains around 154129, 164103, 431361, 577634,725641elements for case 1,2,3,4,5 respectively.Relevance centre is set as fine and smoothing is high and 40 is given,because after that value there is no remarkable change in temperature. All other settings are to be done as default.

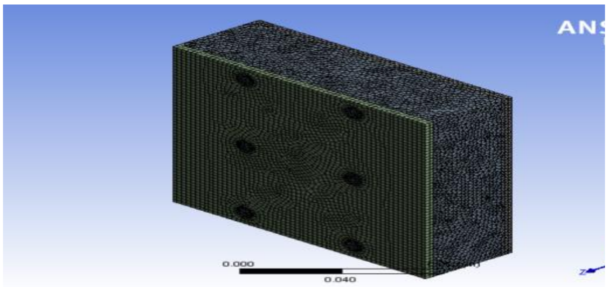

Fig.6.4 Mesh domain

7.1 Element based Study

ELEMENT BASED STUDY

Table I: Element based study(without ribs)

Relevance	Nodes	Elements	Temperature(K)
10	33931	104513	418.61
20	40172	120521	418.29
30	44846	135714	417.91
40	49694	154129	417.85
50	58025	175721	417.83

Table II: Element based study(with ribs)

Table III: Element study (perforated rib of pitch 15mm)

Relevance	Nodes	Elements	Temperature(K)
10	69576	278283	399.68

Relevance	Nodes	Elements	Temperature(K)
10	35481	111184	400.81
20	41872	127912	400.12
30	46769	144291	399.96
40	52016	164103	399.89
50	61426	190324	399.87

20	80606	326813	399.65
30	91488	375501	399.07
40	103770	431361	398.72
50	118010	485641	398.71

Table IV: Element study (perforated rib with 10mm pitch)

Relevance	Nodes	Elements	Temperature(K)
10	87755	358869	397.12
20	105401	438159	396.99
30	119775	503461	396.45
40	136683	581442	396.02
50	154103	651581	396.01

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Table V: Element study (perforated rib with 7mm pitch)

Relevance	Nodes	Elements	Temperature(K)
10	107630	446647	395.21
20	129262	543131	394.68
30	147655	629454	394.58
40	168187	725641	394.55
50	189911	816041	394.54

Above table show the effect of number of elements in the accuracy of results. After the grid based study, it is decided to choose the number of elements and nodes for a relevance of 40, because it is computationally less expensive and relatively high accuracy.

RESULT AND DISCUSSION

In this project the importants given to the flow and temperature characteristics so for all cases the temperature and the velocity contours have more importants,and also the nusselt number comparison for all cases given.

Case 1- Jet impingement cooling without rib

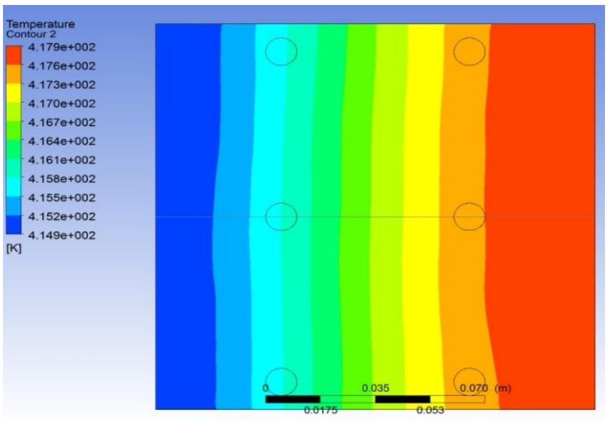

Figure 1: Temperature contour along the heating plate without ribs

This is the temperature contour at the starting point of cross flow its indicated by a blue line where the temperature is low and nusslet number is high and when goes to the right the color changes to red that indicates that temperature increases due to the decrease in Nusslet number it happens because of heating of air. At the starting the nusslet number in the range of 80 and at the end it falls to 76.

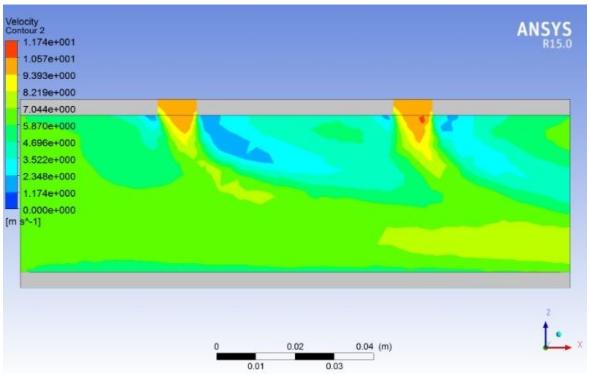

Figure 2: Velocity contour for case 1

Velocity vector gives the characteristics of the flow and its variation. The increment of the flow velocity occurs at the downstream of the second nozzle due to the increase in mass flow rate.

Case 2- jet impingement cooling with ribs on target plate

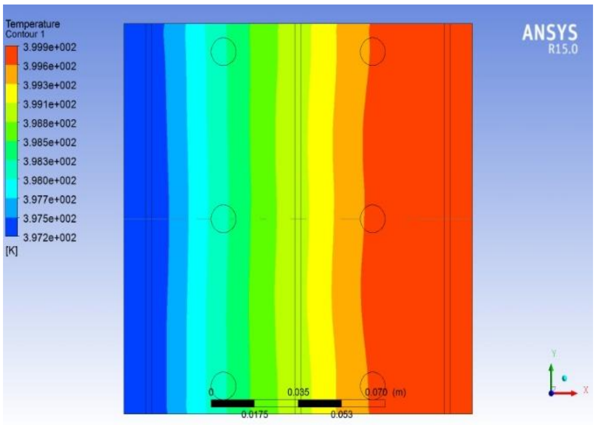

Figure 3: Temperature contour (cross flow with rib on target plate)

In the case with rib the solid rib is attached to the target plate and rib is perpendicular to the direction of the flow. The rib increases the surface area and turbulence which increases heat transfer. The temperature at the starting end is around 397K at the end it is about 400 K. These variation of temperature is less than the without rib.The vortices

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produced at downstream of nozzle and rib which increases local heat transfer.

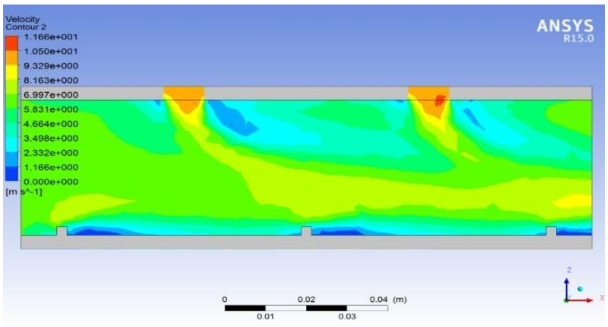

Figure 4: velocity contour for case 2

In case 2 it is understand that there is vorticity formation in the downstream of the nozzle and ribs which causes the flow rotation. So that the rotational velocity of fluid is higher and the translational velocity is lower .so these type of flow rotation helps the heat transfer augmentation.

Case 3- jet impingement cooling with perforated ribof 15mpitxh

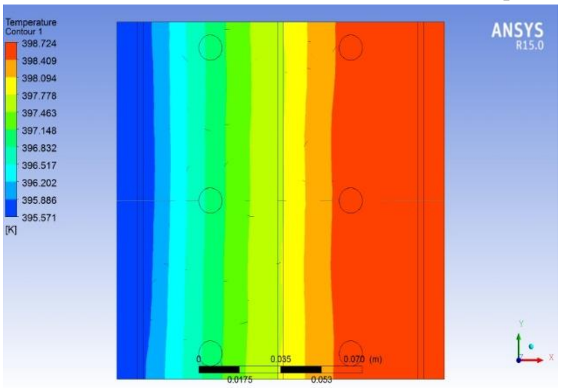

Figure 5: Temperature contour for case 3

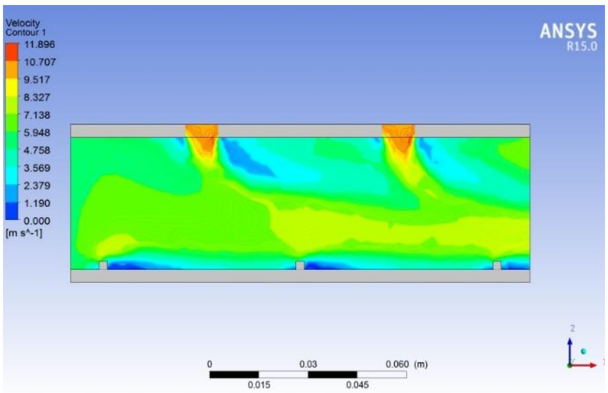

Figure 6: velocity contour for case 3

In case 3 it is same as that of case 2 but the maximum velocity is higher than the case 2. There is also vorticity produced in the downstream of the each rib and nozzles, Which aids heat transfer.

Case 4- jet impingement cooling with perforated ribs of 10mm pitch

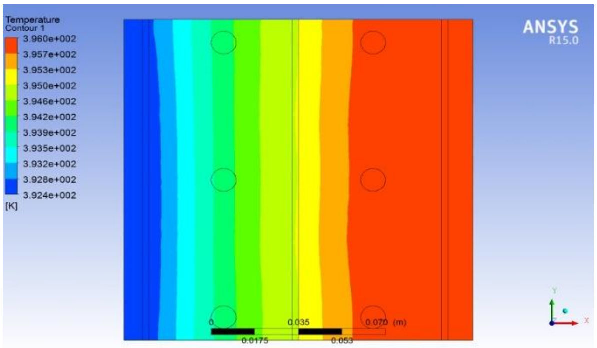

Figure 7: Temperature contour case 4

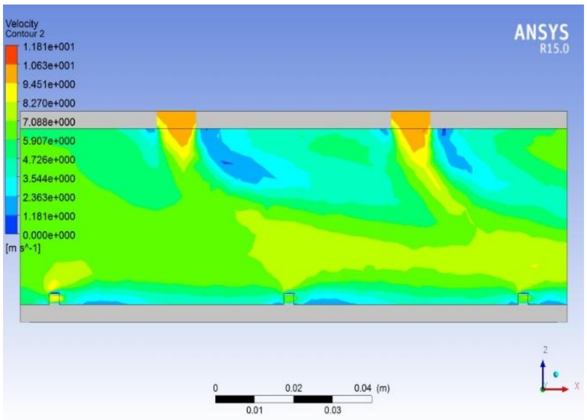

Figure 8: velocity contour for case 4

In this case number of perforation is 13 holes and the pitch of perforation is 10mm and other conditions are being same. Here the increase of Nusslet number occurs due to the increase of surface area and turbulence which enhance the heat transfer.

Case 5- jet impingement cooling with perforated ribs of 7mm pitch

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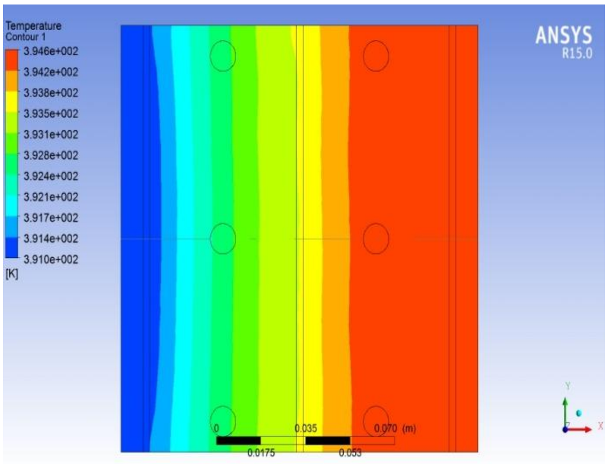

Figure 9: Temperature contour for case 5

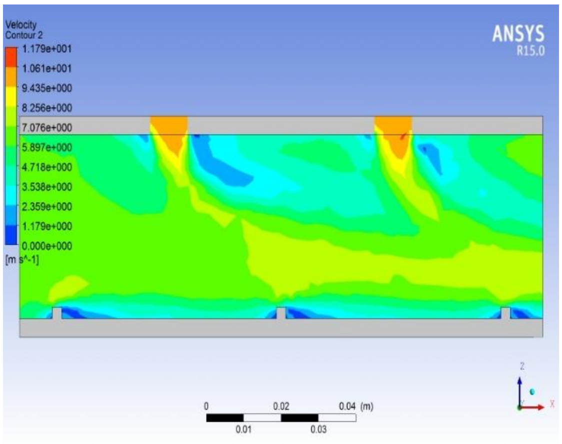

Figure 10 : velocity contour for case 5

Compared to case 1 in all other cases there is obstructions are produced in all other cases due to the modification in design of target plate when the ribs attached to the target plate in the downstream of the nozzle and rib there is a stagnation zone is produced which means that flow will be rotated but the rotational velocity of the flow at the downstream is higher due to high turbulence which aids heat transfer and also the turbulent kinetic energy is higher but the translational velocity is very low ,that indicated by a blue color. In the other cases target plate with perforations then also the nusslet number increases due to the same reason. And also the one of the most important effect is that when the number of perforated holes increases the surface area also increases which helps to increases the heat transfer. So the case 5 has higher nusslet number than other all cases.

COMPARISON OF NUSSLET NUMBER AND TEMPERATURE

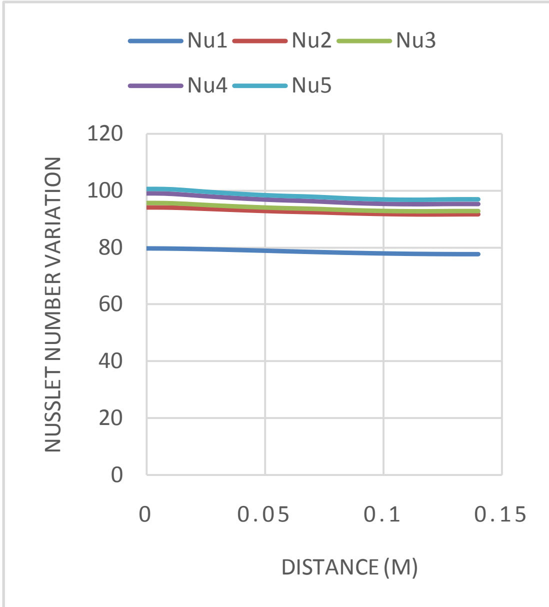

Figure 11: comparison of nusselt number for all cases

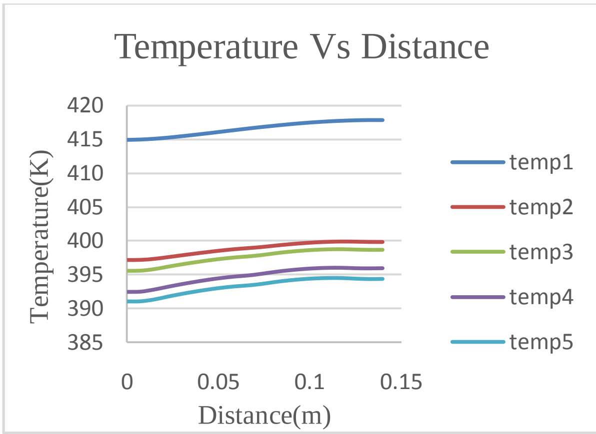

Figure 12: Variation of temperature along the length of plate for different cases .

Temp1 ,temp2 ,temp3, temp4, temp5 are the temperature variation along the length of plate and Nu1,Nu2,Nu3,Nu4,Nu5 are the nusselt number variation for case 1,case 2,case 3,case 4,case 5 respectively.From the graph we can understand that the temperature for jet impingement with cross flow is higher than the other all cases ,it is because

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that there is no ribs or perforation on the ribs . the maximum local Nusselt number for the case1 is around 79.5 but when the ribs attached to the target plate it changes to 94.2 there is higher increment when rib is attached to the target plate. When we given a perforation 8 holes of 1mm radius is given then again Nusslet number increase to 95.8. After that the study is going on variation on number perforated holes. When the perforated holes increases to 13, the Nusselt number increased to 98.8 it is very advantages to some practical applications like turbine blade cooling and electronic cooling etc. then again the varied the number of perforated holes to 18 then the Nusselt number increases to 100.5. in each stage there is an increment in Nusselt number. The temperature range of case 1 is higher than other four cases due to the simple design and low Nusselt number ranges. The case 2, case3,case4 and case5 has the increment of Nusselt number compared with the case 1 are 18.4%,20.50%,24.29% and 26.41% respectively.temp1,2,3,4,5 indicates the cases 1,2,3,4,5 respectively.

VALIDATION OF NUMERICAL RESULT

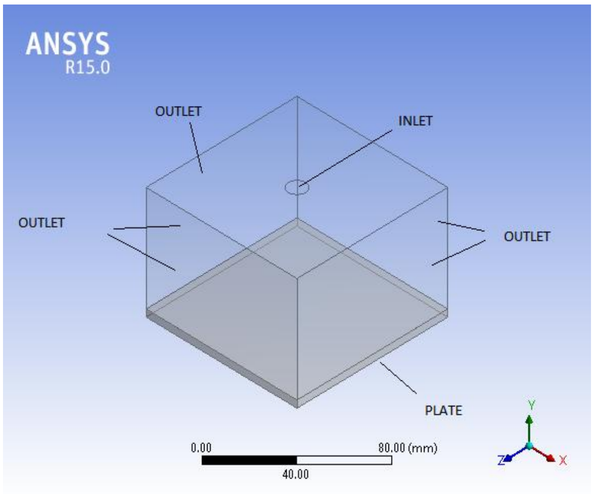

Figure 13: Validation model for numerical result.

Numerical simulation was validated using the experimental results obtained from the previous work done by Lytle and Webb [12]. The local Nusselt number at a given Reynolds number of 23000 and Z/D of 6 is compared with those of the earlier published data as shown in table 6 .

According to Lytle and Webb [12] result has some similarities. The variation of the nusslet no in the radial direction in the same manner of experiment. But there is slight variation in the nusslet number values. At the stagnation region the nusslet no is high and when go to the side of the plate the nusslet number decreases,it is because heating of the air takes place. The k-ϵ model model is used for validating the experimental results. The plate of 4mm thick is used and other part except the inlets are outlet so the flow occurs through all sides.

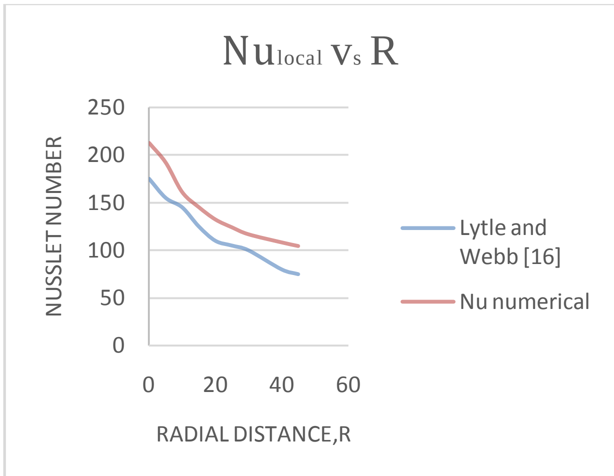

Fig.14 Variation of Local Nusselt number with radial distance for Re=23000, Z/D=6

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location	Lytle and Webb [12]	Numerical
0	**175**	**212.53**
5	**155**	**191.96**
10	**145**	**160.83**
15	**125**	**145.14**
20	**110**	**132.24**
25	**105**	**123.97**
30	**100**	**116.68**
40	**80**	**108.19**
45	**75**	**104.40**

Table VI: Nusselt number variation with location

CONCLUSIONS

The present study is done with the help of is standard k-ε turbulent model which give most accurate result with minimum complexity in calculations. The following results are obtained.

- In this project considered 5 cases, first case is simple jet impingement with cross flow, in second case the study the effect of rib in the target plate is studied, third case the perforated ribs on the target plate is studied and in fourth and fifth case the study done by varying the number of perforated ribs and pitch of the perforated holes.
- In the third, fourth, fifth cases the number of perforation used in the order of 8, 13, and 18 respectively.
- The rib with highest number of perforation has higher Nusslet number than the other 4 cases.
- The maximum Nusslet number obtained for case 1, 2,3,4,5 are 79.5, 94.2, 95.8, 98.9, and 100.5 respectively.
- The variation of the temperature in the target plate in a uniform manner, at the starting the temperature is low it is indicated by blue color and at the end the temperature is higher and is indicated by red color.
- There is vortices generation at the downstream of nozzle and the ribs which enhance the heat transfer.
- The case 2, case3,case4 and case5 has the increment of Nusslet number compared with the case 1 are 18.4%,20.50%,24.29% and 26.41% respectively**.**

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