ISSN (Online) : 2319 – 8753
ISSN (Print) : 2347 - 6710

IJIRSET

International Journal of Innovative Research in Science, Engineering and Technology

An ISO 3297: 2007 Certified Organization, Volume 3, Special Issue 1, February 2014

International Conference on Engineering Technology and Science-(ICETS'14)

On 10th & 11th February Organized by

Department of CIVIL, CSE, ECE, EEE, MECHNICAL Engg. and S&H of Muthayammal College of Engineering, Rasipuram, Tamilnadu, India

Numerical Investigation of Heat Transfer Characteristics in A Square Duct with Internal RIBS

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Abstract— Attaching rib turbulators to a flow passage is an effective means of enhancing heat transfer. Rib turbulators are effectively used in serpentine cooling air channels for the internal cooling of turbine blades. Periodic ribs are frequently employed to enhance the heat transfer process in various cooling passages. The reason that ribs increase the fluid flow turbulence near the wall and disrupt the laminar boundary layer to enhance the heat transfer. The other reason is that the ribs also increase the heat transfer area. However, the thermal/hydraulic performance of the ribs is affected by many factors including the holes in a rib, size and spacing. The present investigation involves the 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. The model is created using GAMBIT 2.4.6 software. Numerical simulations were performed using the CFD software package ANSYS 14.5 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.

Keywords— Ribs, Hole shapes, Shear-stress transport (SST) *k-ω* model

I. INTRODUCTION

In the advanced gas turbines of today, the turbine inlet temperature can be as high as 1500°C. However, this temperature exceeds the melting temperature of the metal air foils. This high temperature within the blade material causes thermal stresses.The use of ribs to enhance the heat transfer is very important in modern advanced gas turbines.Ribs increase the fluid flow turbulence near the wall and disrupt the laminar boundary layer which ultimately enhance the heat transfer. Ribs also increase the heat transfer area.

S. Caliskan[1]investigated the heat transfer and flow characteristics under impingement of a multiple circular jet array with perforated rib surfaces (PRS) and solid rib surfaces (SRS). Correlation has been developed for the average nusselt number for the perforated rib surface and total area. The investigation reports that perforated ribs gives better heat transfer coefficient than solid one.C. Nuntadusit et al.[2]determined the heat transfer and flow characteristics in a channel with different types of perforated ribs. The effects of perforation/hole inclination angle (θ=0°, 15° and 30°) and a location of hole on the rib has been examined. The result reveal that perforated rib considerably improve the heat transfer compared to solid one, resulting in superior overall heat transfer performance.Wei Peng et al.[3]experimentally and numerically investigated the convection heattransfer in channels with different types of ribs. It was found that V-shaped ribs have better thermal/hydraulic performance than 90° ribs and 45° V-shaped ribs have the best thermal/hydraulic performance. It also shows the comparison of the continuous ribs and interrupted ribs and concluded that the heat transfer performance with V-shaped interrupted ribs was lower than with the V-shaped continuous ribs. Giovanni Tanda[4]investigated the effect of ribspacing on the heat transfer and friction in a rectangular channel with 45° angled rib turbulators on one/two walls and found out the optimum value for the rib pitch-to-height ratio for one/two ribbed-wall channel.S.Skullong et al.[7]experimentally investigated airflow friction and heat transfer characteristics ina square channel fitted with different rib heights turbulators for the turbulent regime, Reynolds number of 4000-40,000. It was found that the use of in-line ribs provides considerable heat transfer augmentations, Nu/Nu_0 = 2.6. Nusselt number augmentation tends to increase with the rise of Reynolds number.Thakur Sanjay Kumar et al.[8]

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carried out an experimental study for the enhancement ofheat transfer coefficient of a solar air heater having roughened air duct provided with artificial roughness in the form 60° inclined discrete rib. Based on the experimental results of heat and fluid flow in a rectangular duct with 60° inclined discrete rib roughness on one broad wall, it was observed that the roughened surface yield maximum increase in nusselt number and friction factor.M.R. Shaeri et al.[5]reviewed the heat transfer from a three dimensional array of rectangular perforated fins with square window that are arranged in lateral surface of fins. Computations are carried out at Reynolds number of 2000-5000 based on the fin thickness and Pr=0.71. The results showed that the perforate fins had higher heat transfer and weight reduction compared with solid fins.

The present paper presents a numerical investigation of the heat transfer in a plain, perforated ribbed channel with rectangular with rounded corner and elliptical holegeometries. Gambit software is used for solid modelling and Ansys Fluent is employed for analysis. These results are useful to improve the designs of the internal cooling passages in gas turbine blades.

Nomenclature	
CFD	Computational Fluid Dynamics
D_h	Hydraulic diameter in m
K	Thermal conductivity in W/mK
q	Heat flux in W/ m^2
Ts	Surface temperature in k
Ti	Inlet temperature in k
Nu	Nusselt number
Re	Reynolds number
h_x	Heat transfer coefficient W/m^2K

II. NUMERICAL SIMULATION PROCEDURE

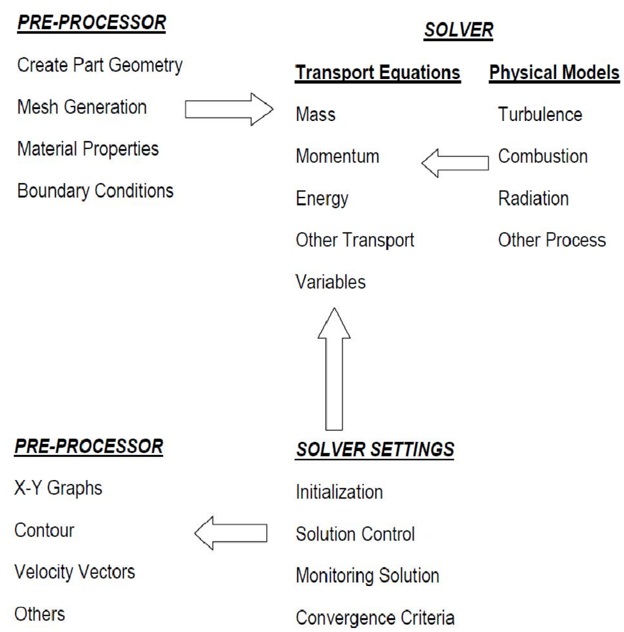

Fig.2.1 Numerical simulation procedure

The basic approaches to solve problem in fluid dynamics include three main subdivisions and they are

- Experimental model
- Analytical solution
- Computation

Gambit is used for geometric modeling and mesh generation,it creates mesh nodes throughout the volume according to the specified meshing parameters.FLUENT is a state-of-the-art computer program for modeling fluid flow and heat transfer in complex geometries. FLUENT provides complete mesh flexibility, including the ability to solve flow problems using unstructured meshes that can be generated about complex geometries with relative ease.

3 GEOMETRIC MODEL

The square channel roughened with ribs on two opposite walls have been created using GAMBIT 2.4.6 software. This paper includes two types of rib arrangements for each setup. The arrangements are periodic and random.

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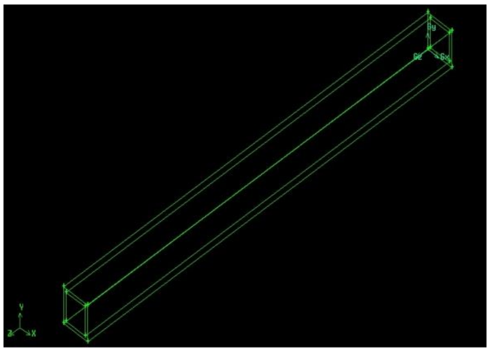

Fig.3.1 Plain channel without ribs

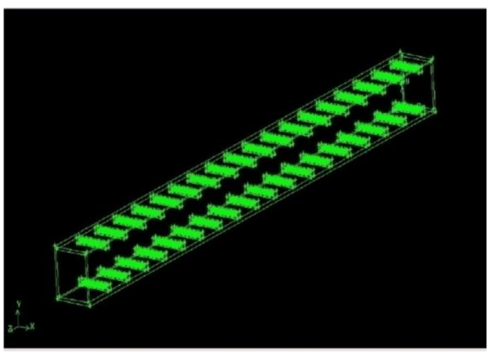

Fig.3.2 Periodically arranged ribs

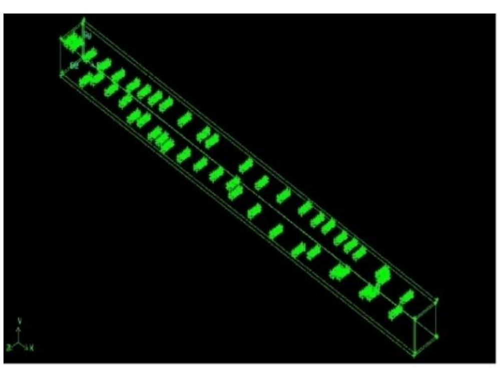

Fig.3.3 Randomly arranged ribs

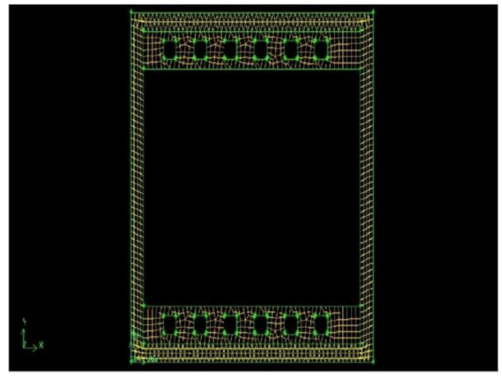

Fig.3.4 Meshed model

3.1 MATERIAL USED

Material chosen for square channel is aluminium and the fluid is considered to be incompressible air. Rib material is selected as same of channel. In this work the inlet velocity is varied as 2.78 m/s, 3.76 m/s, 4.25 m/s, 4.74 m/s, 4.74 m/s and 5.23 m/s respectively as the Reynolds number varies as 8500, 10000, 11500, 13000 and 14500. Inlet temperature of the fluid is assumed to be room temperature which is 33°C.

Table 3.1.1 Fluid Properties

Properties of air at 1atm pressure	Temperature at 33°c [306 K]
Density ρ [kg / m³]	1.1526
Specific heat cp [J / kg K]	1007
Thermal conductivity k [W / m K]	0.026102
Dynamic viscosity μ [kg / m s]	1.8858e-05
Kinematic viscosity γ [m² / s]	1.6362e-05
Prandtl number	0.72736
Molecular weight [kg / kg mol]	28.97

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3.2 BOUNDARY CONDITION

Fluent has a wide range of boundary condition that permits the flow to enter and exit in the physical model. Mass flow, inlet boundary condition is not necessary to be used in incompressible flows, because the density is constant.So in the present investigation the physical model inlet has been considered as velocity-inlet, outlet has been considered as out-flow. Inlet boundary conditions have fixed the mass flow. Wall boundary conditions are used to bounce the fluid and solid regions.In the present work the perforated ribs are attached with on one/two opposite walls of the square channel where constant heat flux is applied, other two sides are insulated.The shear stress and heat transfer between the fluid and wall are computed based on the flow details in the local field.

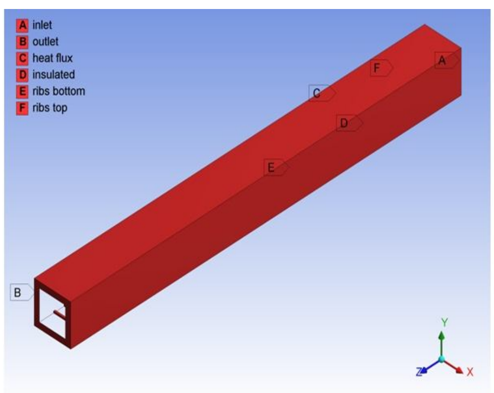

Fig.3.2.1 Boundary conditions in model

NAME	TYPE
Inlet	velocity-inlet
Outlet	out flow
Bottom wall	heat flux
Top wall	heat flux
Right side wall	wall [insulated]
Left side wall	wall [insulated]

Table 3.2.1 Boundary conditions

IV NUMERICAL ANALYSIS

In order to obtain the temperature variation at different Reynolds number for each model contour plot is plotted. The different models and its temperature variation aredetermined for the calculation of Nusselt number. The figures showsone of the contour plot for plain channel.Velocity is calculated using the formula **Re= ρvD/μ**

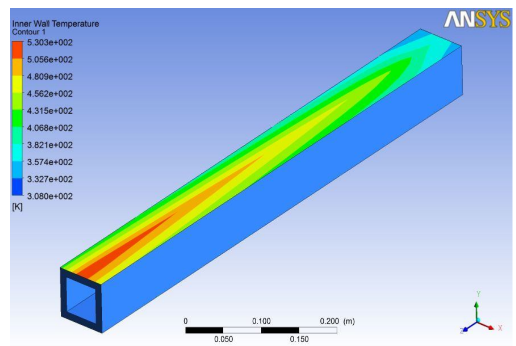

Fig.4.1 Temperature distribution at velocity 2.87 m/s

The Nusselt number is calculated using the formula

$Nu_x = h_x d_e / k$, where $h_x = q / (T_{wx} - T_{fx})$

here,**hx** = heat transfer coefficientw/m^{2}k

q = heat flux = 800 w/m^2

Tw,x = wall temperature = 33°c

Tw,f = fluid temperature

Nu$_x$ = local nusselt number

de = hydraulic diameter = 0.05 m

k = thermal conductivity w/mk

V RESULTS

This research primarily focused on plain channel without ribs, channel with ribs having rectangular with rounded corner perforation and ribs having elliptical perforations. In order to validate the procedure, ref [2] with initial specification were modelled and analysed in Fluent 14.5 and the result were compared with the existing literature result.

Reynolds No. (Re)	Fluent result	Literature result
60000	Nu = 42.723	Nu = 43

Table 5.1Average nusselt number comparison of fluent and literature.

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Thus the present procedure is validated and based on this validation analysis for plain and perforated ribbed channel were carried out.

5.1 Plain channel

In this model the local Nusselt number is obtained by varying the Reynolds number from 8500 to 14500. The distribution of the local Nusselt number, *Nu* in the square channel withoutribs is shown in the ***Table 5.1.1***

Re	Nu
8500	37.5732
10000	41.8174
11500	45.8842
13000	49.8031
14500	53.5966

Table 5.1.1 Nu variation in plain channel

5.2 Ribs having rectangular holes with rounded corners

In the present investigation, rectangular holes with rounded corners have been considered. In each model the local Nusselt number is obtained by varying the Reynolds number from 8500 to 14500. The distribution of the local Nusselt number, *Nu* in the square channel with rectangular ribs having rounded corner on two walls is shown in the ***tables.***

Re	Nu
8500	42.20
10000	47.74
11500	52.22
13000	56.60
14500	60.80

Table 5.2.1 Randomly arranged ribs with rectangular holes of rounded corner

Table 5.2.2 Periodically arranged ribs with rectangular holes of rounded corner

Re	Nu
8500	44.71
10000	49.07
11500	53.59
13000	58.23
14500	62.36

5.3 Ribs having elliptical holes

The variation of average Nusselt number distribution for channel with ribs having elliptical holes is shown in the ***table 5.3.1 and 5.3.2.*** It was found that the Nusselt number increase with increase in Reynolds number. The variation is shown in the graph with respect to different Re and Nu number. In this case also the perforated ribs are randomly arranged onto the channel and then it arranged periodically. The plot for both randomly arranged ribs and periodically arranged ribs were plotted.

Table 5.3.1 Randomly arranged ribs with elliptical holes

Re	Nu
8500	41.04
10000	45.56
11500	49.90
13000	54.07
14500	58.12

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Re	Nu
8500	42.20
10000	47.74
11500	52.22
13000	56.60
14500	60.80

Table 5.3.1 Periodically arranged ribs with elliptical holes

Now the average Nusselt number plot for different model is figured below.

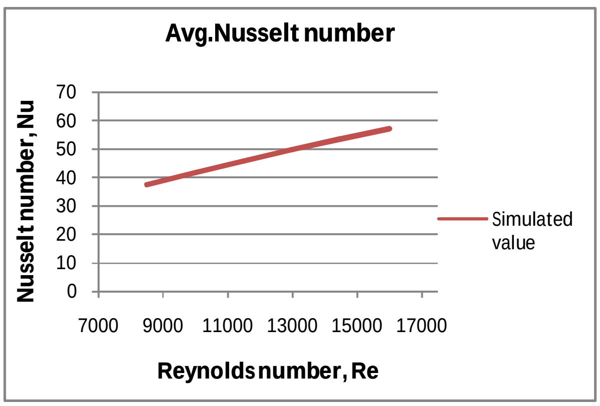
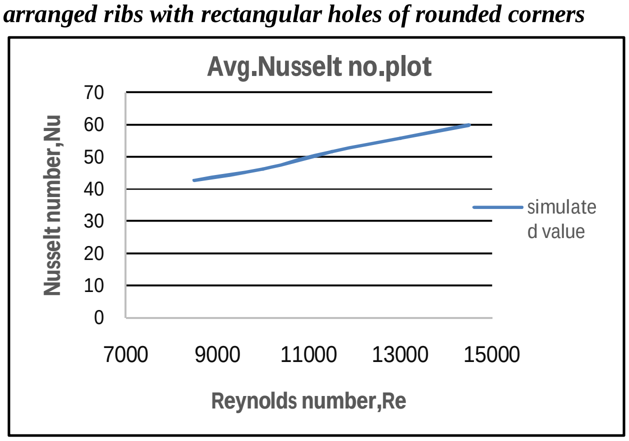


Fig 5.1.1 Average Nu and Re plot for plain channel

Fig 5.2.1 Average Nu and Re plot for randomly arranged ribs with rectangular holes of rounded corners



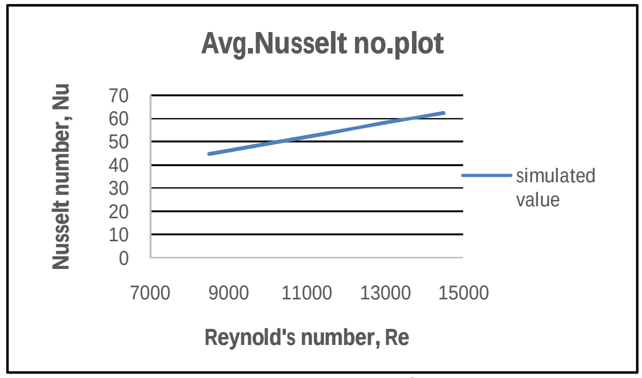


Fig 5.2.2 Average Nu and Re plot forperiodically arranged ribs with rectangular holes of rounded corners

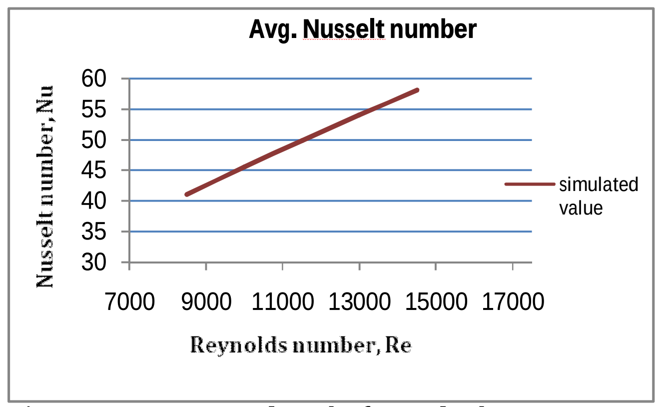


Fig 5.3.1 Average Nu and Re plot for randomly arranged ribs with elliptical holes

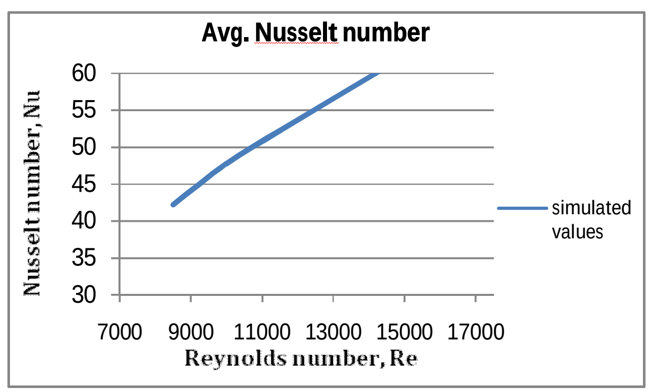


Fig 5.3.2Average Nu and Re plot for periodically arranged ribs with elliptical holes

VI. CONCLUSION

The heat transfer characteristics of plain, rectangularholes with rounded corner perforated ribs and ribs with elliptical holes on two opposite walls in the channel for Reynolds numbers ranging from 8500 to 14500 have been investigated numerically with the help of ANSYS-FLUENT software. Based on the numerical results, the following conclusions are drawn: 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.

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