Experimental study of Heat transfer by turbulator: A Literature Review

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Abstract

Heat transfer is one of the most important topic help in designing compact heat exchanger for various engineering application such as refrigeration industries, internal cooling of steam turbine blades. Several enhancement techniques have been developed in order to improve heat transfer and reduce a heat exchanger size. The main objective of this paper is was to understand the changes in heat transfer and flow characteristics.The minorobjectivesare to study the heat transfer rate of turbulators in square duct &Study the turbulatorsdifferent geometries in duct. Researcher work carried out on turbulator is to study and focus on the V- Shape with 55° geometry for turbulator compare to their work for heat transfer enhancement. So, this paper deals with the Experimental study of Heat transfer by turbulator.

Keywords- Turbulators, square duct, rib angle, heat transfer

I. INTRODUCTION

Many industries are utilizing thermal systems where in overheating can damage the system components and lead to failure of the system. The excessive heat so generated must be dissipated to surroundings to avoid such problems for smooth functioning of system. This is especially important in cooling of gas turbine blades, process industries, cooling of evaporators, thermal power plants, air conditioning equipment's, radiators of space vehicles and automobiles and modern electronic equipment's. In order to overcome this problem, thermal systems with effective emitters such as ribs, fins, baffles etc. are desirable. The need to increase the thermal performance of thesystems, thereby affecting energy, material and cost savings has led to development and use of many techniques termed as heat transfer intensification. There are many heat augmentation techniques available. Some of them are (a) surface roughness, (b) plate baffle and wave baffle, (c) perforated baffle, (d) inclined baffle, (e) porous baffle, (f) corrugated channel, (g) twisted tape inserts, (h) discontinuous crossed ribs and grooves. Most of these enhancement techniques are based on the ribs arrangement lead to increase in heat transfer coefficient but at the cost of increase in pressure drop.

Repeated ribs are used on heat exchange surfaces to promote turbulence and enhance convective heat transfer. Rib arrays inside internal channels are often used in heat exchanger systems to enhance the heat transfer rate. A typical application is the internal cooling of gas turbine blades: the ribs break the laminar sub layer and create local wall turbulence due to flow separation and reattachment between the ribs, thus greatly enhancing the cooling effect. Earlier study deals with uniform heated tubes and square and rectangular duct with rib-roughened walls. Continuous, regularly spaced, transverse ribs have been most common ribbed geometry for years [1-5]. The most important parameter in heat transfer deal with rib height e, rib pitch p, channel aspect ratio A/R, hydraulic diameter D_h, and pressure drop ΔP and Reynolds number Re.

As shown in Fig.1.1, at first, cooled compressed air is forced to enter into the turbine blade through the blade root, and then cooled air is circulated to different passages. Inside the front portion of the blade, compressed air cools down the front wall by impingement. Cooled air is also injected out of the blade through the tiny holes in the wall to form a thin film of cool air between the blade surface and the hot gas flow to diminish the heat transferred from the external gas flow. Inside the rear portion of the blade, compressed air convectively extracts the heat away from the wall while it travels.

Along the internal passage roughened with pin fins; the cooling air is then discharged from theblade's trailing edge. Inside the middle portion, cooled compressed air passes through multi-passserpentine passages, where turbulators are mounted on the walls to enhance heat transfer, andthen the air leaves out of the blade from the small holes on the top of the blade.

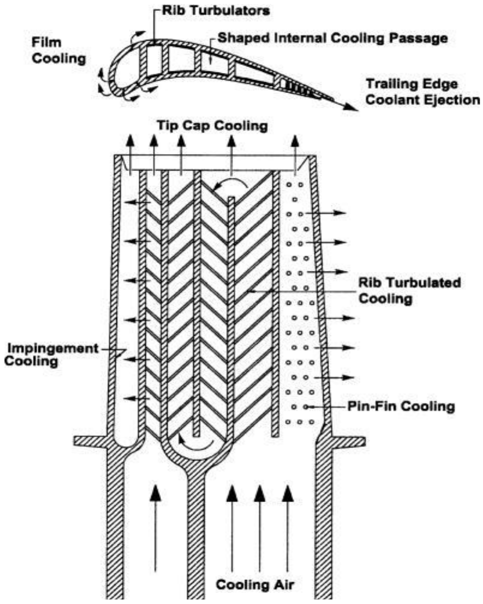

Fig.1.1. Typical Cooling Arrangement in Turbine Blade [5]

In recent years,efforts aimed at improving internal cooling have led to the use of a new method: roughening the Walls of the blade internal channels with different shape turbulators.

II. LITERATURE REVIEW

A lot of research has been done on heat transfer enhancement techniques. A considerable amount of experimental as well as analytical and computational research has been carried out on the enhancement of heat transfer. In this report, a brief survey of the relevant literature is presented to indicate the extent of workalready reported in open literature pertaining to the enhancement of heat transfer by introducing turbulators/protrusions mounted on the heat transfer surfaces.

K. Sivakumaret al[1] the use of the rib turbulators is an effective technique to enhance the rateof heat transfer to gas flow in the gas turbine blades. A number of geometricparameters have been investigated on the heat transfer, flow characteristicsand pressure drop of internal blade cooling of gas turbine blade. In this paper,an attempt has been made to review on how the geometrical parameters ofchannel shape, rib shape, rib orientation and rib spacing will affect the heattransfer rate and pressure drop in a gas turbine internal blade cooling.

PongietP. &Wayo C. [2] investigation has been carried out to examine periodic laminar flow and heat transfercharacteristics in a three-dimensional isothermal wall channel of aspect ratio,AR=2 with 45° staggered Vbaffles. The computations are based on the finite volume method, and the SIMPLE algorithm has beenimplemented. The fluid flow and heat transfer characteristics are presented for Reynolds numbers based onthe hydraulic diameter of the channel ranging from 100 to1200. To generate two pair of main stream wisevortex flows through the tested section, V-baffles with an attack angle of 45° are mounted in tandem andstaggered arrangement on the lower and upper walls of the channel. Effects of different baffle heights onheat transfer and pressure drop in the channel are studied and the results of the V-baffle pointing upstreamare also compared with those of the V-baffle pointing downstream. It is apparent that in each of the mainvortex flows, a pair of stream wise twisted vortex (P-vortex) flows can induce impinging flows on a sidewalland a wall of the interbaffle cavity leading to drastic increase in heat transfer rate over the channel. Inaddition, the rise in the V-baffle height results in the increase in the Nusselt number and friction factorvalues. The computational results reveal that the optimum thermal enhancement factor is around 2.6 atbaffle height of 0.15 times of the channel height for the V-baffle pointing upstream while is about 2.75 atbaffle height of 0.2 times for the V-baffle pointing downstream.

Sutapat K. &PongjetP. [3] hasnumerical work been conducted to examine turbulent periodic flow and heat transfer characteristics in athree dimensional square-duct with inline 60° V-shaped discrete thin ribs placed on two opposite heated walls.The isothermal-flux condition is applied only to the upper and lower duct walls while the two sidewalls areinsulated, similar to internal passage cooling of gas turbine blades. The computations are based on the finitevolume method with the SIMPLE algorithm for handling the pressure–velocity coupling. Air is the working fluidwith the flow rate in terms of Reynolds numbers ranging from10,000 to 25,000. The numerical result is validatedwith available square-rib measured data and found to agree well with measurement. The computation revealsthat the ribbed duct flow is fully developed periodic flow and heat transfer profiles at about x/D=7–11downstream of the inlet. Effects of different rib height to duct diameter ratios, BR, on thermal characteristics for aperiodic ribbed duct floware investigated. It is found that a pair of counter-rotating vortices (P-vortex) caused bythe rib can induce impingement/attachment flows on the walls leading to greater increase in heat transfer overthe test duct. In addition, the rise of BR values leads to the increase in heat transfer and friction loss. The maximumthermal performance is around 1.8 for the rib with BR=0.0725 where the heat transfer rate is about 4.0 timesabove the smooth duct at lower Reynolds number

AnandaTheertha et al [4] has work on Gas turbine plays a vital role in the present day industrial society as they are being extensively used for land based powergeneration and in aircraft propulsion. There is constant challenge to increase the efficiency of the gas turbine engines whichcan be increased by raising the turbine inlet temperature. Present day advanced gas turbine blade inlet temperatures can beas high as 1700°C, here as blade materials are capable of withstanding only 1200°C to 1300°C. Cooling air, extracted fromthe compressor is around 650°C, is passed through the airfoil sections of the blade which lower the temperature to about1000° C which is safe and permissible for reliable operation of the engine. It is practically very difficult and costly to obtainexperimental data on heat transfer and the pressure losses in thin airfoil turbine blade sections at such temperatures androtational speeds. Hence data generated from numerical investigations will play vital role in design, development andimproving the efficiency of gas turbine engines. Flow tripping geometries like pin fin, and dimples are generally used in thetrailing edge regions, where as ribs or tabulators are located at middle of the airfoil to enhance the heat transfer.In this paper, analysis is carried out on three different combinations which are simple U duct, ribs aligned at 45° to flowdirection and combination of ribs and grooves at 45° to flow direction. All turbulators are located on trailing face of duct. Thesimulations are carried on square duct having hydraulic diameter (D_h) of 0.0127m, Reynolds number of 25,000, rotationalnumber (R_o) of 0.24, inlet density ratio ($\Delta\rho/\rho$) of 0.13. Details for relative rib height (e), pitch distance between ribs (P),distance between ribs and groove centre (g), and the groove angle are similar to experimental reference. The numericalanalysis has been carried out on Ansys CFX solving 3D compressible Navier Stokes equation along with k-ω turbulencemodel.It was observed from the investigation, that the numerical results are in good agreement with the experimental results invalidation stages. For the simple U duct and duct with ribs the simulations are carried out for one complete revolution and forrib-grooved case, only partial results are published. The present results for the turbulators show that there is significantenhancement in heat transfer from the heated wall to coolant when compared with simple U tube.

J. C. Han & J. S. Park [5]found the combined effects of the rib angle-of-attack and the channel aspect ratio on the distributions of the local heat transfer coefficient for developing flow in short rectangular channels (L/D = 10 *and* 15) with a pair of opposite rib-roughened walls were determined for Reynolds numbers from 10 000 to 60 000. The rib angle-of-attack was varied from 90° to 60°, to 45°, and to 30°, whereas the corresponding channel width-to-height ratio was varied from 1 to 2 and to 4, respectively. Semi-empirical heat transfer and friction correlations were obtained to account for rib angle, rib spacing, channel aspect ratio, rib height and Reynolds number. The results can be used in the design of turbine blade cooling channels.

Giovanni Tanda [6] experiment carried on repeated ribs are used on heat exchange surfaces to promote turbulence and enhance convective heat transfer.Applications include fuel rods of gas-cooled nuclear reactors, inside cavities of turbine blades, and internal surfaces ofpipes used in heat exchangers. Despite the great number of literature papers, only few experimental data concerndetailed distribution of the heat transfer coefficient in channels with rib turbulators. This issue was tackled by means ofthe steady-state liquid crystal thermography: a pre-packaged liquid crystal film was glued onto the heated surface,and the color map was taken by a video camera at the steady state of a given experiment. After calibration tests toassess the color–temperature relationship had been performed, local heat transfer coefficients were obtained by applyingcustom-made software to process the digitized color images. Liquid crystal thermography was applied to thestudy of heat transfer from a rectangular channel (width-to-height ratio equal to five) having one surface heated atuniform heat flux and roughened by repeated ribs. The ribs, having rectangular or square sections, were deployedtransverse to the main direction of flow or V-shaped with an angle of 45 or 60 deg relative to flow direction. The effect ofcontinuous and broken ribs was also considered. Local heat transfer coefficients were obtained at various Reynoldsnumbers, within the turbulent flow regime. Area-averaged data were calculated in order to compare the overall performanceof the tested ribbed surfaces and to evaluate the degree of heat transfer enhancement induced by the ribs withrespect to the smooth channel.

C. Thianponget al[7] study on Heat transfer, friction factor and thermal performance characteristics in a tube equipped with twisted-rings (TRs) are experimentally investigated. The experiments were conducted using TRs with three different width ratios (W/D = 0.05, 0.1 and 0.15) and three pitch ratios of (p/D = 1, 1.5 and 2) for Reynolds numbers ranging from 6000 to 20,000 using air as a test fluid. The typical circular rings (CRs) were also tested for an assessment. The experimental results reveal that most TRs yield lower Nusselt numbers and friction factor than CRs, except at the largest width ratio (W/D = 0.15) and the smallest pitch ratio (p/D = 1.0). In addition, Nusselt number and friction factor increase as width ratio increases and pitch ratio decreases. However, a maximum thermal performance factor is associated by TRs with the smallest width ratio and pitch ratio. The empirical correlations of the heat transfer (Nu) and friction factor (f) are also included in this paper.

Li-Min Chang et al [8] explained numerical study of the relationship between enhancement and absolute vorticity flux along main flow direction. They have been used secondary flow to enhance heat transfer enhancement. The relation between the intensity of secondary flow and strength of convective heat transfer is studied using a numerical method. They studied flat tube bank fin with three-row tubes. Results were plot in comparison between experimental and numerical simulation.

Muthusamy et al[9] investigate the effect of conical cut out turbulators with internal fins incircular tube on heat transfer and friction factor. The conical cut out turbulator with internal finfitted with three different pitch ratio and two different arrangement mode. Galvanized testsection iron pipe insulated with asbestos rope. Stainless steel conical cut out turbulators attachedto internal surface of pipe. The turbulators are arranged in convergent as well as divergentpatterns with pitch ratio 3, 4 and 5. Air is working fluid and Reynolds number ranging from 6800to 9700 under constant heat flux. The result of D-turbulators arrangement with PR = 3 shows the maximum heat transfer rate of 2.4 and friction factor 3.2 times than plain tube.

Seyyedi et al[10] explained numerical investigation of the effect of a splitter plate on forced convection in a two dimensional channel with an inclined square cylinder. Using the lattice Boltzmann method they studied effects of a splitter plate and an inclined square cylinder with an angle of inclination equal to 45° on two-dimensional unsteady laminar flow and heat transfer in a plan channel. The results are presented in terms of average, time-averaged and instantaneous contours of streamline, temperature and vorticity, with some characteristics of fluid flow and heat transfer

Tauscher et al. [11] carried out experimental and numerical investigation of forced convectionheat transfer in a plate heat exchanger with rib-roughed surface. The adiabatic inlet section leadsto an almost hydro dynamically developed flow, with a thermally developing flow regime in theheated test section. Rib angles with 150, 450, 760 and 900 respectively with different groove angleplaced on bottom side heat exchanger channel. Flow rates have been varied between Reynoldsnumber 500 and 10000. The set up examined experimentally and numerical CFD.

Rahal et al [12] presents study of a numerical simulation of flow and heat transfer by forced convection in a horizontal channel with three blocks attached to its bottom wall. The blocks simulate electronic components. In order to enhance heat transfer, a rectangular cross section control element, acting as a Turbulator, has been attached to the channel top wall. The control element best position, allowing maximal heat dissipation, has been determined. The results indicate that heat transfer in channel is enhanced because of the control element. For each block, the best position of the Turbulator, which allows maximal heat dissipation, is when the control element is located above the considered block.

Lee et al[13] investigated forced convective heat transfer of water near to the critical region in ahorizontal square duct. Near the critical point convective heat transfer in the duct is stronglycoupled with large variation of thermo physical properties such as density and specific heat.Buoyancy force parameter has also severe variation with fluid temperature and pressure in theduct. There is flow acceleration along the horizontal duct resulted from fluid density decreasedue to the heat transfer from the wall. Local heat transfer coefficient has large variation along theinner surface of the duct section and it depends on pressure. Nusselt number on the centre of thebottom surface also has a peak where bulk fluid temperature is higher than the pseudo criticaltemperature and the peak decreases with the increase of pressure. Flow characteristics ofvelocity, temperature, and local heat transfer coefficient with water properties are presented andanalyzed. Nusselt number distributions are also compared with other correlations for variouspressures in the duct.

Zamankhan et al [14] investigates thermo hydraulic processes in a three-dimensional circular tubewith a helical turbulator. Glycol–water blends of various concentrations were used in the innertube, and pure water was used in the outer tube. Changes in fluid physical properties withtemperature were taken into account, and k-ε , k-ω, and large eddy simulations were developedfor turbulence modelling. The simulation results showed a nonlinear variation in Reynolds andPrandtl numbers for a long model of a heat exchanger even in the absence of a turbulator. Thepresence of the turbulator was found to increase the heat transfer, sometimes without inducingturbulence, but also increased the pressure drop. The results demonstrate that the model could beused as a useful tool for optimization of heat exchanger performance in the presence of a turbulator.

Experimental Set Up

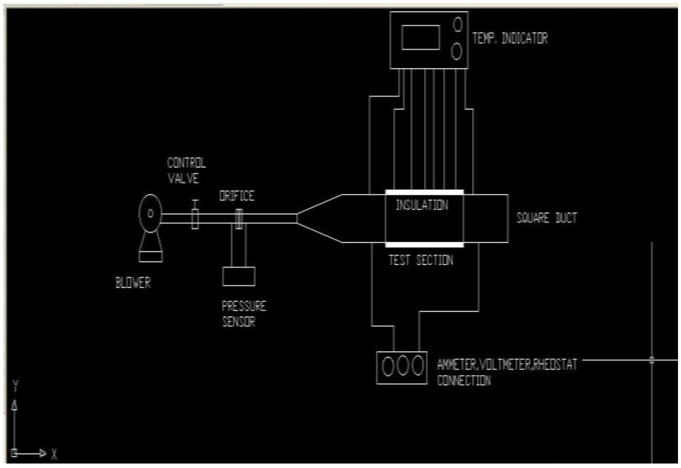

Fig. 2-Block Diagram of experimental setup

Table No.1-Specifications

Turbulator	Material	Aluminum
	Height	3.5mm
	thickness	3mm
	Angle	55
	Horizontal Pitch	15mm
Centrifugal blower	Capacity	1000 CFM/m3/hr.
	Pressure	180 mm/inch.
	Motor	1Hp / 2880 rpm
An orifice	thickness	3mm,
	bevel angle	450
	edge thickness	1mm
	Inner diameter of pipe	44mm
	Outer Diameter of pipe	60mm
Thermocouple	-	Eight K-type, copper constantan thermocouple
S-10 pressure Sensor	-	gives the reading in mm of water column
Heater	-	Galvanized Iron of thickness 4mm. Size of plate heater 700mm x 50 mm..
rheostat, voltmeter and ammeter	-	connected in seriesof heater

III. CONCLUSION

From the study of above literature survey we find out the following point that most important to project data.

- When disturb the boundary layer and increase the hydraulic resistance the heat transfer rate increases.

- The ribbed-rough duct predicted the influence on the secondary flow.
- The application of v-type turbulator and snail entry results in a considerable heat transfer rate and friction loss.
- The v-type turbulator alone provides the best thermal performance over the other turbulator devices.
- When turbulators placed in duct with different arrangement the heat transfer rate will be increases.
- The position of the turbulators and Reynolds number has significant effect on flow separation over the surface of lower channel wall by vortex formation at the downstream of the obstacles.

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