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Numerical Investigation of Fluid Flow and Heat Transfer in a Rectangular Channel with Longitudinal Vortex Generators

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Abstract: Rectangular ducts are used to transfer hot or cold air from one location to other. In case of hot air carriers where more heat has to be dissipated to atmospheric air during its travel, turbulence plays a key role in achieving this. For increasing the turbulence of fluid, the plane surface of duct is provided with different geometrical entities which result in increased heat transfer as compared to plane surface. There is also a pressure drop in fluid because of these disturbances occurring in the fluid. In this work, a number of appropriate designs for these vortex generators are made and simulation has been performed. A balance has been made between heat transfer and pressure drop so that overall effectiveness of the system is improved.

Key words: Heat transfer, Vortex generators, Turbulence, Secondary flow, Thermal boundary layer, Vortices.

1. Introduction:-

Heat exchangers are widely used in many industrial areas such as chemical engineering, automobile manufacturing, refrigeration and internal cooling for gas turbine blades. Universal types of heat exchangers incorporating plate–fins or fin–tubes are designed for the above industrial processes and systems, and for these types the flow is channeled between plates. Longitudinal vortex generators (LVGs) can be mounted on channel walls to generate longitudinal vortices which create a secondary flow and disturb the boundary layer growth, thereby enhancing the heat transfer between the flowing fluid and channel walls. Consequently, micro channels with LVGs as flow-disturbing elements were considered to be an efficient means to dissipate large amount of heat flux within a relatively small area .LVGs have been studied extensively due to their high heat transfer performance.

Results of journal papers indicate that flow loss due to a winglet pair was less than that due to a single wing, and zones of poor heat transfer that occur with a single wing can be eliminated by using a winglet pair. It was found that direction and strength of the secondary flow are the more important fluid dynamic factors affecting heat transfer, followed in importance by fluid velocity, and then turbulent kinetic energy. The mechanism of heat transfer enhancement is based on flow separation and reattachment In general, flow reattachment introduces a strong shear flow on the surface behind each rib or winglet, resulting in an effective disruption of the thermal boundary layer and thus the improvement of the heat transfer

For convective heat transfer intensification three mechanisms may be distinguished as

(1) Developing boundary layers,
(2) Swirl or vortices and
(3) Flow destabilization or turbulence intensification.

All three mechanisms may be caused by vortex generators. The vortex generators considered here are protrusions from a heat transfer surface which are designed to generate vortices. In the following section information is presented on vortex generators and their vortices. Transverse and longitudinal vortices may be distinguished. Transverse vortices and their generators in turbulence heat transfer mainly by flow destabilization which leads to self-excited fluctuating transverse vortices. Longitudinal vortices and their generation may involve all three heat transfer mechanisms.

2. Governing Equations:-

While designing in fluent, it is important to know how fluid will flow for a given condition of constrains. For this purpose software must take the help of numerical solutions to the boundary conditions applied. For the analyst, it is important to have an understanding of both the basic flow features that can occur and so must be modelled and the equations that govern fluid flow. The physical aspects of any fluid flow and heat transfer are governed by three fundamental principles.

Continuity equation

$$\frac{\partial \rho}{\partial t} + \nabla\,(\rho\, u) = 0$$

Momentum equation

$$\rho\left(\frac{dv}{dt} + v.\nabla v\right) = -\,\nabla \mathbf{p} + \nabla\,\mathbf{T} + \mathbf{f}$$

Energy equation

$$\nabla.\big(v(\rho E + p)\big) = \nabla.\,(k\nabla T + (\tau.v))$$

Where

$$\mathrm{E} = \left(h - \frac{p}{\rho} + \frac{v2}{2}\right)$$

Most general energy equations follow this basic rule

Rate of change of Energy inside the Fluid element	=	Net flux of heat in element	+	Rate of working done on element due body and surface forces

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Fluent analysis also has got two platforms of analysis

1. Pressure based analysis
2. Density based analysis

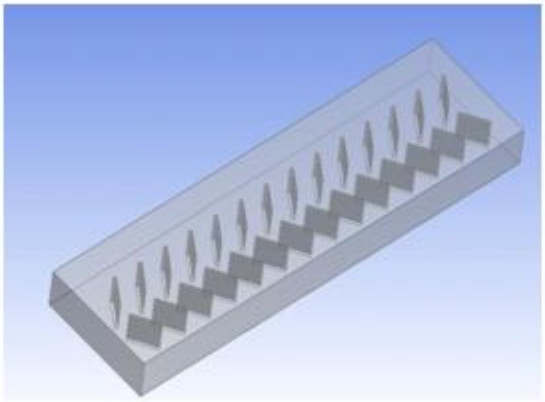
The pressure-based approach was developed for low-speed incompressible flows, while the density-based approach was mainly used for high-speed compressible flows. However due to advancement in numerical methods both platforms can be used to solve and operate a wide range of flow conditions beyond their traditional or original intent.

In both methods the velocity field is obtained from the momentum equations which are stated in the governing equations. In the density-based approach, the continuity equation is used to obtain the density field while the pressure field is determined from the equation of state. On the other hand, in the pressure-based approach, the pressure field is determined by solving a pressure equation which is obtained by solving the continuity and momentum equations. The pressure-based solver traditionally has been used for incompressible and mildly compressible flows. The density-based approach, on the other hand, was originally designed for high-speed compressible flows. Both approaches are now applicable to a broad range of flows (from incompressible to highly compressible), but the origins of the density-based formulation may give it an accuracy (i.e. shock resolution) advantage over the pressure-based solver for high-speed compressible flows.

3. Modelling:-

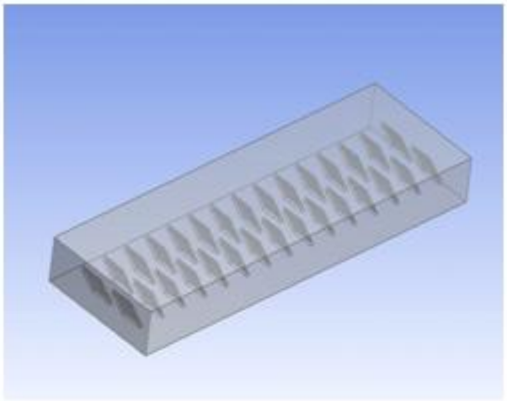
Specifications of rectangular duct:
Length: 600mm
Width: 160mm
Height: 40mm

1) Rectangular vortex generators



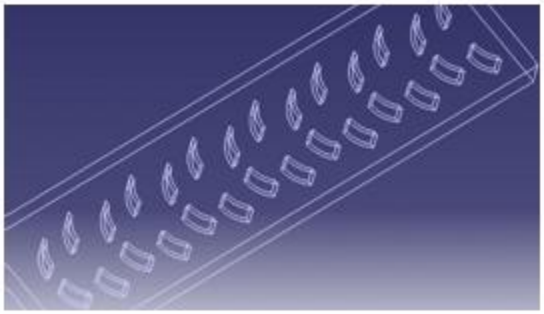
Specifications of LVG:
Width : 40mm
Height : 30mm
Thickness : 4mm
Angle of attack : 60°
Distance between LVGs : 20mm

2) Delta vortex generators



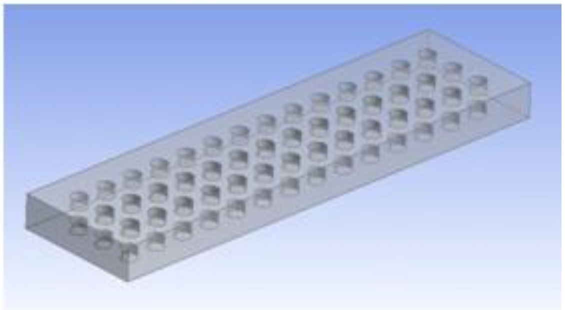
Specifications of LVG:
Width : 40mm
Height : 30mm
Thickness : 4mm
Angle of attack : 55°
Distance between LVGs : 20mm

3) Curved vortex generators



Specifications of LVG:
Radius of curvature : 40 mm
Distance between LVGs : 20mm

4) Cylindrical vortex generators



Specifications of LVG:
Radius of LVG : 10mm
Distance between LVGs : 20mm

4. Analysis:-

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Analysis was performed in ANSYS 14.5 according to the boundary conditions specified below. Variation of flow parameters at horizontal mid-plane are shown in below figures.

Boundary conditions:

For Air:

Inlet temperature: 373 k

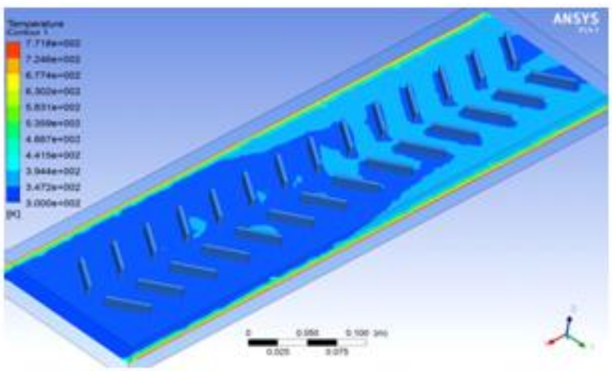
Inlet pressure : 20000 Pa

For walls of the duct:

Surface temperature: 773 k

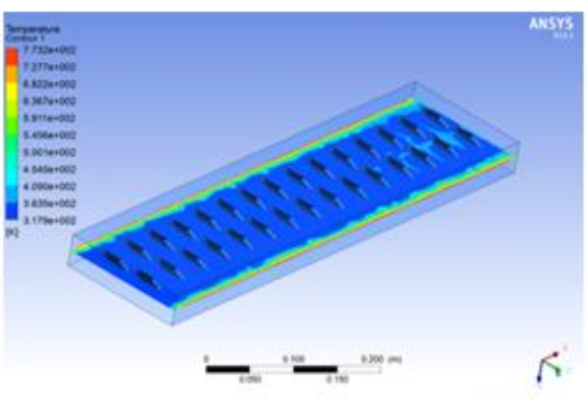
Material selected : Aluminum

1)Rectangular vortex generators



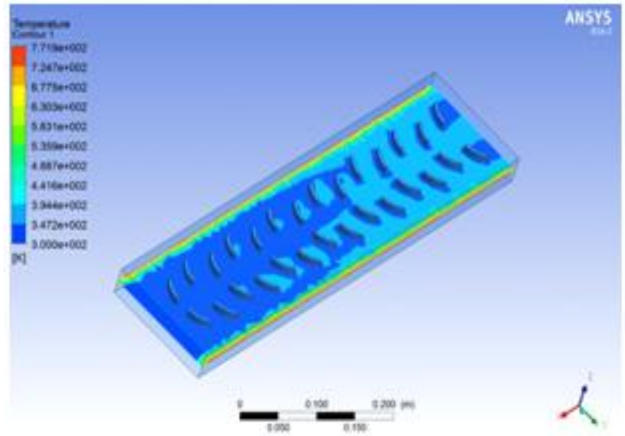
Inlet	Outlet
Temperature: 323k	Temperature: 363.8k
Pressure : 20000Pa	Pressure : 6595Pa

2)Delta vortex generators



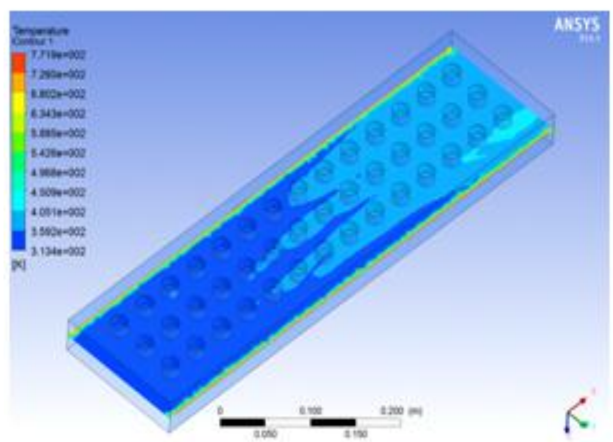
Inlet	Outlet
Temperature: 323k	Temperature: 367.69k
Pressure :20000 Pa	Pressure : 10134Pa

3) Curved vortex generators



Inlet	Outlet
Temperature: 323K	Temperature : 384.62K
Pressure : 20000Pa	Pressure : 9770Pa

4) Cylindrical vortex generators



Inlet	Outlet
Temperature : 323K	Temperature: 410.14K
Pressure : 20000Pa	Pressure : 14556Pa

5. Results:-

The analysis is carried out for different geometries of generators and the graphs below show the variation of temperature and pressure along the length of the duct.

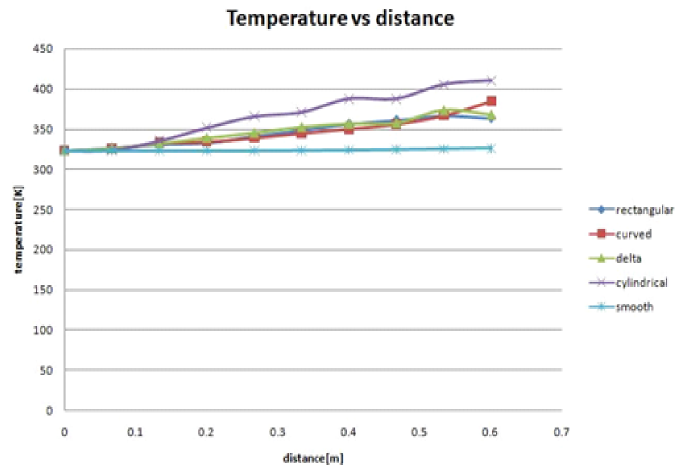


Figure: temperature vs. distance

From the above graph it can be concluded that the outlet temperature of cylindrical LVG is more than rectangular LVG(which is taken as reference).

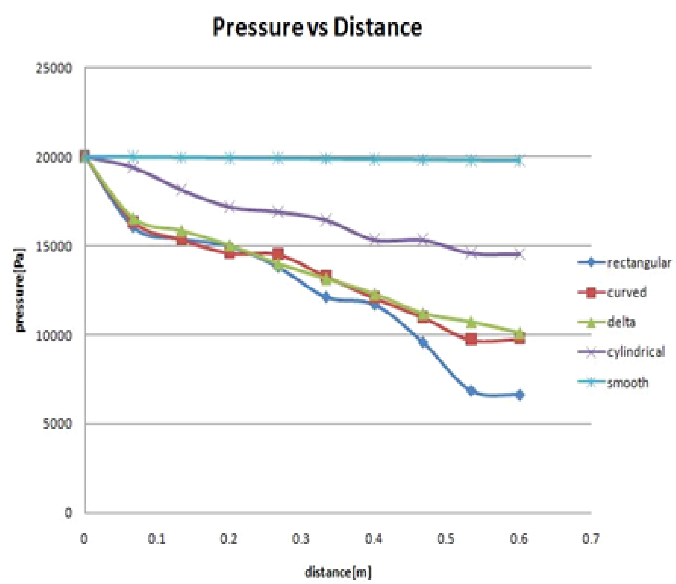


Figure: pressure vs. distance

The pressure loss in cylindrical LVG is less than rectangular LVG which means less pumping power is required for former than latter

6. Conclusion:-

From the results of the flow visualization, the mixing effect was expected in the intermediate region between wing cascades. It is due to the pressure and velocity differences across the passage between the converging pair of winglet and diverging pair of winglet. At each contraction part the boundary layer develops and at the end of the enlargement part, flow separation occurs. In these intermediate regions flow is turbulent. Thus, the heat transfer enhancement of the introduced rectangular channel geometries can be attributed to the secondary flow caused by the venture-type flow effect and the frequent boundary layer interruptions at each enlargement part. The effect of the introduced rectangular channel geometries were studied experimentally for different winglet arrangements. As the inclination angle of winglet increased the mixing effect in the intermediate region between wing cascades improves the heat transfer characteristics. The dimensions of the intermediate region between converging and diverging wing cascades is kept constant in all the tests. Thus, the mechanism of the heat transfer enhancement for these channel geometries coincided with the expectation from the results of the flow visualization. The dependence of Reynolds number on the friction factor is strong, the average Nusselt number increases by the Reynolds number. An increase of heat transfer coefficient was observed with accompanying large pressure drops increasing with the inclination angle.

It is observed that cylindrical LVGs create more turbulence than rectangular LVGs and temperature raise was found to be 12.87% more and pressure drop 27.21% less in case of cylindrical LVGs compared to rectangular LVGs.

7. References:-

i. G. Biswas, K. Torii, D. Fujii, K. Nishino, Numerical and experimental determination of flow structure and heat transfer effects of longitudinal vortices in a channel flow, International Journal of Heat and Mass Transfer 39 (1996) 3441–3451

ii. M.C. Gentry, A.M. Jacobi, Heat transfer enhancement by delta-wing vortex generators on a flat plate: vortex interactions with the boundary layer, Experimental Thermal and Fluid Science 14 (1997) 231–242

iii. G.B. Schubauer, W.G. Spangenberg, Forced mixing in boundary layers, J. Fluid Mech. 8 (1960) 10–31.

iv. S. Tigglebeck, N.K. Mitra, M. Fiebig, Comparison of wing type vortex generators for heat transfer enhancement in channel flow, ASME J. Heat Transfer 116 (4) (1994) 880–885

v. S.R. Hiravennavar, E.G. Tulapurkara, G. Biswas, A note on the flow and heat transfer enhancement in a channel with built-in winglet pair, Int. J. Heat Fluid Flow 28 (2) (2007) 299–305