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Numerical Analysis of Pin -Fin Heat Sinks

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Abstract

In the present work a Computational Fluid Dynamics (CFD) study was conducted to investigate the heat transfer coefficient in a horizontal rectangular channel of width 0.008m and length 0.060m having attachments of circular, square, tri angular and elliptical profile fins over one of its heated surface. The Reynolds number based on the flow averaged inlet velocity and the hydraulic diameter, ranged from 5000, 10,000 and 15,000. Reynolds number, fin arrangement and fin pitch in the flow direction are the numerical parameters. The staggered fin arrangement was studied for one-fixed span wise (Sx/d = 0.002) and three different stream wise (Sy/d = 0.001, 0.004 and 0.007) distances. Standard k-ε turbulent model have been used for the analysis and their results are compared for different fin configuration. The overall enhancement ratio has been calculated in order to discuss the overall effect of fin spacing and operating parameters. All the four heat sinks have equal wetted surface area of 0.00628m, based on this the comparison has been done for the overall heat transfer coefficient.

Keywords: Heat sink, pin-fin, turbulence model, Reynolds number, CFD

1. INTRODUCTION

The study of heat transfer efficiency is very important especially in the electronic industry. Many electronic device applications now generate heat more than before due to the increasing performance. CPU, for example, is being persistently developed to increase its speed performance and, as a result, the thermal management becomes a serious issue in preventing performance failure. There are several solutions to deal with thermal management. The most common electronic cooling is heat sink with the aid of natural air convection. Some heat sinks are accompanied with a fan to improve heat transfer efficiency by increasing the airflow rate over the heat sink. This process called forced air convection. Furthermore, the effective cooling enhances the stability of the component and, more importantly, the right material for thermal management is required to work as heat sink to dissipate heat from local one body quickly to prevent overheating. All electronic equipment relies on the flow of and control of electrical current to perform a variety of functions. Whenever electrical current flows through a resistive element, heat is generated. Regarding the appropriate operation of the electronics, heat dissipation is one of the most critical aspects to be considered when designing an electronic box.

Heat generation is an irreversible process and heat must be removed in order to maintain the continuous operation. With various degrees of sensitivity, the reliability and the performance of all electronic devices are temperature dependent. Generally the lower the temperature and the change of temperature with respect to time, the better they are.

Pure conduction, natural convection or radiation cool the components to some extend whereas today's electronic devices need more powerful and complicated systems to cope with heat. Therefore new heat sinks with larger extended surfaces, highly conductive materials and more coolant flow are keys to reduce the hot spots.

2. LITERATURE REVIEW

Comparisons of round-elliptical-square-parallel fins appear seldom in the literature. Wirtz et al. [1] were amongst the earliest ones to measure the performance of a pin fin heat sink.
R. Karthikeyan and R. Rathnasamy et al. [2] conducted experimental study on fin-pin heat exchanger was carried out in a setup to study the flow and thermal characteristics. This paper presents the heat transfer and friction characteristics of convective heat transfer through a rectangular channel with cylindrical and square cross-section pin-fins attached over a rectangular duralumin flat surface.
Zeinab S. Abdel-Rehim et al.[3] studied Optimization and Thermal Performance Assessment of Pin-fin Heat Sinks. In this work, the calculation is presented that allows design variables in pin-fin heat sink to be optimized.
Yue-Tzu Yang, Huan-Sen Peng et al. [4] carried out the Numerical study of the heat sink with un-uniform fin width designs. The numerical simulation of the heat sink with an impingement cooling at various Reynolds numbers and fin dimensions are proposed.
Christopher L. Chapman, and Seri Lee et al. [5] had performed an elliptical pin fin heat sink. The testing described in this paper incorporates several possible performance factors into two terms; flow bypass and overall thermal resistance.
Massimiliano Rizzi et al. [6] performed an experimental investigation of heat sink effectiveness. A constant surface temperature was desired because the application was a heat sink which removes heat from a IGBT microchip.
An attempt has been made to carry out CFD based analysis to fluid flow and heat transfer characteristics of a hollow rectangular duct attached with circular profile fins by Sunil Chamoli, Ranchan Chauhan, N.S. Thakur et al. [7].
Yoav Peles et al. [8] had performed Forced convective heat transfer across a pin fin micro heat sink. This paper investigates heat transfer and pressure drop phenomena over a bank of micro pin fins.
W. A. Khan et al. [9] had studied the modelling of cylindrical pin-fin heat sink. In this study Analytical models are presented for determining heat transfer from in-line and staggered pin-fin heat sinks used in electronic packaging applications.

3. PROBLEM DESCREPTION

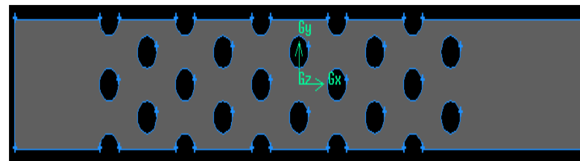
3.1 Introduction

Figure 3.1 shows the geometry and computational domain that is used in this study. In this study, maximum convective heat transfer coefficient will be determined for different fin configuration. The geometry consists of single 2-D circular, elliptical, triangular and square fins. The base-plate has a constant surface temperature along its entire length "L". It's important to note that in this study, convection is approximated to be the only form of heat transfer. While this might not entirely be the case, others have shown that the heat loss due to conduction and radiation makes up only a small percent of the total heat loss.

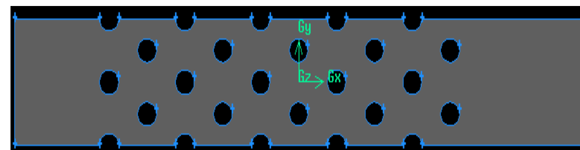
3.2 Objective

The objective of the work is to carryout computational studies on the Steady state heat transfer and friction characteristics and performance analysis for flow through a rectangular channel with heat sinks of Circular Square, Elliptical and Triangular cross section pin fins with staggered arrangement and compare the results on a meaningful and fair basis.

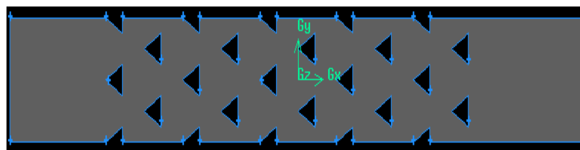
3.3 Geometry and Model



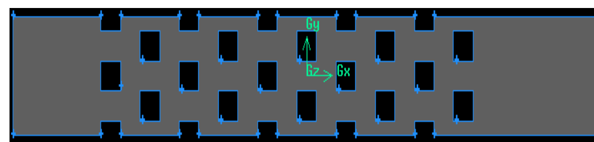
Circular Fin Model



Elliptical Fin Model



Triangular Fin Model



Square Fin Model

Fig.3.1: 2-D Model for different Fin configuration

Some simplified assumptions are required to apply the modelling conditions to the heat transfer process from flat plate.

The major assumptions are:

a. Steady state heat transfer.
b. Uniform heat transfer coefficient (h) over the entire surface of the fin.
c. Negligible radiation heat transfer.
d. No-slip wall.
e. Negligible contact thermal resistance.

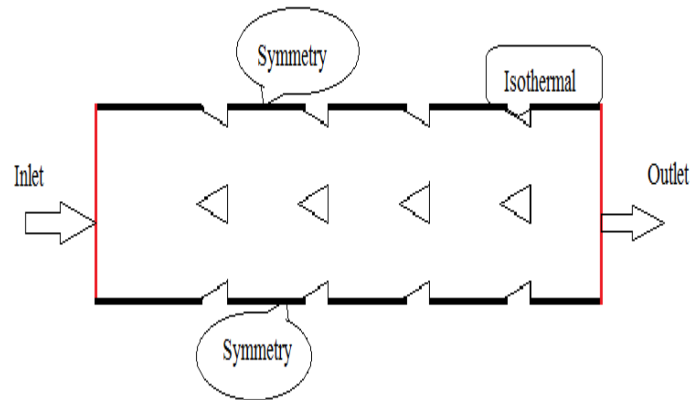


Fig.3.2: Physical domain with Boundary conditions

3.4 Boundary Conditions

Boundary condition is the very important parameters in CFD application. All CFD problems are defined in terms of initial and boundary conditions. Boundary conditions specify the flow and the thermal variables on the boundaries of physical model. Therefore, a critical component of CFD simulations is important that they are specified appropriately. All the boundary conditions that are used in pin fin domain are shown in Figure 3.2

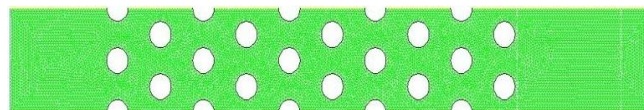
Inlet boundary: In this domain, uniform velocity profile is considered as inlet boundary condition. The flow direction must be through inside of the domain (Figure 3.2). The Reynolds number for inlet is assigned as Re=5000, 10000 and 15000.

Outlet: outflow is used as outlet boundary condition as the pressure at the outlet is not clearly known.

Target wall: The target wall is defined as no-slip wall (i.e. *u=0, v=0 m/s)* with constant temperature.

Upper boundary: The upper non-wall fluid boundary is set to Symmetry.

Circular Configuration Fin



Elliptical Configuration Fin

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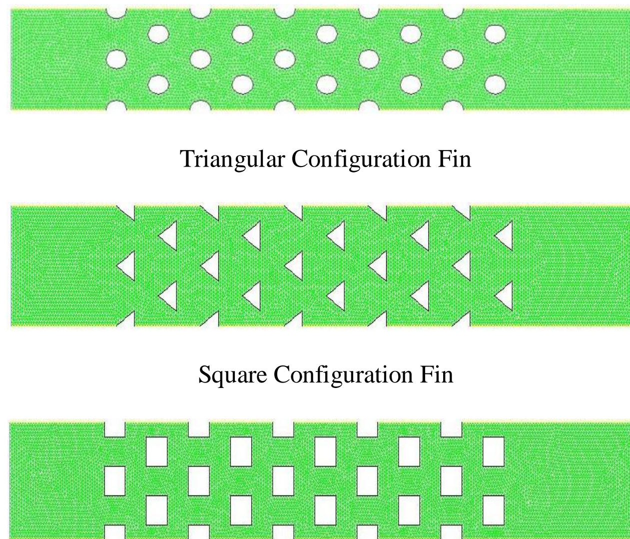

Fig.3.3. Two Dimensional Meshed Model of different Fin Configuration

4. RESULTS AND DISCUSSION

The numerical analysis of pin fin heat sink is carried out using *standard k-ε model* and the results from fluid flow and heat transfer of a pin fin heat sink are presented and analysed in this chapter in the form of contours and graphs for three different Reynolds number (*Re* = 5000, 10000, 15000).

4.1 Contours of Total Temperature

4.1.1 Contours of Total Temperature for Circular Fin:

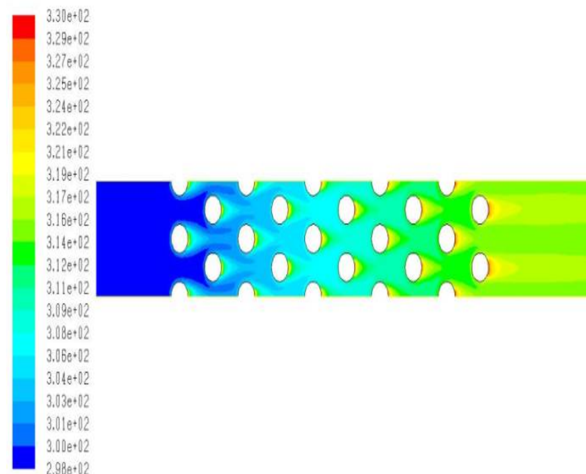

Fig 4.1: Contours of Total Temperature for Re=5,000

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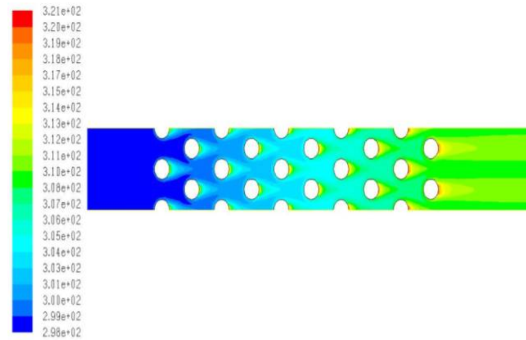

Fig 4.2: Contours of Total Temperature for Re=10,000

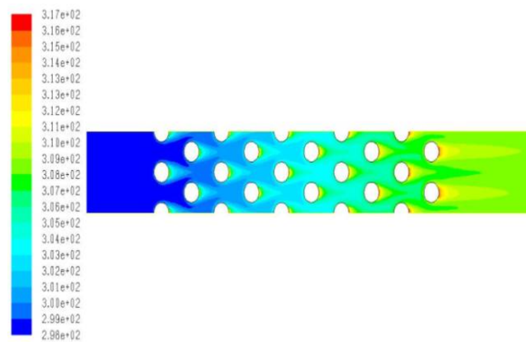

Fig 4.3: Contours of Total Temperature for Re=15,000

4.1.2 Contours of Total Temperature for Elliptical Fin:

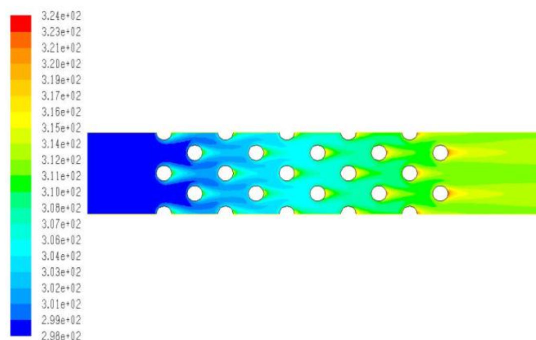

Fig 4.4: Contours of Total Temperature for Re=5,000

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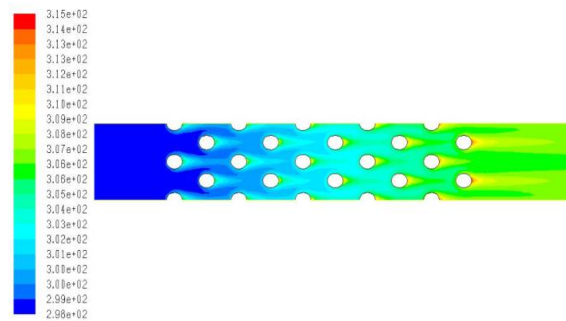

Fig 4.5: Contours of Total Temperature for Re=10,000

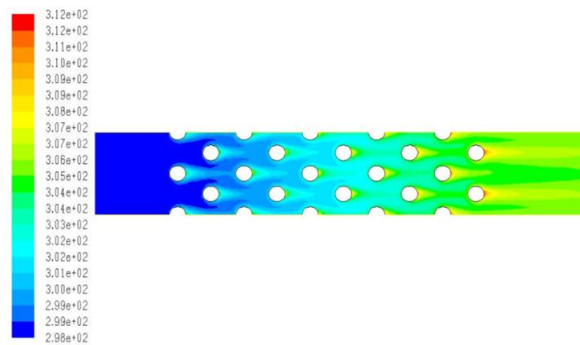

Fig 4.6: Contours of Total Temperature for Re=15,000

4.1.3 Contours of Total Temperature for Triangular Fin:

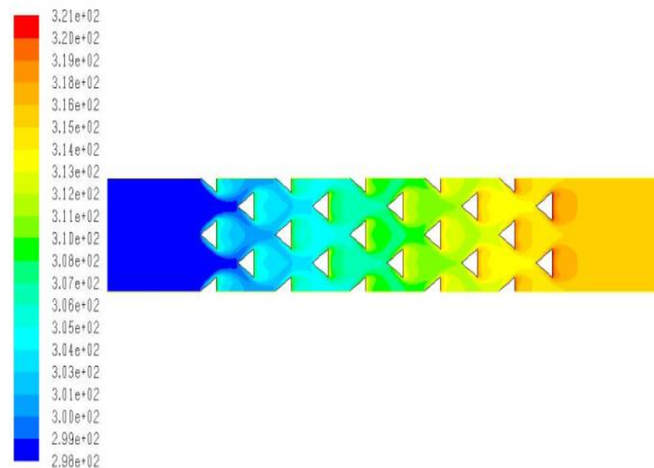

Fig 4.7: Contours of Total Temperature for Re=5,000

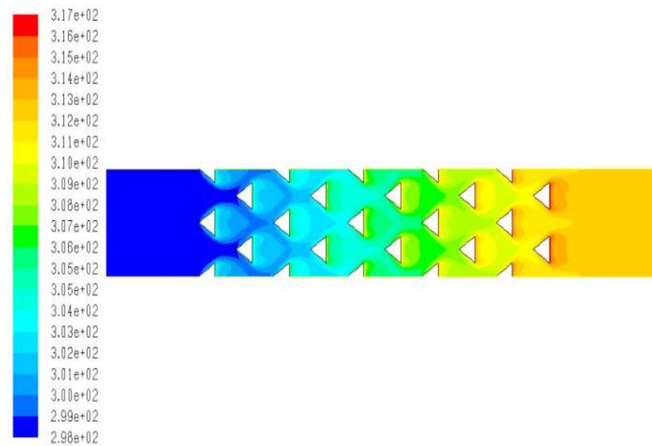

Fig 4.8: Contours of Total Temperature for Re=10,000

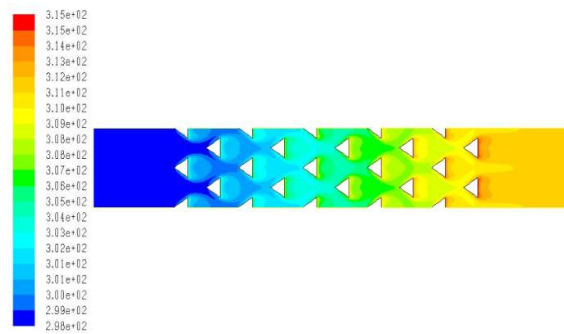

Fig 4.9: Contours of Total Temperature for Re=15,000

4.1.4 Contours of Total Temperature for Square Fin:

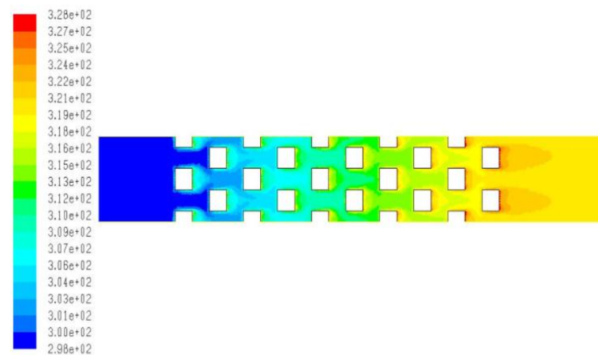

Fig 4.10: Contours of Total Temperature for Re=5,000

Table 1: Comparison of different shapes for different Reynolds numbers & Total Temperature

Reynolds no	Shapes	Total Temperature in k	Remark
5000	Circular	315.68388	Square fin temperature is more compared with other fin configuration
	Square	320.67737	
	Triangular	316.06439	
	Elliptical	312.45114	
10,000	Circular	309.73038	Square fin temperature is more compared with other fin configuration
	Square	316.69409	
	Triangular	312.44302	
	Elliptical	306.73535	
15,000	Circular	308.1778	Square fin temperature is more compared with other fin configuration
	Square	315.29947	
	Triangular	311.26315	
	Elliptical	305.47226	

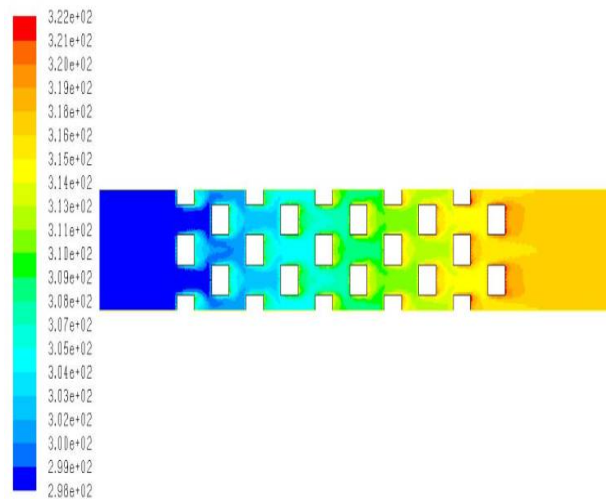

Fig 4.11: Contours of Total Temperature for Re=10,000

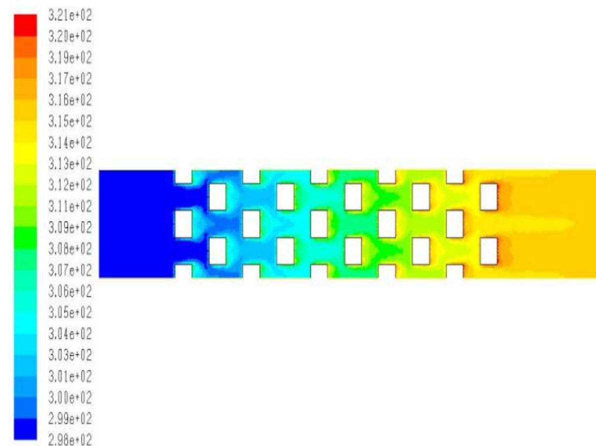

Fig 4.12: Contours of Total Temperature for Re=15,000

Contours of total temperature for different values of Reynolds number for Standard k- ε model are shown in Figure 4.1 – 4.12. In this the air enters inlet at ambient temperature and passes over the fins. The fin temperature is 350 k, as the air moves over the fins its temperature increases gradually and reaches maximum at the outlet. At the entrance the heat transfer will be more so the primary air increases its temperature as it moves over the fins the heat transfer reduces because of the air heating at the end the heat transfer is very low so the temperature is maximum at the end of the heat sink.

GRAPHS:

4.2 Heat Transfer Coefficient

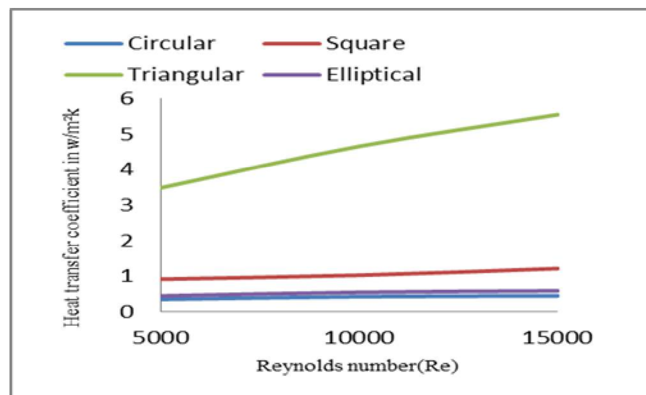

Fig4.13: Variation of heat transfer coefficient with Re for different Fin configuration

Figure 4.13 shows the variation of heat transfer coefficient with Reynolds number for different Fin configuration of length between 0.016m to 0.026m for Standard k- ε model. From the figure we can seen that

the heat transfer coefficient is higher for Triangular Fin when compared to the other Fin configuration for three Reynolds number, so the Triangular Fin have better heat transfer coefficient.

4.3 Total Temperature

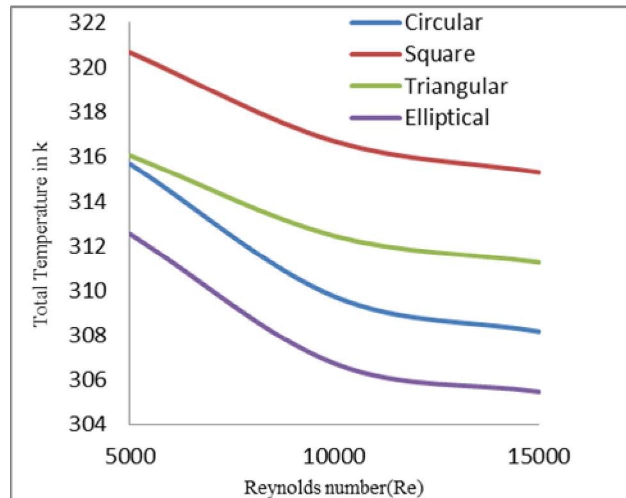

Fig4.14: Variation of Total Temperature with Re for different Fin configuration

Figure 4.14 shows the variation of Total Temperature with Reynolds number for different Fin configuration of length between 0.016m to 0.026m for Standard k- ε model. From the figure it shows that the Square Fin temperature is more compared to other fin configuration, the temperature is more at the lower Reynolds number and decreases as the Reynolds number increases. At the inlet heat transfer is more as it moves the heat transfer reduces.

5. CONCLUSIONS:

An attempt has been made to carry out CFD based analysis to fluid flow and heat transfer characteristics of a hollow rectangular duct attached with circular, elliptical, triangular and square profile fins. Combined effect of swirling motion, detachment and reattachment of fluid which was considered to be responsible in the increase in the heat transfer rate has been observed during CFD analysis.

- The Heat transfer coefficient is maximum in the case of triangular fin compared to the other fin configuration. As the Reynolds number increase the heat transfer coefficient increases.
- Increasing pin-fin spacing reduces the number of pin rows along the stream wise direction thus decreasing the heat transfer rate.
- Heat transfer from heat sink depends mainly on the approach velocity, pin arrangement, heat sink material and properties of flowing fluids. For a specific heat sink, with specified temperature of the assembly, the rate of heat transfer from and pressure drop across the heat sink increases with increase in approach velocity, and increase of heat emitting surface area.
- Nusselt number is found to increase with increase in Reynolds number.
- Friction factor increases with increase in Reynolds number for staggered arrangement of fins geometries.
- The Turbulent kinetic energy increases as the Reynolds number increase, it is more in the case of triangular fin.

- As the Reynolds number increases pressure drop increases, in this case elliptical fin pressure drop is less compare to other fins therefore elliptical fin is more convenient.

Though the triangular fin gives higher heat transfer coefficient, but also high pressure, in practical applications this would require higher capacity fan. Therefore the choice of triangular fin would be a trade off, when heat transfer required is high and it is possible to accommodate a fan capable of higher static pressure.

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