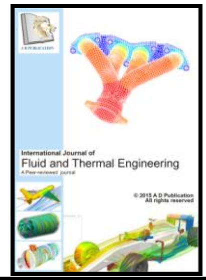
International Journal of
Fluid and Thermal Engineering
A Peer-reviewed journal

ISSN: 2455-3670
Impact Factor : 1.779 (Calculated by I2OR)
IJFTE 05 (2018) 022-031



CFD Analysis of Plate fin heat sink with pin fin having Various Profiles

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A B S T R A C T : In the present study the effect of various profile configurations in the performance of heat sink are studied using the CFD method. The present study also studied numerical and physical insight into the flow and the heat transfer characteristics of a pin fins heat sink of various profiles. The governing equations are solved by adopting a control volume-based finite-difference method with a power-law scheme on an orthogonal non-uniform staggered grid. The Elliptical Pin Fin Heat Sink is composed of a plate fin heat sink and some circular pins between plate fins. This study is performed to examine the effects of the configurations of the pin-fins design on the heat transfer characteristics of the pin fins. The results show that the hexagonal Pin Fin Heat Sink are much better unnaturally than the plate fin heat sink. Computations of the Elliptical Pin Fin Heat Sink and hexagonal pin fin heat sink is provides that hexagonal fins can provide better heat transfer results than others types of study being conducted.

Accepted on:
25/08/2018

Online Available:
29/03/2018

Keywords: Heat sink, Heat transfer, Thermal resistance, Hexagonal Pin Fin Heat Sink,CFD, Pin fins

1. Introduction

With the increase in the heat emission from the electronics devices and the reduction in the overall form factors, thermal management is now becoming more and more important element of electronic component design [1]. Both the performance capability and life cycle of electronic equipment are directly related to the component temperature of the equipment. The working and the operating temperature of a silicon type semi conductor device shows that a small reduction in the temperature will corresponds to exponential increase in the functioning and life expectancy of the device. Therefore, better life and good performance of a component is achieved by effectively controlling the device operational temperature within the limits set by the component design engineers.

The effective use of an electrical component is limited by its maximum operational junction temperature. To achieve a required component temperature, the excess heat dissipated by the device must be transferred to the environment [2]. The most commonly used method for transferring heat from the component to the environment is use of heat sink. To estimate a component's junction temperature, a required value the heat sink's thermal resistance. The thermal resistance of heat sink can be determined analytically or experimentally.

In electronic component systems, a heat sink is a indirect element that cools a device by dissipating the heat into the surrounding air. In computers, heat sinks are generally used to cool the electronic components. Heat sinks are generally used with high-power semiconductor devices such as power transistors and also the electronic devices such as lasers and light emitting diodes (LEDs), wherever the heat dissipation ability of the basic device package is insufficient to control its temperature.

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Nomenclature

Γ_{ij}	Reynolds stress
Ut	Turbulent viscosity
k	Turbulent kinetic energy
$C\mu$	Constant
ε	Dissipation rate of energy
Γ́	Diffusion coefficient of air
λs	Heat sink thermal conductivity

2. Literature Review

Different types of heat exchanger fins ranging from relatively simple shapes such as rectangular, cylindrical, annular, conical or pin fins to a combination of different geometries have been used. These fins can arise from either a rectangular or cylindrical base. One of the commonly used heat exchangers is the needle. A pin is a cylinder or other shaped element fixed perpendicular to a wall where the transfer surface passes across the element. Some of the parameters that characterize the pin fins are shape, height, diameter and height-to-diameter ratio. Other relevant parameters are distances between the fins in the flow direction and the span width and pin fins angle of attack.

There have been many investigations of the heat transfer and pressure drop in channels with pin fins , but are usually limited to pin fins with circular cross section[3-8]. Sparrow and Ramsey [3] investigated the heat-transfer performance of inline and staggered wall attached arrays of cylindrical fins. Babus Haq et al.[5]carried out an investigation that deduced relations between air flow rate, the optimal spacing-to-diameter ratios and heat-transfer rate for each inline and staggered combination of pin fins. Tahat et al.[6] studied the effects of distances between pins on the heat transfer. Tahat et al. in another study [7] determined the optimal spacing of the fins in the span wise and stream wise directions for both in-line and staggered arrangements. Kundu and Das [8]determined the optimum dimensions of the fin for the fins tube heat exchangers for both rectangular and equilateral triangular arrays. It was verified that the concept of an equivalent annular fins could be extended to calculate the optimum fins dimensions.

While the studies regarding circular pin-fins arrays are abundant, the research on pin fins with other cross-section is relatively sparse [9-12]. Sara [9] presented the heat-transfer and friction characteristics and performance analyses of convective heat transfers through a rectangular channel with square cross-section pin-fins attached to a flat surface. Tanda [10] performed an investigation of the heat transfer and pressure drop for a rectangular channel equipped with arrays of diamond shaped elements. Both in-line and staggered fin arrays were considered in thermal- performance analyses under constant mass flow rate and constant pumping-power constraints. Li et al.[11]carried out an investigation of the heat transfer and flow resistance characteristics in rectangular ducts with staggered arrays of short elliptic pin-fins in a cross flow of air. By employing the heat/mass transfer analogy and the naphthalene sublimation technique, the mean heat-transfer coefficient for pin fins and the end wall (base plate) of the channel were presented. Chen et al. [12] deter- mined the convective heat-transfer and pressure-loss characteristics in rectangular channels with staggered arrays of drop-shaped pin-fins in a cross flow of air. They showed that heat transfer of a channel with drop-shaped pin-fins is higher than that with circular pin fins while the resistance of the former is much lower than that of the latter in the Reynolds number range from 900 to 9000.

Some researchers [13-16] studied the effect of various parameters of the longitudinal fin arrays on heat and friction characteristics. El Sayed et al.[13] investigated the effects of height, thickness, inter-fin spacing, number and tip-shroud clearance of fins on the heat transfer, fluid flow and pressure drop. Naik et al.[14] proposed a design correlation which shows the distribution of optimal rib spacing for a wide range of rib geometrical and operational conditions. Sahin et al.[15] determined the optimum design parameters of a heat exchanger having large rectangular fins by the Taguchi method. They found the optimum results occurred for 15 mm fin width, 15 angle of attack, 100 mm fin height, 20 mm span wise distance between fins, 10 mm stream wise distance between fins, 20 mm span wise distance between slices and 20 mm stream wise distance between slices for a 4 m/s flow velocity.Yu et al. [16] performed numerical simulations and some experiments to compare thermal performances of plate fin heat sinks and plate-pin-fin heat sinks. The simulation results showed that thermal resistance of a plate-pin-fin heat sink was about 30% lower than that of a plate fin heat sink used to construct the plate-pin-fin heat sink under the condition of equal wind velocity. The design specification has been taken from the above experiment.

3. CFD Modeling

Computational Fluid Dynamics (CFD) is the science of determining the numerical solution of governing equation for the fluid flow advancement solution for space or time to obtain the numerical description of the complete flow field of interest. The equation can represent steady or unsteady, Compressible or Incompressible, and in viscid or viscous flows, including non ideal and reacting fluid behavior. The particular form chosen depends on intended application. The state of this art is characterized by the complexity of the fluid flow geometry and the computing time required obtaining a solution [18].

The purpose of this research work is to simulate pressure Drop and heat transfer in a heat sink and validate the simulation with actual experimental result [19, 20, 21] using fluent software. . Several solvers and turbulence models have been developed in CFD SOFTWARE for predicting thermal resistance, heat transfer coefficient, Nusselt number using plate fin heat sink, elliptical fin pin heat sink and Hexagonal Pin Fin Heat Sink for various wind velocity.

Computational fluid dynamics (CFD) is a computer-based simulation method for analyzing fluid flow, heat transfer and related phenomena, such as chemical reactions. This paper uses CFD to analyze flow and heat transfer. It would be advantageous to use CFD over traditional experimental analyzes because experiment costs which is directly proportional to the number of configurations desired to be tested as opposed to CFD, where large amounts of results can be produced with almost no additional costs. In this way, the optimization of equipment is very cheap with CFD compared with tests.

The governing equations used in CFD for fluid flow and heat transfer are based upon the principles of conservation of mass, momentum, and energy [22]. These equations solve by the fluent software. The conservation laws of physics form the basis for fluid flow governing equation. The dimensions of the computational domain heat sink were based on the work by Yu et al [23].Geometry of Plate fin heat sink, elliptical pin-fin heat sink and Hexagonal Pin-Fin which are shown in fig.1, 2, 3&4.

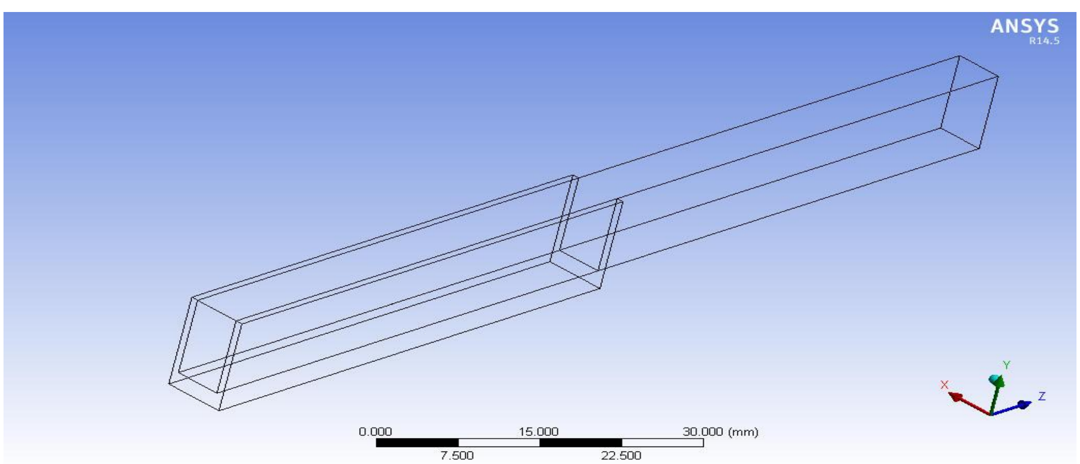


Fig 1: Wire Frame Model of PFHS

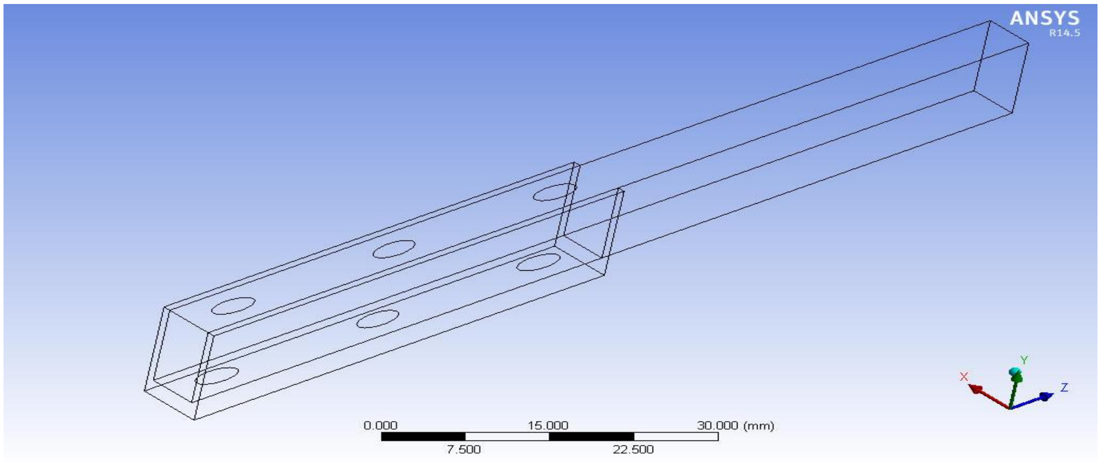


Fig 2: Wire Frame Model of EPFHS

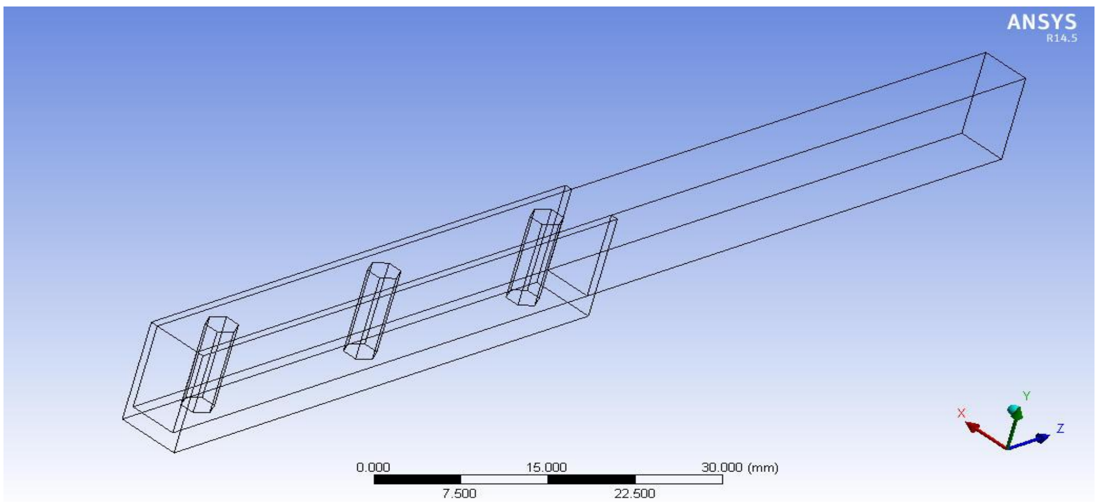


Fig 3: Wire Frame Model of HPFHS

The analysis assumes that the flow is three-dimensional, turbulent, incompressible and stable flow. Breeding and radiant heat transfer is not considered in the crimped fine analysis. All thermodynamic properties, i.e. (P-V-T), are assumed to be constant. The K-ε turbulent model is used to describe the airflow characteristics. Continuity, momentum and energy are described below.

Geometric parameters are listed in Table 1. In this new elliptical and hexagonal pin-fin heating model. Periodic geometry is required. Heat flow from the inside, ie the bottom of the fin to the tip of the fins. The following tables 1 and 2 show the parameters for the hexagonal and the elliptical pins.

Table 1 Geometric parameters of heat sink

Fin Length,	Fin Height, H(mm)	Fin Number, N	Fin thickness, t(mm)	Fin-to-Fin distance,
51	10	9	1.5	5

Momentum Equation (Navier stokes Equation)

X- Momentum equation.

$$\frac{\partial}{\partial x_j}\left(\rho \overline{u_j}\right) = 0 \tag{1}$$

$$\frac{\partial}{\partial x_j}\left(\rho \overline{u_j}\,\overline{u_i}\right) = -\frac{\partial \overline{p}}{\partial x_j} + \left(\mu \frac{\partial \overline{u_i}}{\partial x_j} + \tau_{ij}\right) \tag{2}$$

Where Γ_{ij} is the Reynolds stress in term given by

$$\tau_{ij} = \mu_t \left(\frac{\partial \overline{u_i}}{\partial x_j} + \frac{\partial \overline{u_j}}{\partial x_i}\right) - \frac{2}{3}\rho \delta_{ij} k \tag{3}$$

Where k= $\left(\frac{1}{2}\right)(u^2 + v^2 + w^2)$ is the turbulent kinetic energy. Eq. (3) introduces two unknowns (Ut and k), which require two equations for closure. For high Reynolds number flows the turbulent viscosity can be represented as

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon} \tag{4}$$

The energy equation solved for the fluid flow is

$$\overline{u_t}\frac{\partial \overline{T}}{\partial x_i} = \frac{\partial}{\partial x_i}\left(\Gamma \frac{\partial \overline{T}}{\partial x_i} - \overline{T'u'}\right) \tag{5}$$

The energy equation solving conduction heat transfer within the heat sink is

$$\frac{\partial}{\partial x_i}\left(\lambda_s \frac{\partial T_S}{\partial x_i}\right) + q = 0 \tag{6}$$

Where q is the heat generated per unit volume of the heat sink λs is the heat sink thermal conductivity and Ts is the temperature within the heat sink.

Only one current passage is examined during the design of the heat sink. The material of the heating element is made of aluminum. The bottom of the computer domain is heated to a constant heat transfer rate of 10 W and for different velocity (6.5, 9.5 and 12.5 m/s).The flow is assumed to be three dimensional, incompressible, steady, turbulent, and since the heating is low, constant air properties. Radiation effect is ignored.

Table 2 Boundary condition

Fin type	Velocity(m/s)			Heating
Plane pin	6.5	9.5	12.5	10
Elliptical Pin Fins	6.5	9.5	12.5	10
Hexagonal Pin Fins	6.5	9.5	12.5	10

Result and Discussion

A three-dimensional model is designed to conduct a test on heat transfer in the heat conduction for electronic applications. A number of numerical calculations are performed by FLUENT, and the results are presented for the effects of temperature distribution, total heat transfer coefficient,of thermal resistance, surface Nusselt number in refrigeration elements. Both the simulation results as Yue-Tzu Yang, Huan-SenPeng experimental results [22] for thermal resistances and pressure drops of PFHS are shown in Table 1.2.

Experimental and Simulation Result-

Performance comparison between PFHS and EPFHS

The thermal resistance of the heat sink, Rth, can be defined by-

$$Rth= \frac{\Delta T}{Q} \tag{7}$$

ΔT Is defined as the temperatures difference of base of the fins and ambient temperatures and Q is the heat dissipation power used in the base of the plate fins. Properties of the working fluid is taken same as those of ambient air which is at 294 K, and the material of the heat sinks used is aluminum with thermal conductivity of 202 W/ (m-K). From the table, shows that experimental data and simulation data for both thermal resistance and pressure drop changed.

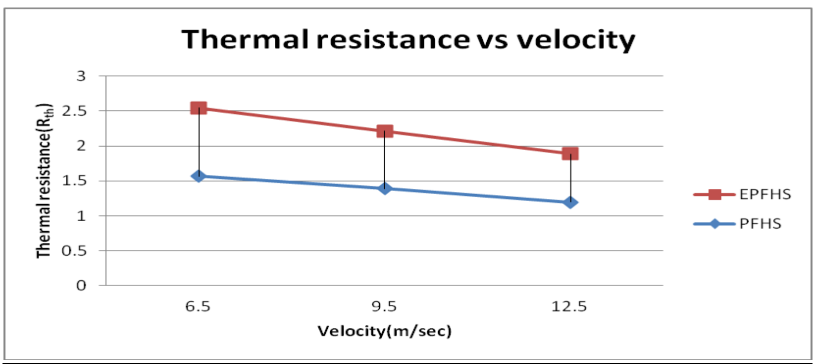
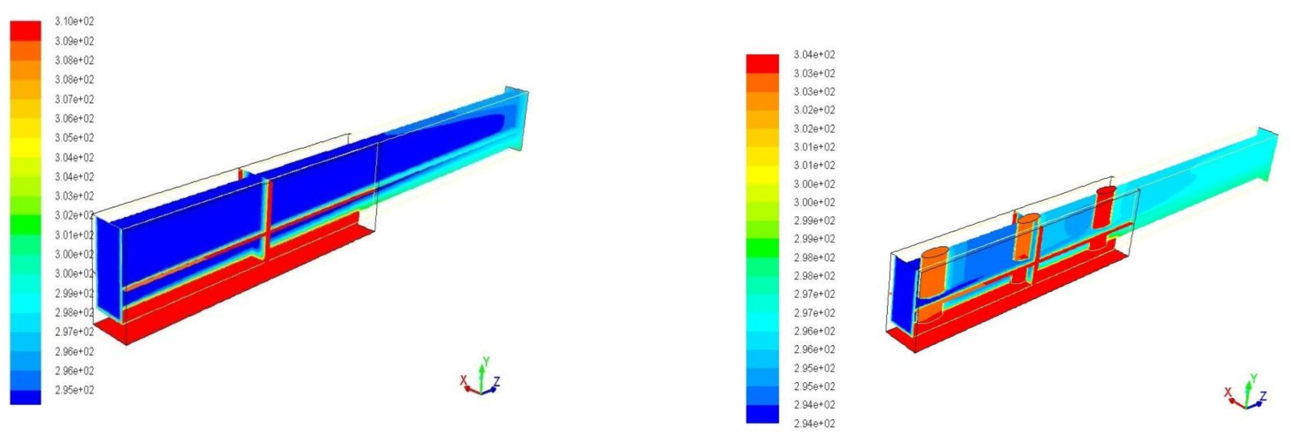


Fig 4: Variation of thermal resistance with velocity



(a) (b)

Fig 5: Temperature contour for (a) PFHS (b) EPFHS

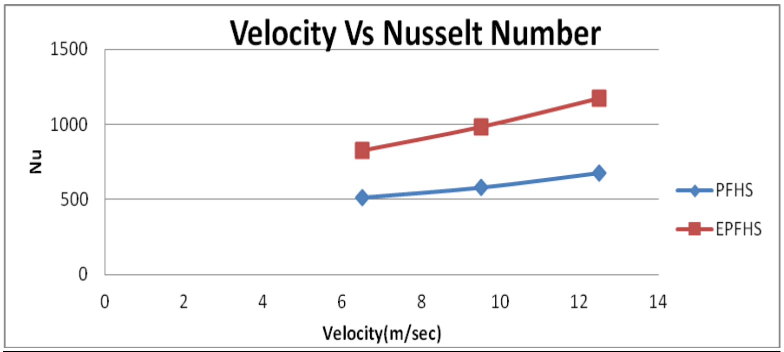


Fig 6: Variation of Nusselt Number with velocity

From the above discussion it may be concluded that for a particular air velocity the performance of EPFHS is founded to be better than that of PFHS on basis of Nusselt Number, Pressure Drop,

Performance Comparison between PFHS, EPFHS, and HPFHS

Thermal Resistance variation for heat sinks with elliptical pin fin and hexagonal pin are compared in which variation gives a constant deviation w.r.t. wind velocity.The thermal resistance for EPFHS is found to be lower than PFHS .and thermal resistance for HPFHS is even more less than EPFHS while we kept the hydraulic diameter for elliptical pin fin and hydraulic pin fin are same .so for the same hydraulic diameter the thermal resistance for HPFHS is founded to be least which gives the better heat transfer rate than EPFHS.

Table 3: Results for Thermal Resistance

Velocity (m/sec)	PFHS	EPFHS	HPFHS PIN
6.5	24.722475	68.370155	271.87787
9.5	38.767818	122.79333	558.04602
12.5	58.54987	195.77229	941.17212

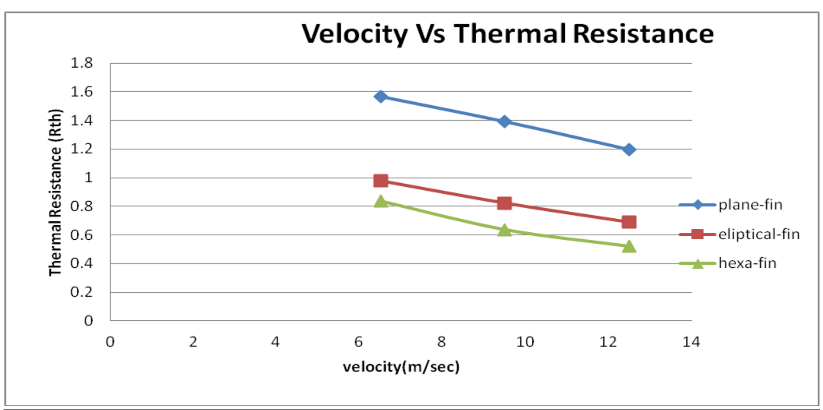


Fig 7: Variation of Thermal Resistance with Velocity

The above Fig. 7 shows the thermal resistance variations for different fin profiles of elliptical pins with compare to the experimental result (7) of PFHS and the simulation result of different pin profiles such as elliptical and hexagonal pins which provides a constant deviation, but in a similar manner. This figure shows the decrease in thermal resistance with increased examined speed (6.5, 9.5 or 12.5 m / s)

Table 4: Results For Pressure Drop

Velocity (m/sec)	PFHS	EPFHS	HPFHS PIN
6.5	1.56755	0.97963	0.83524
9.5	1.39237	0.82319	0.63719
12.5	1.19641	0.68919	0.52164

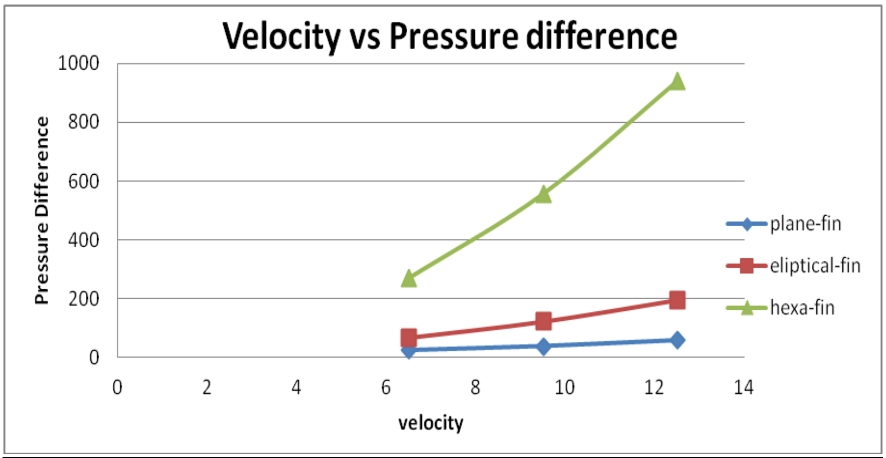


Fig 8: Variation of Pressure with Velocity

The above fig. 8 shows the pressure drop variations for the different fin profile of elliptical and hexagonal fins that compare the experimental result [23] of PFHS. This fig. shows the increase in the pressure drop with increase the wind velocity (6.5, 9.5 & 12.5m/s)

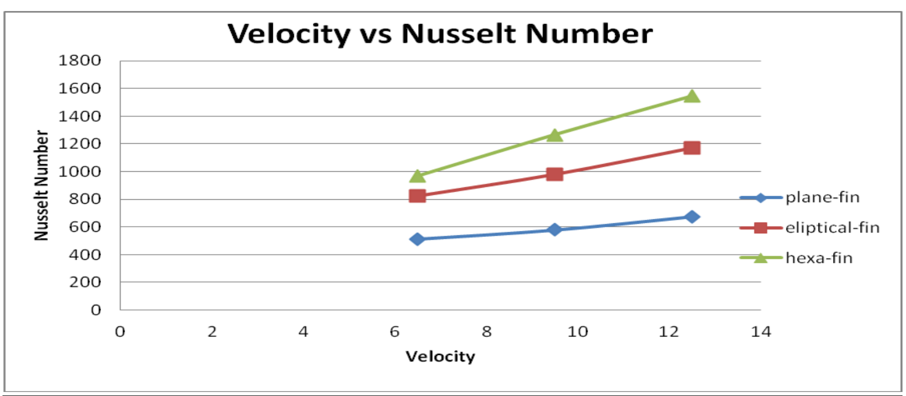


Fig 9: Variation of Nusselt Number with Velocity

The above Figure 9 shows nusselt number variations for different pin fins of elliptical and hexagonal pin fins that is compared to the test result (22) of PFHS the simulation result of different pin profiles of elliptical fin and hexagonal fin provide a constant deviation. This fig. shows the increment in the Nusselt number with increase in the wind velocity (6.5, 9.5 & 12.5m/s).This is better result than experimental result.

Application: Since heating power is uniform over the bottom of the fin base, thermal resistance of HPFHS always lower than PFHS and EPFHS. However over heating of CPU is always the center of concentration on the fin base in the real engineering application. Hexagonal pin fin heat sink creates much turbulence, so it can be use according to the cooling requirements which can reduce the temperature of base plate.

Conclusion

The current analysis had presented the thermal behavior of the Plate fin heat sinks having pin fins of different profiles. CFD analysis had been carried out over the Aluminum material Plate fin heat sink system. The effect of the Elliptical and the Hexagonal profiles having the Pin fins with the constant hydraulic diameter. The Nusselt Number and Thermal Resistance and Pressure drop of the plate fin was studied. From the analysis of the above results, following conclusions can be drawn.

1. The Nusselt Number is calculated to be maximum at inlet velocity 12.5 m/s for all the type of pin fin for all the three profiles. The Nusselt Number is maximum in the case of HPFHS with 3 Pin profile and minimum for PFHS profile, while that of EPFHS profile lies in between the HPFHS with 3 pin fin and PFHS.

2. The magnitude of the Pressure drop is maximum in the case of heat sink having hexagonal profile with pin fin (HPFHS) and least for PFHS profile. Continuously increase in the pressure drop means the higher pumping power required for maintaining air flow.

3. The magnitude of Thermal Resistance is maximum for the case of PFHS profile and the least for HPFHS pin profile.

4. As discussed above for HPFHS, the pressure drop increases with speed, and from the figure it is seen that thermal resistance decreases as speed increases. Increasing pressure drop increases pump work, while a decrease in thermal resistance increases heat transfer. So a common point must be found to get optimized results by plotting the graph's velocity on the common axis and the pressure drop on the primary axis and thermal resistance on the secondary axis. From the graph this point is achieved at a wind speed of 10.5 m / sec, with the thermal resistance being 0.49 K / w and the pressure drop is set to 970 Pa..

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