CFD Analysis of an Elliptical Pin Fin Heat Sink using Ansys Fluent v12.1

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Abstract: *The present study carries out numerical physical insight into the flow and heat transfer characteristics. 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 coupling of the velocity and the pressure terms of momentum equations are solved by the computational fluid dynamics. The Elliptical Pin Fin Heat Sink is composed of a plate fin heat sink and some circular pins between plate fins. The purpose of this study is to examine the effects of the configurations of the pin-fins design. The results show that the Elliptical Pin Fin Heat Sink has better unnaturally performance than the plate fin heat sink. Computations of the Elliptical Pin Fin Heat Sink and provides.*

Key words: *Heat sink, Heat transfer, Thermal resistance, Elliptical Pin Fin Heat Sink (EPFHS)*

I. Introduction

With the increase in heat dissipation from microelectronics devices and the reduction in overall form factors, thermal management becomes a more a more important element of electronic product design [1]. Both the performance reliability and life expectancy of electronic equipment are inversely related to the component temperature of the equipment. The relationship between the reliability and the operating temperature of a typical silicon semi conductor device shows that a reduction in the temperature corresponds to an exponential increase in the reliability and life expectancy of the device. Therefore, long life and reliable performance of a component may be achieved by effectively controlling the device operating temperature within the limits set by the device design engineers.

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

In electronic systems, a heat sink is a passive component that cools a device by dissipating heat into the surrounding air. In computers, heat sinks are used to cool electronic components. Heat sinks are used with high-power semiconductor devices such as power transistors and optoelectronic 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.

II. Cfd Modeling

Computational Fluid Dynamics (CFD) is the science of determining numerical solution of governing equation for the fluid flow whilst advancing the solution through space or time to obtain a 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 the art is characterized by the complexity of the geometry, the flow physics, and the computing time required obtaining a solution [3].

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 [4, 5, 6] using fluent software. Different solvers and turbulence models have been developed in CFD SOFTWARE for predicting Thermal Resistance, heat transfer coefficient, Nusselt number using Plate fin heat sink and Elliptical fin pin 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 dissertation uses CFD for analysis of flow and heat transfer. It will be advantageous to use CFD over traditional experimental-based analyses, since experiments have a cost directly proportional to the number of configurations desired for testing, unlike with CFD, where large amounts of results can be produced at practically no added expense. In this way, parametric studies to optimize equipment are very inexpensive with CFD when compared to experiments.

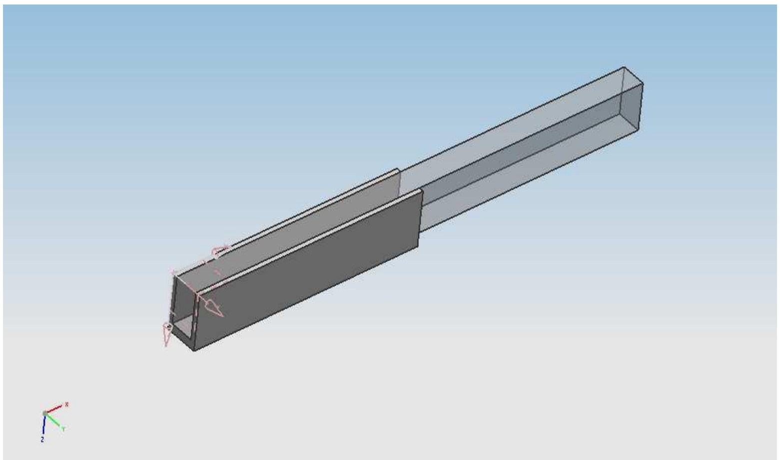


Fig.1 Model of Plate-fin Heat sink

The governing equations used in CFD for fluid flow and heat transfer are based upon the principles of conservation of mass, momentum, and energy [7]. 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 [8].Geometry of Plate fin heat sink and elliptical pin-fin heat sink are shown in fig.1, 2, 3&4.

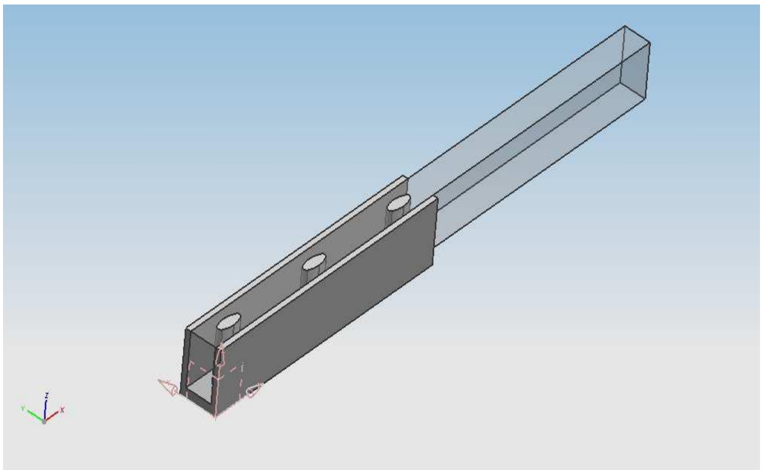


Fig.2 Model of1.5 Elliptical pin-fin Heat sink

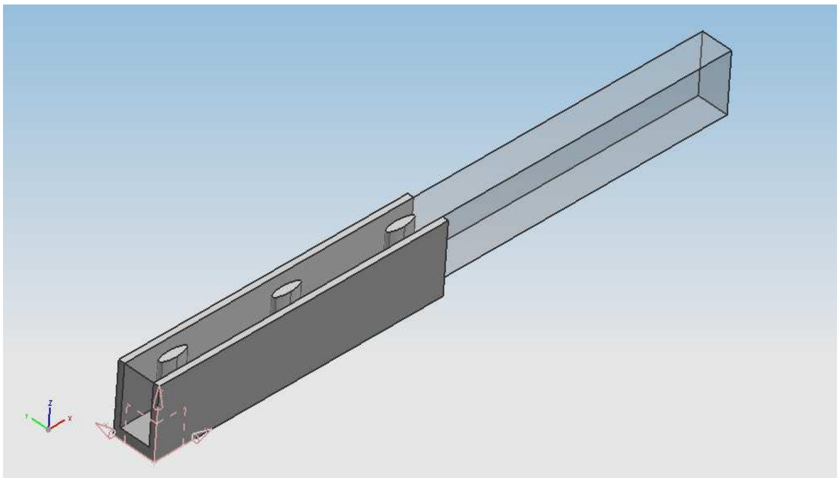


Fig.3 Model of2.0 Elliptical pin-fin Heat sink

In the analysis, the flow is assumed to 3-dimensional, turbulence, incompressible and steady flow. Buoyancy and radiation heat transfer are not consider in the crimped fin analysis. All the thermodynamics property i.e. (P-V-T) is assumed to constant. The K−ε turbulent model is used for describe the air flow characteristics. The continuity, momentum and energy equation are written below.

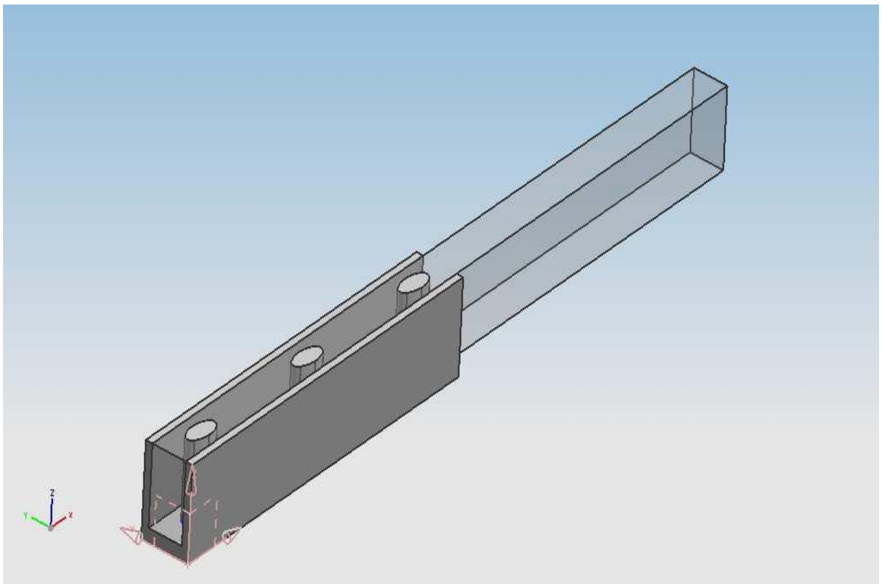


Fig.4 Model of 2.5 Elliptical pin-fin Heat sink

Geometrical Parameters are listed in table-1. In this new elliptical pin-fin heat sink model. There is periodic geometry is use. In which heat is transfer through the periodic wall and elliptical pins. Heat flow from inside i.e. base of the fin to the tip of the fin. The following Table 1 and 2 are showing the parameters of heat sink and elliptical pin fin.

Table 1 Geometric parameters of heat sink

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

Table 2 Dimension of elliptical Pin fin heat sink

Model	Major Axis(mm)	Minor Axis(mm)
1.5Pin fin model	5	1.5
2Pin fin model	5	2.0
2.5Pin fin model	5	2.5

Momentum Equation (Navier-stokes Equation)

X- Momentum equation.

$$\frac{\partial}{\partial x_j}\left(\rho \bar{u}_j\right)=0 \tag{1}$$

$$\frac{\partial}{\partial x_j}\left(\rho \bar{u}_j \bar{u}_i\right)=-\frac{\partial \bar{p}}{\partial x_i}+\frac{\partial}{\partial x_j}\left(\mu \frac{\partial \bar{u}_i}{\partial x_j}+\tau_{ij}\right) \tag{2}$$

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

$$\mu_{ij}=\mu_t\left(\frac{\partial \bar{u}_i}{\partial x_j}+\frac{\partial \bar{u}_j}{\partial \bar{x}_i}\right)-\frac{2}{3}\ \rho \delta_{ij} \kappa \tag{3}$$

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

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

C_μ Is a constant and ε is the dissipation rate of energy.
The energy equation solved for the fluid flow is

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

Where Γ is diffusion coefficient of air .The energy equation solving conduction heat transfer within the heat sink is

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

Where q is the heat generated per unit volume of the heat sink λ_s is the heat sink thermal conductivity andT_s is the temperature within the heat sink.

Given the periodic structure of the heat sinks, only one flow passage is investigated. The computational domain employed is shown in table 3. The material of the heat sink is aluminum. The bottom of the computational domain is heated at a constant heat transfer rateof 10W and different velocity (6.5, 9.5 and 12.5 m/s).The flow is assumed to be threedimensional, incompressible, steady, turbulent, and since the heating is low, constant air properties. Radiation effect is ignored.

Table3Boundary condition

Fin Profile	Fin type	Velocity(m/s)			Heating Power(Q)	Periodic boundary condition
	Plane pin	6.5	9.5	12.5	10	Translate in Y direction
Elliptical Pin	5mm major & 1.5mm minor	6.5	9.5	12.5	10	Translate in Y direction
	5mm major & 2.0mm minor	6.5	9.5	12.5	10	Translate in Y direction
	5mm major & 2.5mm minor	6.5	9.5	12.5	10	Translate in Y direction

III. Result And Discussion

A three-dimensional model is developed to investigate flow and conjugate heat transfer in the heat sink for electronic applications. A series of numerical calculations have been conducted by FLUENT and the results are presented in order to show the effects of temperature distribution, overall heat transfer coefficient, Thermal Resistance, Surface Nusselt number in the heat sinks. Both simulation results and Yue-Tzu Yang, Huan-SenPeng experiment results [7] for thermal resistances and pressure drops of the PFHS are plotted in Fig 3.1-a and 3.2-b respectively.

3.1 Experimental and Simulation Result-

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

$$R_{th} = \frac{\Delta T}{Q} \quad (7)$$

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

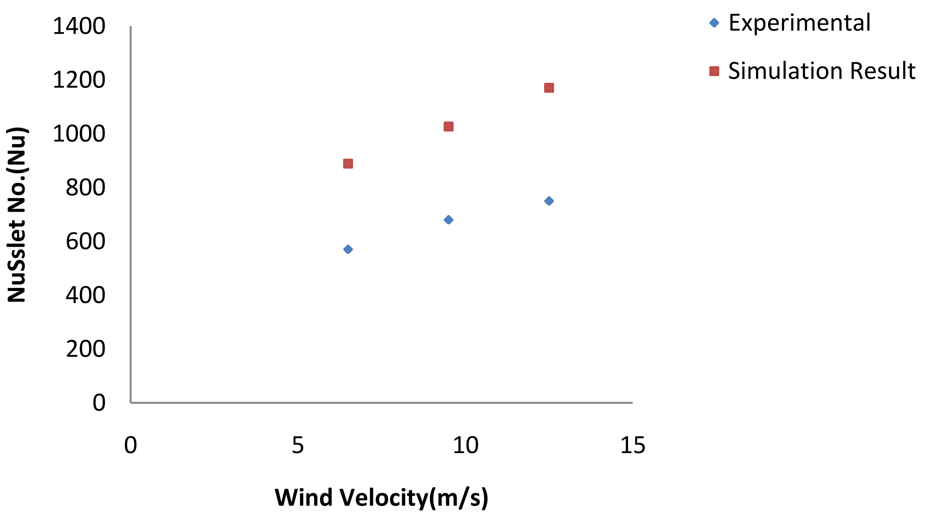


Fig.5Experimental and Simulation results for the PFHS: Nusselt Number vs. wind velocities.

The above fig.5 show experimental and simulation results of PFHS Nusselt number. This gives a slightly large deviation but in similar manner.

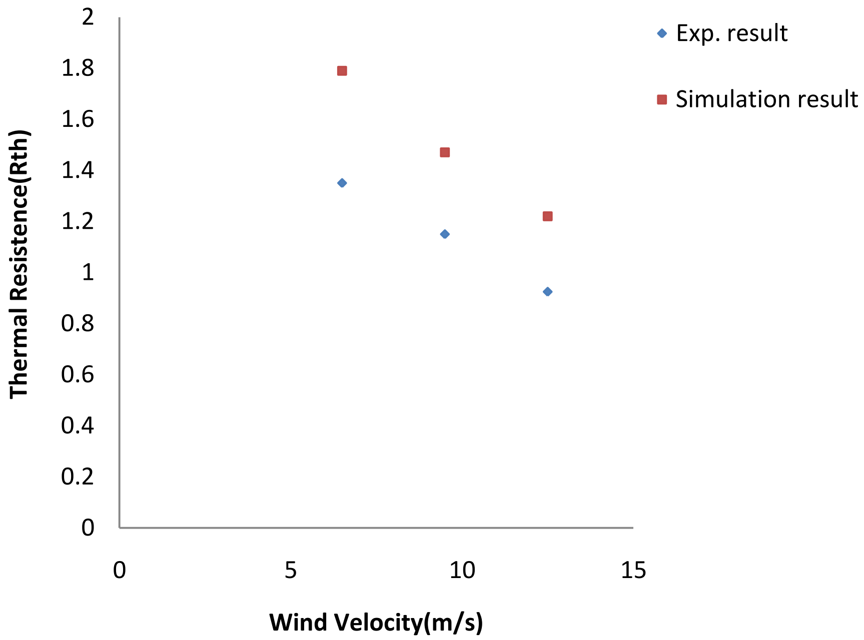


Fig.6 Experimental and Simulation results for the PFHS: Thermal resistance vs. wind velocities

The above fig.6 show thermal resistance for PFHS with experimental and simulation gives a constant deviation but in similar manner.

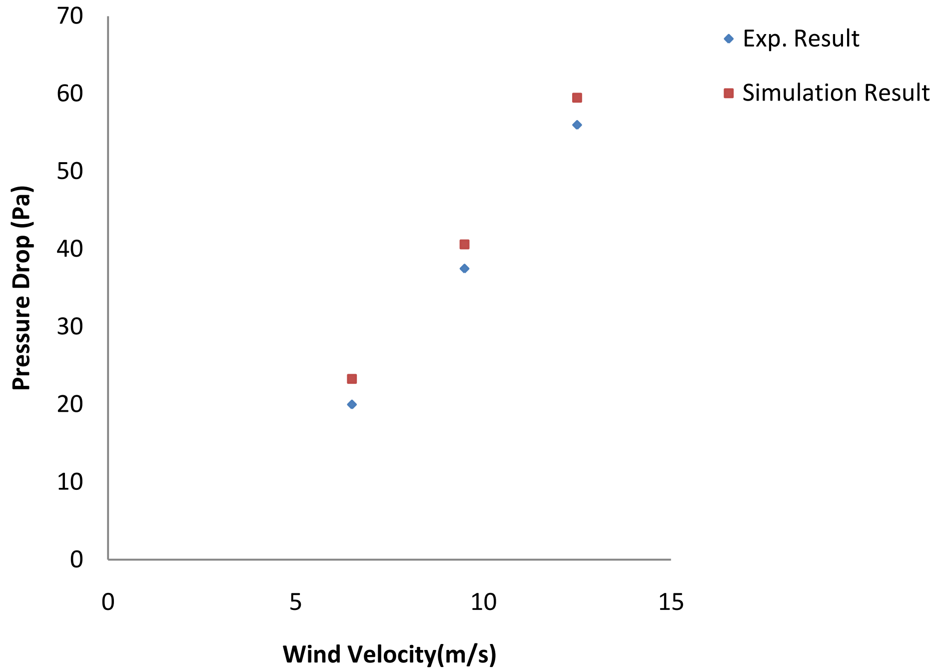


Fig.7 Experimental and Simulation results for the PFHS: Pressure drop vs. Wind velocities.

The above fig.7 show experimental and simulation results of PFHS pressure drop. The results are slightly above than experimental values, the deviation almost constant.

3.2. Compression on the Performance between PFHS and EPFHS

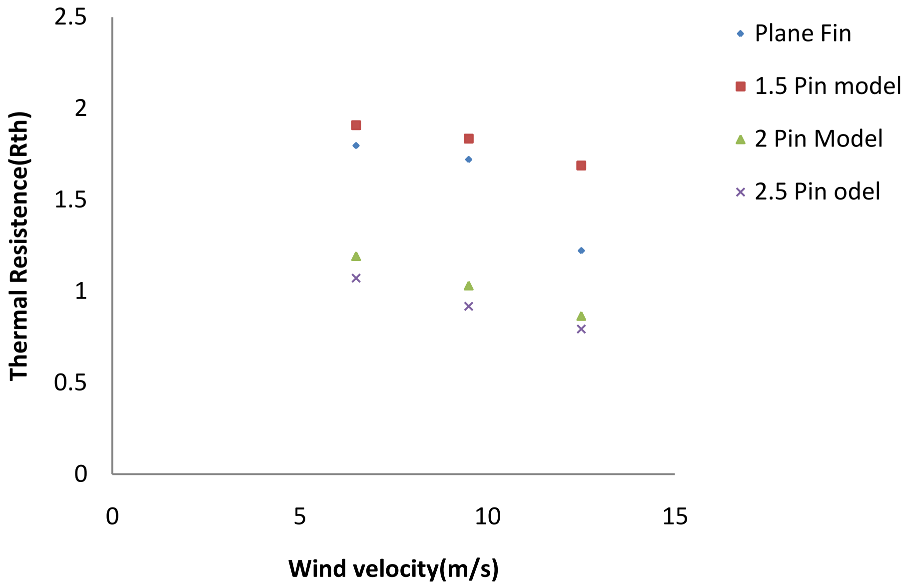


Fig.8 Thermal Resistance Variations for Different Fin Profile of Elliptical Pin

The above Fig.8shows the thermal resistance variations for different fin profile of elliptical pin with compare the experimental result(7) of PFHS and simulation result of various fin profile of elliptical pin gives a constant deviation but in similar manner. This fig. shows the decrease in the thermal resistance with increase the wind velocity (6.5, 9.5 & 12.5m/s).

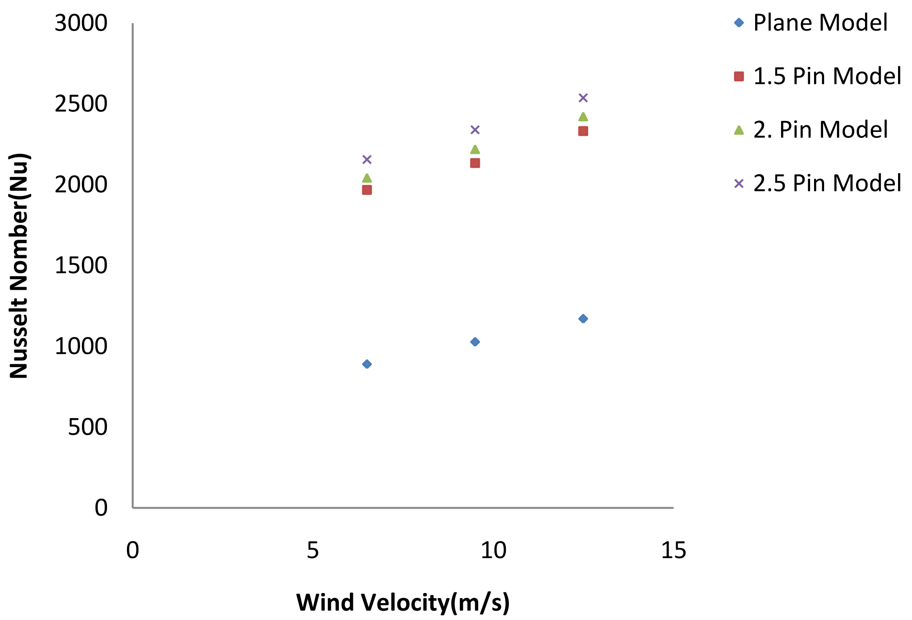
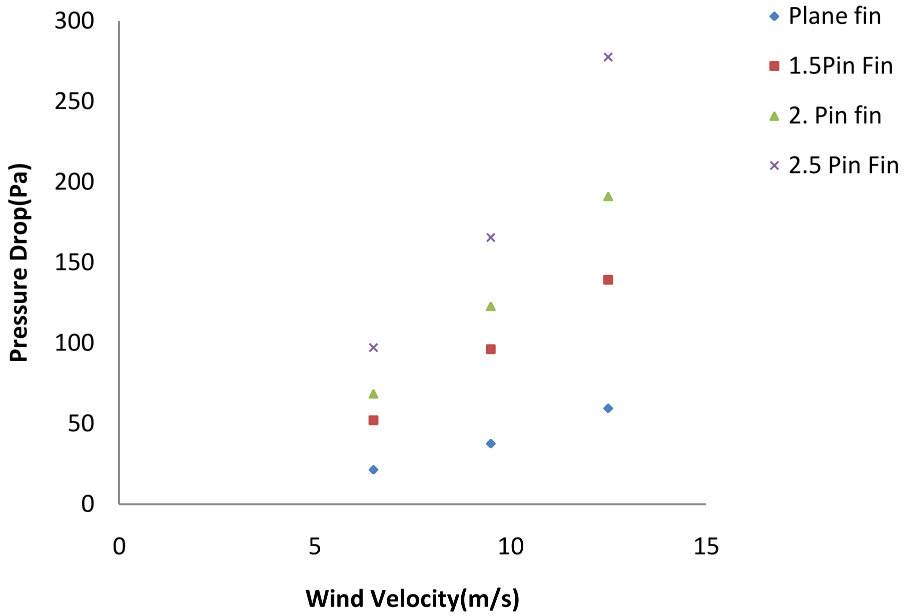


Fig.9Nusselt Number Variations for Different Fin Profile of Elliptical Pin.

The above Fig.9the Nusselt number variations for different fin profile of elliptical pin with compare the experimental result(7) of PFHS and simulation result of various fin profile of elliptical pin gives a constant deviation. This fig. shows the increase in the Nusselt number with increase the wind velocity (6.5, 9.5 & 12.5m/s).This is better result of experimental result.

Fig.10 Pressure Drop Variations for Different Fin Profile of Elliptical Pin.



The above Fig.10the Pressure drop variations for different fin profile of elliptical pin with compare the plate fin result(7) of PFHS and simulation result of various fin profile of elliptical pin gives a constant deviation in elliptical fin pin heat sink but in similar manner of experimental results. This fig. shows the increase in the pressure drop with increase the wind velocity (6.5, 9.5 & 12.5m/s)

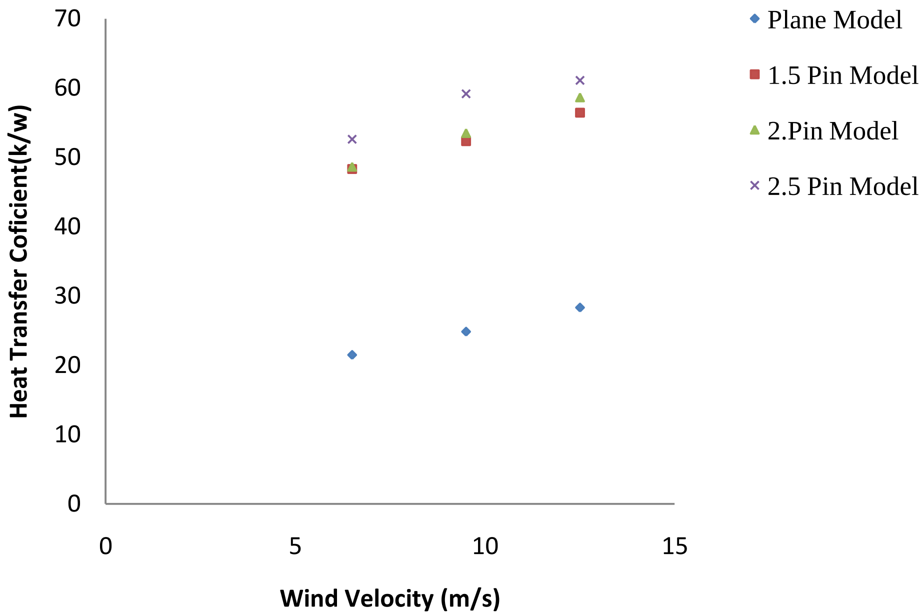


Fig.11Heat Transfer Coefficient Variations for Different Fin Profile of Elliptical Pin.

The above Fig.11as the wind velocity increases the heat transfer coefficient increases along the channel length because of growing boundary layer thickness.

3.3. Application:

Since heating power is uniform over the bottom of the fin base, thermal resistance of EPFHS always lower than PFHS. However heating of CPU is are always center of concentration on the fin base in real engineering application. Elliptical pin fin heat sink creates turbulence, so it can be use according to the cooling requirement.

IV. Conclusion

This paper proposes a special solution for improving heat transfer performance of elliptical pin fin by varying the major axis. Simulated the heat sink of elliptical pin fin having different minor axis (i.e. 1.5mm, 2.0mm & 2.5mm) and different velocities (i.e. 6.5, 9.5, & 12.5m/s) for constant heat input. From the above result we have least thermal resistance in elliptical pin fin with minor axis 2.5mm i.e. 0.7 K/W, after that 2mm minor axis i.e. 0.76K/W, subsequently with 1.5mm minor axis i.e. 1.7K/W. From the above result we have least pressure drop in elliptical pin fin with minor axis 1.5mm i.e. 145Pa, after that 2mm minor axis i.e. 180Pa, subsequently with 2.5mm minor axis i.e. 280Pa. So, from the above we can conclude that the 2mm minor axis elliptical pin fin at all velocity having better thermal resistance and pressure drop compared to 2.5mm and 1.5mm thermal resistance and pressure drop.

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