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THERMAL ANALYSIS ON MICROELECTRONIC HEAT SINK BY CFD USING RECTANGULAR AND TRAPEZOIDAL FIN ARRAYS

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Keywords: **:** trapezoidal array of fins, rectangular array of fins, electronics cooling, heat sink

ABSTRACT

The concern about thermal performance of microelectronics cooling is on the increase due to recent over-heating induced failures which have led to product recalls. Removal of waste heat from microelectronic systems with the use of heat sinks could improve thermal efficiency of the system. The present work investigates the effect of change in aluminum heat sink geometry on thermal performance Sinks with two models with rectangular and trapezoidal fins are taken. heat transfer analysis were conducted to investigate the thermal performance of air cooling through heat sink rectangular cross section with dimensions of 55mm×1mm×20mm and the other of trapezoidal with dimension of 55mm× 0.25mm×20mm. Nine channels of each configuration are modeled on aluminium base. The measurements were performed under steady state with air velocity of 2 m/s, and at temperatures varying from 60°C-110^{0}C in steps of 10^{0}C. Theoretical results are compared with numerical analysis with fluent15.0. Graphs are drawn, to show the performance of array of rectangular and trapezoidal fins using CFD.

INTRODUCTION

Optimal Heat Sink In Microelectronic Cooling System

In all the electronic systems available in the present market, a heat sink is acting as passive heat exchanger which cools the device by dissipating heat into the surroundings. In computer applications, heat sinks Fig.1.1 are used to cool different units such as central processing units or graphic processors. The heat sink is used with high-power semiconductor devices such as opto-electronics such as light emitting diodes (LEDs) Power transistors and lasers where the heat dissipation ability of the device is insufficient in order to moderate its attacking temperature. The heat sink was designed in such a way in maximizing its applicable surface area which is in contact with the considering cooling medium placed surrounding it, such as the atmosphere. The factors that affect the ambient performance of a heat sink are protrusion design, choice of material, surface treatment and air velocity. The integrated circuit temperature is also affected due to the effect of the thermal interface materials. Adhesives which have good thermal properties such as thermal grease improve the heat sink's performance by filling the air gaps between the sink and the heat spreader on the electronic device.

Sukumar et al. [1] in their study described that heat indulgence techniques are the prime concern to remove the waste heat produced by electronic devices, to keep them within permitted operating temperature limits. Heat indulgence techniques include heat sinks, fans for air cooling, and other forms of cooling such as liquid cooling. The choice of an optimal heat sink depends on a number of geometric parameters such as fin height, fin length, fin thickness, number of fins, base plate thickness, space between fins, fin shape or profile, material etc. Therefore for an optimal heat sink design, initial studies on the fluid flow and heat transfer characteristics of standard continuous heat sinks of different designs have been carried through CFD simulations. It is observed from the results that optimum cooling is achieved by the heat sink design which contains interrupted fins with holes. These heat sink design promises to keep electronic circuits cooler than standard heat sinks and reduction in cost due to reduction in material. **Teertstra et al. [2].** in their study said that analytical models are developed for the average heat transfer rate in forced convection-cooled, slotted fin heat sinks. These models for the upper and lower bounds can be used to investigate the effects of slot size and placement on heat sink performance. Experimental measurements are performed for a variety of slot configurations over a range of Reynolds numbers, the data is compared with the proposed analytical models. In this thesis, Approximate model is proposed that predicts the experimental results for the average heat transfer rate to within 12% RMS difference.

Sane et al. [6]. in their thesis analysed the thermal properties by varying geometry, material and thickness of cylinder fins. They also said that transient thermal analysis determines temperatures and other thermal quantities that vary over time. The variation of temperature distribution over time is of interest in many applications such as in cooling. The accurate thermal simulation could permit critical design parameters to be identified for improved life Sandhya and Kishore **[8]**. in their paper conducted heat transfer analysis by putting rectangular and triangular fins on periphery of engine cylinder. They found enhancement in heat transfer by varying length and base temperature on fins..Balanna and Kishore **[9]**. in their article took automotive radiator with coolant in vertical tubes and air in a wavy arch which resembles a fin. They have found heat transfer enhancement using this fin..Mounika et al. **[10]**. in their paper done performance analysis on an automobile radiator treating it to be a heat exchanger. The fins are in a radiator which ultimately shows increase in heat transfer..Jayalakshmi **[11]**. in her thesis investigated thermal performance of air cooling through heat sink using rectangular and trapezoidal fin arrays.

Need Of Optimization

The fins has to be designed in a such a way that the TPFA's and RFA's should have approximately same surface area and the dimensions of the TPFA's have to be determined in such a way that for various temperatures and the combination of them to have same surface area and to calculate heat transfer rate for each combination of TPFA and RFA. The trial and error approach to calculate these dimensions is at tough task and it involves time.

NUMERICAL ANALYSIS

The experimental analysis involves consumption of resources like material, time and hence it becomes expensive to do. In order to do theoretical calculations, they involve solving of many complex equations like continuity, mass and energy equations which is a time taking process and the accuracy of the results also decreases. This comes up with a solution of numerical analysis by using software's developing from decades. As the fast running computers have been developed, which reduces the time required to calculate the solution and many differential equations have been easily solved using software's, this provoked the present work to solve in CFD using ANSYS FLUENT 15.

METHODOLOGY

Methodology of the present work involves the problem identification and then the optimization of the problem by the reduction of material and modification of fin geometry. The fins are modeled using CREO PARAMETRIC by considering dimensions. These models are then analyzed in CFD by using ANSYS FLUENT 15. Along with the TPFA's, RAF is also analyzed in order to compare the performance of RAF and TPFA's for various temperatures in forced convection cases. The RFA modified geometry as TPFA to improve the heat transfer rate in forced convection case. Then the results are compared with the fins theoretical results and then the present work is concluded.

Fig.1.1 Rectangular Heat Sink Model

Part Name : **Heat sink rectangular**
Material : **Aluminum 6061**

Fig.3.4 Trapezoidal Array Of Fin Heat Sink Model

Part Name : **Heat sink Trapezoidal**
Material : **Aluminum 6061**

DISCRIPTION AND WORKING OF HEAT SINK

The heat sink is taken and it is modeled according to the dimensions. The heat sink for straight edges is modeled for the below dimensions:

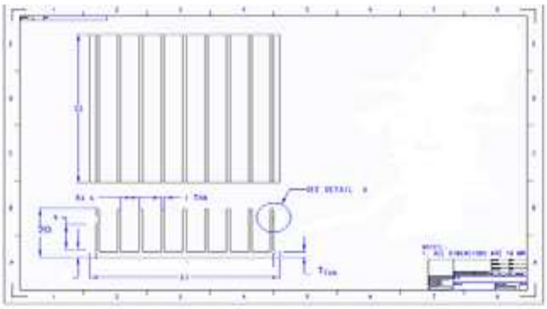


Fig.1.3 Design for Rectangular array of fin heat sink model

Part Name : **Heat sink straight**
Material : **Aluminum 6061**

Design Procedure for Rectangular array of fin heat sink model:

We have designed this model in creo parametric 2.0
The steps involved to create this model are as follows:

1) Click on File →New→ Part → Select the system of units in mm
2) Enter the file name as Hs_straight.
3) Click on extrude to create the feature by entering the dimensions 61, 2thk and enter depth value as 55 as shown in the drawing
4) Click on extrude to create the fin by entering the width as 1 and position from one end as 6 and enter the height as 18.
5) Right click on extrude→click on pattern→select the direction pattern option to create the pattern by entering the number of instances as 9 and distance between the fins as 6.
6) Click on file→prepare→model properties and select the Aluminum 6061 material to apply on the model to know the mechanical properties like density, volume and surface area etc.
7) Click on file→save. The model is as shown in the Figure.

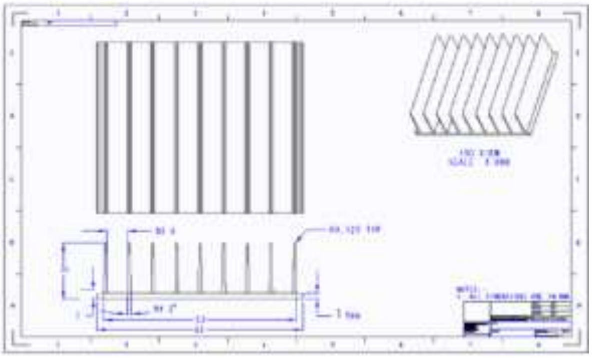


Fig.1.3 Design for Trapezoidal array of fin heat sink model

Part Name : **Heat sink straight**
Material : **Aluminum 6061**

Design Procedure for trapezoidal array of fin heat sink model:
We have designed this model in creo parametric 2.0
The steps involved to create this model are as follows:

1) Click on file→New→part→select the system of units in mm
2) Enter the file name as Trapezoidal.
3) Click on extrude to create the feature by entering the dimensions 61, 2thk and enter depth value as 55 and also add the draft as 2° as shown in the drawing
4) Click on extrude to create the fin by entering the width as 1 and position from one end as 6 and enter the height as 18.
5) Right click on extrude→click on pattern→select the direction pattern option to create the pattern by entering the number of instances as 9 and distance between the fins as 6.
6) Click on file→prepare→model properties and select the Aluminum 6061 material to apply on the model to know the mechanical properties like density, volume and surface area etc.
7) Click on file→save. The model is as shown in the Figure.

COMPUTATIONAL FLUID DYNAMICS

Governing equations of fluid flow:

The governing equations of fluid flow represent mathematical statements of the conservation laws of physics. Each individual governing equation represents a conservation principle. The fundamental equations of fluid dynamics are based on the following universal laws of conservation. They are,

- Conservation of mass
- Conservation of momentum
- Conservation of energy

Continuity Equation:

The equation based on the principle of conservation of mass is called continuity equation. The conservation of mass law applied to a fluid passing through an infinitesimal, fixed control volume yields the following equation of continuity,

$$\frac{\partial \rho}{\partial t}+\frac{\partial(\rho u)}{\partial x}+\frac{\partial(\rho v)}{\partial y}+\frac{\partial(\rho w)}{\partial z}=0$$

$$\frac{\partial \rho}{\partial t}+div(\rho V)=0$$

Where 'ρ' is the fluid density, u, v, and w is the fluid velocity vectors. For an incompressible flow, the density of each fluid element remains constant.

Momentum Equation:
The equations based on the laws of conservation of momentum or on the principle of momentum, states that, the net force acting on fluid mass is equal to the change in momentum of flow per unit time in that direction. The Navier-Stokes equations in conservative form

$$\frac{\partial(\rho u)}{\partial t}+\frac{\partial(\rho u^2)}{\partial x}+\frac{\partial(\rho uv)}{\partial y}+\frac{\partial(\rho uw)}{\partial z}=-\frac{\partial p}{\partial x}+\frac{\partial \tau_{xx}}{\partial x}+\frac{\partial \tau_{yx}}{\partial y}+\frac{\partial \tau_{zx}}{\partial z}+\rho f_x$$

$$\frac{\partial(\rho w)}{\partial t}+\frac{\partial(\rho uw)}{\partial x}+\frac{\partial(\rho vw)}{\partial y}+\frac{\partial(\rho w^2)}{\partial z}=-\frac{\partial p}{\partial z}+\frac{\partial \tau_{xz}}{\partial x}+\frac{\partial \tau_{yz}}{\partial y}+\frac{\partial \tau_{zz}}{\partial z}+\rho f_z$$

Unsteady Convective Pressure Diffusive Source

Where (according to Newton's Law of Viscosity),

$$\tau_{xz}=\tau_{zx}=\mu\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right)$$

$$\tau_{xy}=\tau_{yx}=\mu\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right) \qquad (4.6)$$

$$\tau_{yz}=\tau_{zy}=\mu\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right)$$

$$\tau_{xx}=\lambda(\nabla.V)+2\mu\frac{\partial u}{\partial x} \quad \tau_{zz}=\lambda(\nabla.V)+2\mu\frac{\partial w}{\partial z} \qquad (4.7)$$

$$\tau_{yy}=\lambda(\nabla.V)+2\mu\frac{\partial v}{\partial y}$$

$$\lambda=-\frac{2}{3}\mu \qquad (4.8)$$

Which is Stokes Hypothesis

The Navier-Stokes equations form the basis upon which the entire science of viscous flow theory has been developed. In general the continuity and energy equations are also included in the Navier-Stokes equation.

Energy Equation:
This equation is based on the principle of

$\rho\frac{DE}{Dt}$ = The rate of change energy of a fluid particle

E = Internal energy + kinetic energy + gravitational energy

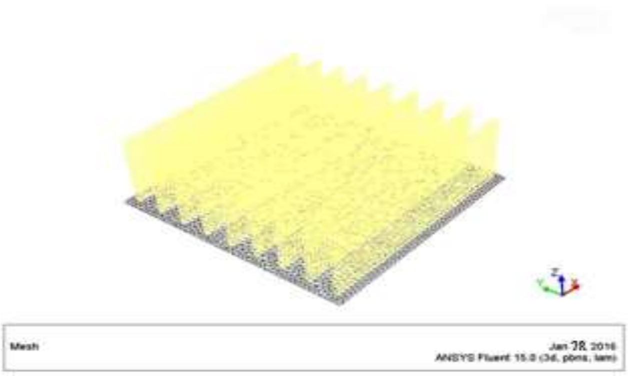
$$E = i + \tfrac{1}{2}\left(u^2 + v^2 + w^2\right) + g \qquad (4.11)$$

conservation of energy; the energy equation is derived from first law of thermodynamics which states that the rate change of energy of a fluid particle is equal to the rate of heat addition to the fluid particle plus the rate of

RESULTS AND DISCUSSION

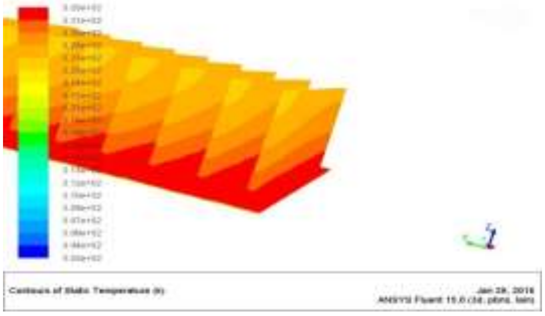
Meshed Model rectangular array of fin :

The meshed model for the Straight Heat Sink is as shown in the Fig. 7.4

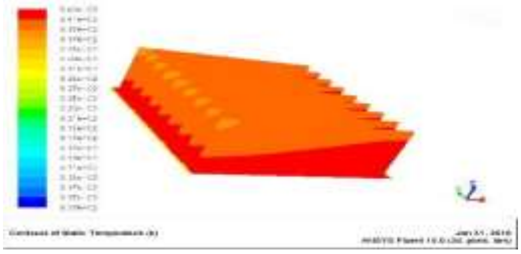


Meshed Model Of The Rectangular Array Of Fin Heat Sink

The Temperature distribution for the rectangular array of fin model Heat Sink is

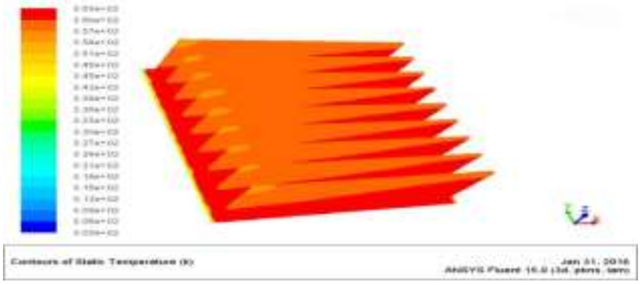


Contours Of Static Temperature Of The Rectangular Heat Sink At 333K

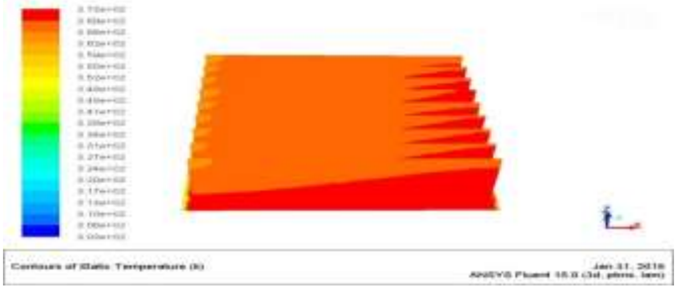


Contours Of Static Temperature Of The Rectangular Heat Sink At 343K

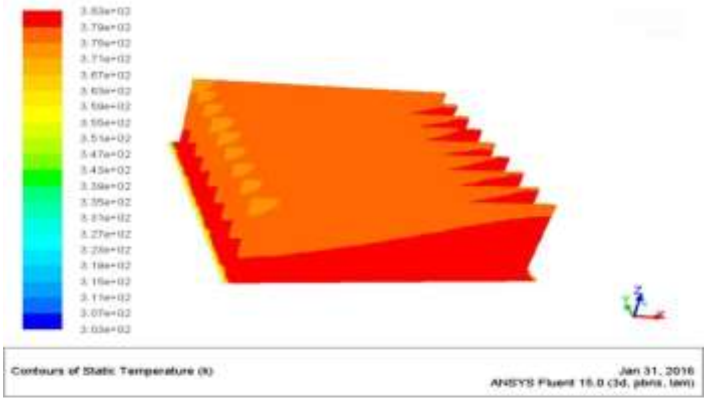
Contours Of Static Temperature Of The Rectangular Heat Sink At 363K



Contours of Static Temperature of the Rectangular Heat Sink at 363K

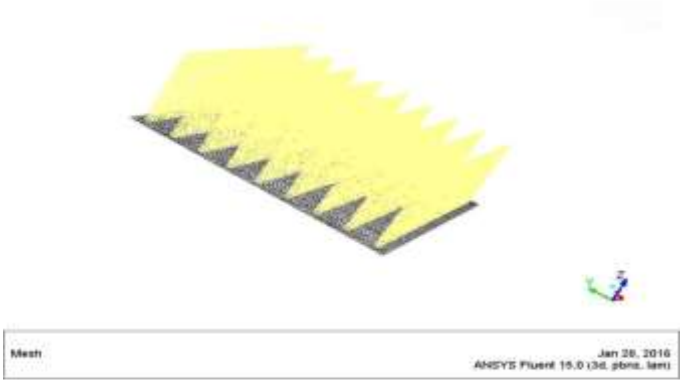


Contours of Static Temperature of the Rectangular Heat Sink at 373K



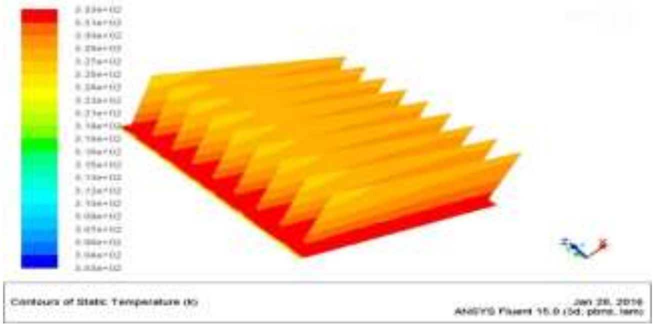
Temperature distributionof the rectangular fin model Heat Sink at 383K

Meshed Model: The meshed model for the Trapezoidal Heat Sink is as shown in the

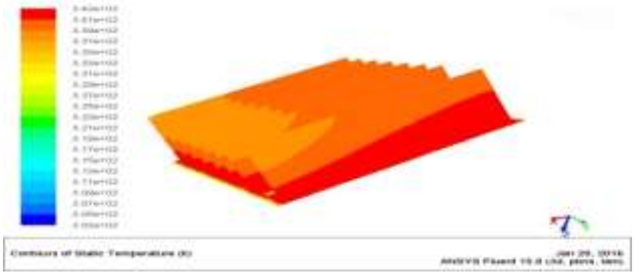


Meshed model of the Trapezoidal Heat Sink

Temperature distribution:
The Temperature distribution for the Trapezoidal Heat Sink is as shown in the Fig.6.8

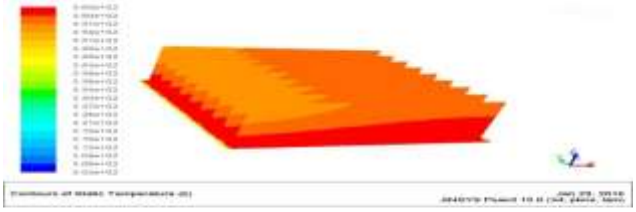


Contours of Static Temperature of the Trapezoidal Heat Sink at 333K

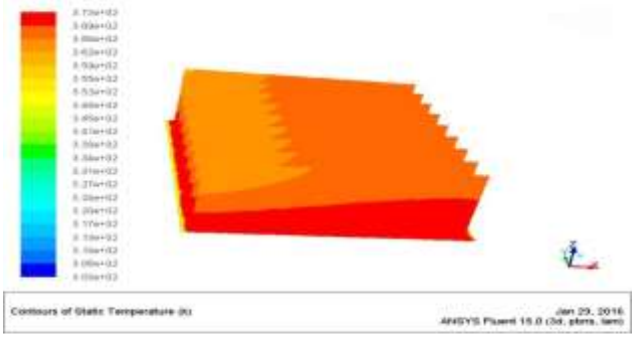


Contours of Static Temperature of the Trapezoidal Heat Sink at 343K

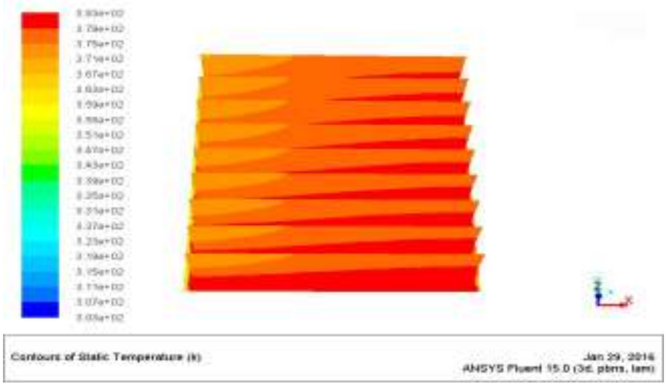
Contours of Static Temperature of the Trapezoidal Heat Sink at 353K



Contours of Static Temperature of the Trapezoidal Heat Sink at 363K



Contours of Static Temperature of the Trapezoidal Heat Sink at 373K



Contours of Static Temperature of the Trapezoidal Heat Sink at 383K

Comparison Between Theoretical And Cfd Analyses Of Single Rectangular Fin at 333K

	THEORTIC AlRECTANGULAR FIN	*CFD RECTANGULAR FIN*	*VARIANCE(%)*
h(W/m^2 K)	*23.0935*	*18.29*	*19*
Nu	*46.774*	*37.129*	*19*
Q(W)	*1.62117*	*1.81*	*11*

GRAPHICAL REPRESENTATION

Heat Transfer Coefficient (H)

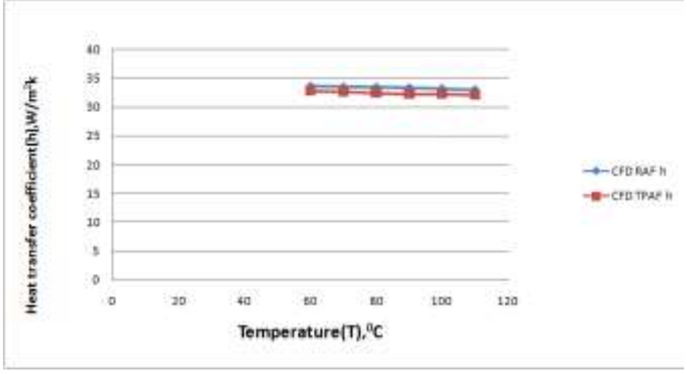


Fig.7.28 Heat Transfer Coefficeint With Temperature

The above Fig 7.28 shows the variation of heat transfer coefficient with the temperature. The results shows that with the increase of temperature ,the heat transfer coefficient decreases gradually because of decrease in air Reynolds number and increase in thermal conductivity and decrease in Nusselt number. Heat transfer coefficient of rectangular profile heat sink more than the trapezoidal profile.

Nusselt Number

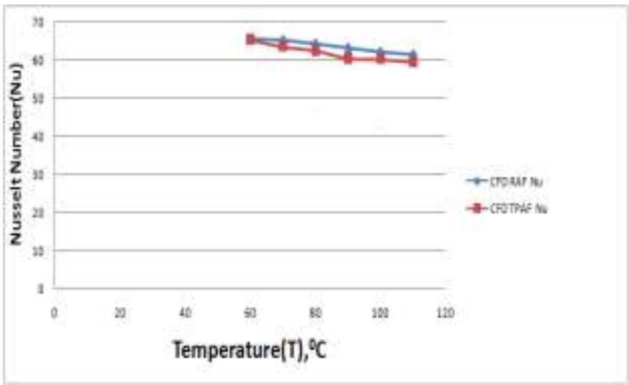


Fig.7.29 Nusselt Number With The Temperature

The above Fig 6.29 shows the variation of Nusselt number with the temperature. The results shows that with the increase of temperature ,Nusselt number decreases gradually because of decrease in air Reynolds number and decrease in Prandtl number . Nusselt number of trapezoidal profile less than rectangular profile because of the small change in the geometry of rectangular profile. For all the three cases Nusselt number decreases with the increase in temperatures.

Heat Transfer Rate

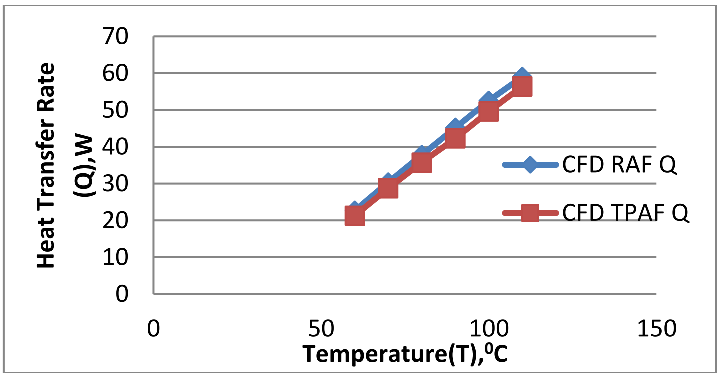


Fig.7.30 Heat Transfer Rate With Temperature

The above Fig 7.30 shows the variation of heat transfer rate with the temperature. The results shows that with the increase of temperature, the heat transfer rate increases gradually because of decrease in Reynolds number of air and increase in thermal conductivity and increase in temperature difference. In the above analyses absorbed that heat transfer rate for trapezoidal profile approximately equal the rectangular profile even increases in surface area. While absolving theoretical rectangular profile and numerical analyses of rectangular profile results are almost coincides.

Temperature Vs Efficiency

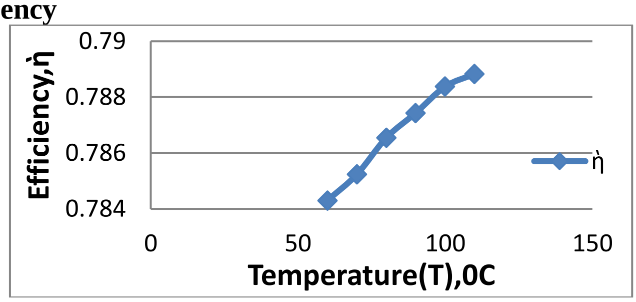


Fig.7.31 Temperature Vs Efficiency

The above Fig 7.28 shows the variation of efficiency of fin with the temperature. as the temperature increases efficiency also increases.fin efficiency is not maximised

with respect to the fin length, but generally with respect to te volume and weight of the material, which also has cost implications. near the fin base fin efficiency is high and it goes on increasing as we moves towards the end of the fin; this is because, the surface temperature of fin falls as we move away from the base towards end.

CONCLUSIONS

The performance of the rectangular array of fin heat sink and trapezoidal array of fin heat sink is evaluated using CFD analysis by varying temperatures on the surface of the fin. Validation from 60^{0}C to 110^{0}C in steps of 10^{0}C .The fins are modeled in CREO PARAMETRIC 2.0 and are meshed in ICEM CFD and analysis is made in ANSYS FLUENT 15.0. From thIS analyses the results concluded that

- CFD analysis of rectangular heat sink array compared with theoretical calculations found to have deviation of 15%
- Heat transfer coefficient calculated for rectangular heat sink is found to be more than 3% compare to trapezoidal array fin
- Nusselt number for array of rectangular heat sink is found to more than 2% compare to trapezoidal array fin
- Heat transfer rate of a array of rectangular heat sink is found to be more than 2% compare to trapezoidal array fin

- Even though the above factors are more for rectangular array of fins, when weight factor is considered the rectangular array fins is replaced with trapezoidal array fin.

FORMULAE

$$\mathrm{Re}_a = \frac{UL}{\upsilon}$$

$$\mathrm{Nu} = 0.664 \times \sqrt{\mathrm{Re}_a} \times Pr^{\frac{1}{3}}$$

$$\mathrm{Pr} = \frac{\mu \times C_p}{k}$$

$$\mathrm{h} = \frac{Nu \times K}{L}$$

$$Q = \mathrm{N}.\frac{k_f A(T_s - T_a)}{Fl}.\eta.\mathrm{N_{ui}}$$

$$T_f = \frac{T_s + T_a}{2}$$

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