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Numerical Investigation of Different Heat Sink Geometries

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Abstract: This paper presents the different geometry of heat sink by using ANSYS Icepak 13.0. ANSYS Ice pak is the effective Analysis software for electronics heat transfer analysis. Heat transfer rate is increased by means fin density, cross cuts, fin spacing and increased surface area. Numerical investigation for heat sink has been investigated for five different heat sink geometries. Round pin fin heat sink and square pin fin heat sink show heat transfer enhancement at the same time increase the pumping power of the system. multiple cross cut sink nearer to single cross cut heat sinks with a cost of slightly increased pressure drop. CFD results show that the single cross cut heat sink, convective heat transfer rate increases up to 15%.

Key words: Heat sink · Forced convection

INTRODUCTION

The development of electronic components is used to increase the speed of processing while it also increases the heat generation rate. In Electronic processors, most of the electric power is converted as heat. Hence amount of heat removals have become big challenge in recent years. Normally aluminum heat sinks are used in electronic device. But these heat sinks are not effective while increasing power density. Generally in electronic cooling, forced convection method is used and air is working fluid. Due to the limitation of thermal resistance between air to heat sink surface, heat transfer rate is decreased. Nanotechnology is the key emerging technology to enhance heat transfer rate. Heat sinks due to their small mass and volume as well as larger area to volume ratio are very attractive for cooling of high heat flux chips. Many researches have been carried out on the performance of heat sinks, investigate the plate-fin heat sink with various spacing, it will give best heat transfer as well as least pressure drop and increase in fin efficiency due to increase the fin spacing [1]. Various flow condition is also involved to increase heat transfer and develop the correlation for transition flow through a plate-fin heat sink, experimental results give heat transfer behavior within acceptable range for Reynolds number ranges from 2000 to 4000 [2]. Further investigation on heat transfer characteristics of various cross cut heat sink and pin-fin heat sink in this investigation gives single cross cut heat sink give best results compare to other [3]. Water as a working fluid to minimize the base temperature and maintaining the pumping power in a micro scale pin-fin heat sink [4]. Flow by-pass also a significant effect to enhance heat transfer rate .By-pass ratio is indirectly proportional to heat transfer rate [5]. To optimize the pin fin heat sink based on fin spacing and heat generation rate using analysis of variance [6].some works has been carried out in the field of coating technology, brass based carbon nanotube coating gives 12% increase in heat transfer rate [7].CNT with copper electroplating tested various thickness of coating over the surface of CNT for thermal interface application it will reduce the thermal resistance [8]. Copper based nanocoatings give more heat transfer than silicon based nanocoatings [9]. From this above works to infer nanocoatings increases the heat transfer rate compare to bare material. Hence nanocoatings on heat sink significantly increase the heat transfer rate without affecting the pumping power.

Mathematical Modeling: Fan-heat sink model can be formulated mathematically based on the following assumptions:

- No flow bypassing since the heat sink is fully ducted
- Isotropic material
- Fin tips are adiabatic
- Uniform approach velocity
- Uniform heat generation

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The model divided in to two parts, calculation of overall fin thermal resistance and finding of pressure drop in heat sink.

Overall Thermal Resistance: The total thermal resistance is the product of the fin thermal resistance and the base spreading resistance, expressed as follow:

$R_o + R_F + R_S$

Due to uniform heat generation rate throughout the base, so spreading resistance (Rs) is neglected, therefore.

$R_o = R_F$

Fin thermal resistance (RF)

Symbols		Nomenclature	Units
Ad	-	Duct cross sectional area,	mm2
Ab	-	Heat sink base area,	mm2
Af	-	Fin surface area,	mm2
Am	-	Fin profile area,	mm2
Asc	-	Heat source contact area,	mm2
A	-	Distance between two adjacent fin	mm
Dh	-	Hydraulic Diameter,	mm
DEQ	-	Equivalent diameter	mm
f	-	Friction factor	-
Fapp	-	Apparent friction factor	-
h	-	Convection heat transfer coefficient,	W/m2K
Hf	-	Fin height,	mm
Kair	-	Air thermal conductivity,	W/mK
km	-	Material thermal conductivity,	W/mK
Kc	-	Contraction coefficient	-
Kcd	-	Duct Contraction Coefficient	-
Ke	-	Expansion coefficient	-
Ked	-	Duct Expansion Coefficient	-
L	-	Fin length,	mm
Lc	-	Corrected length,	mm
Nug	-	Nusselt number	-
P	-	Total input power,	W
Pr	-	Prandtl Number	-
ReDh	-	Hydraulic Diameter Reynolds Number	-
Reg	-	Channel Reynolds number	-
Re	-	Reynolds number	-
Rf	-	Fin thermal resistance,	°C/W
Rs	-	Base spreading resistance,	°C/W
Rt	-	Total resistance,	°C/W
Tamb	-	Ambient temperature,	°C
Tb	-	Heat sink base temperature,	°C
t	-	Fin thickness,	mm
Tb	-	Heat sink base thickness,	mm
w	-	Width of the heat sink	mm
Xl	-	Channel length,	mm
x	-	Dimensionless hydrodynamic entry length	-

Vg	-	Channel velocity,	m/s
Vfs	-	Free stream velocity, m/s	
Va	-	Actual approach velocity,	m/s
ΔP	-	Heat sink pressure drop,	N/m2
ΔPth	-	Theoretical Heat sink pressure drop,	N/m2
Greek words			
ν	-	Fluid viscosity,	m2/s
ρ_a	-	Density of aluminum	Kg/m3
ρ_g	-	Density of air	Kg/m3

The fin tip is adiabatic based on assumptions fin thermal resistance is followed by:

$$R_F = \frac{1}{h\eta_F A_F}$$

In order to compute the coefficient of heat transfer (h), the approach velocity Reynolds number (Rea), must be calculated first. The approach velocity Reynolds number is evaluated by taking the aspect ratio of the channel width to length and it is defined as:

$$\mathrm{Re}_a = \frac{wV_a}{V}\left(\frac{w}{L}\right)$$

The actual approach velocity can be calculated by dividing the volumetric flow rate with duct cross sectional area.

$$V_s = \frac{\textit{volumetic flow rate}}{A_d}$$

Nusselt number is necessary to calculate convective heat transfer co-efficient (h), to find nusselt number is based on composite model proposed by Teertsra [10],

$$\mathrm{Nu}_{\mathrm{lam}} = \left[\left[\frac{\mathrm{Re_a Pr}}{2}\right]^{-3} + \left[0.664\sqrt{\mathrm{Re_a}\mathrm{Pr}^{0.333}}\sqrt{1+\frac{3.65}{\sqrt{\mathrm{Re_a}}}}\right]^{-3}\right]^{0.333}$$

For turbulent condition,

$$\mathrm{Nu}_{\mathrm{tur}} = 0.0214\left[\left[\mathrm{Re_g}\frac{\mathrm{D_{eq}}}{\mathrm{D_h}}\right]^{0.8} - 100\right]\mathrm{Pr}^{0.4}\left[1+\left[\frac{\mathrm{D_h D_{eq}}}{\mathrm{LD_h}}\right]^{0.667}\right]$$

Where equivalent diameter,

$$\mathrm{D_{eq}} = \left[0.667 + 0.45833\frac{\mathrm{a}}{\mathrm{h_f}}\left(2-\frac{\mathrm{a}}{\mathrm{h_f}}\right)\right]\mathrm{D_h}$$

Using the above approximation, the coefficient of heat transfer (h), can be expressed as,

$$h = \frac{Nu_g[k_{air}]}{L}$$

With the assumption that the fin width is sufficiently large compared with the fin thickness and along with the coefficient of heat transfer and fin geometry, the fin efficiency, çf, is given as,

$$\eta_F = \tanh mL_c / mL_c$$

where mLc is defined as,

$$mL_c = \sqrt{\frac{2h}{k_m A_m}L_c^{0.667}}$$

and the corrected fin length and fin profile area are found using these equations,

$$L_c = L + \frac{t}{2}$$

$$A_m = L_c t$$

Total Pressure Drop Calculation: To evaluate the total pressure drop across the heat sink, we must first determine the hydraulic diameter and channel velocity. They are given as follows,

$$D_h = \frac{2wh_f}{w+h_f}$$

$$V_g = V_{f3}\left[1+\frac{t}{w}\right]$$

The channel velocity is related to the free stream velocity and the ratio of fin thickness and the channel width. Using these variables with fluid properties, the Reynolds number is found to be,

$$\mathrm{Re}_g = \frac{D_h V}{v}$$

The total heat sink pressure drop is formulated as,

$$\Delta p = [K_{con} + f + K_{ex}].\left(\frac{\rho V_g^2}{2}\right)$$

Table 1: Geometry details of heat sink

Type of Heat sink	Fin geometry	Heat sink geometry in mm
Plate fin heat sink	No of fin =15	Fin spacing (b) =4
Single cross cut sink		Base thickness (tbp) =4
Multiple cross cut heat sink	Cross cut space = 4mm	Thickness of fin (t)=1
		Total height (H)=30
		Width (W) =69
		Length (L)=88
Square pin fin heat sink	No of fin along width =15	
Round pin fin heat sink	No of fin along length=25	

Table 2: Material properties for analysis

Si. No	Properties	Heat Sink Material	Heat Transfer Fluid
1	Material Used	Aluminum	Air
2	Thermal Conductivity	205 W/m.K	0.026W/m.K
3	Specific Heat	871W/m.K	1005W/m.K
4	Density	2702kg/m^3	1.165kg/m^3

Neglect the co-efficient of friction, expansion and contraction, therefore,

$$\Delta p = \frac{\rho V_g^2}{2}$$

Numerical Analysis: The numerical analysis has been carried out for plate fin, single cross cut, multiple cross cut, plate pin fin and round pin fin heat sinks. The analysis was done by using ANSYS icepak. This software is specially designed for analysis the electronic cooling systems. It's similar to ANSYS fluent but geometry section is creating electronic components only. This chapter is explaining about numerical simulation procedure.

Geometrical Modeling: Geometrical model is generated based on Table 4.1 by using ANSYS icepak modeler. The computational model contains two parts namely the solid part which represents the heat sink domain and the fluid part which denotes the air flowing through the heat sink. The model was meshed in ANSYS icepak is shown in Fig. 1. The meshed model is exported to the FLUENT solver for analysis. The boundary conditions are provided in the developed model.

Define Material Properties: The material properties of the given model is mentioned in Table 4.2.

Boundary Conditions: The air flow was given approach velocities of 1m/s and 2m/s at the inlet of the wind tunnel subsequently. The heat sink base was given heat supply of 60W as heat input. The surface area of the fin the heat sink was exposed to convection. The walls of the duct was given 'no slip' condition to capture the wall shear stress effect and insulated to prevent the heat loss. Thus, it is ensured that the total amount of heat predominantly transferred to the air by convection. The outlet of the duct was given pressure exit boundary condition which was at 0Pa gauge pressure to indicate the atmospheric pressure.

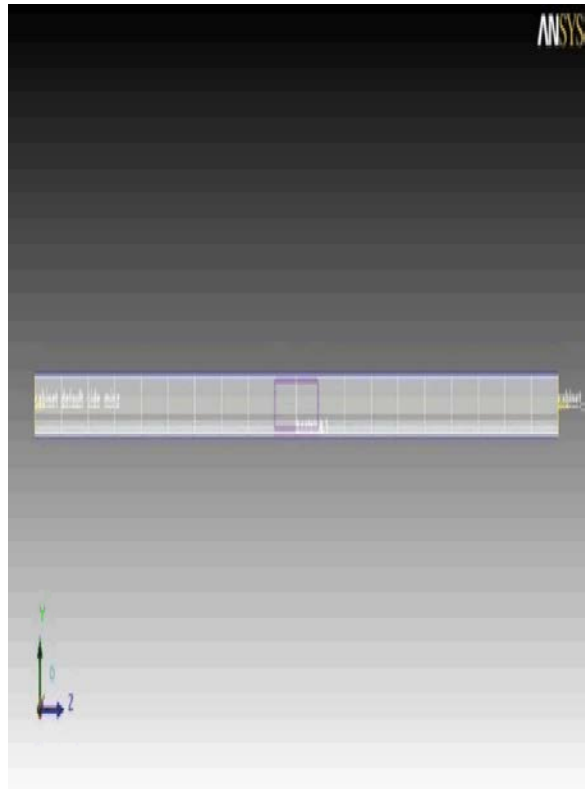

Fig. 1: Meshed model of air with heat sink

Solver Control: The ANSYS icepack solve the problem in finite volume method. Select the basic parameters laminar or turbulent equation model is selected based on inlet velocity condition. The forced convection heat transfer occurs in the problem to solve based on energy equation. Equation is solving after initialize the number of iterations selected. The iterations are selected based on problem complication and meshing condition.

RESULTS AND DISCUSSION

Comparative study between the five heat sinks is explained below.

Heat transfer rate is directly proportional to co efficient of heat transfer, so most of the research work co efficient of heat transfer is compared to other parameters. Heat transfer coefficient of the sink is increases by means of increase of the contact area the variation of convective heat transfer co efficient for different heat sink is shown

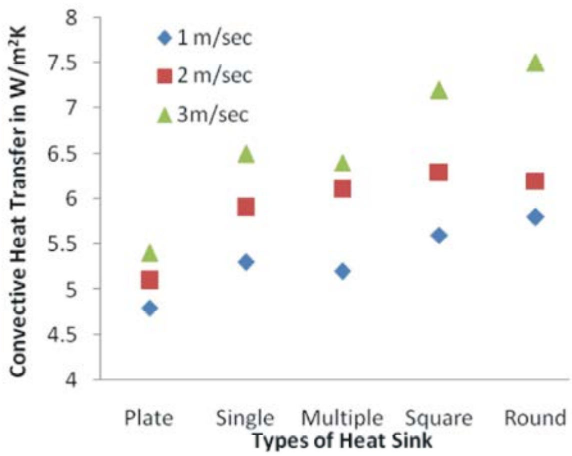

Fig. 2: Heat transfer co efficient Vs type of heat sink at different velocity

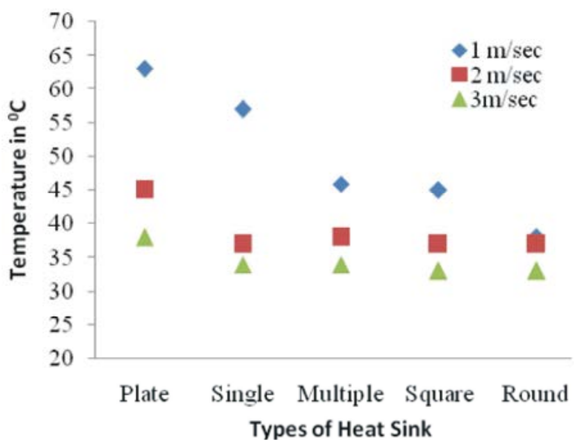

Fig. 3: Temperature of air Vs Type of heat sink at different velocity

in Figure 2 in pin fin heat sink gives greater heat transfer coefficient due to its increase in surface area. velocity of the fluid also an impact factor to increase the heat transfer rate

Average temperature of heat sink is shown in Figure 3 These shows pin fin heat sink shows low temperature, it means that amount heat carried in heat source is transferred to the ambient air is high. Plate fin sink have highest temperature due to lack of heat transfer rate. single cross cut sink have moderate average temperature due to mixing of at space of cross cut. In all velocity conditions multiple cross cut gives equal or slightly improved performance than single cross cut sink.

Heat transfer performance is slightly high compare to rectangular plate heat sink and pressure drop is high due to its increase of fin density. Square pin fin having least temperature difference between base and fin, but pressure drop is same as round pin fin heat sink. The single cross cut heat is give best performance compare to other type heat sinks. High temperature occur in base of the heat sink due to base of the heat sink immediate contact with heat source and low in tip of the fin due to high amount of air contact. Leading edge of the fin tip is very low temperature compare to other portion of the heat sink. Its due to fresh air is first approach at leading edge so more amount of heat transfer takes place. The local heat transfer coefficient value also decreases along the axial length of the heat sink. The temperature difference between the heat sink and the surrounding fluid is higher at the leading edge. Therefore the convective heat transfer is also higher at the front and decreases as the length increases. The pressure drop value increases with increasing of velocity. Temperature and pressure contour show in Fig. 3 and 6. Rectangular plate fin heat sink having least pressure drop but heat transfer low due to low air to surface contact. The temperature difference between the heat sinks single cross cut having low difference. It's denoted that convective heat transfer high

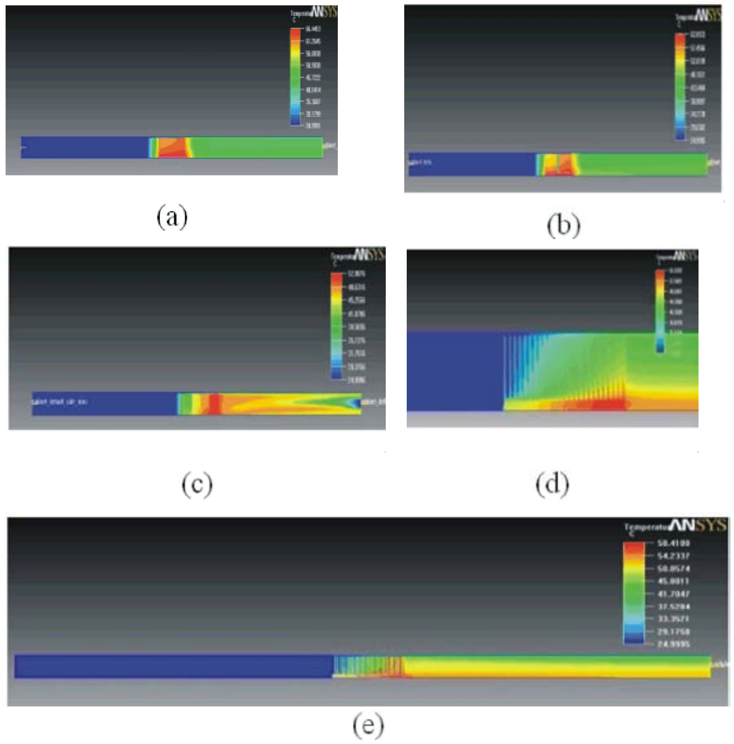

Fig. 4: Temperature profile of heat sink for 1 m/sec (a) Rectangular (b) Single cross cut (c) Multiple cross cut (d) square pin fin (e) round pin fin

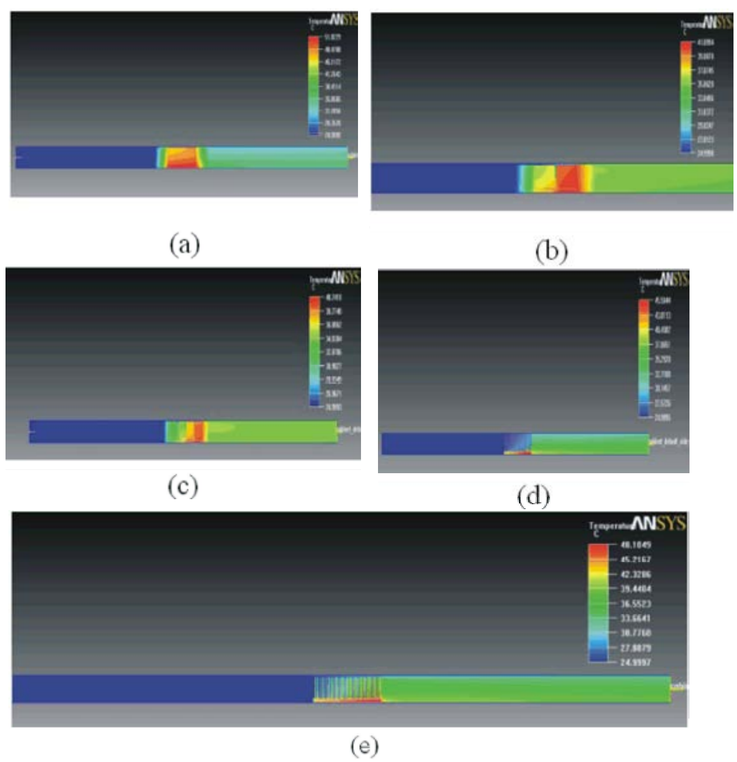

Fig. 5: Temperature profile of heat sink for 2 m/sec (a) Rectangular (b) Single cross cut (c) Multiple cross cut (d) square pin fin (e) round pin fin

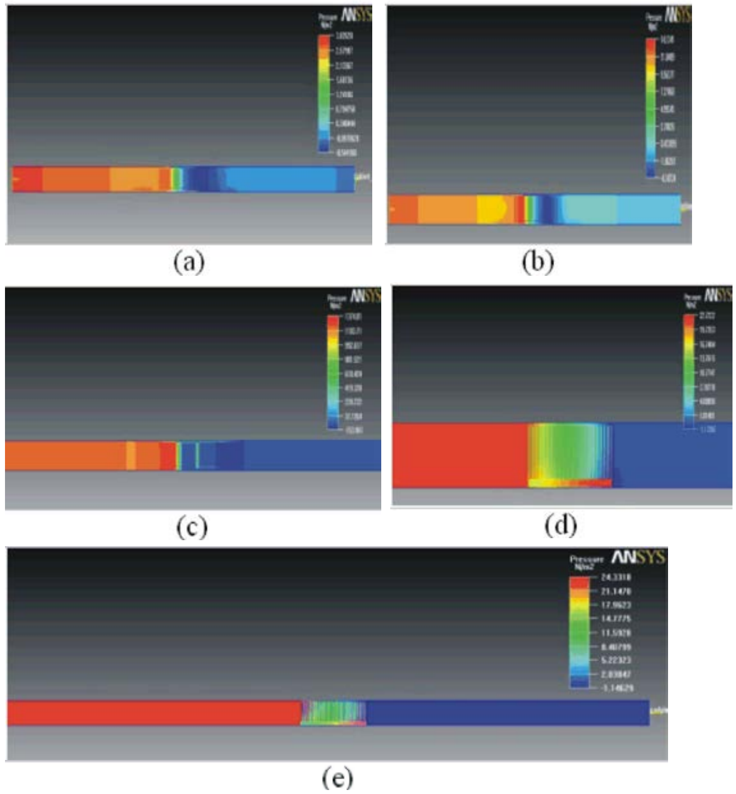

Fig. 6: Pressure profile of the heat sink for 1 m/sec (a) Rectangular (b) Single cross cut (c) Multiple cross cut (d) square pin fin (e) round pin fin

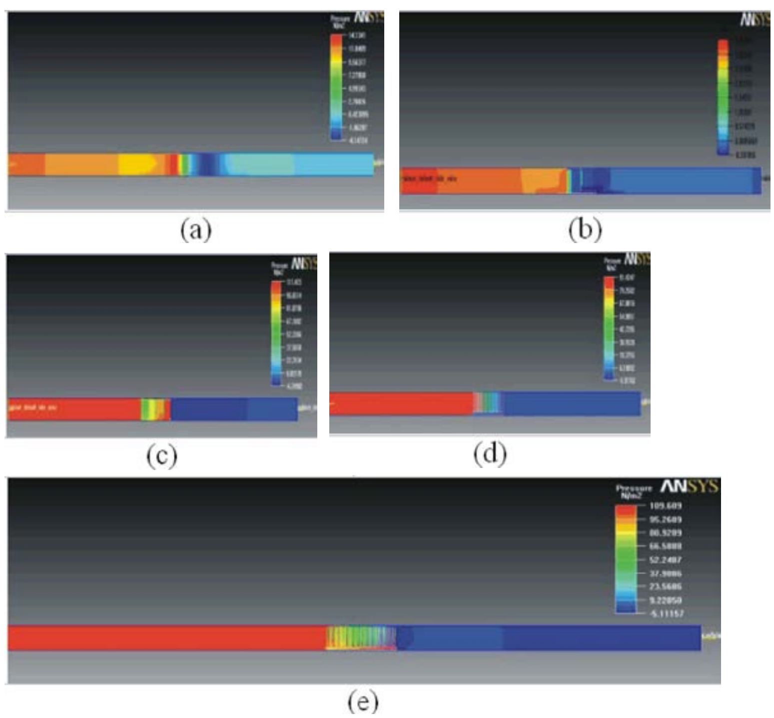

Fig. 7: Pressure profile of the heat sink for 2 m/sec (a) Rectangular (b) Single cross cut (c) Multiple cross cut (d) square pin fin (e) round pin fin

compare to sinks. Thermal resistance between heating element to sink is reduced by means mixing of flow at the place of cross cut region with acceptable pressure loss. Generated heat is maximum amount is transfer to air compared to other sinks. in the same case multiple cross heat sink is relatively same temperature difference but pressure drop increases with increase of cross cut. Round pin fin having high temperature difference between source and fin due to its spreading resistance between base and fin.

Normally convective heat transfer increases with increasing velocity due to mass flow rate of air contact in fin surface also increased. fin density is also important factor in enhancement of heat transfer. Fig. 3 and Fig. 4 shows pressure in the heat sink, this shows the increase in fin density is also increase the pressure drop so the pumping power for the system also increased. finally results need slightly high power pumping device has been required get an effective heat transfer rate. fin spacing is also a important factor in hat sink.

CONCLUSION

The heat sink is widely used in the electronic cooling. This work observed from the numerical analysis single cross cut heat sink having better than rectangular, multiple cross cut, square and round pin fin heat sinks due to its heat transfer rate. The single cross cut heat sink having slightly increased the pressure drop but its acceptable range of increase the heat transfer rate compares to other heat sinks. Round pin fin heat sink and square pin fin heat sink increase the heat transfer rate with increase fin density. The single cross cut heat sink related works countable only. This investigation may lead to development in single cross cut heat sink to change of cross cut length and cross cut spacing. The convective heat transfer co efficient has been increased by 15% for single cross cut sink compare to other heat sinks. In future this work will be changed to effective fin materials in form of coatings to reduce the air to fin surface resistance.

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