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Numerical Analysis of Forced Convection in Novel Cylindrical Oblique Finned Heat Sink

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ABSTRACT— In this paper ,forced convection heat transfer of laminar flow through novel cylindrical discrete oblique fin heat sinks were simulated by Computational fluid Dynamics method(CFD).The multi-channel structure was imported into fluent V 15.0 as a physical model to be simulated. In this paper were going to found various heat transfer rates with respect angles for the entire oblique heat sink. According to the results the average of heat transfer is 1.99W with respect to fin angle at 60^0. because of the above reason we will get minimum wall temperature and temperature gradient of the oblique heat sink in addition to the we were investigate the various velocities of fluid pressure and Nusselt number, Reynolds number. Lastly the guide lines for optimising cylindrical heat sink structure in different applications were also discussed.

Key words: cylindrical oblique fin, electronics cooling, heat sink.

Nomenclature

D_h	Hydraulic diameter, mm
D	Heat source dimension, mm
H	Channel height, mm
L	Heat sink length, mm
Nu	Nusselt number
ΔP	Pressure drop, Pa
P	Pumping power, W
Q	Total heat, W
Re	Reynolds number
ΔR	Thermal resistance reduction, $^oC/W$
R	Thermal resistance, $^oC/W$
T	Temperature, ^oC
a	Oblique fin length, mm
b	Secondary channel length, mm
t	Footprint height, mm
c_p	Specific heat capacity, KJ/Kg.K
h	Heat transfer coefficient, W/m^2K
k	Thermal conductivity, W/mK
n	Number of channels
q″	Heat flux, W/m^2
u	Velocity, m/s

Greek symbols

α	Aspect ratio
θ	Oblique angle, ^{o}
Δ	Gradient
μ	Dynamic viscosity, Ns/m^2
ρ	Mass dengsity, kg/m^3

Subscripts

Ave	Average
Ch	Channel
m	Mean bulk fluid
w	Wall

I. INTRODUCTION

Cylindrical heat sources such as batteries, motors, drills, high power lasers and nuclear fuel rods, are widely used in high energy applications and play an essential role in our modern society. Commonly during use, these heat sources could be overloaded for a brief period of time, and the heat generation in these cylindrical heat sources can be very intensive [1]. For example, batteries could face excessive high discharge rate during use and suffer thermal runaways; electric motors could be overloaded and heated up during start up thereby losing their torque, and the drill will heat up faster as it drills through denser materials. If effective cooling is not provided at these instances, these heat sources could be overheated and resulted in catastrophic failures.Conventional cooling methods such as air cooling are unable to keep up with the increasing demand of high heat removal with increasing miniaturization of the heat sink. Even though two-phase cooling can dissipate large heat fluxes in the order of tens of MW/m^2, its flow system is more complicated compared to a single-phase flow system. Furthermore, the complex nature and fundamental mechanism of two-phase flow in microchannel is not well-established. One novel cooling concept is the micro/mini channel heat sink introduced by Tuckerman and Pease in 1981 [2]. Figure 2-1 shows a typical microchannel heat sink, consisted of a series of parallel small channels and fins. The heat generated by the electronic device is firstly transferred to the channels by conduction through the substrate and subsequently to the cooling liquid by convection. Microchannels have a much higher heat transfer surface area to fluid volume ratio. As the hydraulic diameter decreases in a microchannel, the heat transfer coefficient increases, providing an excellent cooling mechanism. They offer several advantages such as high convective heat transfer coefficient, ease of implementation, compactness, light weight, higher surface area to volume ratio and small coolant inventory requirement. As a result, liquid cooling by single-phase flow through micro/mini channel heat sinks has become popular solutions to many thermal issues.

2. CFD Simulation Approach

2.1 Microchannel geometry consideration

The cylindrical heat sink design is based on the concept of sectional oblique fins in microchannel heat sink which was proposed by DONG LIU **[4]**In this design, oblique fin are cut along the fins to create smaller branching channels. Finally, it can fulfill the following objectives: (1) to disrupt the thermal boundary layer development, (2) to generate secondary flows,
(3) to increase the heat transfer area and to push the flow rotate along the circumference from entrance to outlet. Fig.1 illustrates the 3D view of the enhanced microchannel along with the flow paths for the main flows and secondary flows.

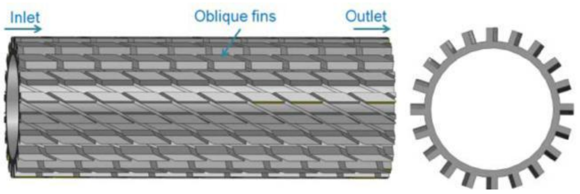

Fig 2.1 3D Structure of cylindrical oblique fin heat sink

Characteristic	Oblique fn Heate d sink
Fluid	Water-liquid
Material	Copper
Heater source dimension D,(mm)	18
Footprint height t,(mm)	1
Fin length L,(mm)	65
Channel height H,(mm)	2
Oblique angle θ, (°)	

In this simulation, the geometry details for both enhanced microchannel and conventional microchannel are tabulated in Table.1. In order to facilitate a fair performance comparison and to study the fin length and cross section in details, both heat sinks in the simulation study share the same aspect ratio, channel width, fin width and overall footprint. Apart from these common characteristics, the oblique fin microchannel has openings that are obliquely cut at 30^{0} from the main channel.

NEED OF OPTIMIZATION The fins has to be designed in a such a way that the cylindrical oblique heat sink with angles 0^{0},30^{0},45^{0},60^{0},$90\ ^{0}$should have approximately same surface area and the dimensions of the cylindrical oblique 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 various angles. 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.

3.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 cylindrical oblique is also analyzed in order to compare the performance of cylindrical oblique for various temperatures in forced convection cases. The cylindrical oblique modified geometry as cylindrical oblique 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.

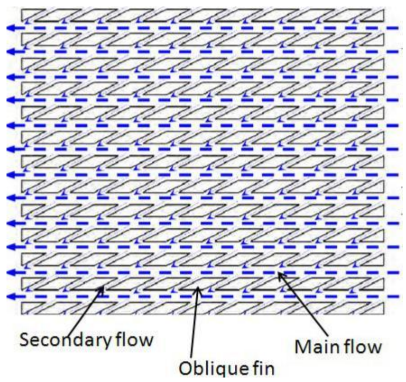

Fig. 3. 1 D Plan view of microchannel with oblique fins

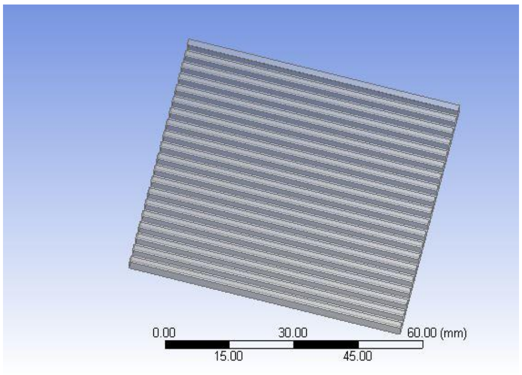

Fig 3.2 **3D Plan view of microchannel with oblique fins**

Part Name : Oblique fined Heat sink

Material : Copper

II. **DISCRIPTION AND WORKING OF HEAT SINK**

Fig.3.1Design for oblique fin heat sink model

3.2 Design Procedure for oblique fin heat sink model:

We have designed this model in creole parametric 3.0
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 65, 2thk and enter depth value as 56.55 as shown in the drawing.
4) Click on extrude to create the fin by entering the width as 1 .
5) Right click on extrude→click on pattern→select the direction pattern option to create the pattern by entering the number of instances as 19 and distance between the fins as 1.45.
6) Click on file→prepare→model properties and select the copper 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.

4.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),

$$\tau_{xz}=\tau_{zx}=\mu\left(\frac{\partial w}{\partial x}+\frac{\partial u}{\partial z}\right) \quad (4.6)$$

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

$$\tau_{yz}=\tau_{zy}=\mu\left(\frac{\partial v}{\partial z}+\frac{\partial w}{\partial y}\right) \quad (4.7)$$

$$\tau_{xx}=\lambda(\nabla.V)+2\mu\frac{\partial u}{\partial x}$$

$$\tau_{zz}=\lambda(\nabla.V)+2\mu\frac{\partial w}{\partial z}$$

$$\tau_{yy}=\lambda(\nabla.V)+2\mu\frac{\partial v}{\partial y} \quad (4.8)$$

$$\lambda=-\frac{2}{3}\mu$$

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.

4.1.3 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

$E = i + ½\left(u^2+v^2+w^2\right) + g$

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 .

5.RESULTS AND DISCUSSION

1 Meshed Model of oblique heat sink at an angle 30^0 :

The meshed model for the oblique Heat Sink is as shown in the Fig. 5.1

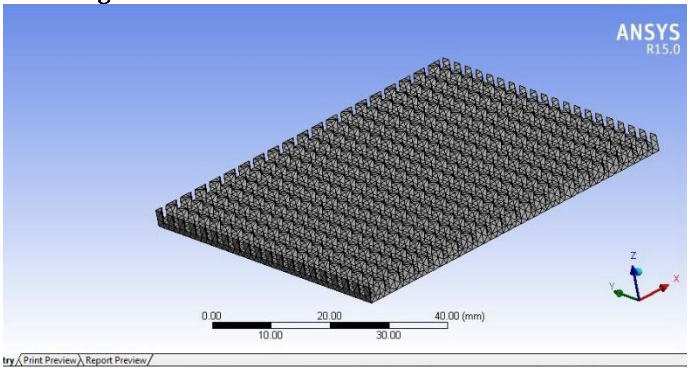

Fig 5.1.1 Fig shows Meshed Model of oblique heat sink at an angle 30^0

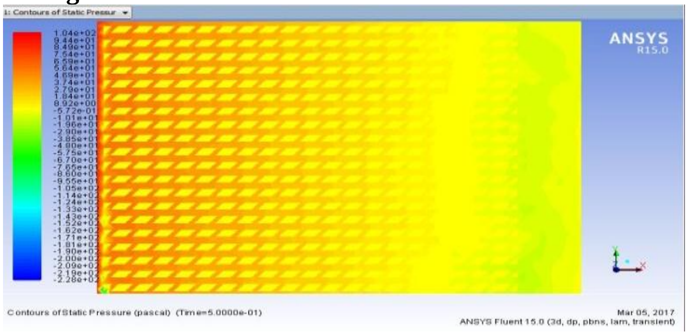

Fig 5.1.2 Shows Contours Of Static pressure for cylindrical fin with 30^0 oblique angle

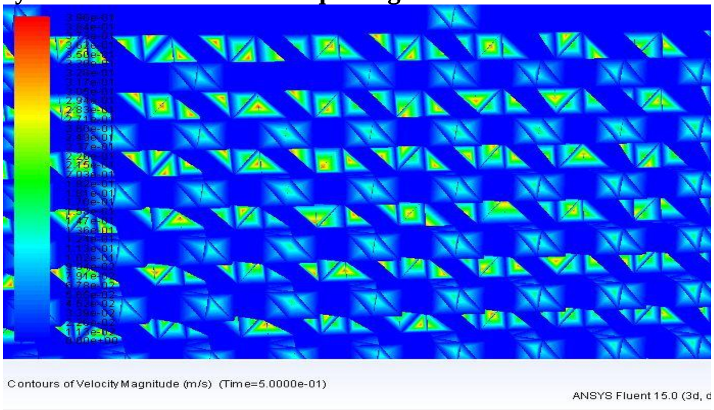

Fig 5.1.3 Shows Contours Of velocity for cylindrical fin with 30^0 oblique angle

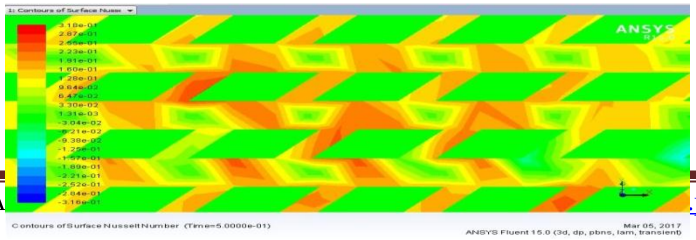

Fig 5.1.4 Contours of Nusselt Numberof the oblique heat sink at 30^0 oblique angle

2. Meshed Model of oblique heat sink at an angle 45^0 :

The meshed model for the oblique Heat Sink is as shown in the Fig 5.2.1

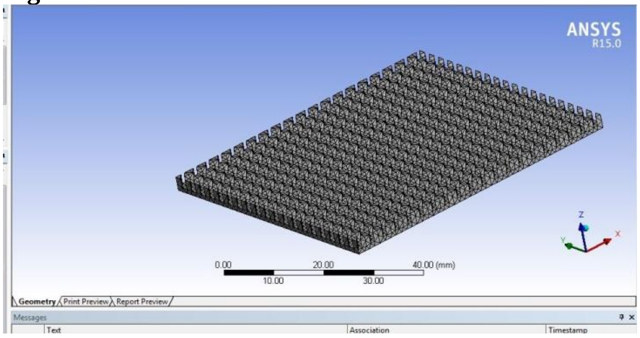

Fig 5.2.1 shows Meshed Model of oblique heat sink at an angle 45^0

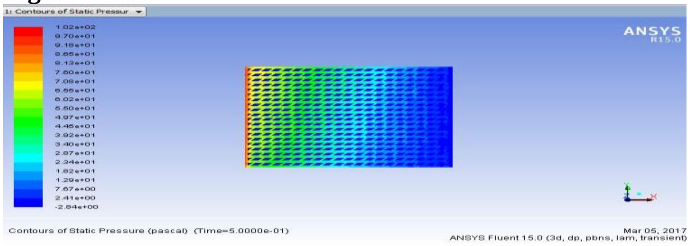

Fig 5.2.2 Shows Contours Of Static pressure for cylindrical fin with 45^0 oblique angle.

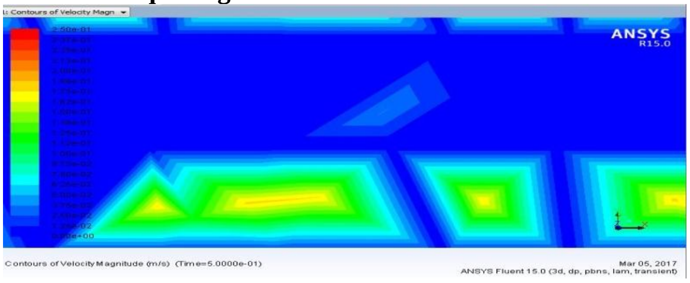

Fig 5.2.3Contours Of velocityOf The cylindrical fin with 45^0 oblique angle.

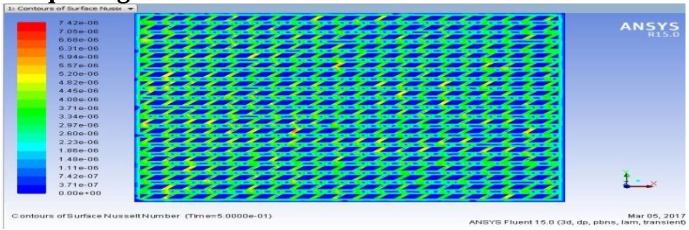

Fig 5.2.4Contours of Nusselt Numberof the cylindrical fin with 45^0 oblique angle.

3.Meshed Model of oblique heat sink at an angle 60^0 :

The meshed model for the oblique Heat Sink is as shown in the Fig 5.3.1

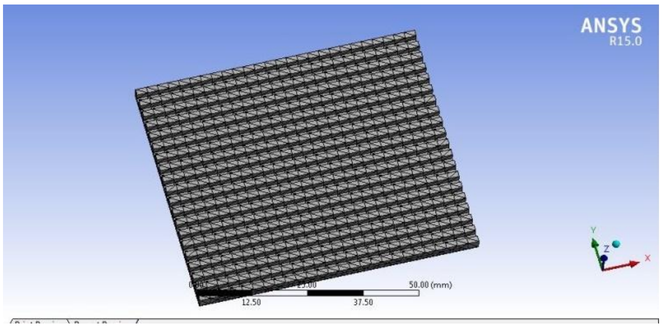

Fig 5.3.1 shows Meshed Model of oblique heat sink at an angle 60^0

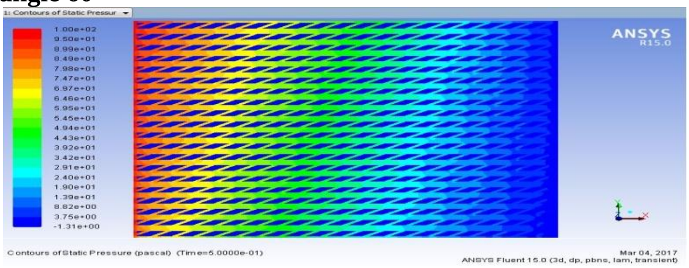

Fig 5.3.2Shows Contours Of Static pressure for cylindrical fin with 60^0 oblique angle

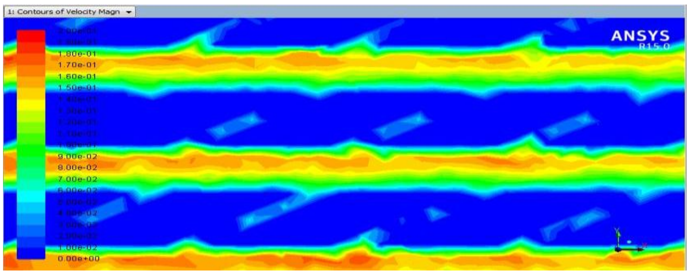

Fig 5.3.3Contours Of velocityOf The cylindrical fin with 60^0 oblique angle

Fig 5.3.4 Contours of Nusselt Numberof the cylindrical fin with 60^0 oblique angle.

4.Meshed Model of oblique heat sink at an angle 90^0 :

The meshed model for the oblique Heat Sink is as shown in the Fig 5.4.1

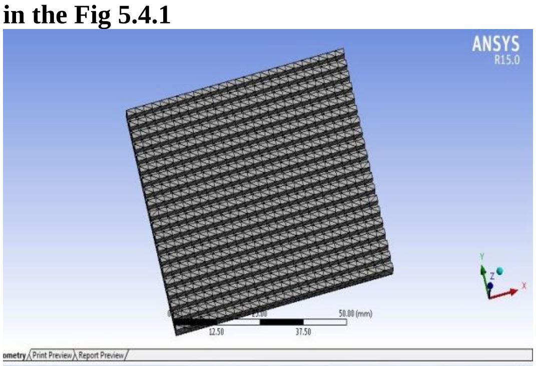

Fig 5.4.1 shows Meshed Model of oblique heat sink at an angle 90^0

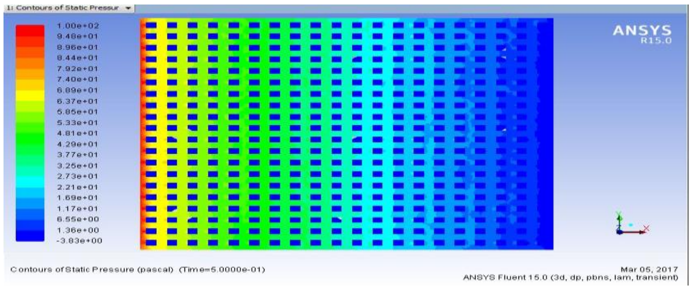

Fig 5.4.2 Shows Contours Of Static pressure for cylindrical fin with 90^0 oblique angle

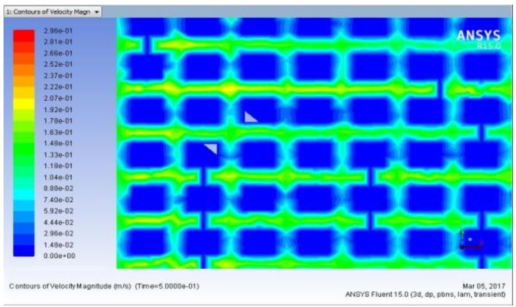

Fig 5.4.3 Contours Of velocityOf The cylindrical fin with 90^0 oblique angle

Fig 5.4.4 Shows Contours Of Static pressure for cylindrical fin with 90^0 oblique angle

Oblique angle	30^0	45^0	60^0	90^0
Reynolds Number	43.09544	41.276212	37.00282	29.102065
Total Heat Transfer Rate (W)	0.65483369	0.8453079	1.997469	0.72
Max static pressure	100.28565	124.0572	113.0591	101.3067
Max velocity magnitude	43.09544	41.276212	37.00282	29.102065
Nusselt number	1.4419E-05	1.0935632	1.28E-05	-1344555.3

6.RAPHICAL REPRESENTATION:

Fig 6.1 TOTAL HEAT TRANSFER RATE (W) WITH OBLIQUE ANGLE

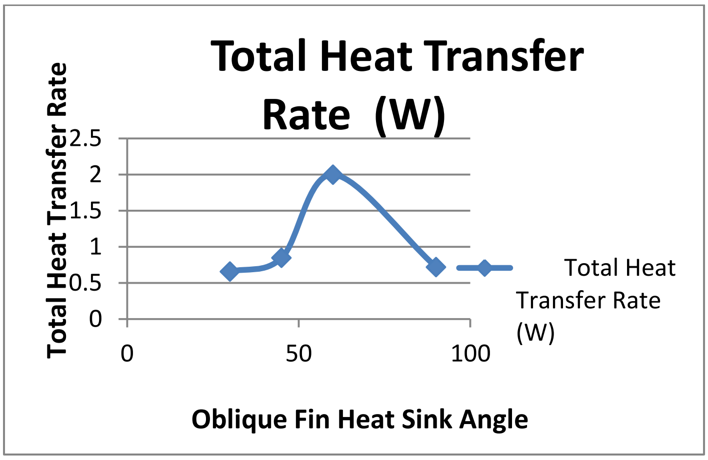

Fig 6.1 Shows heat transfer rate with oblique fin angle

The above Fig 6.1 shows the variation of heat transfer Rate with oblique angle. The results shows that with the increase of the heat transfer rate at an angle 60^0. Decreases gradually because of changing the angle.

Fig 6.2 REYNOLDS NUMBER WITH OBLIQUE FIN HEAT SINK

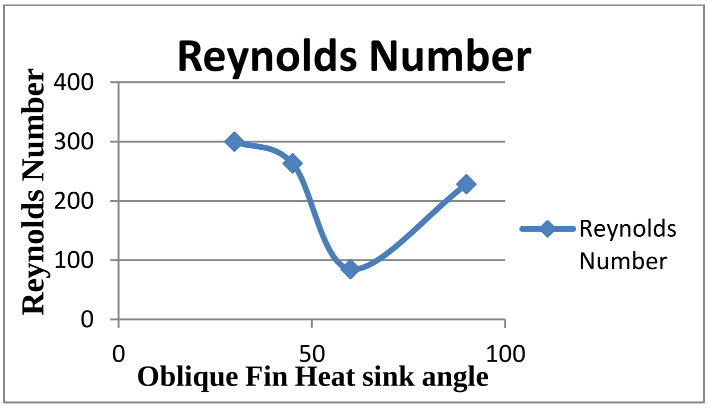

Fig 6.2 Reynolds number with Oblique fin heat sink angle

The above Fig 6.2 shows the variation of Reynolds number with the Oblique fin heat sink at the highest heat transfer rate is obtained at an angle of 60^0.then Reynolds number will be gradually decreases .angle will be changes Reynolds number gradually increases.

Fig 6.3 VELOCITY MAGNITUDE VS OBLIQUE ANGLES.

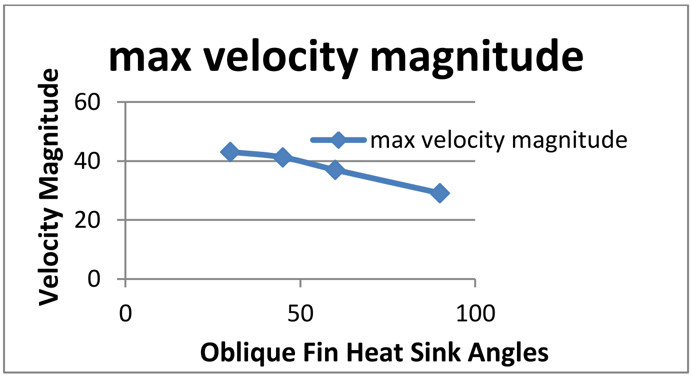

Fig 6.3 Velocity magnitude vs Oblique fin angles

The above Fig 6.3 shows the variation of oblique angle with velocity. The results shows that with the increase of velocities with respect with angles angles will be changes velocities either fall or down . at the angle of 45^0 the velocity will be at maximum and then angles will be changes velocity will be decreses

Fig 6.4 STATIC PRESSURE VS OBLIQUE FIN ANGLES

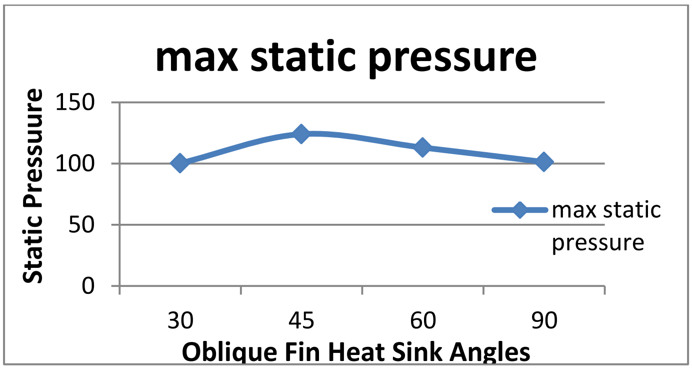

Fig 6.4 static pressure vs oblique fin angles

The above Fig 6.4 shows the variation of oblique heatsink angles of fins with the velocity. as the fin angles at 30^0 100 kpa and angle will be changes at 45^0 maximum pressure will be obtained .and then angle changes at 60^0 pressure will be decreases and angle will be changes as well as pressure decreases .

With respect to the fin angles will be changes pressure is rise or fall down and then maximum pressure will be obtained at 45^0 oblique angle.

CONCLUSIONS

The forced convection of laminar flow through the novel cylindrical oblique fin heat sink was simulated by FLUENT v 15.0. the various heat oblique fin angles were investigated, and higher heat transfer rate was found. The results shows that various heat transfer rates with respect angles for the entire oblique heat sink. According to the results the average of heat transfer is 1.99 with respect to fin angle at45^0. Because of the above reason will get minimum wall temperature and temperature gradient of the oblique heat sink in addition to the we were investigate the various velocities of fluid pressure and nusselt number, Reynolds number. it was concluded that the novel cylindrical oblique heat sink fin angle $60^0$is superior to other oblique angles in novel cylindrical oblique finned heat sink.

FORMULAE:

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

where,
U = average velocity in channel, m/s
L = base plate length, m
υ = kinematic viscosity = m^2/s

NUSSELT NUMBE(Nu):

In heat transfer at a boundary (surface) within a fluid, the Nusselt number (Nu) is the ratio of convective to conductive heat transfer across (normal to) the boundary

$$Nu_{avg} = \frac{\sum Nu_x dL}{L}$$

where Nu x is the local Nusselt number, while L is the length of the channel which is 65mm

TO CALCULATE AVERAGE HEAT TRANSFER COEFFICIENT

h= average heat transfer coefficient, W/m^2K

$$h_x = \frac{q''_x}{T_{wx} - T_{mx}}$$

$$R = \frac{T_{area...weighted...avg} - T_{mass...weighted...inlet}}{Q_{total...heat}}$$

q″ is the local heat flux, Tw(x) and Tm(x)are the local wall temperature and local fluid bulk mean temperature respectively, defined as follow:

$$T_{w(x)} = \frac{\sum_{y,z} T_w(x,y,z)dA(x,y,z)}{\sum_{y,z} dA(x,y,z)}$$

$$T_m = T_{in} + \frac{1}{mc_p}\sum_{x,y,z} q(x,y,z)dA(x,y,z)$$

$$N_{u(x)} = \frac{h(x)Dh}{k_f}$$

$$q_p = \frac{h}{p} = \frac{Q/N}{A_W P \Delta T_m}$$

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