Study And Analysis Of Micro Fins

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Abstract: Fins are used to increase the rate of heat transfer to or from the environment by providing excess surface area. Fins performance can be increased by reducing perimeter by area ratio, using material with high coefficient of thermal conductivity(K) and by optimizing size and distance between fins over surface. Boundary layer generation over fin also effects heat loss widely. If boundary layer(BL) of one fin intersects BL generated from other fin then fin performance reduces. Same concept is also applicable on Macro-fins. In our paper we simulated thermodynamic boundary layer over Bell shaped fins (Gaussian distribution) and used these fins to model increase in heat transfer with surface roughness

Index Terms: Micro- fins, Effectiveness, Fin- Array, Thermodynamic Boundary layer, Roughness, Normal distribution, Miniturarization,

1 INTRODUCTION

In the study of heat transfer, fins are surfaces that extend from an object to increase the rate of heat transfer to or from the environment by increasing convection. The amount of conduction, convection, or radiation of an object determines the amount of heat it transfers. Increasing the temperature gradient between the object and the environment, increasing the convection heat transfer coefficient, or increasing the surface area of the object increases the heat transfer. Sometimes it is not feasible or economical to change the first two options. Thus, adding a fin to an object, increases the surface area and can sometimes be an economical solution to heat transfer problems[1] Fins made up of different shapes, sizes, and materials can be placed in different arrangements to increase the channel surface area and widely affects the heat transfer performance and pressure drop characteristic. Many modifications to the micro-channels surface have been investigated in enhancing the thermal performance. Many studies have demonstrated some progress in the development of enhancing cooling for electrical devices but the optimal shape and geometry of fin and material of fins still need modification and. With the increasing desire to improve the cooling techniques for small electrical components, advanced materials with high thermal properties need to be exploited. Fins made up of silicon or carbon nanotubes (CNTs), both containing high thermal properties, have been the choice of materials to improve thermal performance.[2] Shape of the fins affect the motion of flow by producing a mixing in the flow as the fluid passes through the channel, improves performance. Optimizing the fins shapes, topology (texture) and dimensions to achieve the maximum thermal performance has not been thoroughly executed with corresponding heat transfer and friction factor correlations. In order to completely optimize the fins used Optimum fin height, width, and spacing of the square shaped pin fin are modeled. The report also studied use of bell shaped fins (Gaussian distribution) by simulating thermodynamic boundary layer over the fin . In our report we are taking roughness as bell shaped fin. An explicit relationship has been derived to model increase in surface roughness and increase in heat transfer.

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NOMENCLATURE

A_c = Cross section area
A_s = Curved surface area
h = Convective heat transfer coefficient
P = perimeter of Fin
$\theta(x) = T(x) - T_\infty$
k = conduction coefficient
Q= heat transfer
$\beta = \frac{1}{T_b}$; T_b = bulk temperature
μ = coefficient of viscosity
υ = coefficient of kinematic viscosity
Ra_L = Rayleigh's number
R_a = Root mean height of surface from the mean line within the measuring length.
S_m = the mean spacing between peaks known as roughness spacing parameter that used to describe the horizontal dimension of roughness.

2 FIN EQUATION AND EFFECTIVENESS

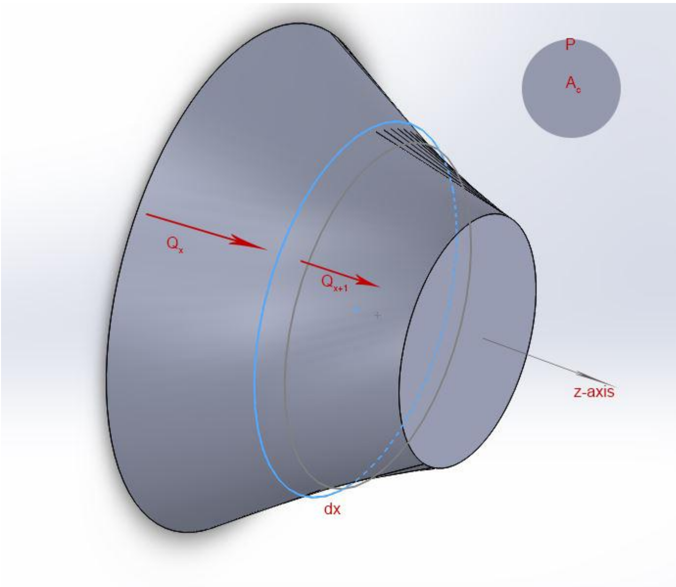
2.1 Shape Factor

There are different types of fins like longitudinal, Pin, Radial, Plate type and shape are like Triangular, Trapezoidal, Convex and Concave Parabolic, Radial, etc,. All types of fin have different surface area and parameter. The Parameter by Area ratio P/Ac of fin is called Shape factor. For different fins, shape factor plays very important role in changing heat transfer rate. [3][4].

2.2 Effectiveness

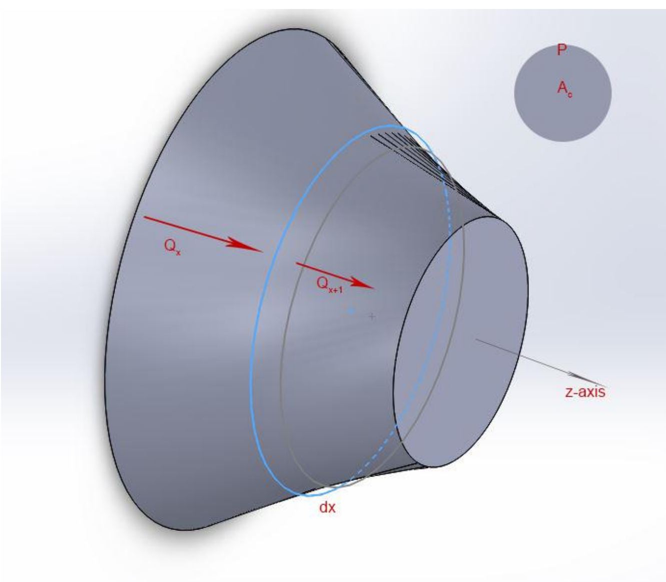
Fin are used to improve heat transfer by increasing convection and radiation surface areas and therefore reducing convection and radiation thermal resistances. On the other hand, a fin creates an additional conduction thermal resistance between its base and outside ambient. Therefore, a fin may or may not increase heat transfer rate from the surface. A measure of fin performance is Fin Effectiveness. It is defined by ratio of heat transfer rate from the fin to heat transfer rate from the base of the fin if the fin was not there. The additional cost and weight can be justified if effectiveness of fin is reasonably high.[3]

Fin Equation



Effectiveness of fin with constant cross section area given by [1]

$$\epsilon_{fin} = \frac{Q'_{fin}}{Q'_{nofin}} = \frac{\sqrt{hPkA_c}(T_b - T_\infty}{hA_b(T_b - T_\infty)} = \sqrt{\frac{kP}{hA_c}}$$



For more effectiveness

- k(Thermal conductivity) should be high, (Cu, Al, Fe).
- p=Ac should be as high as possible. (Thin plate fins and slender pin fins)
- Most effective in applications where h is low. (Use of fins justified if when the medium is gas and heat transfer is by natural convection).

3 MULTI-FIN ARRAY

For a single fin, the consideration is given to the thickness and length of the fin to get the maximum heat transfer rate. For an array of fin, fin spacing z and number of fin n for a given plate area LxW is considered.

3.1 Small Spacing Channel

Consider a small hot parallel plate with constant wall temperature T0 Cold air at T1 enters through the bottom of the channel by natural convection.

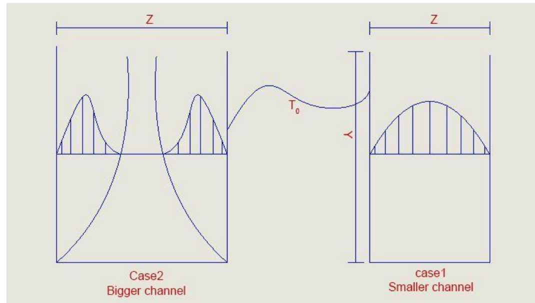


Fig. 1: *Spacing small channel and wide channel*

Assumption

- Streamline flow
- Length of channel is such that at the outlet air temperature is T_0
- $n = \frac{W}{z+t}, Z >> t$,so $n \approx \frac{W}{z}$

  Navier Stokes eqn.

$$\frac{du}{dt} = -u(\nabla u) - \frac{1}{\rho}\nabla p + \mu(\nabla)^2 u + f$$

here $f = -g\alpha(T_0 - T_\infty)$ where α is coefficient of thermal expansion.

Continuity eqn.

$$\frac{d\rho}{dt} + \nabla(\rho u)$$

Using Boussineq approximation[5]:

$$\frac{\delta^2 v}{\delta y^2} = -\frac{g\beta(T_0 - T_\infty)}{nu}$$

On integration the average velocity can be calculated as

$$v_{avg} = \frac{g\beta(T_0 - T_\infty)z^2}{12\nu}$$

$$m' = \frac{\rho g\beta(T_0 - T_\infty)z^2}{12\nu}Wb$$

$$q_f = m' c_p(T_0 - T_\infty)$$

Heat transfer from fin array with small spacing

$$q_{f_{small}} = \rho c_p Wb\frac{g\beta(T_0 - T_\infty)^2 z^2}{12\nu}$$

$$q_{f_{small}} \alpha z^2 \qquad (1)$$

3.2 Small Spacing Channel

Consider a large spacing for boundary layer to be isolated between isothermal plates The Nusselt number(Nu) for natural convection for a vertical plate.

$$Nu_{avg} = \frac{h_{avg}L}{K_{air}} = 0.517Ra_L^{0.25}$$

Here Rayleigh number is

$$Ra_L = \frac{g\beta(|T_0 - T_\infty|)L^3}{\nu\alpha}$$

The heat transfer rate from large channels can be

$$q_{f_{large}} = A_s h_{avg}(T_0 - T_\infty)$$

here $A_s = 2bln = 2bL\left(\frac{W}{z}\right)$

$$q_{f_{large}} = 1.034\frac{W}{z}bk_{air}Ra_L^{0.25}(T_0 - T_\infty)$$

$$q_{f_{large}}\alpha\frac{1}{z} \qquad (2)$$

Optimum Spacing

$$q_{f_{small}} = q_{f_{large}}$$

$$\frac{Z_{opt}}{L} \approx 2.3\left[\frac{g\beta(T_0 - T_\infty)L^3}{\alpha\nu}\right]^{-1/4} = 2.3Ra_L^{-1/4}$$

Increasing number of fins increase the available area for heat transfer, but decreasing fin spacing cause intersection of Thermodynamic boundary layer .[6] Intersecting boundary layer decrease overall effectiveness of fins.

4 Surface Roughness and Micro fins

In this section Surface roughness is considered equal to micro fins. The closest shape that can be approximated as surface roughness is multi variable Gaussian distribution curve.[7] Normal distributions are important in statistics and are often used in the natural and social sciences to represent real-valued random variables whose distributions are not known.[7][8]

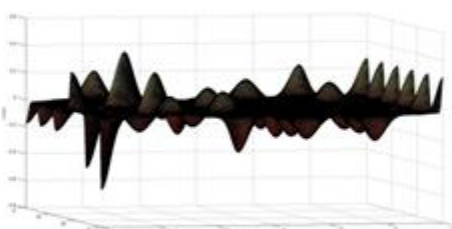


Fig. 2: *Random surface generated using matlab*

The two dimensional probability density function of a vector [X,Y] is similar to $f(x,y) = e^{\left[\frac{(x-\mu_x)^2}{\sigma_x^2} + \frac{(y-\mu_y)^2}{\sigma_y^2}\right]}$

Where $\sigma_X > 0$ and $\sigma_Y > 0$ [8].

The thermodynamic boundary layer of these fins have a bulging-in shape[Fig. 3]. So, Possibility of intersection is less.

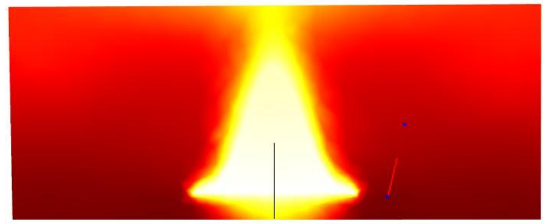


Fig.3: *Boundary layer of fin is visible by graphing temp. distribution around the fin*

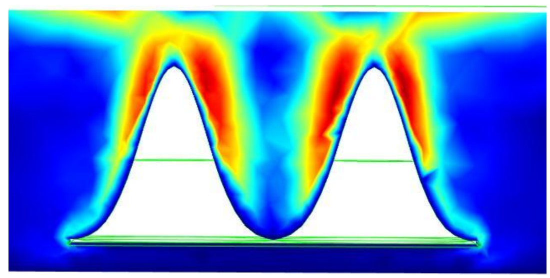


Fig.4 *Velocity of air over the fin*

Therefore large number of fins can be placed side-by side without decrease in efficiency.

5 Roughness and Heat Transfer

5.1 Miniaturization

As miniaturization of the fin is done the temp. difference between tip of the fin and bottom of the fin goes down as in table 1. Therefore for fin with dimension in mm. consideration of constant temp. all over the surface is a good assumption. Eqn. to describe temp. distribution over bell shaped fin surface.

$$4h\sqrt{4r^2e^{-3r^2} + e^{-r^2}} + k\frac{d^2T}{dr^2} = 0$$

r= cross section radius of fin

The BVP was likely to be stiff and in order to solve this problem,the Lobatto IIIA , a collocation method from routine bvp4c of matlab ,was used [9]

T[max]- T[min]	R at base	Scale of R
920.86	2.146	R
33.486	0.678	R=$10^{0.5}$
2.9594	0.215	R=10
0.291	0.067	R=$10^{1.5}$
0.0290	0.021	R=10^2
0.0029	0.007	R=$10^{2.5}$
0.0002	0.002	R=10^3

Table 1: *Temp. difference in a bell shaped fin for different cross section radius*

5.2 Roughness Parameters

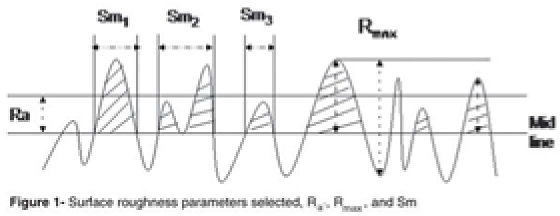


Fig. 5: *Roughness Parameters[10]*

WHERE

$$Ra = \sqrt{\frac{\sum_{i=1}^{n} y_i^2}{N}}$$

$$Sm = \frac{\sum_{i=1}^{n} Sm_i}{N}$$

For normal distribution we considered Sm equal to value at which Ra decrease by 99% than at mean.

$$Ra = Ra_0 \, e^{-\frac{1}{4} sm^2}$$

There is a 200% increase in area is for $Ra/Sm = 1.15$ for this arrangement. This would increase for even closer arrangement.

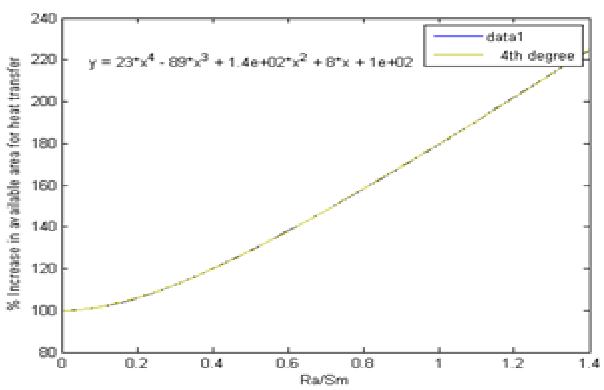


Fig. 6: *Ra/Sm vs Increase in area for heat transfer*

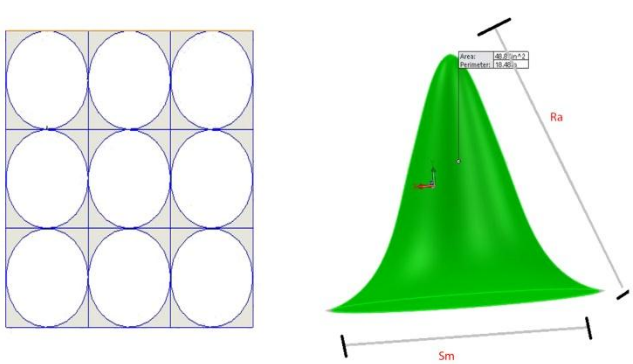


Fig. 7: *Placing of gaussian surface also refer fig. 2*

From methods of curve fitting[11] 4th degree polynomial that approximate increase in area of heat transfer as a function of $Ra/Sm = x$.

$$y(x) = 0.23x^4 - 0.89x^3 + 1.4x^2 + 0.08x + 1$$

and heat transfer in a plate of surface area A_s

$$H = hA_s\delta(T)y(x)$$

4 CONCLUSION

Section wise conclusions

1. Introduction
2. Fins with high P/A_c (Bell shape fin in this paper) ratio give high effectiveness for fin.
3. In multi-fin array, effective spacing is possible when thermodynamic boundary layer do not intersect.
4. Close spacing of normal distributed fin do not lead to intersection of thermodynamic boundary layer. Due to bulging in shape of thermodynamic boundary layer.
5. Methods of curve fitting are use to obtain optimum relationship between increase in heat transfer and surface roughness.

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