E-ISSN: 2321–9637
Volume 1, Issue 4, November 2013
International Journal of Research in Advent Technology
Available Online at: http://www.ijrat.org

PARAMETRIC ANALYSIS OF PLATE-FIN HEAT SINK OVER HEAT TRANSFER

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ABSTARCT:

The steady-state natural convection from heat sinks with parallel arrangement of rectangular cross section vertical plate fins has significant application in electronics component. Natural convection heat transfer has major dependence on geometric parameters and orientation of heat sink. Thus, parametric analysis of heat sink has got vital importance in heat transfer analysis. In this review, systematic study of effects of fin spacing, fin height, fin length, temperature difference between fin and surrounding and orientation of heat sink on free convection is done. Also, various set of correlations of dependent parameters are studied. Since, natural convection is buoyancy driven phenomenon, flow separation and velocity field over a fin-array is studied. Large impact of geometric parameters and orientations of heat sink over a flow pattern is found.

Keywords: *natural convection, heat sink, fin array, buoyancy*

1. INTRODUCTION

Heat is generated as a by-product in many engineering applications. This usually unwanted by-product can decrease the performance of the systems since almost every engineering system is designed to work in a certain temperature limit. If these limits are exceeded by overheating, this may even lead to total system failure.

It is possible to increase the heat transfer coefficient, *h* by forcing the fluid to flow over the fins by means of fans. But this option costs more and also requires more volume for the fans to operate. Therefore sometimes the designer has to rely on natural convection heat transfer for dissipating unwanted heat from the fins. The surface area of the fins can also be increased by adding more fins to the base material in order to increase the total heat transfer from the fins. But the number of the fins should be optimized because it should be noted that adding more fins also decreases the distance between the adjacent fins. This may cause resistance to air flow and boundary layer interference which in return decrease the heat transfer coefficient.

Thus, heat sinks with extended surfaces have been widely used in various engineering applications especially in electronics cooling. Due to ease of manufacturing, parallel arrangement of rectangular cross section plate fins on a flat base is the most common heat sink geometry. Heat sinks with this geometry have been used for both forced and natural convection. In the case of forced convection, the geometric parameters of a heat sink highly depend on the remaining components of the cooling system, such as the fan and the enclosure; therefore, the optimal values of these parameters depend on the considered application.

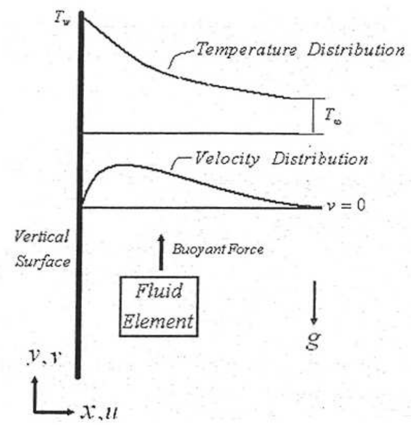

Fig. 1 Co-ordination system

2. LITERATURE REVIEW

One of the earliest studies about natural convection heat transfer from fin arrays was conducted by

Starner and McManus [1]. Four different fin array configurations with three base types were investigated and heat transfer coefficients were calculated. Flow patterns for each case were observed by using smoke filaments. It was concluded that fin height, fin spacing and base orientation have significant effect on rate of heat transfer from fin arrays.

Filino Harahap and Herry Lesmana [2] studied, entitled as 'Measurement of heat dissipation from miniaturized vertical rectangular fin arrays under dominant natural convection condition', a square-based fin arrays for different orientations. A correlation for vertically based fin arrays was reported showing fin length as a prime geometric parameter.

B. Yazicioglu, H. Yuncu [3] presented, entitled as 'Optimum Fin Spacing of Rectangular Fins on A Vertical Base in Free Convection Heat Transfer', optimum fin spacing which maximize heat transfer rate for each fin height and temperature difference. It was observed that larger the fin height higher the convective heat transfer rate. At low temperature difference, increase in the convective heat transfer is not very significant. Also, for given fin spacing, heat transfer rate increases with fin height and base to ambient temperature but it is steeper for smaller fin spacing. The optimum fin spacing was found between 10.4 and 11.9 mm while range was 4.5 to 85.5 mm. Though, fin spacing depends on all geometric parameters of fin array, it does not change the value more than 1.5 mm. Effect of geometric parameter and base to ambient temperature difference on heat transfer for vertically oriented base plate was determined. Furthermore a correlation was developed to estimate fin spacing for maximum value of convective heat transfer rates.

H.Yuncu, G.Anbar [4] entitled as 'An Experimental investigation on performance of rectangular fins on a horizontal base in free convection heat transfer' studied the separate role of fin height, fin spacing and base to ambient temperature difference over free convection. Horizontal base was taken for the experimentation. It was observed that enhancement of free convection heat transfer is strongly depend on the fin spacing to fin height ratio and no. of fins. There is optimum fin spacing for each fin height is estimated while optimum fin spacing

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decreases with increase in fin height. A correlation was formulated for convection heat transfer as function of fin spacing to fin height ratio and no. of fins.

Senol Baskaya, Mecit Sivrioglu, Murat Ozek [5] entitled as 'Parametric Study of Natural Convection Heat Transfer from Horizontal Rectangular Fin Array' studied interaction among all the design parameters and their dependence over the convection heat transfer for horizontal fin array. They found optimum fin spacing 6 mm and 7 mm for the fin lengths 127 mm and 254 mm respectively. This study concludes that overall heat transfer enhance with increase in fin height and decrease with length, hence increase with fin height to fin length ratio.

L. Dialameh, M. Yaghoubi and O. Abouali [6] studied, entitled as 'Natural Convection from an Array of Horizontal Rectangular Thick Fins with Short Length', flow pattern in the channel of fin array. Experiments were carried for 128 fin geometries with thick fins of 3 mm < t <7 mm and short lengths (L<=50mm) over a horizontal base plate. Natural convection heat transfer has been simulated for thick fins at low temperature differences. A set of correlation was developed for Nu as a function of Rayleigh number (Ra), fin height to length ratio, fin spacing and height ratio, fin height to thickness ratio.

M. Mobedi, H. Yuncu [7] studied, entitled as 'Three Dimensional Study on Natural Convection Heat Transfer from Short Horizontal Rectangular Fin Array', flow configuration for short fins with different geometries and numerical results were obtained. It was found that (H/L) ratio has great significance over flow pattern. The study was limited to Rayleigh number based on fin spacing, ranging from 120 to 39000.

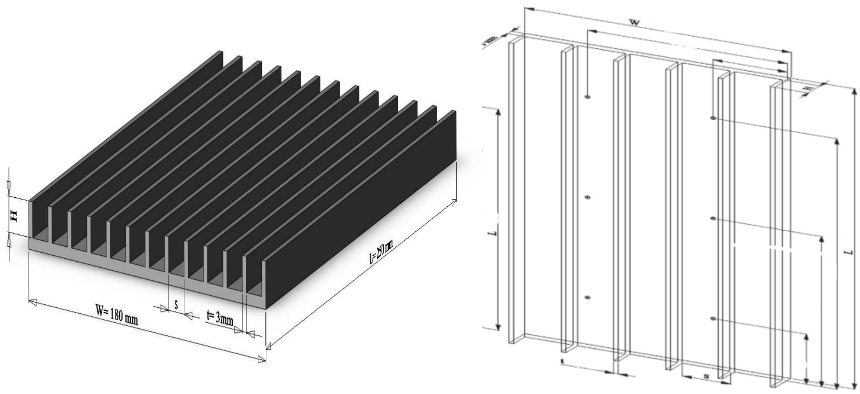
Ilker Tari and Mehdi Mehrtash [8] studied, entitled as Natural convection heat transfer from inclined plate-fin heat sinks, steady-state natural convection from heat sinks with parallel arrangement of rectangular cross section vertical plate fins on a vertical base are numerically investigated in order to obtain a validated model that is used for investigating inclined orientations of a heat sink. For the inclination angles from the vertical, the extent of validity of the obtained vertical case correlation is investigated by modifying the *Grashof* number with the cosine of the inclination angle. It is also observed that the flow separation inside the fin channels of the heat sink is an important phenomenon. For upward facing inclinations, they observed that the flow separation location plays an important role. Also, they found that the optimum fin spacing does not significantly change with inclinations suggesting the value as 11.75 mm.

Table 1: Ranges of parameters in the literatures

Reference No.	**Fin Length**	**Base width**	**Fin Height**	**Fin Thickness**	**Fin Spacing**	**Optimum Fin spacing**	**Angle from vertical**
1	127	254	6.35-25.4	1.02	6.35-7.95	-	0,-45,-90
2	25,33,49	25,33, 49	13.5	1	3 and 11	-	0
3,14	250,340	180	5,15,25	3	5.85,8.8,14.7 ,32.4,85.5	11.2	0

4	100	250	6,16,26	3	6.2,9.4,19,35,8383	19.5,11.6,10.4	-90
5	127,254	-	6.3,13,25,38	-	6.3,8	6,7	-90
6	50,25,12,7	-	7,12	3,7	4,7,10,12	7	-90
7	100	-	5,15,35	-	5,20	-	-90
8	250,340	180	5-25	3	5-85.5	11.75	0,4,10,20,30,45,60,75,80,85,90

3. EXPERIMENTAL SETUP



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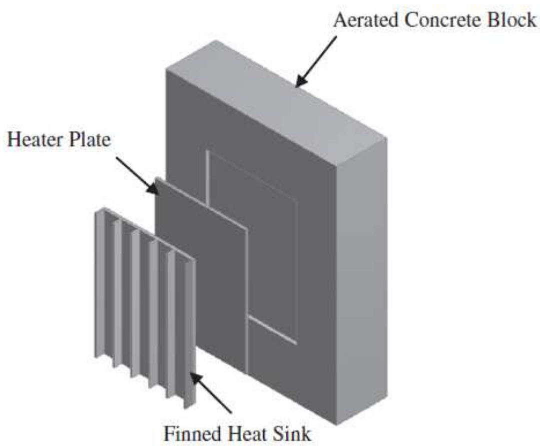

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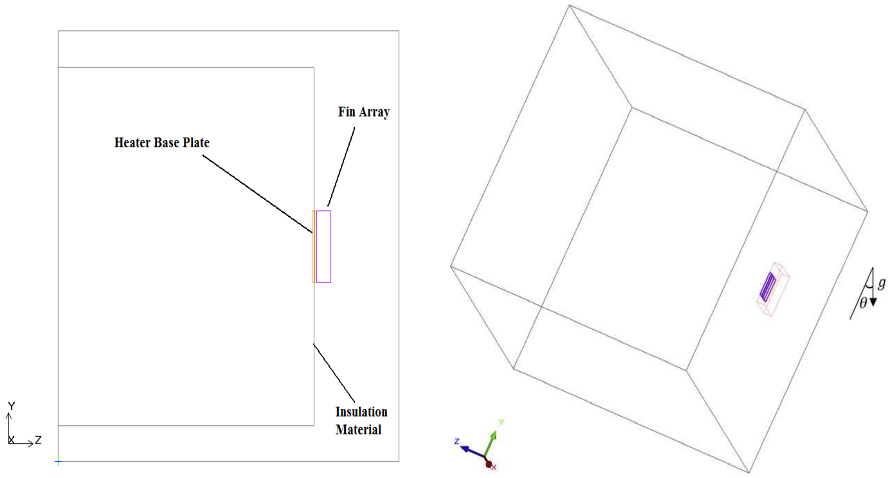

(c)

Fig. 2 Horizontal and vertical base plate (a), Experimental setup with aerated concrete support and heater plate (b), channel with inclination θ (c)

The model assembly is schematically depicted in Fig. 2. It includes an aerated concrete insulation, a heater plate, and a heat sink attached to the heater. The assembly in Fig.2 is placed in an air filled cubical room of 3m sides with walls that are maintained at uniform 20̊ C. The six locations marked on each heat sink base are the locations of the thermocouples in the experiments. In the analysis (with ANSYS Fluent), steady-state

solutions are obtained by using the zero equation- turbulence model with initial ambient air temperature of 20̊ C. Air is taken as an ideal gas at atmospheric pressure. No slip boundary condition is used for all surfaces. There is no contact resistance between solid surfaces.

4. RESULT AND DISCUSSION

4.1 Effect of temperature difference on heat transfer rate

The effect of base to ambient temperature difference on convective heat transfer which is plotted as a function of fin spacing by B. Yazicioglu, H. Yuncu [2]. It found that for given fin spacing, heat transfer from the heat sink varies with ambient-to-base temperature difference.

Experimental results reported by M. Mobedi, H. Yuncu [7] that heat transfer coefficient increases with increase of fin spacing and base temperature difference. The rate of increase of heat transfer coefficient for lower values of spacing (S<=10 mm) are higher than those for higher values of fin spacing, as shown in Fig.3.

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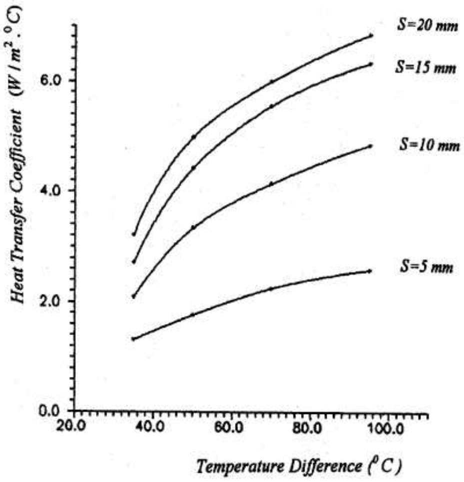

Fig. 3 Effect of temperature difference over heat transfer coefficient for different Fin spacing

4.2 Effect of fin spacing on heat transfer rate

H.Yuncu, G.Anbar [4] found that the heat transfer rate from a fin-array is strongly dependent on the fin height, fin spacing and temperature difference between fin base and surroundings. The heat transfer rate increases monotonously with the temperature difference (T_w-T_a) but for fin-arrays with small fin height, the rate of increase of heat transfer rate with temperature difference is smaller than those ones with large fin height.

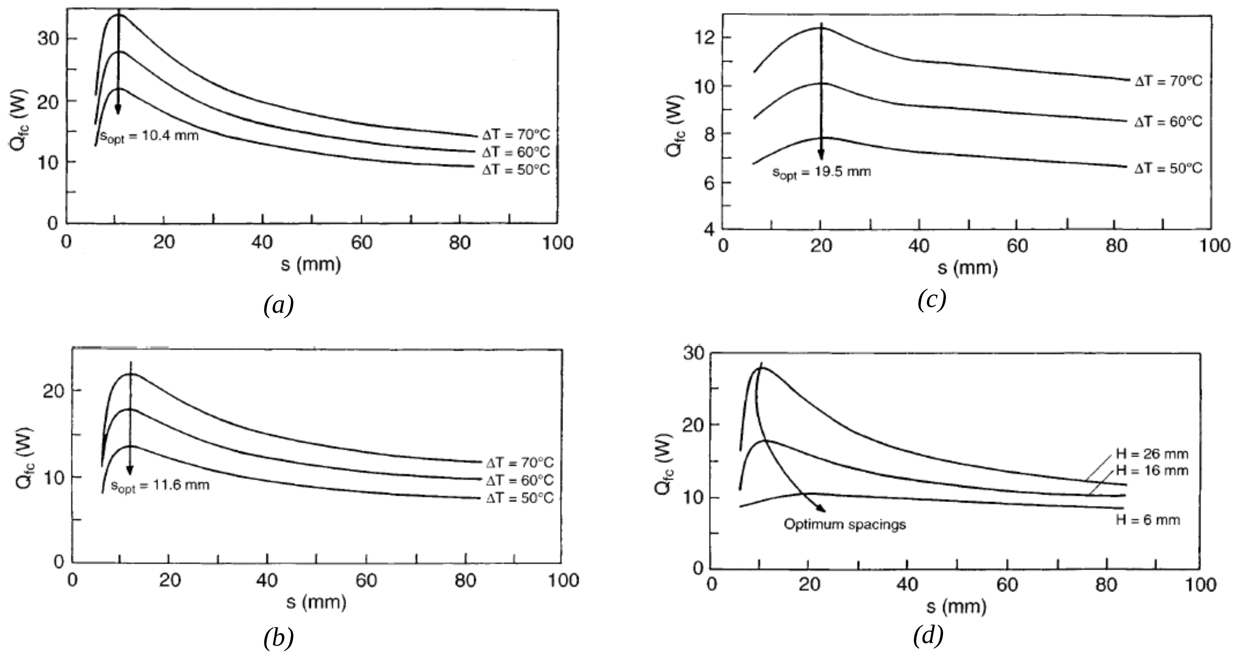

Fig. 4 Effect of fin spacing over heat transfer at different fin height and temp. difference

[H=26 mm (a), H=16mm (b), H=6mm (c), temp. difference=60˚(d)]

With increasing fin length, change of the flow characteristic from a single chimney type to a multiple chimney flow pattern is occurred. Fig.5 shows effect over heat transfer rate due to fin spacing and H/L ratio are very small in lower range of H/L values, where small change was observed with increasing fin spacing. However for large values of H/L, a change with fin spacing was more effective as reported by Senol Baskaya, et al. [5].

The change of heat transfer per unit base area (Q/A_b), with fin spacing for different ratios of fin height to fin length (H/L) and for t = 3 mm and θ = 60̊ is shown in Fig.6. For H/L>0.24, heat transfer per unit base area decreases with increasing fin spacing. However, optimum fin spacing found S_{opt}=7 for H/L<=0.24 as stated by L. Dialameh, et al. [6].

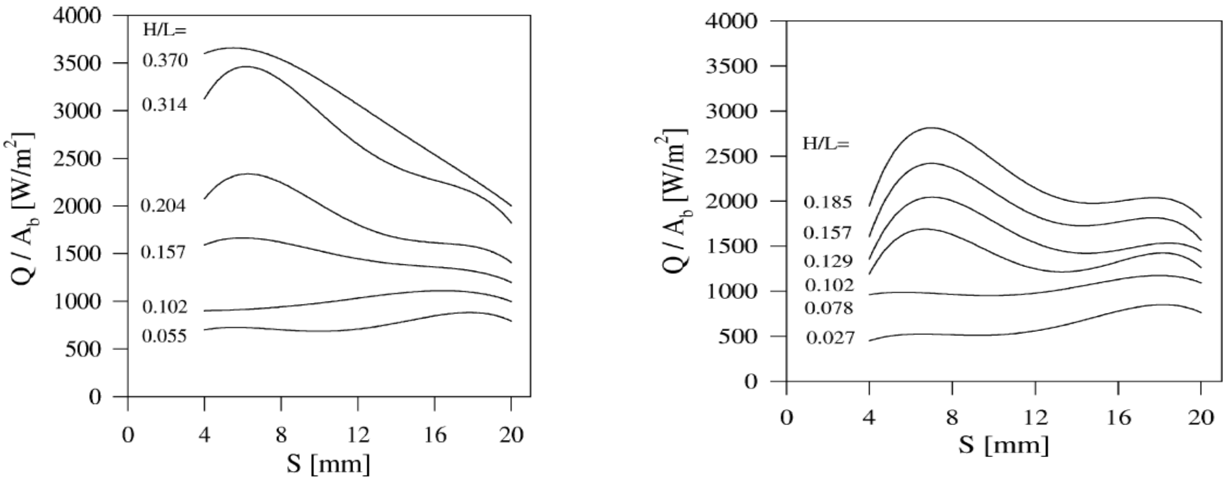

Fig.5 Effect of fin spacing on heat transfer per unit surface area for different H/L [L=127mm and L=254mm]

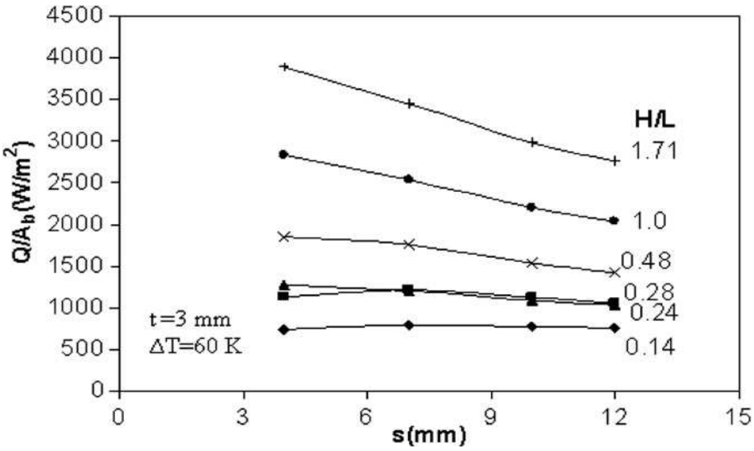

Fig. 6 Effect of fin spacing over heat transfer per unit surface area for different H/L.

4.3 Effect of fin height on heat transfer rate

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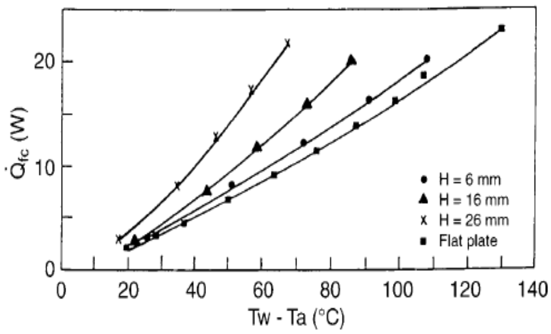
Heat transfer monotonously increases with increase in temperature difference ($Tw-T_a$), as shown in Fig.8. However, fin arrays with small fin height; rate of increase of heat transfer with temperature difference is smaller than those ones with large fin height.

The heat transfer coefficient values increases with increase in the fin height, as shown in Fig.9. It is reported by Senol Baskaya, et al. [5], although a small drop in heat transfer coefficient is observed for small fin spacing, its value increases with increase in fin spacing.



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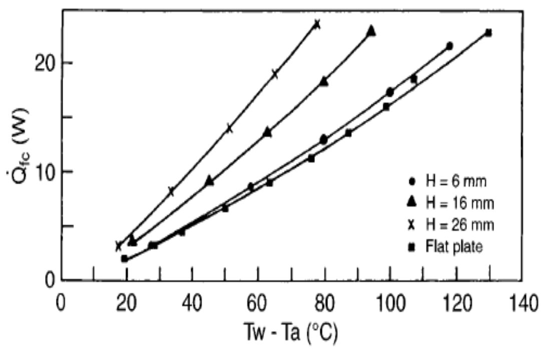

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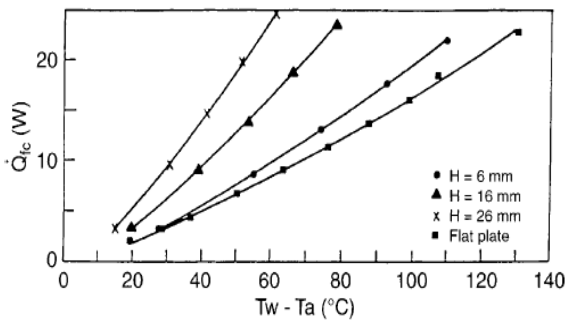

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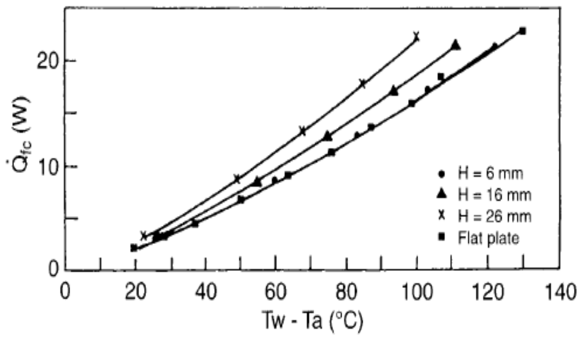

(d)

Fig.8 Effect of fin height on heat transfer at different fin spacing [S=6.2 mm (a), S=9.4 mm (b), S=35mm (c), S=83mm (d)]

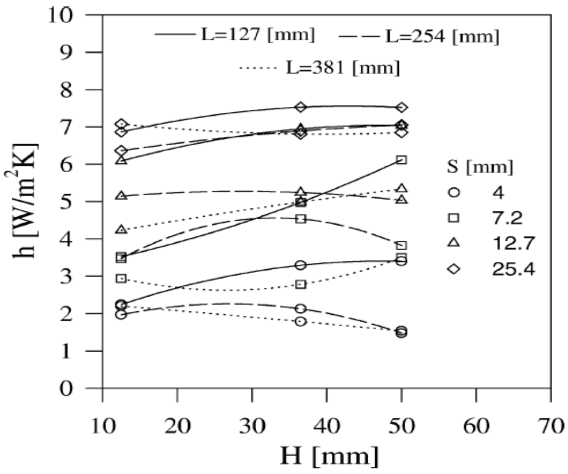

Fig. 9 Effect of fin height over heat transfer coefficient for different fin length and fin spacing

When the fin height is increased while keeping all the other parameters constant, the convective heat transfer rate increases due to the increased extended surface area, as shown in Fig.10. As the fin height increases, it is observed that distinguishably more air enters from the open side of the heat sink throughout its length, as reported by Ilker Tari [8]. The velocity vector is presented in Fig. 11 for H=5, 15,25mm.

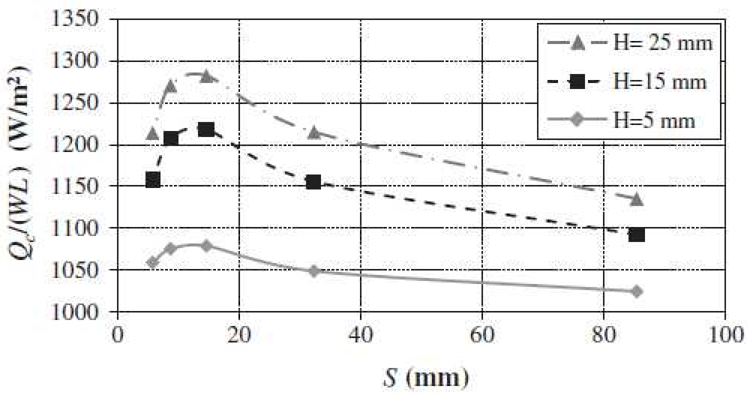

Fig.10 Effect of fin height on heat transfer for different fin spacing

5. CONCLUSION

- For given fin spacing, heat transfer rate increases with fin height and base-to-ambient temperature difference. However, optimum fin spacing decreases with increase with fin height.
- Natural convection heat transfer decreases with increase in fin length whereas it is insensitive regarding fin thickness and fin height.
- Fin height should be large enough to avoid flow instabilities.
- The highest convection heat transfer values are achieved at the vertical orientation.

- Although, the optimum fin spacing for all inclinations varies between 9 mm for the downward facing horizontal to 13 mm for the upward horizontal, its value does not significantly change with inclination in -60̊ <= θ <= +80̊.
- The value of optimum fin spacing does not vary more than an amount of 0.1mm i.e. it is insensitive to variation in fin height for given fin length.
- As inclination increases, flow velocities at the exit (top end) of the heat sink reduce. For the upward case the separation location starts to move from the tip towards the center after -60̊ of inclination. At -90̊, the flow is symmetric around the center of the heat sink, placing the separation location to the center.

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