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Effect of Low Aspect Ratio on Convective Heat Transfer from Rectangular Fin Array in Natural Convection

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Abstract

Experimental and CFD analysis is conducted in order to establish effect of geometrical fin parameters for natural convection heat transfer from vertical rectangular fin arrays.Natural convective heat transfer from rectangular vertical plates has been reviewed. Study revealed that most of the work was carried out considering various configurations. Experimental work carried on steady state natural convection heat transfer from vertical rectangular fins made of aluminum. Experimental work carried investigates the effect of fin spacing, fin height, fin length on the performance of heat dissipation from the fin arrays. It is found that convection heat transfer rate depends on fin height and fin length. For a given fin spacing, the convection heat transfer rate from fins increases with fin height. For a given fin spacing, the convection heat transfer rate from fins increases with fin length .This trend is observed for every fin configuration. It is found that convection heat transfer rate is more for less aspect ratio fin array for same power input.

Keywords: Rectangular fins, heat sink, natural convection, aspect ratio.

Introduction:

The operation of many engineering systems results in the generation of heat. This unwanted by-product can cause serious overheating problems and sometimes leads to failure of the system. This is especially important in modern electronic systems. In order to overcome this problem, thermal systems with effective heat dissipater as fins are desirable.

Fins are generally used to increase the heat transfer rate from the surface. Generally there are two types of materials used for fins aluminum and copper. Different types of fins ware used to increase the heat transfer rate. The fin shapes used was rectangular, V-shapes, triangular, trapezoidal and circular. Rectangular fins are the most popular fin type because of their low production costs and high thermal effectiveness.

In 1970, Kamal-Eldin Hassan And Salah A. Mohamed ,[1] measured Local heat-transfer coefficients along a flat plate in natural convection in air using Boelter-Schmidt type heat flux meters. They carried out experiments for different temperature differences in heating and cooling, and with inclinations varying from the horizontal "facing upwards" position, through the vertical position, to the horizontal "facing downwards" position. E. M. Sparrow And L. F. A. Azevedo [2], did an experimental and computational study of the heat transfer characteristics of natural convection in an open-ended vertical channel, bounded by an isothermally heated wall and by an unheated wall.The experiments were performed with water (Pr ≈ 5) as the medium, for the aforementioned parametric variation in spacing and for an order of magnitude range of wall to ambient temperature difference. The numerical analysis was made taking into account both natural convection and wall conduction, and a highly accurate correlation for Nusselt number was presented by the authors.Rong-hua Yeh, Shih-Pin Liaw and Ming Chang [3], theoretically find out optimum spacings of longitudinal fin arrays in force convection. They took four different fins array such as rectangular, convex-parabolic, triangular and concave-parabolic. They investigated aspect ratio, inter fin spacings, and heat transfer characteristics of optimizes fin arrays with given geometry of base plate, total fin volume and transverse biot number.They concluded that the optimum aspect ratio as well as spacing is the largest for rectangular fin and smallest for concave-parabolic profile fin. The maximum total heat duty is largest for concave-parabolic fin array and is smallest for rectangular fin array. It was also found that for heat transfer point of view larger number of fins of smaller fin should be preferred than larger ones at a given total fin volume. Witold M. Lewandowski ,

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Ewa Radziemska [4] presented A theoretical solution of natural convective heat transfer from isothermal round plates mounted vertically in unlimited space. Correlation was developed between the dimensionless Nusselt and Rayleigh numbers. They concluded that the coefficient for natural convection heat transfer from vertically- mounted circular plates is approximately 6% greater than that from vertical rectangular or square plates having heights equal to the diameter of the circular plate.J.J.Wei, B.Yu, H.S. Wang, W.Q. Tao [5], conducted a numerical study to investigate the natural convection heat transfer around a uniformly heated thin plate with arbitrary inclination. Plate width and heating rate were used to vary the modified Rayleigh number over the range of 4.8×10^6 to 1.87×10^8.They found that for inclination angle less than 10^0, the flow and heat transfer characteristics are complicated and the average Nusselt number cannot be correlated by one equation while for inclination angle greater than 10^0, the average Nusselt number can be correlated ..A. Giri 1, G.S.V.L. Narasimham, M.V. Krishna Murthy[6] developed a mathematical formulation of natural convection heat and mass transfer over a shrouded vertical fin array . A numerical study was performed by varying the parameters of the problem. Their results show that beyond a certain stream wise distance, further fin length does not improve the sensible and latent heat transfer performance, and that if dry fin analysis is used under moisture condensation conditions, the overall heat transfer will be underestimated by about 50% even at low buoyancy ratios.A.S. Krishnan, B. Premachandran, C. Balaji, S.P. Venkateshan,[7] did an experimental and semi-experimental investigation of steady laminar natural convection and surface radiation between three parallel vertical plates, viz., a central hot plate coated with blackboard paint and two unheated side plates that are polished, symmetrically spaced on each side, with air as the intervening medium. Their analysis brings out the significance of radiation heat transfer rate even at low temperatures of 310 K. They concluded that the radiation contribution even for spacing as large as 52.2 mm is less than that for an isolated plate by around 20% .Xiaoling Yu , Jianmei Feng, Quanke Feng, Qiuwang Wang[8], constructed a new type of plate-pin fin heat sink (PPFHS) Based on plate fin heat sinks (PFHSs), which is composed of a PFHS and some columnar pins staggered between plate fins. Numerical simulations and some experiments were performed to compare thermal performances of these two types of heat sinks. Their simulation results showed that thermal resistance of a PPFHS was about 30% lower than that of a PFHS used to construct the PPFHS under the condition of equal wind velocity. S.A. Nada [9] experimentally investigated the natural convection heat transfer and fluid flow characteristics in horizontal and vertical narrow enclosures with heated rectangular finned base plate at a wide range of Rayleigh number (Ra) for different fin spacings and fin lengths. A quantitative comparison of finned surface effectiveness (e) and heat transfer rate between horizontal and vertical enclosures was also done. He gives optimization of fin-array geometry. His results gave an optimum fin spacing at which Nusselt number (NuH) and finned surface effectiveness (e) were maximum. Burak yazicioğlu and Hafit Yüncü [10] developed a new expression for prediction of the optimal fin spacing for vertical rectangular fins protruding from a vertical rectangular base. From their analysis they revealed that convection heat transfer rate from fin arrays is dependent on fin height, fin length and base-to ambient temperature difference. Essentially, fin heat transfer rate increases with fin height, fin length and base-to -ambient temperature difference. At low temperature differences, heat transfer rates are closer to each other and tend to diverge at higher temperature differences. For all fin arrays, the convection heat transfer rate is higher than that of the vertical flat plate. As fin spacing is increased, fin heat transfer rates approach each other and the vertical flat plate, and fin height does not play a significant role. Hung-Yi Li , Shung-Ming Chao[11], considered the effects of the Reynolds number of the cooling air, the fin height and the fin width on the thermal resistance and the pressure drop of heat sinks. They found that increasing the Reynolds number can reduce the thermal resistance of the heat sink.

B. Kundu, P.K. Das[12] developed a model analytically to carry out the performance and optimum design analysis of four fin arrays, namely, longitudinal rectangular fin array (LRFA), annular rectangular fin array (ARFA), longitudinal trapezoidal fin array (LTRA) and annular trapezoidal fin array (ATFA) under convective cooling conditions. They evaluated the performance parameters such as fin efficiency, fin effectiveness and augmentation factor for a wide range of design variables.The optimum fin dimensions in a fin assembly have been determined by consideration of the constant total height of the fin assembly and inter fin spacing. From the results, it can be highlighted that the optimum fin dimensions in fin arrays differ from that of the individual fins.Tae Hoon Kim , Kyu Hyung Do , Dong-Kwon Kim [13] performed both experimental and numerical studies and suggested a

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closed form correlations that allow for thermal optimization of vertical plate-fin heat sinks under natural convection in a fully-developed-flow regime. They gave a simple way to predict the optimal dimensions of plate-fin heat sinks.. From the analytical solutions author proposed explicit correlations for optimal fin thickness and optimal channel width, which minimize thermal resistance for given height, width, and length of heat sink. The correlations showed that the optimal fin thickness depends on the height, the solid conductivity, and the fluid conductivity only and is independent of the Rayleigh number, the viscosity of the fluid, and the length of the heat sinkShwin-Chung Wong, Guei-Jang Huang [14] did A parametric study on the dynamic natural convection from long horizontal fin arrays (L = 128, 254 and 380 mm) using a 3-D unsteady numerical analysis. The investigated range of height H was 6.4– 38 mm and that of spacing S is 6.4–20 mm. The time-averaged overall convection heat transfer coefficients h found larger for high and short fin arrays, due to the stronger buoyancy and thinner boundary layers.

Experimental setup

Main components of Set up are channel, concrete block, base plate, fin array, plate heater, and power mains. The dimensions of the setup are given in Table 4.2. The dimensions of the aerated concrete block is 250×200×100 mm which act as insulator in one direction.. Moreover an aluminum base plate is modeled as the heat generation source of the system. The dimensions of this heater base plate are taken as 180×200×5 mm for the first set-up with 200 mm heat sink length and 180x200x5 mm for the second set-up with 100 mm heat sink length. In both set-ups this heater base plate is kept on concrete block. A thin copper plate is inserted in between base plate and fin array in order to avoid a thermal contact resistance, all the fin configurations are then mounted directly onto these heater base plates. The dimensions of the channel (surrounding air) are taken as 550×550×550 mm for set-ups.

Figure: Experimental Setup

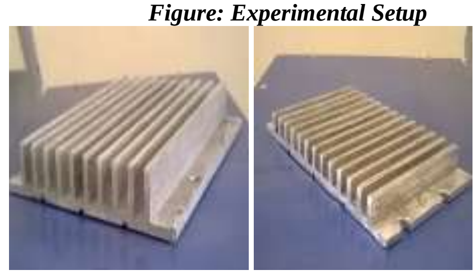


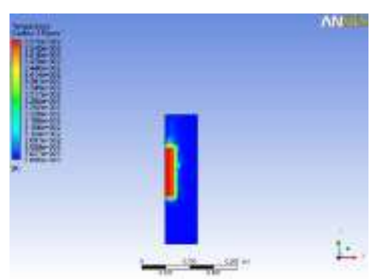
Figure: Fin Array

Fins are made up of Aluminum because of its high thermal conductivity. We used different heights of fin for different length of block. We have analyze 6 number of arrays of which 3 arrays are of 100 mm length and remaining 200 mm length with keeping aspect ratio 0.1,0.2 and 0.3. No of fins were 10 and 13 respectively for 100 mm and 200 mm length fin array.

Result and discussion

1 Variation of Temperature contour with Fin Height

From the figures 3.1 it can be observed that the fin configuration with the highest fin height mm dissipates more heat energy to the air.



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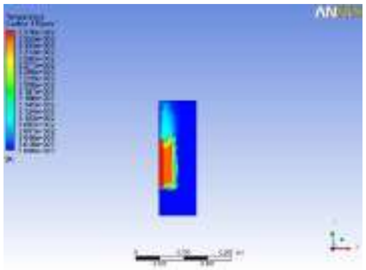

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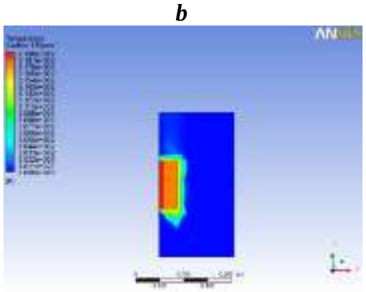

Figure 3.1Temperature contours for Fin height 10,20 30mm

2 Variation of Temperature contour with Fin Length

From the figures 3.2 it can be observed that the fin configuration with the fin length that L=200 mm dissipates more heat energy to the air. This shows heat transfer rate more for less aspect ratio fin array for same power input. Heat transfer from the fins to the air is directly proportional to the surface area of the fins

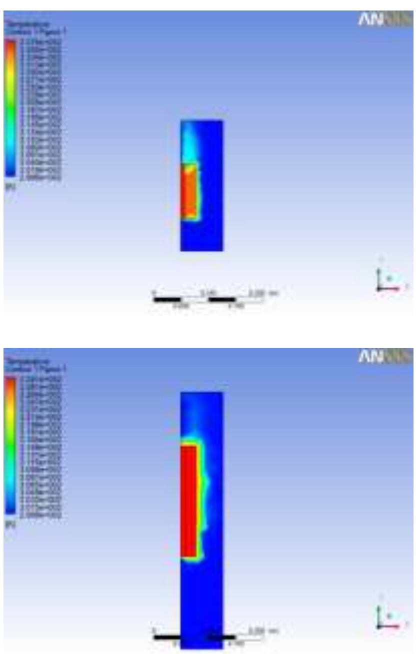

Figure 3.2Temperature contours for Fin height 20 mm and fin length 100mm, 200 mm

3 Variation of Flow velocities with Fin height

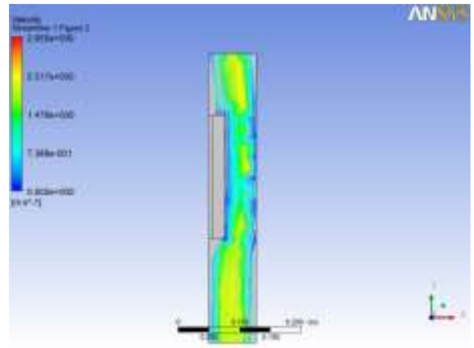

Figure3.3. Streamline for fin array with Fin length L=200 mm and Fin height H=20 mm, velocity 2 m/s

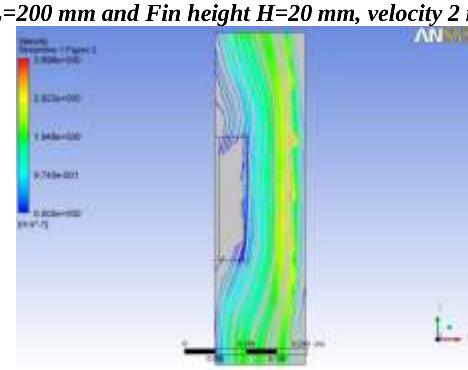

Figure. 3.4Streamline for fin array with Fin length L=200 mm and Fin height H=40 mm, velocity 2 m/s

4. Variation of Nusselt Number with different power input for array:

Figure 3.5-3.6 shows that experimental Nusselt number with that of calculated from various existing equations.

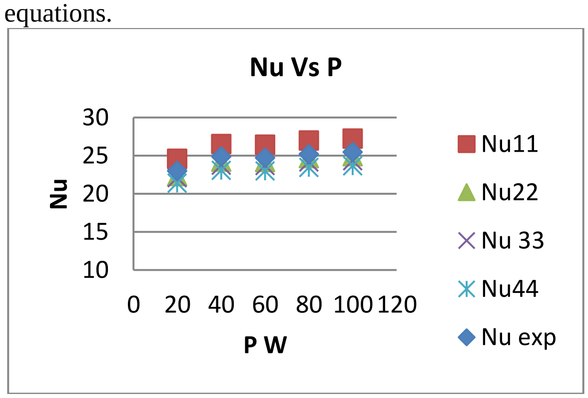

Figure 3.5 Variation of Nusselt Number with different power input for array 10010

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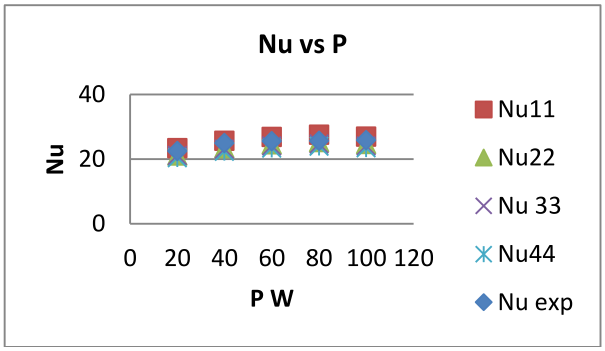

Figure 3.6 Variation of Nusselt Number with different power input for array 10020

From figure it can be seen that as the power input increases the Nuseelt number increases. Values of Nuseelt number ffrom experiment are close to that of from the existing equation

5 Variation of convective heat transfer with different power input for different fin array:

Figure 3.7-3.8 shows that as the power input increases h increases for all array. The convective heat transfer coefficient is more for a smaller fin array i.e. smaller height fin array with constant length for given power input. This is because h not only depends on area but temperature difference between fin and surrounding air.

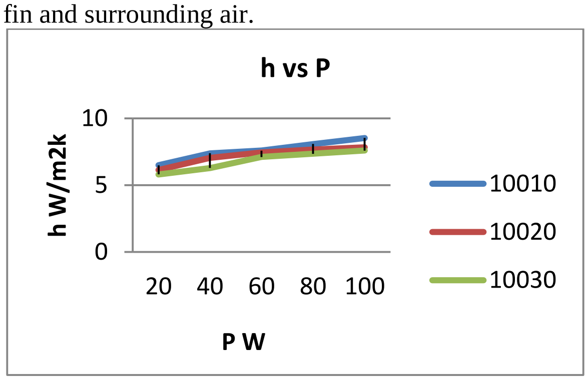

Figure 3.7 Variation of convective heat transfer with different power input for different fin array of 100 mm length

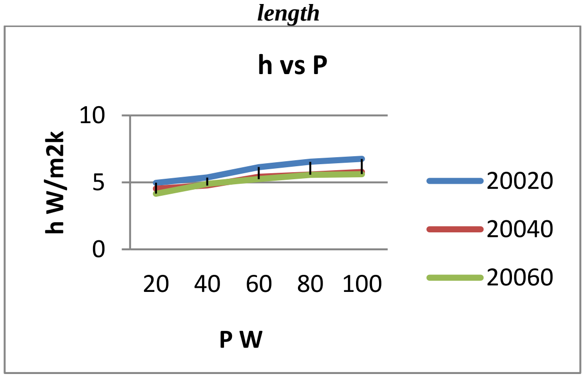

Figure 3.8 Variation of convective heat transfer with different power input for different fin array of 200 mm length

6. Variation of convective heat transfer with different power input for fin array with aspect ratio:

Figure 3.9-3.11 shows variation of convective heat transfer with different power input for fin array with aspect ratio. Aspect ratio is ratio of height of fin to its length. Figure shows for a same aspect ratio (AR) heat transfer coefficient is more for smaller dimension fin array.

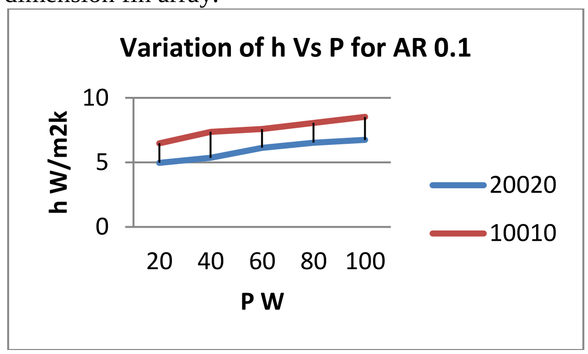

Figure 3.9 Variation of convective heat transfer with different power input for fin array with aspect ratio 0.1

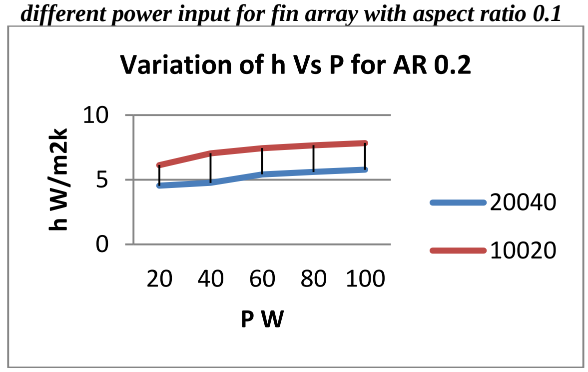

Figure 3.10 Variation of convective heat transfer with different power input for fin array with aspect ratio 0.2

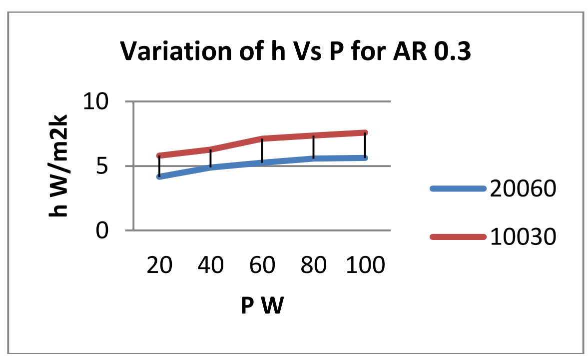

Figure 3.11 Variation of convective heat transfer with different power input for fin array with aspect ratio 0.3

7. Variation of convection heat transfer rate with fin height for different fin length

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The convection heat transfer rate from the fin arrays are plotted as a function of fin height for different power inputs. From the figure 3.12-3.13 it can be observed that for every power input and fin length combination, the convection heat transfer rate from the fin array increases with the increase in the fin height. With an increase in fin height, the total heat dissipation area also increases. Since the convection heat transfer rate directly related to the surface area in contact with air, increasing fin height increases the total heat dissipation.

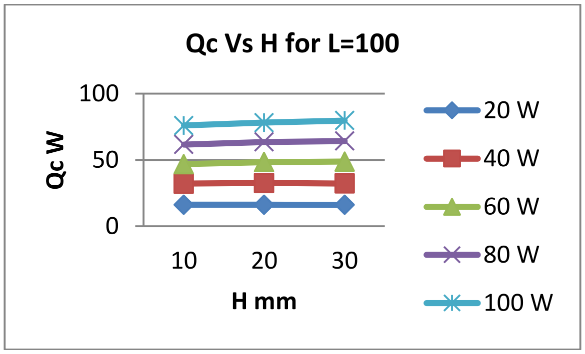

Figure 3.12 Variation of convection heat transfer rate with fin height for fin length L=100 mm

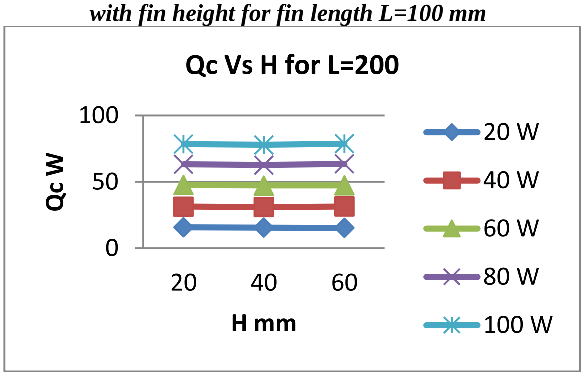

Figure 3.13Variation of convection heat transfer rate with fin height for fin length L=200 mm

Conclusion

Experimental and CFD analysis is conducted in order to establish effect of geometrical fin parameters for natural convection heat transfer from vertical rectangular fin arrays .Steady state natural convection heat transfer from vertical fin arrays is experimentally presented. Also, CFD analysis is done in ANSYS Fluid Flow FLUENT 14.0 software. . It is found that convection heat transfer rate depends on fin height and fin length. For a given fin spacing, the convection heat transfer rate from fins increases with fin height. For a given fin spacing, the convection heat transfer rate from fins increases with fin length .This trend is observed for every fin configuration. In order to find combine effect of fin height and fin length a dimensionless parameter called aspect ratio which is ratio of fin height to length is used.

It is found that convection heat transfer rate is more for less aspect ratio fin array for same power input. This is because heat transfer rate not only depend on surface area but also on temperature difference. Again for a same aspect ratio it is found that fin array with smaller dimension fin array has more heat transfer rate than larger one.

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