REVIEW OF NATURAL CONVECTIVE HEAT TRANSFER FROM RECTANGULAR VERTICAL PLATE FINS

[1] V.S.Daund, [2]A.A.Walunj, [3]D.D.Palande

[1]PG STUDENT,Heat Power, MCERC, Nasik (India)
[2,3]Asst. Prof., Mech. Dept., MCERC,Nasik (India)

ABSTRACT

In many engineering applications heat transfer rate is important factor. From many years efforts have been taken to develop heat transfer enhancement techniques for improving performance of equipments. Enhancement of heat transfer takes place by active method and passive method. Among passive method Fins are widely use to enhance heat transfer rate. Fins are use in a wide variety of engineering applications of passive cooling of electronic equipment such as compact power supplies, portable computers and telecommunications enclosures. In this paper, convection heat transfer through rectangular fins is reviewed. Many researchers studied convective heat transfer through rectangular fins and fin arrays. Various experimental studies have been made to investigate effect of fin height, fin spacing, fin length and fin thickness over convective heat transfer. Experimental and numerical studies are done in natural, mixed and forced convection. Some investigators found sets of correlations to give relation between various parameters of heat sink.

Keywords: Heat sink, Natural convection ,Rectangular fins, Vertical orientation

I. INTRODUCTION

Many engineering devices generate heat during their operation. If this generated heat is not dissipated rapidly to its surrounding atmosphere, this may cause rise in temperature of the system components. This cause overheating problems in device and may lead to the failure of component. Passive techniques generally use surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. They promote higher heat transfer coefficients by disturbing or altering the existing flow behavior (except for extended surfaces) which also leads to increase in the pressure drop. In case of extended surfaces, effective heat transfer area on the side of the extended surface is increased. Passive techniques hold the advantage over the active techniques as they do not require any direct input of external power.

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.

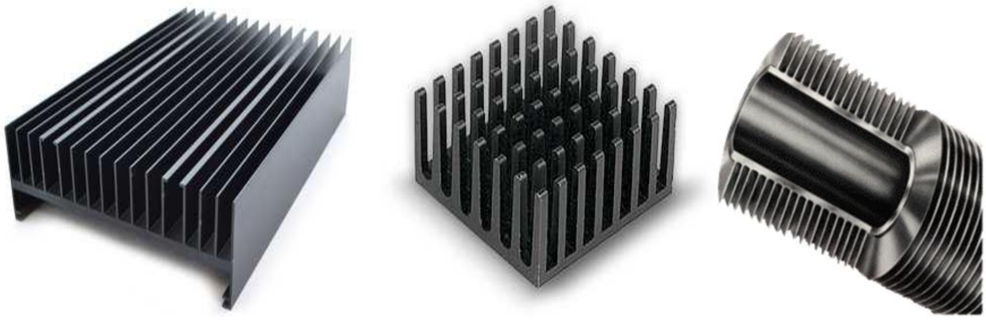

Figure No.1: Different fin types, a) Rectangular b) Pin fins c) Radial.

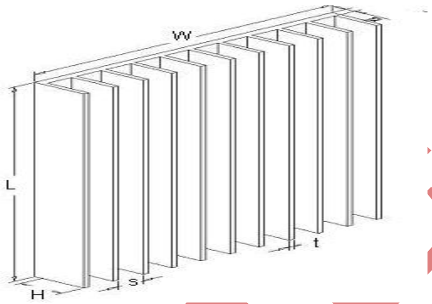

Figure No.1.7.1: Rectangular fin array geometry

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. Some researcher used notched fins. The heat transfer rate through notched fins was more than without notched fins.

II. LITERATURE SURVEY

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. Results showed that along the surface, and well before the boundary layer turns to turbulence, separation of flow takes place along the trailing part at positive angles of inclination. In other localities, and at small inclinations, the results agree closely with those predicted by modem analyses of laminar boundary-layer flow.

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. Experiments were carried out with a 50-fold variation of the inter plate spacing along with an order of magnitude variation of the wall-to ambient temperature difference. They found the influence of S/H on the heat transfer characteristics of vertical channels. For a given Rayleigh number, there is a range of low S/H where the Nusselt number is highly sensitive to variations of the inter plate spacing. They also identified the regimes of high and low sensitivity of the heat transfer to inter plate spacing.

Sparrow and Azevedo conducted experimental and numerical studies on natural convection in an open ended channel bounded by an isothermal wall. A 50 fold variation in spacing between the isothermal wall and the unheated wall was investigated, encompassing the full range of operating conditions of the channel, i.e., the limit of fully developed channel flow to the limit of the single vertical plate. The experiments were performed with water ($Pr \approx 5$) 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 was the largest for rectangular fin and smallest for concave-parabolic profile fin. The maximum total heat duty was 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 , Ewa Radziemska [4] presented A theoretical solution of natural convective heat transfer from isothermal round plates mounted vertically in unlimited space. With simplifying assumptions typical for natural heat transfer process, equations for the velocity profile in the boundary layer and the average velocity were obtained. Using this velocity, the energy flow within the boundary layer was balanced and compared with the energy transferred from the surface of the vertical plate according to the Newton's law. Correlation was developed between the dimensionless Nusselt and Rayleigh numbers.

$Nu = 0{:}587 * Ra^{1/4}$ for water $\qquad$ $Nu = 0{:}655 * Ra^{1/4}$ for air

They concluded that the coefficient for natural convection heat transfer from vertically- mounted circular plates was 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, 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, the average Nusselt number can be correlated. They also found that for inclination angle less than 20, the local natural convection heat transfer was very different for the upper and lower heated surfaces.

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 .The base plate was maintained at a temperature below the dew point of the surrounding moist air. 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. The 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% and an isothermal approximation for the heated plate is valid, even when the variation in plate temperature as high as ±5 0C.

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. Another obvious advantage of PPFHSs is that users can change an existing unsuitable PFHS into a required PPFHS by themselves to achieve better air-cooling results.

C.J. Kobus ,T. Oshio [9] carried out a comprehensive theoretical and experimental study on the thermal performance of a pin-fin heat sink. A theoretical model Author formulated a theoretical model that has the capability of predicting the influence of various geometrical, thermal, and flow parameters on the effective thermal resistance of the heat sink. They concluded that the thermal performance of the finned heat sink is improved when fin length is increased. For a given fin spacing, fin performance, is only a weak function of fin diameter, d.

Moghtada Mobedi, Bengt Sunden[10] performed a steady state conjugate conduction–convection investigation on vertical plate fin in which a small heat source was located. Heat from the fin surface is transferred to the surroundings by laminar natural convection. The best location of the heat source in the fin for maximum heat transfer rate depends on two parameters which are the conduction–convection parameter and the Prandtl number. The numerical results obtained showed that for fins with large conduction–convection parameter ξ=0.54 (ξ was dimensionless heat source location) is approximately the best location for the heat source because it provides maximum heat transfer from the fin.

S.A. Nada [11] 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.

Burak yazicioğlu and Hafit Yüncü [12] developed a new expression for prediction of the optimal fin spacing for vertical rectangular fins protruding from a vertical rectangular base. Data collated from literature covered the range of fin spacing from 2.85 mm to 85.5 mm. The range of base-to-ambient temperature difference was quite extensive, from 14 ºC to 162 ºC. The fin length range was from 100 mm to 500 mm, the fin height from 5 mm to 90 mm, the fin thickness from 1 mm to 19 mm, the width of rectangular base plate from 180 mm to 250 mm. 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. The effect of fin height can be seen more clearly on fins with smaller fin spacings.

Hung-Yi Li *, Shung-Ming Chao[13], 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. Enhancement of heat transfer by the heat sink is limited when the Reynolds number reaches a particular value. For a given fin width, the thermal performance of the heat sink with the highest fins exceeds that of the others, because the former has the largest heat transfer area. For a given fin height, the optimal fin width in terms of thermal performance increases with Reynolds number.

B. Kundu, P.K. Das[14] 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. They observed that the conduction through the supporting structure and the convection from the inter fin spacing have a pronounced effect on the performance of a fin array. From the results showed that the optimum fin dimensions in fin arrays differ from that of the individual fins.

Hussam Jouhara , Brian P. Axcell [15] did a comprehensive description of the thermal conditions within a heat sink with rectangular fins under conditions of cooling by laminar forced convection. Their calculations show how key heat transfer parameters vary with axial distance, in particular the rapid changes in heat transfer coefficient and fin efficiency near the leading edges of the cooling fins. They analyzed heat transfer conditions in the flow channels formed by the rectangular fins of a heat sink using analytical, numerical and computational methods of varying complexity. Result showed that heat transfer coefficients and fin efficiencies vary substantially along the flow path and good engineering accuracy for heat sink performance can be obtained for laminar flow using calculations in which mean values for the Nusselt number and fin efficiency are calculated from analytical expressions.

Patrick H. Oosthuizen, Jane T. Paul [16] , studied natural convective heat transfer from narrow vertical plates which have a uniform surface heat flux With a narrow plate the heat transfer rate is dependent on the flow near the vertical edges of the plate. They numerically investigated the effect of the edge condition on the heat transfer rate. They revealed that the dimensionless plate width has to have a significant influence on the mean Nusselt number for natural convective heat transfer from a vertical flat plate with a uniform heat flux at the surface both for the case where there are side adiabatic sections and for the case where there are no adiabatic side sections. These edge effects increase with decreasing dimensionless plate width and decreasing Rayleigh number. Empirical equations for the mean heat transfer rate from narrow plates have been derived from the numerical results. The protrusion of the heated plate from the surface tends to increase the Nusselt number, this effect increasing with decreasing heat flux Rayleigh number.

F. Bazdidi-Tehrani , H. Nazaripoor[17] studied the laminar ascending flow and combined mixed (free and forced) convective-radiative heat transfer within symmetrically heated vertical parallel plates. Radiative heat transfer between two opposite walls was considered and the gas was assumed as gray, absorbing, emitting and scattering. They revealed that the occurrence of reversed flow enhances both heat transfer and the fanning friction coefficient, and the radiation mode amplifies heat transfer, while reducing the fanning friction coefficient.

Tae Hoon Kim , Kyu Hyung Do , Dong-Kwon Kim [18] performed both experimental and numerical studies and suggested a 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. They presented analytical solutions using the volume averaging approach for velocity and temperature distributions for high channel aspect ratios, high conductivity ratios, and low Rayleigh numbers. 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 sink.

Shwin-Chung Wong, Guei-Jang Huang [19] 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.. The optimum fin spacing Sopt occurs near the threshold S, below which the benefit of increasing heat transfer area surrenders to the decrease of h caused by excessive viscous drag. The heat transfer rate per unit base area Q/Ab decreases with increasing L and decreasing H. The heat transfer rate per unit base area, Q/Ab, is largest for a fin array with a shortest length (L = 128 mm), a highest H (38 mm).and a narrower S (6.4 mm).

Summary Table

Table 1: Experimental works on the Fins in natural convection

Year	Authors	Working fluid	Keywords	Observation
1970	Kamal-Eldin Hassan and Salah A. Mohamed	Air	Natural convection, flat plate	1. Along the surface, and well before the boundary layer turns to turbulence, separation of flow takes place along the trailing part at positive angles of inclination.
1985	E. M. Sparrow And L. F. A. Azevedo	Water	Natural convection, boundary layer	1. It was found that the flat plate heat transfer does not form an upper bound for the channel heat transfer.
1997	Rong-hua Yeh, Shih-Pin Liaw and Ming Chang	Air	Optimum spacing, fin array, forced convection	1.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.
2001	Witold M. Lewandowski , Ewa Radziemska	Water, Air		1.Correlation was developed between the dimensionless Nusselt and Rayleigh numbers and 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.

2002	J.J.Wei, B.Yu, H.S. Wang, W.Q. Tao	Air	Inclination, natural convection	1. For inclination angle less than 20^0, the local natural convection heat transfer is very different for the upper and lower heated surfaces.
2003	A. Giri 1, G.S.V.L. Narasimham, M.V. Krishna Murthy	Air	Natural convection; Heat and mass transfer; Vertical fin array	1. Beyond a certain stream wise distance, 2.further fin length does not improve the sensible and latent heat transfer performance. 3. 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.
2004	A.S. Krishnan, B. Premachandran, C. Balaji, S.P. Venkateshan	Air	Vertical channels; Free convection—radiation interaction; Semi-experimental; Multi-mode heat transfer	1.The radiation contribution even for spacing as large as 52.2 mm is less than that for an isolated plate by around 20% 2. An isothermal approximation for the heated plate is valid, even when the variation in plate temperature as high as ±5 ^{0}C.
2005	Xiaoling Yu , Jianmei Feng, Quanke Feng, Qiuwang Wang	Air	Heat sink; Heat transfer; Thermal resistance; Electronic device cooling	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.
2005	C.J. Kobus ,T. Oshio	Air	Mixed; Combined; Convection; Heat sink; Heat transfer	1. For a given fin spacing, fin performance, is only a weak function of fin diameter, d. 2. The optimal fin spacing appears to be 1.8 ≤s2 ≤2.3 cm, although it was not as pronounced for the smaller sized base.
2006	Moghtada Mobedi, Bengt Sunden	Air	Natural convection; Conjugate conduction–convection; Vertical fins	1. The best location of the heat source in the fin for maximum heat transfer rate depends on two parameters which are the conduction–convection parameter and the Prandtl number. 2. For fins with large conduction–convection parameter ξ=0.54 (ξ was dimensionless heat source location) was approximately the best location for the heat source because it provides maximum heat transfer from the fin.

2007	S.A. Nada	Air	Heat transfer; Narrow enclosure; Rectangular fins array; Vertical and horizontal	1.for a high range of Ra, increasing Ra increases Nusselt number and decreases fin effectiveness; 2.for a small range of Ra and at large S/H, increasing Ra increases both of Nusselt number and finned surface effectiveness; 3. The Nusselt number and finned surface effectiveness increased with increasing fin length.
2009	Burak yazicioğlu and Hafit Yüncü	Air	Optimal fin spacing, Extended surfaces, Natural convection	1. Good enhancement was achieved by attaching fins to a vertical flat plate. 2. The optimum fin spacing depends on fin height, fin length and base-to-ambient temperature difference, but the dependence on fin length is not very significant.
2009	Hung-Yi Li *, Shung-Ming Chao	Air	Cross flow ,Plate-fin heat sink ,Thermal resistance, Infrared thermography	1.For constant fin width, the heat sink with the highest fins has the best thermal performance 2.For constant fin height, the fin width that provides the best thermal performance increases with the Reynolds number. Further increasing the fin width will degrade the thermal performance.
2009	B. Kundu, P.K. Das	Air	Heat exchanger Optimization, Finned tube, Fin Parameter Geometry	1. The conduction through the supporting structure and the convection from the inter fin spacing have a pronounced effect on the performance of a fin array. 2. The optimum fin dimensions in fin arrays differ from that of the individual fins.
2009	Hussam Jouhara , Brian P. Axcell	Air	Fins, Heat sink, Laminar heat transfer,Parallel flow	1. heat transfer coefficients and fin efficiencies vary substantially along the flow path
2010	Patrick H. Oosthuizen, Jane T. Paul	Air	Natural Convection, Free Convection, Narrow Plates, Edge Effects, Numerical.	1. Edge effects increase with decreasing dimensionless plate width and decreasing Rayleigh number. 2. Protrusion of the heated plate from the surface tends to increase the Nusselt number, this effect increasing with decreasing heat flux

				Rayleigh number.
2011	F. Bazdidi-Tehrani , H. Nazaripoor	Air	Mixed convection; Radiative heat transfer; Finite volume method; Discrete ordinates method; Fanning friction coefficient	1.The occurrence of reversed flow enhances both heat transfer and the fanning friction coefficient 2. As wall emissivity increases from 0 to 1, effects of radiation on flow and thermal fields rise 3. As ε increases, the bulk temperature increases more quickly and reaches the wall temperature.
2013	Shwin-Chung Wong, Guei-Jang Huang	Air	Natural convection Fin array Sliding-chimney plume, Optimum fin spacing	1. The heat transfer rate per unit base area Q/Ab decreases with increasing L and decreasing H. 2. The heat transfer rate per unit base area, Q/Ab, is largest for a fin array with a shortest length (L = 128 mm), a highest H (38 mm).

REFERENCES

[1] Kamal-Eldin Hassan and Salah A. Mohamed, Natural Convection From Isothermal Flat Surfaces, ht. J. Heat Mass 7kznsjer. Vol. 13, pp. 1873-1886. Pergamon Press 1970.

[2] E. M. Sparrow And L. F. A. Azevedo, Vertical-channel natural convection spanning between the fully-developed limit and the single-plate boundary-layer limit, Int. Journal Heat mass transfer. Vol. 28, No. 10, pp. 1847-1857, 1985

[3] Rong-hua Yeh, Shih-Pin Liaw and Ming Chang, optimum Spacings of Longitudinal convective fin arrays, Journal of marine science and technology.,Vol.5, No.1, pp.47-53 (1997)

[4] Witold M. Lewandowski , Ewa Radziemska, Heat transfer by free convection from an isothermal vertical round plate in unlimited space, Applied Energy 68 (2001) 187-201

[5] J.J.Wei, B.Yu, H.S. Wang, W.Q. Tao, Numerical study of simultaneous natural convection heat transfer from both surfaces of a uniformly heated thin plate with arbitrary inclination, Heat and Mass Transfer 38 (2002) 309-317.

[6] A. Giri 1, G.S.V.L. Narasimham, M.V. Krishna Murthy, Combined natural convection heat and mass transfer from vertical fin arrays, International Journal of Heat and Fluid Flow 24 (2003) 100–113

[7] A.S. Krishnan, B. Premachandran, C. Balaji, S.P. Venkateshan, Combined experimental and numerical approaches to multi-mode heat transfer between vertical parallel plates, Experimental Thermal and Fluid Science 29 (2004) 75–86

[8] Xiaoling Yu , Jianmei Feng, Quanke Feng, Qiuwang Wang, Development of a plate-pin fin heat sink and its performance comparisons with a plate fin heat sink, Applied Thermal Engineering 25 (2005) 173–182

[9] C.J. Kobus ,T. Oshio, Development of a theoretical model for predicting the thermal performance characteristics of a vertical pin-fin array heat sink under combined forced and

natural convection with impinging flow, International Journal of Heat and Mass Transfer 48 (2005) 1053–1063

[10] Moghtada Mobedi, Bengt Sunden, Natural convection heat transfer from a thermal heat source located in a vertical plate fin, International Communications in Heat and Mass Transfer 33 (2006) 943–950

[11] S.A. Nada, Natural convection heat transfer in horizontal and vertical closed narrow enclosures with heated rectangular finned base plate, International Journal of Heat and Mass Transfer 50 (2007) 667–679

[12] Burak yazicioğlu and Hafit Yüncü, a correlation for optimum fin spacing of vertically-based rectangular fin arrays subjected to natural convection heat transfer, J. of Thermal Science and Technology ISSN 1300-3615 29, 1, 99-105, 2009

[13] Hung-Yi Li *, Shung-Ming Chao, Measurement of performance of plate-fin heat sinks with cross flow cooling, International Journal of Heat and Mass Transfer 52 (2009) 2949–2955

[14] B. Kundu, P.K. Das, Performance and optimum design analysis of convective fin arrays attached to flat and curved primary surfaces, International journal of refrigeration 32(2009)430-433

[15] Hussam Jouhara , Brian P. Axcell, Modelling and simulation techniques for forced convection heat transfer in heat sinks with rectangular fins, Simulation Modelling Practice and Theory 17 (2009) 871–882

[16] Patrick H. Oosthuizen, Jane T. Paul, natural convective heat transfer from a narrow vertical flat plate with a uniform surface heat flux and with different plate edge conditions, Frontiers in Heat and Mass Transfer (FHMT), 1, 013006 (2010)

[17] F. Bazdidi-Tehrani , H. Nazaripoor, Buoyancy-assisted flow reversal and combined mixed convection–radiation heat transfer in symmetrically heated vertical parallel plates: Influence of two radiative parameters, Scientia Iranica B (2011) 18 (4), 974–985

[18] Tae Hoon Kim , Kyu Hyung Do , Dong-Kwon Kim , Closed form correlations for thermal optimization of plate-fin heat sinks under natural convection, International Journal of Heat and Mass Transfer 54 (2011) 1210–1216

[19] Shwin-Chung Wong, Guei-Jang Huang, Parametric study on the dynamic behavior of natural convection from horizontal rectangular fin arrays, International Journal of Heat and Mass Transfer 60 (2013) 334–342.