International Research Journal of Engineering and Technology (IRJET) e-ISSN: 2395-0056
Volume: 06 Issue: 12 | Dec 2019 www.irjet.net p-ISSN: 2395-0072

The Impact of Split-Distance on Pin-fins over Natural Convection Heat Transfer Enhancement

Aishwarya A. Patil[1]

[1]*ME(Heat Power) Mechanical Engineering, DYPSOEA, Ambi, Pune, Maharashtra, India*

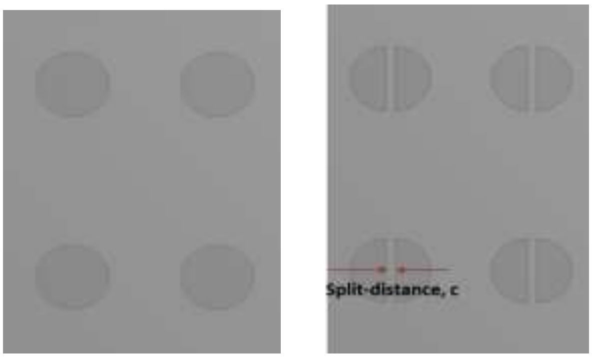
***

Abstract - *Natural convection heat transfer enhancement from the heat sinks with the help of extended surfaces, or fins as they are widely known, had been researched extensively for parameters like variation of fin geometry, the relative positioning between the fins, orientation of fins e.t.c. However, there had been very limited research towards split-fin approaches for natural convection heat transfer enhancement. This work focused on investigating the influence of splitting pin-fins on the heat transfer rate from the heat sink. Four configurations of split distance were studied for varying operating conditions. The results from the split pin-fins were compared against the solid pin-fin. It was observed that by introducing the split in the pin-fins, the heat transfer rate increases significantly. This could be attributed to a) the increased surface area for heat transfer b) flow turbulence created by the split arrangement. The study was conducted by both experimental and CFD simulation approaches. ANSYS FLUENT was employed for the CFD simulations. A good correlation between these approaches had been observed.*

Key Words: *Natural Convection, Pin-fins, CFD, Optimization*

1. INTRODUCTION

Most Heat Sinks uses Plate fins or Pin fins to increase the heat transfer rate. Various researches had been focused on such fins. However, when the Pin fins were to be split, it results in two semi-cylindrical fins. Here, the surface area that was available for the heat transfer increases as compared to continuous Pin fins. Besides, the distance between them also permits for further fluid motion. Overall, this might result in better heat transfer characteristics.



Solid Pin-fins Split Pin-fins

Fig.1 Schematic Comparison of Continuous Pin-fins and Split Pin-fins

Based on the available literature, there had been no research towards the split pin-fins under the natural convection flow regime. The research had been focused on the impact of the split-distance [clearance] between the fins on the heat transfer performance of the system. Also, the research objective included studying these effects over a wide range of thermal conditions in order to assess the applicability of such fin designs for the Heat Sinks.

2. LITERATURE REVIEW

Younghwan and Sung Jin Kim [1] had developed an analytical co-relation to compare the performances of plate-fin and pin-fin on a vertically oriented heat sink. Their analytical expression was validated experimentally. An analytical model for steady state natural convection in iso-thermal vertical ducts of arbitrary shape was developed by **M.M. Yovanovich**[2]. By combining the asymptotic solutions for fully developed flow and developing- boundary layer flow, an expression was derived. This was found to be applicable for the entire range of modified Rayleigh Number.The natural convection heat transfer from a vertically placed heat sink was studied by **Mehran Ahmedi**[3]. In this study, the fins were of plate-fin. The 2-dimensional CFD simulation results, performed using ANSYS FLUENT, were found to be in good agreement with the experimental results. A triangular fin for natural convection heat transfer from the vertical hot plate was investigated by **Hamid Reza Goshayeshi**[4]. Their work involved both experimental and numerical analysis; They had observed the reduction in heat transfer resistance as fin spacing was increased; **SyeedJishan Ali** [5] had investigated the heat transfer enhancement using un-notched fins and inverted notched fins. **Jin-CherngShyu**[6] had investigated the orientation effects of plate-fin array in LED back light panel. The tilted angle of the LED was varied from 0° to 180° with an interval of 30°. **Donald W Mueller Jr** [7] had approached the natural convection with the consideration of a long rod, of circular cross-section, with one side of the fin at an elevated temperature. **Mahdi Fahiminia**[8] had studied the natural convection heat transfer mechanism for the computer heat sink cooling application. In their study, six types of heat sink designs were investigated for parameters such as fin thickness, inter-fin gap and the fin shape. **Avram Bar-Cohen** [9] had studied optimum heat transfer rate from plate-fins under natural convective heat transfer with the objective of least fin material. In their optimization study, **Ana Christina Avelar**[10] had used numerical and experimental analysis to find the optimal fin spacing between heated vertical plates. **A.Giri**[12] had developed a mathematical formulation that governs the natural convection heat and mass transfer over the vertical fin array with the shroud with an application for low temperature application such as air-conditioning. **Saurabh D. Bahadure**[13] had investigated the effect of perforations on pin-fins under the natural convection field. The authors had varied the perforations, fin material in their study. The increased surface area due to the fin perforations resulted in high heat transfer rate. **Shivdas S Kharche**[14] had compared the fin array with and without notches under the natural convection conditions. A comparison of fin performance – in terms of heat transfer rate – between triangular shaped fins and rectangular shaped fins were made by **Sandhya Mirapalli**[15]. **Murtadha Ahmed** [16] had investigated the influence of heat input and the fin geometry – in terms of perforations – over the thermal performance of fins. Based on their results, they conclude that the addition of perforation on the fins improve the heat transfer characteristics as compared to the solid fins. This had been observed in both plate-fins and the pin-fins. The turbulence induced by the fins of V-Shape was expected to increase the heat transfer rate as compared to other fin types and was studied experimentally by **M. J. Sable** [17] for four configurations of fins – Plain vertical plate, vertical fin array, V fin array with 20 mm spacing, V fin array with fin height of 20 mm. The natural convection heat transfer characteristics surrounding an annular composite fin were studied analytically by **Padma LochanNayak**[18]. The authors had the MATLAB programs to solve the analytical equations.**G. A. Ledezma**[19] had conducted experimental studies to optimize the vertical, rectangular fins under the laminar natural convection flow field ($10^3 \leq Ra \leq 10^6$). The impact of perforations on fins for the natural heat transfer enhancement was studied by **Wadah Hussein** [20] using the experimental methods. The number of perforations on the fins was varied from 24 to 56.

3. PROBLEM DESCRIPTION

A heat sink with a width of 120 mm and a height of 180 mm was considered in this research. The thickness of the heat sink was 10 mm. The heat sink contained 16 fins, having a height of 56 mm and a diameter of 30 mm, were arranged in a rectangular array as shown in fig 2.

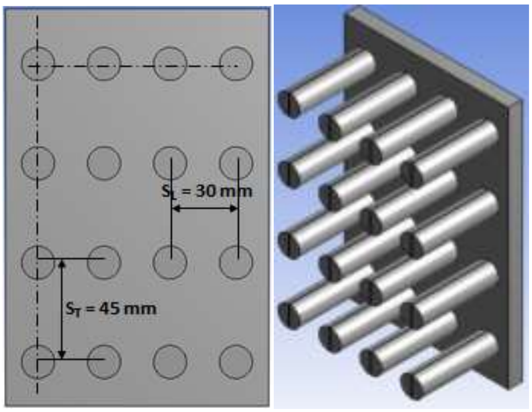
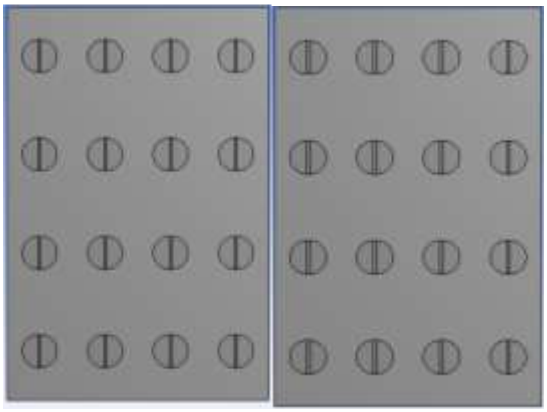


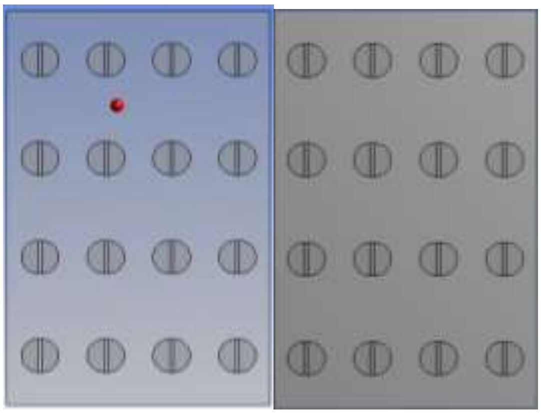
Fig.2 Fin Arrangements in Heat Sink

The split-distance between the pin-fins will be varied as per the following definition, Clearance Ratio CR = $\dfrac{FinDiameter, D}{SplitDist, c}$

Here, four clearance ratios [0.07, 0.10, 0.13 and 0.17] were investigated and the results were compared against the solid pin-fins. The lateral and transverse pitch of the fin arrangement was kept constant. In order to assess the performance of the Heat Sink over a wide range of operating conditions, the heat load on the system was varied.



Split fin A [CR = 0.10] Split fin B [CR = 0.13]



Split fin C [CR = 0.13] Split fin D [CR = 0.17]

Fig.3 Fin configurations

The heat load was characterized by the following expression, ΔT = $T_{Fin} - T_{ambient}$, K. Heat loads of ΔT = 40, 60, 80 and 100 K were imposed and the resulting flow and thermal fields were studied in this research work.

4. EXPERIMENTAL APPROACH

The fins were assembled at the top of the 'base-plate' with the respective position. Five thermocouples – as shown in the fig 4– were placed at the rear side of the 'base-plate'. This model was placed vertically in a static room.

Fig.4 Experimental Set-up

With the help of Voltmeter and Ammeter, the heat input to the base plate was monitored.

Table -1: Experimental Readings for Solid Pin Fins

Heat Transfer Rate, Q, Watts		
Temperature Difference, K	Solid Pin-fins	
	Experiment	CFD
40	15.7	17.0
60	25.0	27.4
80	35.0	38.8
100	45.2	50.2

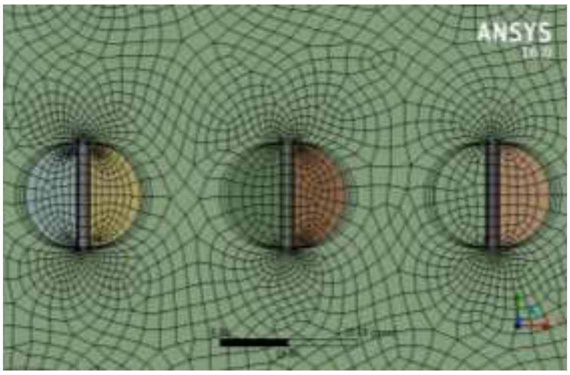
Table -2: Experimental Readings for Split-Pin Fins configurations

Heat Transfer Rate, Q, Watts				
Temperature Difference, K	Split Pin-fins A	Split Pin-fins B	Split Pin-fins C	Split Pin-fins D
	Experiment	Experiment	Experiment	Experiment
40	16.7	17.2	17.5	20.1
60	26.5	28.1	30.2	31.7
80	38.0	39.4	42.8	48.0
100	48.2	51.1	49.1	54.2

5. CFD SIMULATION APPROACH

The CFD methods solve the discretized governing equations (Navier Stokes equation) using numerical algorithms. The Reynolds Averaged Navier-Stokes, or popularly known as RANS, approach that was available in the commercial CFD solver ANSYS FLUENT was used. For creating the necessary geometry and the subsequent meshing operations were performed using the modules in ANSYS WorkBench. The simulation domain and a cross-sectional view of meshes had been shown in fig3.

Fin Surface Mesh



Cross Sectional View of Mesh

Fig.5 Mesh images of computational volume

In this project work, the heat conduction in the base plate and the fins along with convection heat transfer to the air were simulated. The heat sink walls were specified as 'constant wall temperature' boundary conditions. This temperature gradient, between the heat sink wall and the atmosphere, ensured the fluid motion due to density difference. The remaining wall surfaces were modeled as adiabatic. While the bottom and top surfaces were modeled as flow inlet and flow outlet with atmospheric condition.

6. ASSUMPTIONS

This research was undertaken to study the changes in the fluid motions surrounding the heat sink due to the splitting of fins. So, the radiation heat transfer, which might be significant in this temperature range, was not considered.

The properties of air such as viscosity, thermal conductivity and specific heat might vary in these operating conditions. However, these properties were assumed to be constant in this research work. Also, the thermal conductivity of Aluminum and Air was considered as constant during the study.

Steady-state natural convection CFD simulations were considered even though the transient effects under these working conditions might exist.

7. RESULTS & ANALYSIS

In the figure 6, the heat transfer rate from the heat sink predicted from the experimental and the CFD simulations were plotted. These results were obtained for the solid-pin-fin configurations [without any splits]. There was close agreement in results between these approaches when the temperature difference between the atmosphere and heat sink were lower.

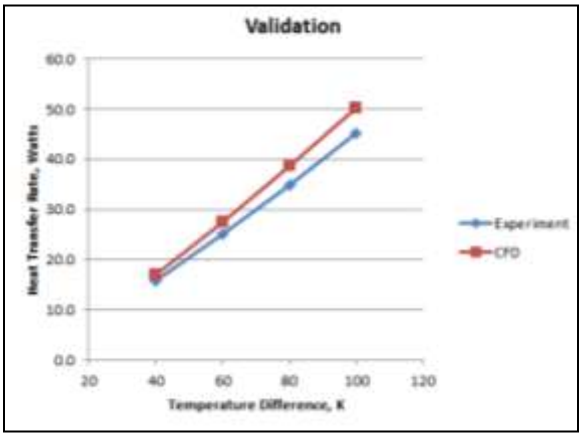


Fig.6 Results validation for CFD simulations

As this temperature difference increases, the CFD simulations were over-predicting the heat transfer rate from the heat sink. A similar trend between the experimental data and the CFD results were observed for the remaining fin configurations. Since the difference between the experimental and CFD results were in the range of ~14%, it had been concluded as validation for the project work.

Table -3: CFD Readings for Split-Pin Fins configurations

Heat Transfer Rate, Q, Watts				
Temperature Difference, K	Split Pin-fins A	Split Pin-fins B	Split Pin-fins C	Split Pin-fins D
	CFD	CFD	CFD	CFD
40	18.4	19.1	19.9	22.2
60	29.7	30.4	33.3	35.9
80	41.9	43.4	47.5	51.2
100	54.0	56.7	58.2	60.5

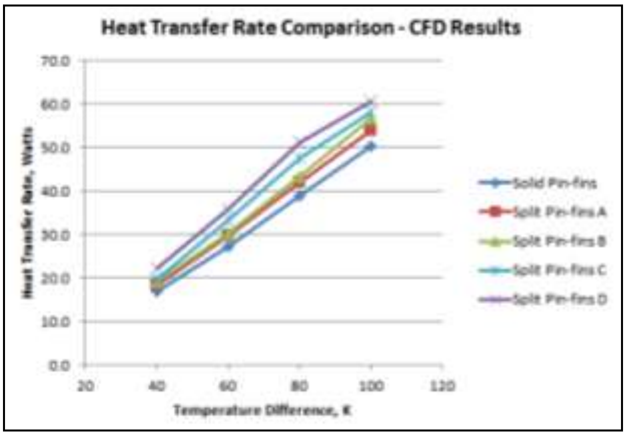


Fig.7 Comparison of heat transfer rate predictions for all fin configurations

In the Figure 7, the heat transfer rate from the heat sink from all the fin configurations was plotted for comparison. With the comparison of the solid-pin-fins, the heat transfer rate increases with the increase of split distance. This was evident with the marginal heat transfer enhancement for the split-fin-A and the substantial improvement for split-fin-C and split-fin-D.

In the following figure 8, the comparison of heat transfer enhancement from the heat sinks between the 'solid pin fins' and the 'split pin fin D' had been made. The 'split pin fin D' configuration provided 20 – 30% higher heat transfer rate as compared to the 'solid pin fin'. This had been a substantial improvement thermal performance by the split of fins.

As the temperature difference between the atmosphere and the heat sink increases, the split fins provided higher heat transfer rate.

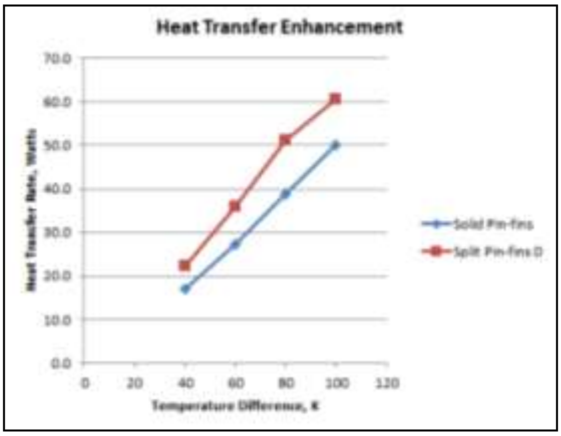


Fig.8 Heat transfer enhancement due to fin splitting

The flow field surrounding the fins under the natural convection would typically involve counter-rotating vortices from the pin fins. This vortex motion would be modified in the presence of any neighboring fins.

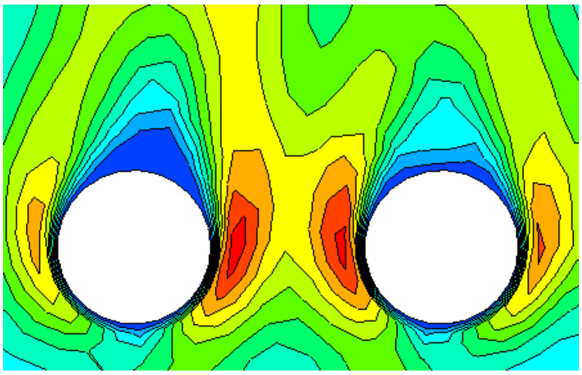


Fig.9 Velocity Contour lines surrounding solid pin fins

However, there will be low velocity / stagnation zones at 180° from the stagnation point. Due to the lack of fluid motion in these areas, the heat removal will be minimal. This could be observed in figure 9.The images correspond to the operating condition of $\Delta T = 100$ K. A similar flow and thermal profile was observed in remaining cases and hence were not repeated here.

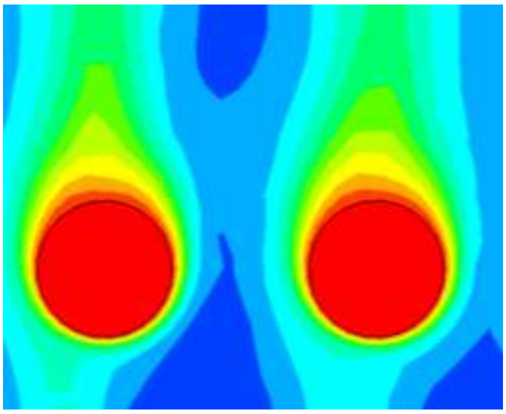


Fig.10 Velocity Contour lines surrounding solid pin fins

Now, by splitting the fins, the fluid motion between the fins resulted in increased surface area for heat transfer.

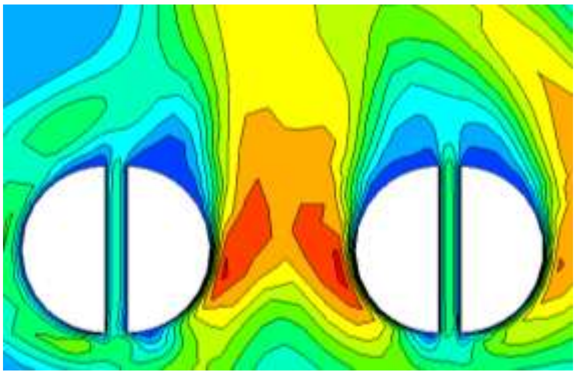


Fig.11 Velocity contour lines surrounding split pin fins

Also, this fluid movement prevented any low velocity / high temperature regions as mentioned earlier. The overall impact from these factors resulted in high heat transfer rate.

8. OBSERVATIONS

The thermal performance, in terms of heat transfer rate, of the heat sink was enhanced by splitting the fins with equal volume.

The fluid motion in the clearance gap was observed. This had been attributed for enhanced heat transfer rate.

The heat transfer rate from the heat sink was found to be increasing with the increase in the clearance gap [split distance].

A close agreement in results obtained by the experimental and CFD simulation approaches for this natural convection research work.

Even though heat transfer rate was improved, this could be optimized by conducting further research on varying split distance.

REFERENCES

[1] YounghwanJoo, Sung Jin Kim, (2015), “Comparison of Thermal Performance between Plate-fin and Pin-fin heat sinks in Natural Convection” International Journal of Heat and Mass transfer.

[2] M.M. Yovanovich and P. Teertstra, January -March 2002, “Natural Convection inside Vertical Isothermal Ducts of Constant Arbitrary Cross Section” Journal of Thermophysics and Heat Transfer Vol.16, No.1

[3] Mehran Ahmedi, GolnooshMostafavi, Majid Bahrami, Sciences (2014), “Natural Convection from Rectangular interrupted fins” International Journal of Thermal.

[4] Hamid Reza Goshayeshi, Reza VafaToroghi, (2014), “An Experimental Investigation of Heat Transfer of Free Convection on Triangular Fins in order to Optimize the arrangement of fins” International Journal of Science, Technology, and Society.

[5] SyeedJishan Ali, M. K. Chopra, April 2015, “Performance Evaluation of Different Shapes of Plane Un-notched fin and Inverted Notched fin using CFD tool and Validation Experimentaly” International Journal of Engineering, Management & Medical Research; vol-1, Issue 4.

[6] Jin-CherngShyu, Keng-Wei Hsu, Kai-Shing Yang, Chi-Chuan Wang, (2013), “Orientation Effect on Heat Transfer of a Shrouded LED backlight panel with a plate-fin array” International Communications in Heat and Mass Transfer.

[7] Donald W Mueller Jr, Hosni I Abu-Mulaweh, "Estimation of the average heat transfer coefficient for a Long horizontal cylindrical fin rod" Proceedings of the 2004 American Society for Engineering Education Annual Conference & Exposition.

[8] Mahdi Fahiminia Mohammad Mahdi Naserian, Hamid Reza Goshayeshi and H. M. Heravi, September 2012, "Experimental Investigation of Natural Convection Heat Transfer of the Fin Arrangement on a Computer Sink", Scientific Research and Essays, vol.7(36).

[9] Avram Bar-Cohen, Madhusudan Iyengar, Allan D Krauss, (2013),"Design of Optimum Plate-Fin Natural Convective Heat Sinks" Transactions of ASME.

[10] Ana Christina Avelar, Marcelo Moreira Ganzarolli, November 2013, "Optimum Spacing in an Array of Vertical Plates with Two-Dimensional Protruding Heat Sources Cooled by Natural Convection" 17th International Congress of Mechanical Engineering;.

[11] H. K. Versteeg and W. Malalasekera, (2015), "An Introduction to Computational Fluid Dynamics; the Finite Volume Method" Longman Scientific & Technical

[12] A. Giri, G. S. V. L. Narasimham, M. V. Krishna Murthy, (2003), " Combined Natural Convection Heat and Mass Transfer from Vertical Fin Arrays" International Journal of Heat and Fluid Flow;

[13] Saurabh D. Bahadure, G. D. Gosavi, (September 2014) "Enhancement of Natural Convection from Perforated Fin" International Journal of Engineering Research; vol-3, issue -9

[14] Shivdas S Kharche, Hemant S Farkade, April 2012, "Heat Transfer Analysis through Fin Array by Using Natural Convection" International Journal of Emerging Technology and Advanced Engineering; vol-2, Issue 4.

[15] Sandhya Mirapalli, Kishore. P. S, January 2015, "Heat Transfer Analysis on a Triangular Fin" International Journal of Engineering Trends and Technology; vol-19, number -5,

[16] Murtadha Ahmed, Abdul Jabbar N. Khalifa, November 2014,"Natural Convection Heat Transfer from a Heat Sink with Fins of Different Configuration" International Journal of Innovation and Applied Sciences; vol-9, No-3.

[17] M. J. Sable, S. J. Jagtap, P.S. Patil, P. R. Baviskar, S. B. Barve, November 2010, "Enhancement of Natural Convection Heat Transfer on Vertical Heated Plate By Multiple V-Fin Array" International Journal of Recent Research and Applied Studies.

[18] Padma LochanNayak, SuvenduMohanty, November 2010, "Evaluation Performance of an Annular Composite Fin by using MATLAB Programming" International Journal of Engineering Research and Applications; vol-5, issue 4, (Part-1)

[19] G. A. Ledezma, A. Bajen, November 1997, "Optimal Geometric Arrangement of Staggered Vertical Plates in Natural Convection" Transactions of ASME;vol-119

[20] Wadhah Hussein Abdul Razzaq Al-Doori, July-December 2011,"Enhancement of Natural Convection Heat Transfer from Rectangular Fins by Circular Perforations" International Journal of Automotive and Mechanical Engineering;vol-4