International Journal of Technical Innovation in Modern Engineering & Science (IJTIMES)

Impact Factor: 5.22 (SJIF-2017), e-ISSN: 2455-2585

Volume 5, Issue 12, December-2019

A Literature Review on Natural Convection Heat Transfer Mechanism using Fins

Aishwarya A. Patil[1]

[1]ME(Heat Power) Mechanical Engineering, DYPSOEA, Ambi

Abstract:

Heat transfer under the natural convection occurs due to the temperature difference between the solid surfaces and the surrounding cold atmosphere. The buoyancy motion enables the fluid movement, initiating the heat transfer between the Heat Sink and the Surroundings. This heat transfer mechanism shall be enhanced further by the optimal location, orientation and placement of fins in such a way that the flow turbulence was introduced. This review journal provides a comprehensive summary of the recent research work on fins for improving the heat transfer rate. Also, the numerical simulation (CFD) methods, experimental studies on natural convection, various fin shapes and their influences on natural convection heat transfer rate.

Introduction:

Natural convection transport processes play an important role in many applications like ice-storage, air-conditioning [12]. In order to prevent the over-heating issues on electronic components, the heat generated from the heat sinks must be carried away. Though the forced convection methods provide superior heat removal, they also would increase the cost in terms of Fans or Blowers.

The heat transfer mechanism under the natural convection occurs due to the temperature difference between the solid surfaces and the surrounding cold atmosphere. The buoyancy motion enables the fluid movement, initiating the heat transfer between the Heat Sink and the Surroundings. A significant cost reduction shall be achieved since the natural convection mechanism doesn't require fans or blowers. Also, without the moving components, vibrations in the electronic components were also prevented. This would ensure of no structural failures of the component as well.

Natural convection heat transfer mechanism shall be enhanced further by the optimal location, orientation and placement of fins in such a way that the flow turbulence was introduced. The most common techniques in estimating as well as studying the natural convection heat transfer mechanisms were; analytical methods, experimental procedure and the CFD simulations. This journal reviews the open literature available in the field of natural convection.

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. For the optimization study, the authors had utilized two objective functions; the total heat dissipation and the total heat dissipation per unit mass for a given base to ambient temperature difference. The authors had observed that the optimized plate-fin heat sinks dissipate a larger amount of total heat than the optimized pin-fins when the objective function was total heat dissipation. This trend reverses when the objective function was heat dissipation per unit mass. Under these criteria, the optimized pin-fin heat sinks dissipate higher heat per unit mass as compared to the optimized plate-pin heat sinks.

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 authors had considered duct shapes as triangle, square, circle and rectangle. They had also considered the parallel plates as a special case too. The results from their analytical model were validated from the experimental and numerical results.

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 numerical simulations were performed using ANSYS FLUENT by the authors. The 2-dimensional CFD simulation results were found to be in good agreement with the experimental results. This work had studied the effects of fin spacing, fin interruptions on the heat transfer rate. The authors had observed that the interruptions will increase the heat transfer rate by resetting / interrupting the thermal and hydrodynamic boundary layers.

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; ANSYS FLUENT was used by the authors for their numerical studies in that work. The authors had studied four configurations of triangular fins; the number of fins was the differentiation factor among the configurations. Temperature difference between the base surface and environment was considered to be 45, 72 and 100 K by the authors for the research work. They conclude that the heat transfer resistance decreases with the increase in fin spacing; after the minimal heat transfer resistance, the increase in fin spacing results in increased resistance for heat transfer rate.

Several researches had been performed on the shape and orientation of the fin geometry to enhance the heat transfer rate under the natural convection flow field. **Syeed Jishan Ali** [5] had investigated the heat transfer enhancement using un-notched fins and inverted notched fins. They had performed CFD simulations using ANSYS FLUENT along with an experimental study. The authors had concluded that the heat transfer rate increased by 50% for triangular notched fins in comparison with the plane fins. Meanwhile, the inverted rectangular notched fins produces 26% higher heat transfer rate as compared to the plane fins.

The application of natural convection heat transfer are far reaching; one such critical area of natural convection shall be in the field of LED backlight panel where the consistent heat removal will be crucial to the continual operation of the Panel. **Jin-Cherng Shyu** [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°. The heat input in terms of power was also varied in their study along with the clearance. The authors had noted that the heat transfer rate reduces as the tilted angle of LEDs was increased. Expectedly, in their work, the heat transfer rate increases with an increase in heat input.

Certain researchers had focused on obtaining heat transfer rate on individual fins; a pin-fin – under these criteria – would become a long rod. Such configurations shall be solved using analytical methods. **Donald W Mueller Jr** [7] had undertaken such a study, considering a long rod, of circular cross-section, with one side of the fin at an elevated temperature. The authors had estimated the heat transfer rate from this fins with the consideration of radiation heat transfer as well. The results from their analytical expression were found to be in good agreement with the experimental studies.

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. The flow conditions corresponding to Ra = 1.4E6 till Ra = 1.9E6 were considered in their study. The experimental results from their study were in close agreement with the analytical solutions for the high Rayleigh number conditions. The authors concluded the fin shapes with the material removed in the central zones of the heat sink provide better thermal performance.

The positioning of the fins on heat sinks will have influence on heat transfer rate. Various researchers had investigated the optimal positioning of heat sink fins using analytical as well as experimental and numerical studies. In their study, **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. The optimally placed plate-fin was found to be superior in performance. However, the authors observe the difficulties associated in manufacturing such optimized plate-fin shapes.

In their optimization study, **Ana Christina Avelar** [10] had used numerical and experimental analysis to find the optimal fin spacing between heated vertical plates. In those plates, the heat sources were protruding and thus the flow field resembles of fins in natural convective flow field. The authors had used finite volume based SIMPLEC [11] algorithm for the flow velocity and pressure coupling. The authors had identified that for a smallest plate to plate distance, the flow pattern around each protruding heat source remain same and the flow was periodically fully developed.

Even though fins find application in high temperature zones, certain research include fins for condensation process as well. **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. Here the base plate was maintained below the dew point temperature. Based on their study, the authors reported that the local and average Nusselt numbers decrease in stream-wise direction.

Saurabh D. Bahadure[13] had investigated the effect of perforations on pin-fins under the natural convection field. Their study included the analytical as well as experimental methods. The authors had varied the perforations, fin material in their study. And, they had observed that the heat transfer rate increased with the increase in the number of perforations. This could be attributed to the increased surface area because of more perforations.

In another innovative technique of fin orientation, **Shivdas S Kharche** [14] had compared the fin array with and without notches under the natural convection conditions. In their experimental study, the notched fins provide 20% higher heat transfer rate as compared to the fins without the notches. The authors had conducted the experiments for varying thermal conditions from 50 W to 80 W and the results were consistent for the entire range.

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]. Their work was focused on enhancing the heat transfer rate from air-cooled engine. The authors had placed the fins on a circular cylinder, with the surface temperature varied from 200°C to 600°C. Also, the fin length was varied in their study as well. Even though the rectangular fins provide better effectiveness and efficiency, the triangular shaped fins provide high heat transfer per fin mass.

Murtadha Ahmed [16] had investigated the influence of heat input and the fin geometry – in terms of perforations – over the thermal performance of fins. Their study was conducted for the thermal conditions corresponding to 12.15X106 ≤ Ra ≤ 58.59X106. The heat sink, in their study,had 50 fins of square shaped Aluminum fins. The authors had also included the pin-fins in their study. 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.

A heat transfer enhancing technique under the natural convection mechanism for the hot-vertical plate using V-Shaped partition fins was studied experimentally by **M. J. Sable** [17]. The turbulence induced by the fins of V-Shape was expected to increase the heat transfer rate as compared to other fin types. The authors had studied 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 authors noted that a low pressure suction region was created near the nose region on the bottom side for each V fins. This phenomenon ensured the flow motion of low temperature fluid to the separation region that resulted in higher heat transfer rate.

The natural convection heat transfer characteristics surrounding an annular composite fin were studied analytically by **Padma Lochan Nayak** [18]. The authors had the MATLAB programs to solve the analytical equations. Their study included the effects of material coatings over the fin surfaces. They had also varied the fin base diameter to investigate the changes in heat transfer rate. They observed that the material coatings over the fin surface to be more effective on thinner fins rather than for the thick fins.

G. A. Ledezma [19] had conducted experimental studies to optimize the vertical, rectangular fins under the laminar natural convection flow field ($10^3 \leq Ra \leq 10^6$). In this research, the authors had varied the horizontal spacing between the fins, number of fins, stagger between the fin columns etc. They highlighted that for selecting the optimum spacing between the vertical fins, the boundary thickness must be considered.

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. The study was conducted for the heat input of 6 – 220 Watts while the perforation diameter was kept as constant at 15 mm. The averaged heat transfer coefficient was increasing as the number of perforations was increased.

Observations:

Heated vertical plates without any fins would have the least heat transfer rate among all the configurations. The heat transfer rate will be increased since the available surface area for the heat transfer increases with the addition of fins (extended surfaces)

Fin spacing – distance between the adjacent fins – plays a major role in deciding the optimum fin arrangement. This must be decided based on the boundary layer thickness. Optimal fin spacing should not be much larger than the boundary layer thickness.

Multiple researchers had compared the experimental study results with the numerical simulation (CFD) results and found both the results were in agreement to each other.

Researchers had investigated fins with cross-sections such as circular, rectangular, elliptical, triangular, to study the effect on overall heat transfer rate. Certain researches were focused in the fin arrangement such as 'in-line', 'staggered', 'radial'. The results from such configurations might be applicable for the corresponding geometrical, thermal conditions.

References:

[1]Younghwan Joo, Sung Jin Kim, "*Comparison of Thermal Performance between Plate-fin and Pin-fin heat sinks in Natural Convection*" International Journal of Heat and Mass transfer (2015)

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

[3]Mehran Ahmedi, Golnoosh Mostafavi, Majid Bahrami, "*Natural Convection from Rectangular interrupted fins*" International Journal of Thermal Sciences (2014)

[4]Hamid Reza Goshayeshi, Reza Vafa Toroghi, "*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 (2014)

[5]Syeed Jishan Ali, M. K. Chopra, "*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, April 2015.

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

[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, "*Experimental Investigation of Natural Convection Heat Transfer of the Fin Arrangement on a Computer Sink*", Scientific Research and Essays, vol.7(36) September 2012.

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

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

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

[12]A. Giri, 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; (2003)

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

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

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

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

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

[18]Padma Lochan Nayak, Suvendu Mohanty, "*Evaluation Performance of an Annular Composite Fin by using MATLAB Programming*" International Journal of Engineering Research and Applications; April 2015, vol-5, issue 4, (Part-1)

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

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