Review Journal on Various Fin Types as Heat Removal Mechanism under Natural Convection Heat Transfer

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ABSTRACT

Fins serve as a heat removal mechanism from the heat sources where the presence of additional components such as pumps, fans and blowers are not feasible due to product design, overall cost, and availability of package space etc. Various configurations of fins such as pin-fins, plate-fins, triangular fins etc had been investigated by the researchers to identify the optimal fin design. This journal provides a comprehensive report on the studies of fin configurations and their influences on heat transfer mechanisms, the CFD simulation methods to model the fins, experimental procedures for the fins under natural convection field, application of fins for various applications and optimizing the heat sinks. The observations from this literature review had been briefly summarized in the Observations section.

Keywords: Fins, Natural Convection, Heat Sinks, Fin Optimization, CFD Simulations for Fins

I. INTRODUCTION

Fins serve as a heat removal mechanism from the heat sources where the presence of additional components such as pumps, fans and blowers are not feasible due to product design, overall cost, availability of package space etc. Numerous studies had been performed on the investigation for the optimal fin designs, fin arrangement. The most popular fin configurations are pin fins (circular cross-section) and plate fins (rectangular cross-sections).

In the fin arrangement, the surface area that is available for heat transfer play a critical area in the overall heat transfer rate. Another important factor is the flow turbulence in the vicinity of the fins. If flow turbulence is higher, it would result in higher heat transfer rate. So, the fin arrangement should be preferred in such a way that higher flow turbulence is created.

II. LITERATURE REVIEW

Rossano Comunelo [1] had studied the influence of neighborhood of fins under the natural convection field using vertical plates. The vertical plate that was considered had a length of 0.15 m. Their study included the numerical simulations along with experimental studies. The authors had used ANSYS CFX for the CFD simulations. Their meshing near the wall boundary was sufficiently refined to capture the flow and thermal boundary layers. The temperature difference, which drives the flow under natural convection, was applied to the neighborhood. The authors had found good co-relations between the numerical CFD simulations and the experimental studies.

The pin-fins, fins with circular cross-section, were applied heat removal mechanism in the electronic packaging by **Waqar Ahmed Khan [2]**. The authors had developed analytical methods for estimating the heat transfer rate from heat sinks with pin-fins arranged in in-line as well as staggered pattern. They had estimated the thermal resistance for the heat sinks and observed that the staggered arrangement of cylindrical pin-fins have lesser thermal resistance as compared to the in-line arrangement of pin-fins. Their analytical predictions were in good agreement with the experimental data for various operating conditions. The enhancement of fin effectiveness under the natural convection was investigated by varying the perforations on the fins by **Gaurav A Chaudhari [3]**. The plate fins, rectangular cross-sectional area, were considered by the authors in this experimental study. They had investigated for 10%, 20% and 30% fin perforations for varying operating conditions. From their results, they had concluded that fin configuration with 30% perforation provided higher heat transfer rate.

An annular composite fin for dissipating heat in the radial direction was studied experimentally by **Padma Lochan Nayak [4]**. The authors had also investigated the impact of surface coatings on the fin surfaces over the fin effectiveness. The zinc surfaces coatings were compared with the fin configuration of without any surface coatings. However, they had not included the contact resistance between the zinc coatings and the fin surfaces as well as between the cylindrical tube and fin base. They conclude that the zinc coating on the fin surface enhances the fin efficiency by as much as 14%.

A radial heat sink is composed of plate fins, which have rectangular cross-section, arranged in radial fashion on a circular plate. **Mangesh D Shende [5]** had analyzed such a radial heat sink for heat removal mechanism in LEDs under the natural convection field. Their experimental study was conducted by varying three parameters – fin length, fin height and number of fins – for a specified heat flux condition. Based on their results, they had noted that as the fin length, fin height and the number of fins were increased, the thermal resistance and the heat transfer coefficient decreased.

The natural convection field formed inside a square cavity with horizontal adiabatic walls and vertical isothermal walls was investigated by **Himsar Ambarita [6]**. They had investigated the heat transfer enhancement due to the addition of baffles. The flow conditions corresponding to Rayleigh Number = 104 to 108 was considered in their study. The authors had varied the baffle length as well as the baffle positions. For the numerical simulations, they had conducted the grid independence study to decide the mesh size for the simulations. They had observed that the presence of the baffles completely modifies the fluid and thermal fields in comparison to the cavity without the baffles.

Ana Cristina Avelar [8] had conducted numerical and experimental analysis for optimizing the space between the plates that were under the natural convection heat transfer field. The heat source for each of these vertical plates had been mounted on the protrusion. The laminar, 2-dimensional numerical simulation was carried out by the authors with the periodicity boundary condition for simplifying the simulation domain. SIMPLEC algorithm was employed to model the pressure-velocity coupling in the simulations. The authors had observed a close match in the results between the experimental and the numerical data. As the distance between the plates was increased, the temperature in the channel decreases sharply.

Fins with various shapes for improving the heat transfer characteristics had been researched by multiple authors. **Hamid Reza Goshayeshi [9]** had investigated triangular shaped fins under the natural convection flow conditions over the influence on heat transfer rate. They had analyzed the influence of the triangular fins with four variants of fins – by changing the number of fins and hence the fin spacing. Their study included both the experimental and the CFD simulations. They had considered the operating conditions of 45°, 72°and 100° C temperature difference between the fins and the surroundings. Based on their results, the authors had concluded that the heat transfer resistance decreases with the increase of the space till the optimum distance and beyond this distance the heat transfer resistance increases.

In an experimental investigation by **Murtadha Ahmed [10]**, the square shaped fins with multiple variants – solid, hollow, perforated - were studied for the flow conditions corresponding to Ra = 12.45 X 106 to Ra = 58.59 X 106. The fins were attached to the base plate which was covered with two layers of insulation to prevent any heat loss. Electrical heater was used to supply the energy to the base plate. The power supply to the heater was controlled using variac transformer. K-type thermocouples, with the calibration of 0.2 C were used by the authors to measure the temperature during the experimental study.

Sandhya Mirapalli [11] had employed triangular shaped fins and rectangular fins for heat removal mechanism from a cylinder that was at 200 C to 600 C. In their experimental investigation, the authors had also varied the length of the fins from 6 cm to 14 cm. The results from the triangular and the rectangular fins were compared in terms of fin efficiency, fin effectiveness and rate of heat flow per unit mass of fins. The authors noted that the heat flows from the triangular fins were increased by 33% as compared to the rectangular fins for the identical operating conditions. Based on their results, they concluded that the triangular fins provide better heat transfer characteristics as compared to the rectangular fins.

Mehran Ahmadi [12] had, in their study, investigated the influence of the plate-fin arrangement over the natural convection heat transfer from a vertically heated plate. They had conducted the steady-state, 2-Diemensional CFD simulations using ANSYS FLUENT while the results were validated using their experimental work. The radiation heat transfer from these cases had been neglected. The ‘pressure-inlet’ boundary condition was employed by the authors to model the inlet conditions while the ‘pressure-outlet’ was used for modeling the flow outlet. The heat input was specified using ‘wall-heat-flux’ option. Their study included continuous plate-fins, in-line arrangement of interrupted plate-fins, staggered arrangement of plate-fins. The authors had varied the interruption length to observe the changes in the heat transfer rate. They concluded, based on their results, that the interruptions will enhance the convection heat transfer rate by resetting/interrupting the thermal and hydro-dynamic boundary layers.

The application of natural convection heat transfer methods for removing the heat from LED panels had been explored by **Jin-Cherng Shyu [13]**. In their experimental study, 270 evenly distributed 1-W LEDs with an aluminum plate-fin array was considered. The study was conducted for four different thermal operating conditions, with heat supply of 140 W, 170 W, 200 W and 230 W. They had also studied the influence of tilted angle by varying from 0° to 180 ° at an interval of 30°. Another parameter that was studied by the authors was the clearance [0 mm to 20 mm, at an interval of 5 mm]. From their results, they had suggested that the clearance gap influences the heat transfer only in the range of 5 mm – 15 mm.

In their experimental work, **Anagha Gosavi [14]** had compared the heat transfer enhancements by changing the plate-fin configurations – continuous array, fin array with 40% staggering, fin array with 50% staggering. The thermal conditions were varied from 25 W to 125 W with an increment of 25 W. The study was conducted for two fin heights – 38 mm and 48 mm. From their experimental data, the increase in Nusselt number shall be observed as the % staggering was increased. This trend was observed for both fin heights as well as the all the heat load conditions.

Saurabh Bahadure [15] had studied using the theoretical as well as experimental methods on enhancing the heat transfer of a pin-fin heat sink. They had used three materials – Mild Steel, Aluminum and Copper – as fin material for comparing the thermal performance. Also, in order to study the influence of perforations over the natural convection characteristics, they had considered four fin configurations – solid pin-fin, pin-fin with one perforation, pin-fin with two perforations, pin-fin with three perforations. Their study was conducted for thermal loads corresponding to 5 W to 30 W with an increment of 5 W. They had observed high heat transfer coefficient for the fins made of copper. Also, the heat transfer rate was increased as the number of perforations on the fins was increased.

In one of the application of Natural convection heat transfer methods, **Mahdi Fahiminia [16]** had conducted experimental studies for enhancing heat transfer from computer heat sinks. They had used 6 types of fin configuration in this research work. The laminar, steady state, three-dimensional CFD simulations were also conducted by the authors in ANSYS FLUENT, with an assumption of negligible radiation heat transfer from the heat sink surfaces. Air was modeled as ideal-gas in the CFD simulations. They had observed close agreement in results between the analytical, experimental and the CFD simulations for the Nusselt number. They had suggested that reducing the fin material in the middle, thereby increasing the mixing of fluid layers, would enhance the heat transfer rate from the heat sinks.

Younghwan Joo [17] had performed optimization study for the heat sinks – of both plate-fins and pin-fins - with vertically oriented base. The study was conducted using the analytical and experimental methods. The objective functions for the optimization were the total heat dissipation and heat dissipation per unit mass for a given base to ambient temperature difference. The authors also conducted the CFD simulations using ANSYS ICEPAK. The computational volume was considered larger to increase the simulation accuracy with 10H for the height, 5L for the width and 7L for the length.

Wadhah Hussein [18] had conducted experimental studies by varying the number of perforations on plate-fins. The set-up consisted of 5 fins connected to a cylindrical heat sink. The perforations were varied such as fin with 24 holes, fin with 32 holes, fin with 40 holes, fin with 48 holes and fin with 56 holes. The thermal load was also varied – 6 W, 22 W, 40 W, 50 W, 75 W, 90 W, 120 W, 150 W and 220W – to fully predict the influence of the perforations over a wide range of operating conditions. The temperature along the fin height was compared in each fins and it was observed that fin 56 holes had minimum surface temperature as compared to other fin configurations. This had been observed for all thermal load conditions.

I-Wen Chou [19] had conducted a numerical study to understand natural convection flow from the arrays of horizontal rectangular fins within perforated chassis. The authors had applied symmetry boundary conditions to reduce the simulation time. The three-dimensional, incompressible, laminar simulation was performed in ANSYS FLUENT with the Boussinesq approximation in the buoyancy term in Navier-Stokes equation. They had neglected the radiation heat loss in the simulations. The pressure correction for the incompressible flow was achieved by SIMPLE algorithm. The convergence for the simulation was achieved when the residuals for continuity and momentum equation were less than 10-6 while that of energy equation was less than 10-10.

Iman Jafari [20] had conducted numerical analysis using lattice Boltzmann method for predicting the effects of radial fins – number of fins as well as arrangement – on laminar natural convection flow field (Ra = 103 to Ra = 106) in the horizontally placed circular and rectangular cylinders.

III. OBSERVATIONS

In the pin-fin heat sinks, the staggered arrangement of fins has lesser thermal resistance as compared to the in-line arrangement of fins.

The surface coatings on the fin surfaces could play critical role in enhancing heat transfer rate from fins.

For the CFD simulations, the inlet conditions shall be modeled using ‘pressure-inlet’ boundary condition with static conditions while the flow outlet shall be modeled using ‘pressure-outlet’ boundary condition.

Natural convection heat transfer from plate-fins shall be enhanced by arranging them in staggered pattern as compared to the ‘in-line’ arrangement.

By introducing perforations on the fins, the heat transfer rate could be improved under the natural convection flow field.

While modeling the natural convection heat transfer flow field, the radiation heat transfer mode br neglected and the necessary corrections in the results be carried out.

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