International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 23s, 2025
https://www.theaspd.com/ijes.php

Numerical And Ansys Analysis On Forced Convection With Rectangular Slitted Fins

Dhavamani Chinnathambi[1], Bothiraj T[2], Vetrivel Kumar Kandasamy[3], Pugazhenthi V[4], Pradeepkumar M[5], Silambarasan Rajendran[6], Balu Pandian[7*], Ruby Pant[8],
[1]Department of Aeronautical Engineering, Mahendra Engineering College, Mallasamudram, Tiruchengode, Namakkal, 637503, Tamil Nadu, India.
[2]Department of Mechanical Engineering, R.V.S College of Engineering, Dindigul,624005, Tamil Nadu, India.
[3]Department of Mechanical Engineering, Dhanalakshmi Srinivasan College of Engineerin, Coimbatore, 641105, Tamil Nadu, India.
[4]Department of Mechanical Engineering, Mailam Engineering College, Mailam, Tindivanam, 604304, Tamil Nadu, India.
[5]Department of Mechanical Engineering, Sona College of Technology, Salem, 636005, Tamil Nadu, India.
[6]Department of Mechanical Engineering, Annapoorana Engineering College (Autonomous), Seeragapadi , Salem-636308, Tamil Nadu, India. [6]Department of Mechanical Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences,Chennai, Tamil Nadu, India.
[7]Department of Automobile Engineering, Bharath Institute of Higher Education and Research, Chennai, Tamil Nadu, India,600073.
[8]Department of Mechanical Engineering, Uttaranchal Institute of Technology, Uttaranchal University, Uttarakhand, 248007.
[7*]Corresponding author: balumitauto@gmail.com

Abstract
The present study investigates thermal transfer from rectangles positioned vertically with interrupted fins by external forced convection. Analysing and validating continuous fins based on current analytical results, and an extensive experimental, analytical, and numerical investigation research is carried outto evaluating the impact of fin arrays and interruptions on single walls. A two-dimensional numerical model is created using ANSYS Multiphysics software to study the consequences of fin disruption. A specially created tasted was created in ANSYS to conduct experimental research and validate the analytical and numerical results.According to the results, adding breaks to vertical rectangular fins improves their thermal efficiency and lightens the fin arrays, which can minimise manufacturing costs. On the basis of geometrical parameters, an interrupting wall model has been developed, andA compact relationship based on the Nusselt number has been developed for identifying the optimal interruption length for fin arrays, using blending techniques for the two asymptotes. Heat transfer area is reduced with increasing interruptions, lowering overall heat transfer.As a result of these two antagonistic effects, the most efficient heat transfer from forced-cooled heat sinks can be achieved by an "optimal" fin interruption.
Keywords: Micro-channel Heat sink (MCHS), Slitted in fins, Forced convection, Phase change materials (PCM).

INTRODUCTION

High power density electronics require dependable performance, which requires the creation of effective cooling solutions. Thermal impacts are linked to a multitude of failure processes in electronic devices, including void formation, metal migration, and intermetallic growth. High power electronics' failure rates double every 12°C beyond their working temperature (about 90°C). About 90% of the market is made up of thermal management gear, such as fans and heat sinks. Cooling products are also categorized into software, connectivity materials, and substrates, according to the market, each holds approximately 5 and 7%.With a market share of around 40%, the North American market will continue to lead over this time, followed by the Asia-Pacific region with a range of 25% to 30%. Since virtually every engineering system requires a specific temperature range to operate, this undesirable by-product might reduce the performance of the systems. Failure of the system might result from exceeding these limitations through overheating. At the moment, power electronic devices' heat losses are rising. Their sizes are also getting smaller at the same time. As a result, with every new design, heat sinks must dissipate larger heat fluxes. As a result, developing effective cooling solutions to address these issues is crucial and directly affects the functionality and dependability of electrical and power electronic systems. Electronics and power electronics benefit from passive cooling techniques because they provide a reliable, quiet, and affordable solution. Among passive cooling strategies (PCS), heat pipes, forced convection system for cooling of air, and PCMscan be used to store heat. Heat pipes are effective at transporting heat from high power density converter components to heat sinks due to the phase shift of their working fluid. The fins can be circular, rectangular, triangular, or pin fins;for an example, see Figure 1.

Figure 1: Different fin types, a) rectangular b) radial c) pin fins.

Forced convection is employed to transfer heat from rectangular fins, interrupted and vertical. Detailed discussion of fin heat transfer is outlined in this section. A coefficient model has been developed for the forced convective process from vertical plates and vertical channels using theoretical expressions, graphical correlations, and empirical formulas. This model is based on theoretical and empirical data.Heat sink and fin geometry, such as spacing between fins, height between fins, length between fins, and orientation between fins, were investigated. It provides an overview of the literature review for work that is analytical, numerical, or experimental. The Nusselt (Nu), Prandtl (Pr), and Rayleigh numbers are three dimensionless numbers that are significant in heat transmission (Ra). In the heat transfer literature, these three non-dimensional integers are frequently employed for analytical reasons. The Nusselt number represents the ratio of fluid conduction heat transfer to convection heat transfer under identical circumstances.

$$Nu_l = \frac{h\,l}{k}, \qquad 1\text{-}1$$

where, correspondingly, h - convective coefficient, l- length of the fins, and k - fluid's thermal conductivity. The ratio of heat diffusivity to momentum diffusivity (kinematic viscosity) is known as the Prandtl number.

$$Pr = \frac{\nu}{\alpha}, \qquad 1\text{-}2$$

Where, ν- kinematic viscosity, α - thermal diffusivity of the fluid.

Rayleigh number used to describe flows generated by buoyancy. In a uniform surface heat flow, Ra represents the interaction between buoyancy and viscosity inside a fluid as a product of Prandtl number and Grashof number.

$$Nu_L = \left\{0.825 + \frac{0.387 Ra_L^{\frac{1}{6}}}{\left[1 + (0.492/Pr)^{\frac{9}{16}}\right]^{\frac{8}{27}}}\right\}^2, \quad 1\text{-}3$$

$$Ra_L = \frac{g\beta \, \Delta T L^3}{\alpha \vartheta}, \quad 1\text{-}4$$

$$Gr_L = \frac{g\beta \, \Delta T L^3}{\vartheta^2}, \quad 1\text{-}5$$

WhereΔT - temperature difference between the fins and ambient, $\boldsymbol{\beta}$ - thermal expansion coefficient, and g - gravitational acceleration.

LITERATURE REVIEW

Research on existing electronic systems, a heat sink dissipates heat into the environment so that the device can be cooled. The heat sink's relevant surface area that comes into contact with the surrounding air cooledsystem, the environment, was maximised during design (1-2). Protrusion design, material selection, surface treatment, and air velocity are the variables that impact how well a heat sink performs under ambient conditions.The impact of the thermal interface materials also has an impact on integrated circuit temperature. Thermal grease fills the air spaces between heat sinks and heat spreaders in electronic devices to enhance heat sink performance(3-5).

The device volume and weight grow and their production costs rise, it is crucial to optimise the fins (6). The experimental design of fins currently is the focus of many researchers, including a number of academics who are working on optimizing fins, using either of two strategies: either reducing the volume for a given dissipation quantity, or increasing the amount of heat dissipation for a specific volume. In addition to the fin material's corrosion resistance and thermal, the weight also affects the efficiency of convective heat transfer.An evaluation of performance is provided of the fin is greatly influenced by the geometrical factors like fin length, height, and spacing. It is critical to optimize the fins of the devices since the volumeand weight increase along with the cost of manufacture (7-8). Numerous academics are focusing on optimising fins, which typically involves increasing A volumetric measure of heat dissipation,while also decreasing volume for a given level of heat dissipation.Convective heat transfer efficiency is influenced by thecorrosion resistance, material's weight, and thermal stability of a fin material. The performance of the fin is greatly influenced by the geometrical factors like fin length, height, and spacing. By experimentally examining free convection and radiation heat transmission, explored a vertical sinusoidal wavy type fin structure that was oriented horizontally. They deduced from the findings that wavy fins perform better in terms of heat transmission than traditional rectangular fins(9-12).

Forced convection was used in an experiment using three fin exchangers and a square fin array.An experiment was conducted by changing fin spacing by 5, 9, and 14 mm. The results of the trials revealed that free convection accounts for around 80% of heat transfer from the entire input power to the heating element and radiation accounts for 10%. Convective coefficient grows to a particular value when fin spacing is increased (13).A horizontally oriented array of rectangles was studied for its average heat transfer coefficient using forced convection. According to experimental findings, arrays with shorter fin lengths have an average convection coefficient that is noticeably greater). A solitary chimney flow was observed in the middle of the fins when the flow pattern was examined (14-16).

Horizontal rectangular fin arrays were examined and to determine a parametric modification of the fin impact on heat transmission, investigations based on forced convection were conducted. In order to solve governing equations, CFD code was created (17-18). To understand the impact of heat transfer, a parametric analysis of the fins (fin length fin spacing, and fin height) and the temperature gradient between the fin and surroundings was carried out. A study revealed that each parameter's modification has an impact on the total heat transmission. According to their findings, heat transmission was improved when fin height was increased and fin length was decreased (19-20).

METHODOLOGY

The forced convective process from thefins mounted vertically, rectangular as well as interrupted, which is investigated in this work using a systematic manner. In view of the intricate and non-linear relationships between momentum and energy equations.Which is exceedingly improbable that a universal analytical solution can be found for forced thermal convection heat transfer. As a result, the technique listed below has been used. The goal of this work is to create small, user-friendly thermal models that can forecast how much heat will forcedly convective through broken, rectangular walls and into the surrounding air.Using the effective fin length as a characteristic length, we have created a compact relation between the Nusselt number and the effective fin length by providing two asymptotes and combining them with a hybrid approach. Using ANSYS Multiphysics software, the fin array problem is numerically investigated, and To maximize forced convection, a formula is developed to determine the optimal interruption length of fin arrays. To validate the created models and the suggested correlations, SFU has constructed and built two new experimental test beds.

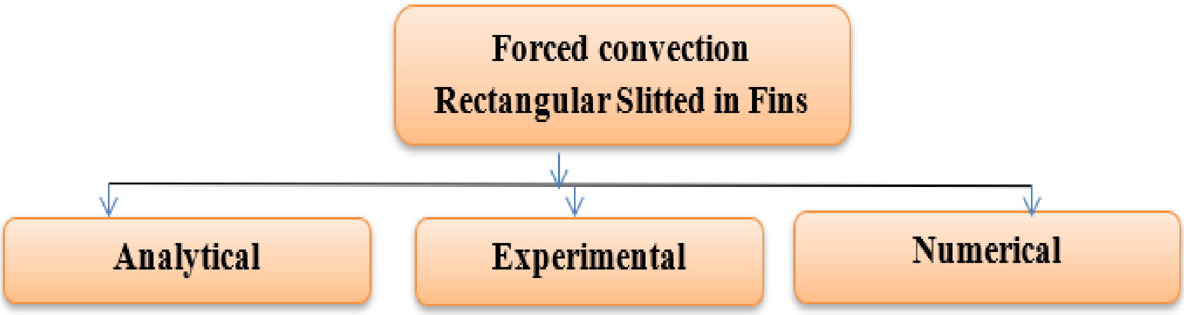
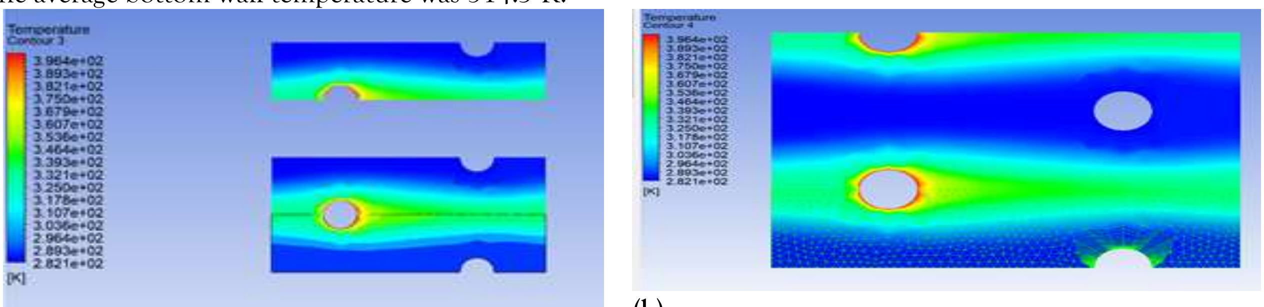


Figure 2: Structure of Process

DISCUSSION

Temperature fluctuation is seen in Figures 3 (a) and (b) for a MCHS with a single branching Slitted in fin. Figure 10 shows that, among all geometries, the MCHS with Slitted single branching fins and a height measurement of the stem of 0.7 mm and with the aid of this slitted in fins, the fluid temperature at the outlet is the lowest and the average bottom wall temperature is the lowest. The MCHSwith single branching slitted fins and aheight measurement of the stem 0.5 mm with a velocity of 5 m/s shows the greatest temperature decrease. In this instance, the fluid collected had an exit temperature of 298 K, while the average bottom wall temperature was 314.5 K.



(a) (b)

Figure 3 (a) and (b) Temperature Distribution of Slitted in Fins

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 23s, 2025
https://www.theaspd.com/ijes.php

In figure 4,Mesh around fins inMCHS sink with twin branching slitted in fins and a height measurement of the stem0.6 mm having a 5 m/s velocity, which exhibit theresults in the greatest temperature decrease. In this instance, the fluid's exit temperature is stated to be 300.45 K, whereas the typical bottom wall temperature is 310.24 K. The branching fin's stem height growing has a similar effect.In the range of 0.4 to 0.7 mm in stem height, the MCHS with double branching fins is better than the MCHS with branching fins and for velocities between 0.25 and 5 m/s because the double branching fins have more branches that enhance the fin's surface area and cause a greater temperature decrease.

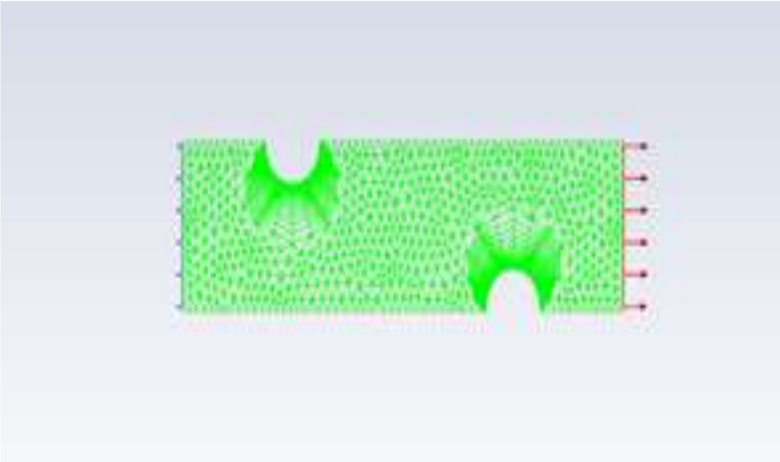


Figure 4 Mesh around Slitted in Fins

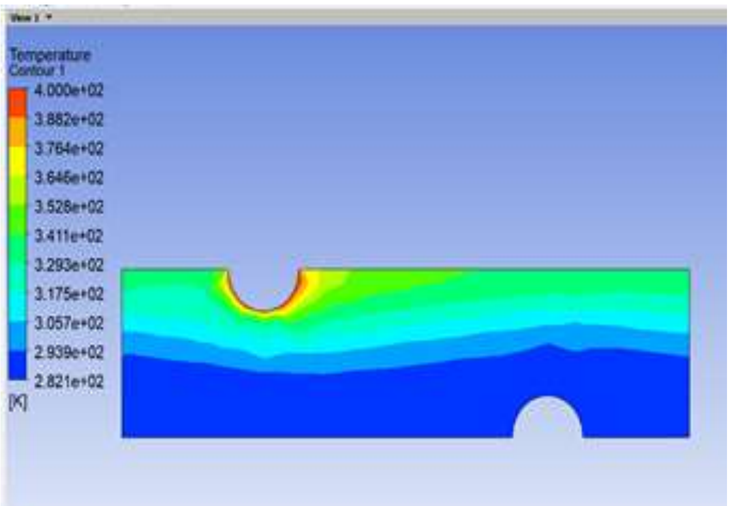
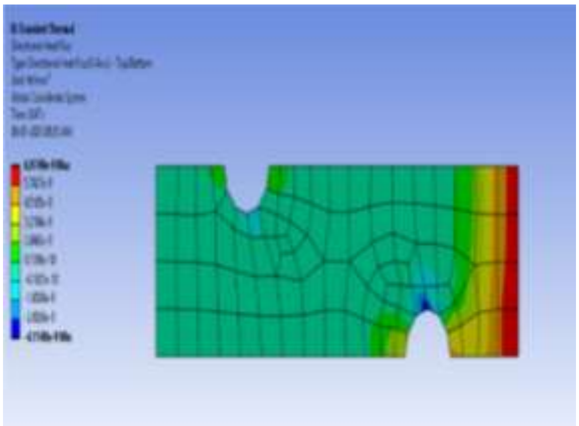


Figure 5Streamwise central plane for pin

Figure 5 presents the temperature change along the stream in the MCHS with double branching slitted in fins.Among all geometries, the MCHS with double branching slitted in fins and a height measurement of the stem0.7 mm.The lowest outlet temperature of the fluid as well as the lowest average temperature of the bottom wall are achieved with this process.Due to buoyancy, air enters from the lower end of the channel, rises as it is heated, and exits from the upper end. Figure 5 shows a heat sink with vertical and horizontal configurations simulated at the same boundary condition. Comparing the performance of vertical plates with vertical fins to horizontal plates, it has been observed that vertical plates provide the best forced cooling.



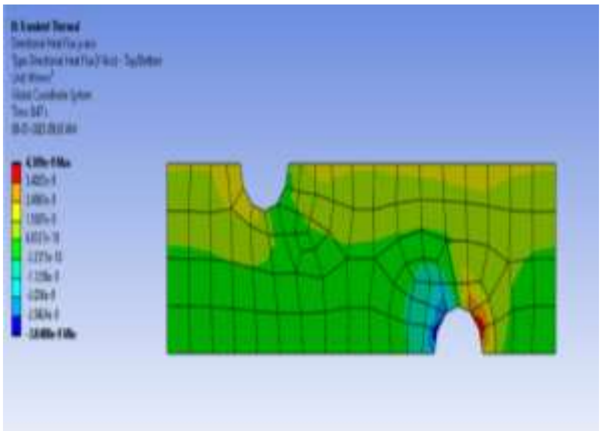


Figure 6 (a)Transient heat flux on X-axis **Figure 6 (b) Transient heat flux Y-axis**

The contours of local Nusselt numbers for fins are shown in Figure 6 (a) and (b), which are exhibited the transient heat flux on X and Y axis of slitted fins. Thermal performance is also assessed using local Nusselt numbers for slitted finsUsing a local heat flux, a local wall temperature, and the local Nusselt number for the fin wall, the bulk mean fluid temperature on the wall of the fin is calculated using the bulk mean fluid temperature on the wall of the slitted fins.Also, heat transfer is reduced near the end region due to low-momentum. Figure 7 shows the total heat flux on heat sink slitted fins.

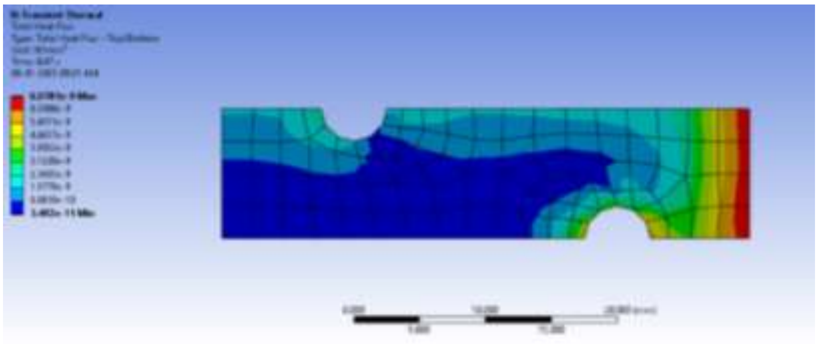
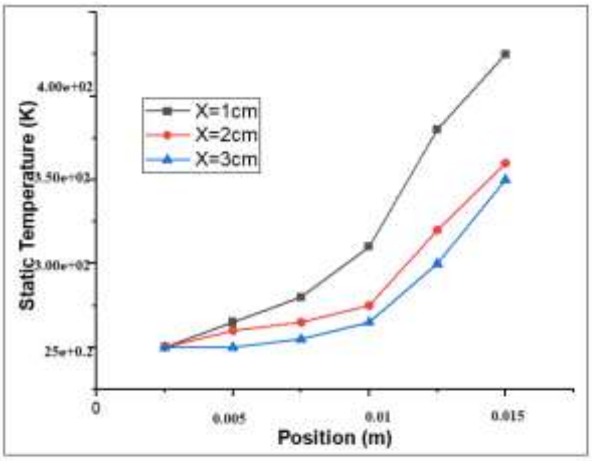


Figure 7 Transient Total heat flux



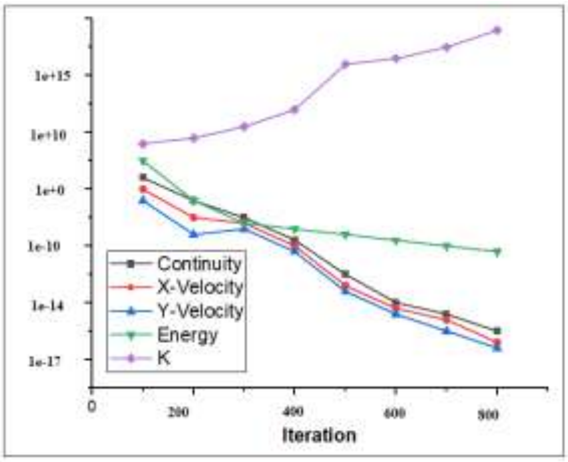


Figure 8 and 9Validation of CFDresults with theexperimental results

The fluctuation of position with static temperature is seen in Fig. 8 above. According to the findings, the heat transfer coefficient steadily reduces as temperature rises due to a drop in air Reynolds number, an increase in thermal conductivity, and a decrease in Nusselt number. Trapezoidal profile heat sink has a lower convective coefficient than rectangular profile.The fluctuation of heat transfer rate with temperature is seen in Fig. 9.Above. The findings demonstrate that when temperature rises, the rate of heat transfer increases gradually due to a combination of factors including an increase in thermal conductivity, a drop in air's Reynolds number, and a rise in temperature differential. According to the calculations above, the surface area of the rectangular profile rises while the heat transfer rate for trapezoidal profiles is almost identical. The findings of numerical studies of rectangular profile while absolving theoretical rectangular profile virtually correspond.

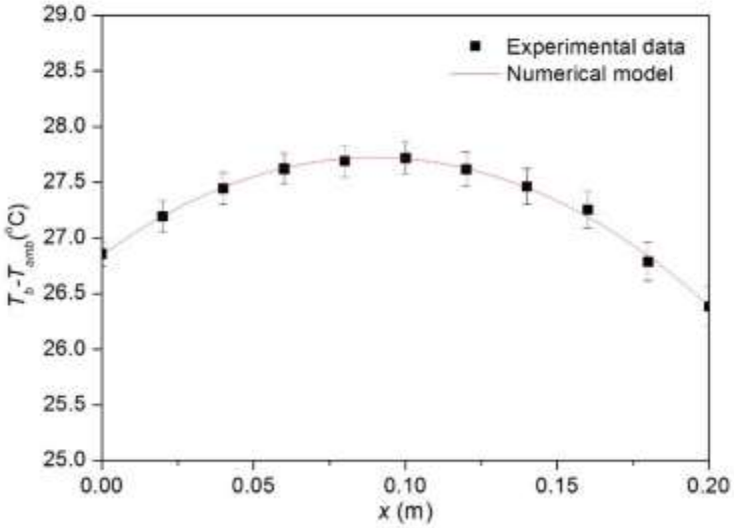


Figure 10 Comparison chart of Numerical and Experimental Model

In Figure 10, a numerical model computes temperature profiles at the base and ambient temperatures when ambient temperature differs from base temperature is the same, while experimental results are compared. Even though the simple numerical model was not able to accurately predict each temperature profile, it was able to adequately forecast some of them.

CONCLUSION

An approach is presented in this work for uniform distribution of temperature on the top surface of a traditionally designed heat sink by using rectangular fins mounted vertically that are slitted and operate under forced airflow.As a result of this approach, standard heat sinks have vertically mounted slitted fins. Inlet airflow is redistributed by the slitted fins that are attached to the heat sink's top surface in order to change the conditions of heat transfer.The proposed new enclosure designs were tested by building slitted in fin arrays and interrupted walls to demonstrate their feasibility across a wide range of fin geometric features.

The designed heat sink was numerically evaluated with Ansys software. On top of the heat sink are convective rectangle slitted fins mounted with forced airflow at a constant speed of 5 m/s.Experimental data validated the numerical and analytical findings; the standard relative difference was 5% and the most significant relative difference was 15.5%.By distributing heat uniformly across the heat sink, the temperature gradient is significantly reduced. The main objective of this study is to determine the interruption length associated with forced convection fin arrays through rigorous numerical analysis. Having a uniform temperature distribution and a high heat flux enhances the performance of the heat sinks.

REFERENCE

- B. Yazicioglu and H. Yuncu, "Optimum fin spacing of rectangular fins on a vertical base in free convection heat transfer," Journal of heat and mass transfer, vol. 44, no. 1, pp. 11-21, 2007.
- S. Ostrach, "An analysis of free convection flow and heat transfer about a flat plate parallel to the direction of the generating of the body force," NACA, 1953.
- K. Starner and H. N. McManus, "An experimental investigation of free-convection heat transfer from rectangular-fin arrays," Journal of heat tranfer, vol. 85, no. 3, pp. 273-278, 1963
- Kobus, C. J., and 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 forced convection with impinging flow." International Journal of heat and mass transfer 48, no. 6 (2005): 1053-1063. https://doi.org/10.1016/j.ijheatmasstransfer.2004.09.042
- He, M.; Li, Z.; Han, X.; Cabassud, M.; Dahhou, B. Development of a Numerical Model for a Compact Intensified Heat-Exchanger/Reactor. Processes 2019, 7, 454.
- Cho, E.S.; Choi, J.W.; Yoon, J.S.; Kim, M.S. Experimental study on microchannel heat sinks considering mass flow distribution with non-uniform heat flux conditions. Int. J. Heat Mass Transf. 2010, 53, 2159–2168
- Maji and G. Choubey, "Improvement of heat transfer through fins: A brief review of recent developments," Heat Transfer, vol. 49, no. 3, Nabeel AbdulhadiGhyadh, Sahib Shihab Ahmed, " Enhancement of Forced Convection Heat Transfer from Cylindrical Perforated Fins Heat Sink-CFD Study", Journal of Mechanical Engineering Research and Developments, Vol. 44, No. 3, pp. 407-419, 2021pp. 1658–1685, Feb. 2020
- Senthilkumar, P., S. Rajesh Babu, B. Koodalingam, and T. Dharmaprabhakaran. "Design and Thermal Analysis on Circular Fin." Materials Today: Proceedings 33 (2020): 2901– 2906. doi:10.1016/j.matpr.2020.02.784.
- N. Senthilkumar, C.K. Dhinakarraj, B. Deepanraj, N. Manikandan Babu, A. Santhosh Kumar, Modification and Analysis of Compressor Inter-Cooler Fin in Turbocharger using FEM, Procedia Engineering, Vol. 38, pp. 379-384, 2012. DOI: 10.1016/j.proeng.2012.06.047.
- Al-Damook, N. Kapur, J. L. Summers, and H. M. Thompson, "An experimental and computational investigation of thermal air flows through perforated pin heat sinks," Applied Thermal Engineering, vol. 89, pp. 365– 376, Oct. 2015
- N. Raja Sekhar, Dr.V.Lakshmikanth Chowdary, "Design and Thermal Analysis of IC Engine Fins for Effective Heat Transfer by Modifying Material and Geometry", International Journal Of Research In Aeronautical And Mechanical Engineering, Vol.8 Issue 6, June 2020 Pg: -12- 22, ISSN: 2321-3051
- G. Naresh , G. Akhil Sai "Steady State Thermal Analysis on Heat Sinks by Varying Fin Configuration Using ANSYS" , MuktShabd Journal, Volume IX, Issue IV, APRIL/2020, ISSN NO : 2347-3150
- Abhishek Jha, Prateek Gupta, "Thermal Analysis of Different Perforated Pin Fins Using ANSYS", Journal of Material Science and Mechanical Engineering (JMSME) Vol. 5, Issiue 2, April-June 2018 pp.71-76,ISSN:2393-9095
- Nilesh Khamkar, AvinashWaghmode, Atul Joshi, Pramod Supekar, Dr. Ashwini Kumar, Prof. Kiran Londhe and Prof. Vipul R.Kaushik,. Heat Sink design for optimal performance of compact electronic appliances-A Review, Journal for Advanced Research in Applied Sciences. Volume 4, Issue 5, Oct-2017 Pages: 13-21
- Sachin R. Pawar, R. Yadav, Computational Analysis of Heat Transfer by Forced Convection from Triangular Notched Fin Array, IJST- International Journal of Science Technology & Engineering, Vol-1, Issue 10, April 2015
- Anuj Kumar,AmitDhiman,LaszloBaranyi, CFD analysis of power-law flow and heat transfer around a confined semi-circular cylinder , International Journal of Heat and mass Transfer 82 (2015) 159-169
- Mon, M. S. and Gross,U. Numerical study of fin-spacing effects in annular-finned tube heat exchangers. Int. J. HeatMass Transf., 2004, 47, 1953–1964.
- V. Kumar, Dr. V. N. Bartaria, CFD Analysis of an Elliptical Pin Fin Heat Sink Using Ansys Fluent V12.1, International Journal of Modern Engineering Research (IJMER), Vol-3, Issue 2, April 2013
- Bopanna K, D Nizamuddin Ali khan, Experimental and CFD Analysis of Aluminum Heat Sinks for Avionics Applications. IJIRST –International Journal for Innovative Research in Science & Technology| Volume 3 | Issue 02 | July 2016.
- R. Kumar, D. Singh, and A. K. Sharma, "Static Thermal Analysis Of Fins Models Using Ansys," May 2020
- V. Karlapalem and S. K. Dash, "Design of perforated branching fins in laminar forced convection," International Communications in Heat and Mass Transfer, vol. 120, p. 105071, Jan. 2021