International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 8 Aug. 2022, pp: 1267-1279 www.ijaem.net ISSN: 2395-5252

Analysis of Fins with Varying Shapes for their thermal behavior in heat sink: A Review

Manisa Irshad Wani[1], Abhishek Sanjay Shinde[2]
(M-Tech, Fluid and Thermal Engineering, Sharda University)
M-Tech, Machine Design, Sharda University)

Submitted: 10-08-2022 Revised: 22-08-2022 Accepted: 24-08-2022

ABSTRACT
At present, the trend to design lighter, thinner and smaller, mechanical cooling equipment's has put the thermal engineers into dire competition to devise the compact cooling techniques. As a result, innumerable engineering setups during their functioning evacuate heat and if this heat is not removedexpeditiously to its surrounding atmosphere, thermal rise may result in system damage and breakdown and if we keep up our current pace of miniaturization, laptops and other electronic gadgets will get heated up tremendously. To solve this problem, efforts are being done by the thermal engineers on manufacturing heat sinks with optimal design in fin profiles to play a major role for dissipating heat and thus maintaining a small heat source at an acceptable temperature range. This requires the thermal management system to be tuned to achieve improved performance with increased heat dissipation, higher reliability, and thus increased life of the electro-mechanical components.This study's primary goal is to consolidate earlier analytical, experimental, and computational efforts based on several heat sink types with varying fin profiles and related design factors.In a review article, it is shown how the ideal heat-sink conditions are determined when forced and free convection, material thermal conductivity, heat sink specifications, and other factors are taken into account.Based on review studies, it can be concluded, that the augmentation in heat transfer performance of a heat sink depends on the geometry of the heat sink which gives the optimal cooling with least material requirement. Thus, the literature studies overview that the design and optimization of heat sink with different fin parameters with varying profiles is an important study to be considered.

Keywords: Heat sink, Miniaturization, cooling techniques, augmentation, design optimization

I. INTRODUCTION

Heat Sink

1.1 Evolution of heat sink design

Now a day's electronic devices have been developed for high performance and consistent stability. For working they need the current to flow through their circuits and hence, become the reason of excessive heating. The need of smaller sizes for well-defined portability and mobility are the major considerations which affect the installation of cooling system, which means the cooling systems must be smaller whilst the performance needs to be greater to maintain the temperature distribution and thus avoid overheating (1-3). A heat sink is an electrical component or device used in an electronic circuit that dissipates heat generated by other components (or devices) into the surrounding medium, cools them, and postpones the premature failure of the components. It incorporates any cooling device, such as a fan, to prevent failure difficulties (4-6). Selection of the most practical heat sink design for a given application The preservation of the operational temperature range, dependence on the thermal conductivity of the chosen material, impact of overall dimensions and weight, type of flow, and thermal budget of the specific design are some of the intrusive requirements that have an impact on the design is a cumbersome job. The following intrusive necessities which affect the design include maintenance of operating temperature range, dependency on the thermal conductivity of the selected material, effect of overall dimensions and weight, type of the flow, thermal budget of the particular design (7-8). The design parameters such as available pressure drop, induced flow velocity, cross-sectional geometry of incoming flow, amount of heat dissipation required, ambient fluid temperature, maximum heat sink temperature, orientation with respect to gravity, cost, and appearance are just a few of the design constraints

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 8 Aug. 2022, pp: 1267-1279 www.ijaem.net ISSN: 2395-5252

for a heat sink design (9-13). As a result, there are a number of different design limitations that apply to heat sink design, and a design engineer must ascertain a heat sink's heat dissipation performance within those restrictions. Thus, applications where a designer has control over optimization, such as fin length, fin height, number of fins or density of the fins, fin spacing, fin shape, base plate thickness, and cross-cut patterns, can result in the best design for a heat sink (14-17). The heat sink evolution uses a variety of improvement strategies to handle the fundamental configurations, such as in-line and staggered, necessary for a specific application. An important area of thermal engineering is the acceleration of heat transport. There are two ways to improve the rate of heat transfer: (1) by increasing the surface area (As) and (2) by increasing the heat transfer coefficient (h) between a surface and its surroundings (10, 30, 18-20).

Rising demand for high performance and multiple functions has resulted in a large increase in power densities thanks to recent advancements in semiconductor technology, yet the amount of physical space available for heat dissipation has reduced (21-22). Modern electronics' tendency toward compact packing and high performance has resulted in a pressing need for efficient cooling systems. The development of efficient cooling systems that are reliable in heat dissipation and thermal control remains a major issue. For effective cooling technologies, a number of heat transfer augmentation approaches are available, and numerous initiatives have been made to create optimum heat sink designs for heat transfer improvement (23). Several research works have focused on determining the best shapes for heat sinks with extended surfaces (fins) that are widely used in heat-exchanging devices to improve heat transfer in the given space in order to benefit from one of the following: increased thermodynamic process efficiency, size reduction, lower operating costs, improved heat generation per unit volume, and thus maintaining the electronics at an acceptable temperature levels below 100°C (24-26). Fin height, fin thickness, fin length, base plate thickness, number of fins, fin profile, space between the fins, material to produce low thermal resistance, and low-pressure drop are some geometric factors and design considerations that affect the choice of an ideal heat sink (27). At present, there are two main categories for popular temperature control techniques: (1) To lower the temperature of the workspace. (2) To focus on new technologies, new structures, and new materials in order to develop a good heat dissipation (28). Recent developments with the problems related to increasing high heat flux with the conventional heat sink designs and applications have made the thermal designer's design high-performance cooling techniques with less surface area and considerably weight and material advantage (29). A simple and advanced used configuration is obtained by using different fin shapes with honeycombs throughout the fin cross-sectional area in-addition to the literature availability on different designs with varying perforated fin diametrical area that mainly leads to material cost reduction, favoring the efficient cooling method in the optimized designed model of the different cross-sectional area of fins in heat sink (30). The present paper reviews the literature dealing with various aspects of cooling methods, including how orientation, perforation, forms, the distance between fins, slots, interruptions, arrangements, and material properties affect the heat sinks' thermal performance. So, a brief literature has been summarized to evaluate the different geometrical designs with main focus for better cooling under different shapes and varying perforations of fins and usage of newly researched material advancement properties/and usage of different materials for advancement for/of high heat removal with tremendous heat flux generation so, the included papers are on experimental work, numerical modeling, under natural and advanced forced cooling methods (31-32).To consolidate this work primarily focuses on the two types of heat sinks with pins and flat surface fins under natural and forced convection, as well as the optimization approaches utilised in designing for the selection of heat sinks, in order to integrate the limited literature.

1.2 Review presentation

Previous studies tried to increase the heat sink's thermal dissipation rate and provide a better understanding of cooling processes by using a variety of heat sink shapes with variable fin profiles. The fin profiles, which serve as a superior approach for improving heat transfer, have been the subject of numerous studies. Therefore, the best selection practises for a given application area are taken into account for effective results. This literature review's goal is to evaluate diverse studies and determine their most effective methodologies. The full analysis of micro-pin fins (cylindrical) was carried out by Ayoobi et al. employing genetic algorithm optimization with seven different fin parameters (size of the root and tip radius, fin and fluid thermal conductivity coefficients, length of the micro pin fin, convection heat transfer coefficient and relative roughness). The study's evaluation of the heat flux and temperature distribution was based on four separate situations. According to the analytical findings, changes in fin root radius had little impact on heat flux function and temperature distribution. While temperature remained constant with respect to other parameters, heat flux increased as relative roughness was increased (33). Furthermore, to enlighten the (33) readings Bahrami et. al validated the analytical results, that increase in roughness leads to enhancement of surface area and heat transfer rate not only in the cylindrical fins but the validation was in good agreement with the tapered and rectangular micro-fins (34). However, with the advancement in electro-mechanical devices heat sink flux also increases accordingly. So, for this high research is in the pipeline to devise the high enhancement procedures to eradicate the ill effects of high heat flux. To investigate such procedures G. Singh investigated circular pin fin at different angles of inclination by analytically analyzing the results with the traditional fins. The results revealed that by increasing the inclination, heat flux function decreased (35). In order to further enhance more improvement in heat flux functions at varying angles of orientation with the various fin parameters and to evaluate the theoretical analysis S.K Farooq conducted analytical evaluation of varying fin height, and fin thickness with heat sink base material and the temperature difference. The results showed best optimal solution at 60^0inclination with better convective heat transfer coefficient and minimal thermal resistance (36). Based on the orientation phenomenon and previous analytical results same validations were investigated experimentally by Kadbhane and Palande who performed a steady state thermal analysis with same conditions on vertical and rectangular fin array. The results were validated with same fin parameters for optimal solution and it was concluded that vertical fin array orientation gave the better optimized heat transfer coefficient when compared with the horizontal orientation fin array (37). Further, the other optimized technique like numerical method was also implemented in various other research studies for heat transfer enhancement using the different fin parametric optimization methods. The enhancement in different heat sink configurations like trapezoidal shape has been numerically compared with the rectangular fin shape by Sharma et al. (38) in four alternative microchannel heat sink topologies. The findings showed that, as compared to the rectangular fin form, the trapezoidal shape was superior in terms of thermal resistance and maximum temperature distribution. Based on the above literature the very basic cooling techniques prefered by the fin designers and thermal engineers are the water cooled and air-cooled mechanisms to cool the heat sinks. The air has the lower thermal properties for conduction so the focus is done on water cooling methodologies but the disadvantages of pressure drop, pumping power and the larger density of liquids makes them more susceptible to leakages but still the heat transfer enhancement by water cooling mechanism is greater than the air-cooling technique. Depending on the application point of view a lot of research is going on for heat dissipation augmentation and a lot has already been done. Khan and Kim numerically investigated the thermal performance of micro-channel heat sinks of seven geometrical shapes (rectangular, varied with rectangular, inverse trapezoidal, trapezoidal bottom, triangular bottom, W shape and semi-oval) by using ANSYS®. A comparison of the seven geometries with Reynolds numbers ranging from 50 to 500 was done using the thermal characteristics of friction factor, Nusselt number, and thermal resistance. According to the findings, the inverse trapezoidal geometry produced the best heat transmission outcomes (39), same analysis was done by (40) for oblique cross sections of microchannel heat sinks with three different geometries (square, semi-circular and trapezoidal) to enhance thermal characteristics and it was concluded that the trapezoidal geometry poses the least thermal resistance and hence better performance. Depending on high researches for better results in geometric designs for fins Xia. G et al. conducted an experimental and numerical investigation to compare the corrugated microchannel heat sinks with the rectangular microchannel heat sink in terms of thermal resistance and heat transfer enhancement. According to the findings, corrugated microchannels had a greater enhancement factor for heat transfer than rectangular heat sinks (41). The design of splayed and wavy arrangements is one such effort to provide even greater performance with new, creative geometry. Lin. L et.al (42) numerically investigated the wavy microchannel to determine the flow and the heat transfer characteristics under a constant pumping power and the changing amplitude of flow direction. The results were compared with the normal and the straight wavy microchannel and it was concluded that the influence of the thermal resistance and the temperature differential reduced with the decrease in the aspect ratio, either by increasing or reducing the wavelength of flow direction. Kim. Y et.al (43-44) conducted the same research as above experimentally but at the varying pumping power and it was concluded that the manifold

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 8 Aug. 2022, pp: 1267-1279 www.ijaem.net ISSN: 2395-5252

microchannel (MMC) has lower thermal resistance when compared with the traditional microchannel heat sink (TMC). To enhance the concept in various other geometries; Junaidi et al. (45) compared the performance of a heat sink with a regular pin fin, , and a hybrid pin fin, a splayed pin fin Using ANSYS FLUENT. The findings showed that the splayed pin fin performed better than the hybrid and regular pin fins in terms of junction temperature. When compared to a typical pin fin heat sink, the cooling effect of splayed pin fin heat sinks produced an improvement of roughly 20% to 30%. But because liquid leakage has drawbacks, high pumping power and greater density of liquids and needful of high maintenance researchers are preferring air cooling over liquid cooling due to easy availability of air, reduced cost, easy transfer mechanism and simplicity of design and for heat enhancement evaluation. With the use of high aspect channels, high heat flux conventional heat sinks can be largely reduced, and thus heat transfer and heat dissipation can be further improved. (46-49). Gunnasegara. P et al. numerically investigated the effect of various geometrical parameters (height, width and diametrical diameters) on rectangular, triangular and trapezoidal microchannel heat sink using finite volume method to evaluate the liquid and the heat flow characteristic for Reynold's number ranging from 100-1000. Comparing rectangular microchannel heat sinks to trapezoidal and triangular microchannel heat sinks, the results showed that rectangular microchannel heat sinks displayed the best overall performance (50). Further investigation was carried out for the comparisons between double layered microchannels and the single layered microchannels and based on the results evaluations, DLMCHS outperformed SLMCHS. (51-53). Due to the above literature, still the researchers feel more problems under forced convection methods due to the fan maintenance as its reliability reduces noise production increases within the time. In addition to cost effectiveness if fan breaks during mid-way then extra charges. Therefore, it can be concluded and addressed that air cooling by natural convection can have impactful effects on the performance of CPU heat sink designs. So, for this design engineers have been using the concept of perforated fins for heat sinks under various geometries both in terms of material effectiveness and cost reduction.

1.3 Perforated Fin Arrays under Natural and Forced convection

Most of the recent works carried out in the exhaustive literature considering various configurations and the evaluation for heat transfer augmentation with respect to either experimental, numerical, analytical or a combination of all the three involving comparative investigation for a modified heat sink design with the fin profiles for a particular application. But the pipeline research demanding the high heat flux removal and thus, better reliability in terms of performance and heat dissipation has put a new concept of perforating fin arrays and with regard to the aforementioned problems related to compactness and heat flux removal various studies has been under literature involving the different heat sink designs with various fin profiles for design optimization in terms of cost and weight reduction. For this, various literatures put into the heat sink design modification include: Initially the researches were done on solid fins and for better performance the continuity shifted toward various comparisons of notches and dimples but due to overheating and high heat flux problems the required amount of heat should be transferred with the smallest quantity of material. Using inline and staggered chords, Maji A, et al. (54) carried out a numerical analysis on the improvement of heat transmission via a pin fin with varying numbers, shapes, and drilling sizes under forced convection. Perforated fins of various geometries were compared to equivalent solid fins in terms of heat transfer rate, pressure drop, and system enforcement. The system models were created using the ANSYS 14 software fluent. The bottom of the base plate, which has an area of (0.10.1) m2 and a thickness of 3mm, received a constant heat flux of 5903 W/m2 coupled to a 60 W AC power source. The results showed that, up to a particular perforation number and size, the heat dissipation rate of all the drilled fins was always greater than that of the corresponding solid fins. It was found that the staggered elliptical fin outperformed the linearly oriented solid circular fins in terms of Nusselt number (Nu), pressure drop (ΔP), and system performance (highest thermal transfer speed). Additionally, it was found that circular perforations perform better at higher velocity when fins are positioned in a staggered fashion, whereas elliptical perforations at lower velocities offer stronger heat dissipation against reduced pressure loss. Similarly, S.C. Muthuraja, et al (55) experimentally investigated the comparative study between rectangular fin with circular perforations with the non-perforated fin of same dimensions by using natural convection. The dimensions and thermal properties of the fin design and the properties of the perforations were taken into the experimental studies to find the improvement in heat surface area and the heat enhancement improvement. It was concluded that the perforated fin has improved thermal properties when compared with the solid fin of same dimensions. Same study was enhanced in the vertical fins by Sudheer et al. (56) under same conditions using finite element analysis and it was concluded that the perforated fin results in the reduction of temperature as the diameter of perforation increased. In-order to further attain the better performance many researchers tried to expand their research field of work by using rectangular fins with rectangular perforations and validate the same with other type of perforation under same dimensions and such study was carried by Abdullah H. AIEssa et al. (57) conducted a numerical analysis of the heat transfer from a horizontal rectangular fin implanted with square and rectangular dimples of two orientations during natural convection. The finite element approach was used to conduct the investigation. Based on perforation characteristics, the study compared the heat dissipation rates of solid fins with perforated fins. For a specific range of the perforation dimension, they discovered that square perforations to the fin body maximise surface area and heat dissipation. Based on the perforation of geometry and positioning of fins in previous literatures it was elaborated that with increase in fin inclination heat dissipation increases so with this thought various researchers put a brief study on the effect of fin inclination with a variety of fin perforations, so for this in an experimental research using steady-state natural convection, Awasarmoland Pise (58) looked at the thermal performance of a perforated rectangular fin array in a thermal sink with various hole diameters and inclination angles. The drill's diameter was between 4 and 12 mm, the input power was between 15 and 35 watts, and the tilt angle was between 0 and 90 degrees. The impact of these variables was investigated, and the outcomes with the matching solid fins under the identical circumstances were compared. The heat transfer coefficient of the fins with a 12mm drilled diameter and a 45° tilt angle was found to be 32% greater than that of the solid fins. It was determined that the drilled fins conserved around 30% of the material by mass and improved heat transfer with consistently lower temperatures along the fin length. The size and number of perforations became the subject of more research, and it was found that larger perforations generally transferred more heat than smaller ones, improving the qualities of heat transmission. Same type of study was conducted by K. Shivasheesh et. al (59) to evaluate the effect of heat transfer coefficient depending on 'the number and location of perforations'. It was concluded that as number of perforations increases, temperature drop decreases and thus, the heat transfer coefficient increases and to further enhance this concept in further geometries the same study was further enhanced by P.K and Siddikh (60) who evaluated the steady state heat transfer between various fin perforations and the equivalent solid fin in a number of fin arrays with various types of perforations, including square, elliptical, circular, and triangular using Ansys. The study was based on the fin size perforation, the location of the perforation and on the geometrical parameters. It was concluded that at 12mm circular fin perforation showed better performance as compared to other fin perforation and the equivalent solid fin. As the literature suggested that the fins height has a positive relationship with the number and size and location of perforations and all posses a good outcome effect on heat transfer augmentation and as such Hamadani et al. (60) experimentally evaluated the impact of fins height on location as well as on number of circular perforations under natural convection using vertical fins. They concluded that the fin with five circular perforation of 6cm height outperformed the other fin numbers of 8cm and 10cm height. They found that the heat transfer coefficient increased with number of holes. Further in-order to support the above literature same study was performed by Goshayeshi et al. (62) who numerically investigated the effect of horizontal and vertical fins. The results concluded that the vertical fins outperformed the horizontal fins and gave the better performance for natural cooling. However various literature have proved that as the number of perforation increases beyond a certain limit for a particular application area reduction in heat dissipation occurs and as such Prasad. L et al. (63) experimentally investigated the effect of number of perforations under steady state thermal analysis. The study compared the effect of number of perforations with the fin without perforations. They concluded that heat dissipation increased almost 20-60% more as the number perforation increased and beyond that heat dissipation decreased (64). Many multiple researches are improving the heat transfer mechanism from the fin design optimization and based on the modern-day devices that utilizes more power for performing the particular operation demand higher advancement in the heat dissipation techniques and the studies performed for such measures involve advancement in natural convection and thus researches are also focused on the forced convective heat transfer methods and as such the effects of perforated pin fins on thermal performance, temperature

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 8 Aug. 2022, pp: 1267-1279 www.ijaem.net ISSN: 2395-5252

distribution, pressure loss, and level of perforation under forced convection were studied numerically and experimentally by Tijani and Jaffri (65). The thermal sink was positioned inside a channel with air flowing through it at speeds ranging from 1 m/s to 3 m/s, and the experiment was conducted at an ambient temperature of 25^0C. In this piece, base plate, perforated fins, and solid fins were all designed in tandem and contrasted. The perforated flat plate and pin fin heat sinks enhanced the heat transfer coefficient by 8.95% and 6.23% more, respectively, than the comparable solid pins and flat plate, according to the results.The experimental work showed the effect of perforation and Reynold's number on heat transfer coefficient, it was observed that as the convective surface area increases, the heat transfer also increases. In addition, the Nusselt number was increased from 2% to 4% when perforated fins were used instead of a solid pin fin, therefore, thermal efficiency of the fins for perforated pin fins was higher due to higher Nusselt number when compared to solid pin-fins. The base temperature for the experiment, on the other hand, was typically 6.05% to 9.52% higher than the base temperature of the CFD simulation. The experiment's perforated fin was found to have a reduced pressure drop, which boosted the heat sink's thermal efficiency. Various studies have used different fin parameters and focused on the location of perforations for heat transfer enhancement and to validate this theoretical analysis Damook. et al (66) experimentally investigated the effect of fin perforation parameters (location and number) under forced convection. The study evaluated the heat transfer and pressure drops across the pin fin heat sinks and concluded that with increase in the number of perforations heat transfer also increased but the effect of perforation location did not show any effect on the heat transfer augmentation. Additionally, the outcomes were in strong accord with the findings of the analysis. However, later during the same year more researchers found that the location of perforation can contribute a crucial role in heat transfer enhancement and for this Shadlaghani et al. (67) numerically investigated the different heat sink fins (triangular, rectangular and trapezoidal) under forced convection, they found the triangular fin provides better heat transfer characteristics as compared to rectangular and trapezoidal fins. Later they also concluded that the effect of thermal parameters also contributes in the overall performance of the heat sinks fins with different perforations and thus concluded that the location of perforation is also essential in liquid flow as the increase in fin perforations is limited after a certain limit. Further advanced researches were conducted for better performances required for the particular applications and Chingulpitak. S et al (68) numerically investigated the lateral perforated plate-fin heat sink (LAP-PFHS) with circular perforations to evaluate the thermal effects of design parameters (perforation diameter, number of perforations) on pressure drop and heat transfer rate and a comparison between the solid fin heat sink (SFHS) and LAP-PFHS is made based on the computational results and the experimental data from the previous literatures. The outcomes concluded that the heat transfer rate increased about 10.6% and 28% reduction in volume in LAP-PFHS was seen when compared with the SFHS under same dimensions. Later to develop the relationship of temperature difference between the base and the atmosphere Patil et al(69) experimentally investigated the effect of perforation in a rectangular perforated fin to evaluate the temperature difference (between the base and the atmosphere) and to evaluate the effect of percentage of perforation to select the better and optimal design. The results were found in good accord with the analytical findings using CFD. It was concluded that the thermal behavior increased with the 30% perforation when compared with the other percentage perforations. Various design considerations are a new research hunt for design engineers to attain the ideal surface area for thermal management of high-performance applications. The hexagonal honeycomb construction offers a large surface area that effectively facilitates conduction and natural convection in the fins of electronic devices. To validate the assumptions Maidin and Azmi (70) analytically investigated the design structures of the honeycomb for cooling of LED street lamps using Ansys workbench. A comparison was made between the normal LED street lamp fin and a lamp containing the honeycomb structure fin. The results were validated based on the heat flow rate, contact surface area and cooling efficiency. It was concluded that the fin with honeycomb structure was better in performance and thus, possess the potential of increasing the working life of the device when compared with the normal working fin in the LED street lamp. With continuous research going on to improve the effectiveness and to investigate the performance of hexagonal honeycombs with other fin profiles Jassem. R (71) experimentally investigated the heat transfer enhancement in the rectangular fin plate. The study involved five fin plates containing the first as without perforation and rest four plates consisting of perforations of different shapes (square, circular,

International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 8 Aug. 2022, pp: 1267-1279 www.ijaem.net ISSN: 2395-5252

triangular, hexagonal) under natural convection and same cross-sectional area. The results showed the maximum heat transfer in the triangular perforation followed by the circular, square, hexagonal and the solid fin. Liu et al (72) conducted an experimental study on the honeycomb microchannel to determine efficient cooling performance and heat transfer characteristics for a multilayered flat thin rectangular plate with honeycomb perforations under steady state conditions. The experimental validation was done using different flow rates under different pumping powers and it was found that the best cooling performance was at 2.4W pumping power and removed a heat flux of about $15.7W/cm^2$. Further, to enhance a reduction in the heat power density (70) same study was carried under same conditions using different arrangements of multilayered honeycomb structures and obtained better removal of heat flux of about 18.2 W/cm^2 and better heat transfer characteristics (73-74). A serious issue faced by the thermal design engineers is the need for high thermal conductivity property. Pure Aluminum, Copper etc. have low coefficient thermal expansion and to overcome this issue various alloys of different elements are tested for the required heat transfer enhancement in the specific application. The devices where high level of thermal management is required for optimal results both in terms of designing and the methodology and such needs can be fulfilled by the right choice of materials. The various literatures using different materials for better testing results include: In an experimental investigation of the relationship between circular dimple sizes and forced convection heat transfer characteristics in both the longitudinal and lateral directions, Dafedar et al. demonstrated that larger dimple size improves heat transfer performance. The study's methodology involved comparing the flow rates of stainless steel with galvanised iron. Reynold's number, Nusselt number, Prandtl number, coefficient of friction, heat transfer coefficient, and heat transfer rate for a constant Prandtl number were the parameters taken into consideration for the study. It was concluded that galvanized iron possesses more heat coefficient and hence better cooling was obtained as compared to the result where stainless steel was used (75). To enhance the concept of same study was done in natural convection under steady state conditions (76). The study was done using different perforation shapes (circular, triangular, square) under same condition as above and the triangular was evaluated to present better cooling benefits than the rest of perforation shapes. Wen et al. numerically and experimentally investigated the pressure drop and heat transfer effect in sandwich metallic honeycomb (square, trapezoidal and hexagonal shapes) under uniform heat flux using forced convection. It was proved that the heat transfer rate depends on the thermal conductivity of the material and the geometric properties (surface area, density and cell shapes), they also concluded a better relationship agreement between the numerical and the experimental results. (77). Further to enhance same concept with the cell shape morphology T. J. Lu. investigated the performance of metallic honeycomb cells subjected to forced convection. The method was examined to determine the impact of thermal factors on cell morphology and heat transfer coefficient. The outcomes were found to be similar to those seen in metallic foams (78), Gu et al. (79) expanded the strategy and created analytical models and dimensionless indices that allow for the simultaneous evaluation of the structural and heat transfer performance of metallic honeycomb structures with triangular, square, and hexagonal cells in order to improve the concept of T.J. Lu. To find cell shapes that improve structural heat transfer performance for a given relative density, a two-stage optimization process was used. In addition to the theoretical analysis Kumar and Mc Dowell (80) introduced the concept of using different materials for a given set of applications to improve the design and obtain the better cooling for optimal multifunctionality. For superior designs Seepersad et al (81) focused on designing a periodic and functionally graded honeycomb structure in addition to the structural and thermal performance characteristics with tradeoffs between the different cellular metallic designs. Later various other performance based material studies were conducted and Dempsey et al.(82) experimentally conduced comparative performance measurements between the stochastic cellular materials and the linear cellular alloys (LCAs). The measured study was done to determine the thermal properties of LCA materials. The results were compared to the results obtained from finite difference method and CFD software and were proved to be in good agreement with each other. From the previous literature it was suggested and investigated that more number of perforations generate more heat transfer rate and as such multilayered perforations also generates an excellent heat dissipation rate, but Bower et al. (83) experimentally performed the pressure drop and heat transfer characteristics in a single and multi-layer carbide heat sinks. They concluded that the single layer outperformed the multilayered carbide heat sink. Later this concept was validated with other shapes and for this Liu et al. (84) experimentally investigated the multilayered staggered honeycomb cell microchannels of rectangular metal plate heat sink. The parameters (pipe diameters, pumping power) were studied to evaluate the heat transfer performance under very low flow rate conditions. The result showed the production of uniform temperature production on the heat sink substrate and a double inlet and outlet pipe heat sink outlined the better performance as compared to single inlet/outlet pipes. The results showed a better heat flux removal rate of 17.7 W/cm^2 under 0.7 W pumping power and thus concluded that the above heat sink caused be used for long-electronic devices under a small flow rate. In recent years, due to high package densities, thermal management of compact devices has been a great research for engineers and a trending concept of PCMs has been widely invested as the forced convection needs bulky and the massive fans and thus is not preferable in handheld devices. The main advantage of PCM is that they are relatively light possess good energy storage density and possess desirable thermal management properties (85-89).Similarly, to evaluate the effect of material property Fok et al. (90) experimentally conducted a study to investigate the heat transfer characteristics using n-eicosane as the phase change material. Transient thermal analysis was done on the heat sinks with and without fins. The analysis was based on the device's orientation, fin count, and power output under demanding and appropriate usage conditions.It was concluded that the heat sink with fins gave better heat transfer enhancements than the one without fins. In the previous studies it was known that as the number of fins is increased beyond a certain limit it would result in poor cooling performance but Arulmurugan et al (91) experimentally investigated the different fins with and without PCM to evaluate the thermal performance based on PCM usage. Pin fin heat sinks were used, the results concluded that the usage of PCM lead to increase in heat retention property for a longer period of times with more number of fins as compared to those pin fins without using PCM and hence, the results were in better performance as compared to those which did not use PCM. Similarly, Guesaab and Aris (92) conducted a numerical simuation using ANSYS fluent under forced convection. The simulation was carried out to examine the thermal and hydraulic performance of a copper-cored plate fin heat sink. The analysis and investigation of the fin parameters—pressure distribution, pressure drop, velocity, and temperature for a solid and fluid—resulted in good agreement with previous research. Besides to implement the use of notches and to investigate the thermal effects Zaidshah and Yadav (93) analyzed different types of fins with notches of different shapes and materials to present a review of different types of materials used in enhancing the thermal properties and better cooling performance. So, in this paper various fin geometries with varying fin design constraints have been studied and based on the above literature it can be consolidated that the semiconductor industry is heading towards further advancements in their technology for the required electronic devices and aid in further advancements in the designing of respective devices both in terms of performance and cost effectiveness.

II. CONCLUSION

This paper has provided a brief literature in the geometrical designing era of heat sinks required for the enhancement in heat dissipation with decrease in heat flux for the aid in keeping in pace the technological advancements and requiring necessities in the semiconductor industry. In this paper both active and passive heat sinks have been studied with different fin arrangements. Different cooling technologies have been studied and depending upon the need both forced and free convention has been studied. High-tech devices with better conductive materials have also been reviewed for heat sinks. In addition new optimized designs with varied perforations of heat sinks has also been suggested. So, it can be concluded that although a lot of literature is available and already a heap of research has been done in this field but a lot is still to do with the new technologies and thus, aiding in the new innovative designs for the semiconductor industry.

BIBLIOGRAPHY

[1]. Kim DK, Jung J, Kim SJ. Thermal optimization of plate-fin heat sinks with variable fin thickness. International Journal of Heat and Mass Transfer. 2010 Dec 1;53(25-26):5988-95.

[2]. Dewan A, Srivastava P. A review of heat transfer enhancement through flow disruption in a microchannel. Journal of Thermal Science. 2015 Jun 1;24(3):203-14.

[3]. Ndao S, Peles Y, Jensen MK. Multi-objective thermal design optimization and comparative analysis of electronics cooling technologies. International Journal of Heat and Mass Transfer. 2009 Sep 1;52(19-20):4317-26.

[4]. Zhao CY, Lu TJ. Analysis of microchannel heat sinks for electronics cooling.

International Journal of Heat and Mass Transfer. 2002 Nov 1;45(24):4857-69.

[5]. More AJ, Kore SS. Advance Heat Sink Cooling Technologies for High Power Chips.

[6]. AkshendraSoni., 2016. Study of Thermal Performance between Plate-fin, Pin-fin and Elliptical Fin Heat Sinks in Closed Enclosure under Natural Convection. International Advanced Research Journal in Science, Engineering and Technology, Vol. 3, Issue 11.

[7]. Arularasan R, Velraj R. CFD analysis in a heat sink for cooling of electronic devices. International Journal of the computer, the internet and management. 2008;16(3):1-1.

[8]. Joshi Y, Ikhar D. A Literature Review on Design and Performance analysis of Graphite metal as Heat sink for Microprocessor in CPU. (ISSN: 2321–5747) International Journal on Mechanical Engineering and Robotics (IJMER). 2015.

[9]. Baldry M, Timchenko V, Menictas C. Optimal design of a natural convection heat sink for small thermoelectric cooling modules. Applied Thermal Engineering. 2019 Sep 1;160:114062.

[10]. Cucumo M, Ferraro V, Kaliakatsos D, Marinelli V. Theoretical and experimental analysis of the performances of a heat sink with vertical orientation in natural convection. International Journal of Energy and Environmental Engineering. 2017 Sep;8(3):247-57.

[11]. Shende MD, Mahalle A. Cooling of electronic equipments with heat sink: a review of literature. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE). 2013 Jan;5(2).

[12]. Dhaiban HT, Hussein MA. The Optimal Design of Heat Sinks: A Review. Journal of Applied and Computational Mechanics. 2020 Oct 1;6(4):1030-43.

[13]. Unni, R.V. and Majali, V.S., 2019. A review on rectangular heat sinks under natural convection.

[14]. 14) Kumar, V.M., Farooq, S. and Rao, B.N., 2016. A Review of Microchannel Hear sink. Australian Journal of Basic and Applied Sciences, 10(9), pp.230-238.

[15]. Shende, M.D. and Mahalle, A., 2013. Cooling of electronic equipments with heat sink: a review of literature. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE), 5(2).

[16]. Khonsue, O., 2018. Enhancement of the forced convective heat transfer on mini pin fin heat sinks with micro spiral fins. Heat and Mass Transfer, 54(2), pp.563-570.

[17]. Gu, L., Ling, X. and Peng, H., 2012. An experimental and numerical investigation of air side heat transfer and flow characteristics on finned plate configuration. Heat and Mass Transfer, 48(10), pp.1707-1721.

[18]. Saste, S., Doshi, H., Khalate, P., Jedhe, S. and Yadav, N., 2018. Modification in Heat Sink Design to Improve its Heat Dissipation Capacity for Current CPU Design.

[19]. Khattak, Z. and Ali, H.M., 2019. Air cooled heat sink geometries subjected to forced flow: A critical review. International Journal of Heat and Mass Transfer, 130, pp.141-161.

[20]. Peles, Y., Koşar, A., Mishra, C., Kuo, C.J. and Schneider, B., 2005. Forced convective heat transfer across a pin fin micro heat sink. International Journal of Heat and Mass Transfer, 48(17), pp.3615-3627.

[21]. Sparrow, E.M., Ramsey, J.W. and Altemani, C.A.C., 1980. Experiments on in-line pin fin arrays and performance comparisons with staggered arrays.

[22]. Gunjal, V.N., Kothare, C.B., 2015. A review on experimental investigation of heat transfer of pin fin heat sink. International Journal of Advance Research and Innovative Ideas in Education IJARIIE-ISSN(O), pp.475-481. Vol-1, 5

[23]. Bilen, K., Akyol, U. and Yapici, S., 2001. Heat transfer and friction correlations and thermal performance analysis for a finned surface. Energy Conversion and Management, 42(9), pp.1071-1083.

[24]. Abdualh, M., 1993. Enhanced Heat Transfer Missing Ping and Optimization for'Cylindrical Pin Fin Arrays.

[25]. Tahat, M.A., Babus' Haq, R.F. and Probert, S.D., 1994. Forced steady-state convections from pin-fin arrays. Applied Energy, 48(4), pp.335-351.

[26]. Lee, S., 1995. Optimum design and selection of heat sinks. IEEE Transactions on Components, Packaging, and Manufacturing Technology: Part A, 18(4), pp.812-817.

[27]. Khan, W.A., Culham, J.R. and Yovanovich, M.M., 2006. The role of fin geometry in heat sink performance.

[28]. Mokheimer, E.M., 2002. Performance of annular fins with different profiles subject to variable heat transfer coefficient. International Journal of Heat and Mass Transfer, 45(17), pp.3631-3642.

[29]. Bar-Cohen, A., Iyengar, M. and Kraus, A.D., 2003. Design of optimum plate-fin natural convective heat sinks. J. Electron. Packag., 125(2), pp.208-216.
[30]. Sharma, G., Sharma G.S., and Panchaity, A.,2017. Fem analysis of fins with varying shapes and material for their thermal behavior and applications: A Literature Review. International Journal for scientific Research and Development, pp.798-800 vol-5,9.
[31]. Gaurang Sharma, AkshayPanchaity, AvinChandrakar. Fem Analysis of fins With Varying shapes and Material for their thermal behaviour and applications.International Journal of Research.Vol 4, No 10.
[32]. Wen, M.Y. and Yeh, C.H., 2017. Numerical study of thermal performance of perforated circular pin fin heat sinks in forced convection. Heat and Mass Transfer, 53(6), pp.2031-2044.
[33]. Ayoobi, A., Ramezanizadeh, M. and Alhuyi-Nazari, M., 2020. Optimization of temperature distribution and heat flux functions for cylindrical and conical micro-fins by applying genetic algorithm. Journal of Thermal Analysis and Calorimetry, pp.1-12.
[34]. Bahrami, M., Yovanovich, M.M. and Culham, J.R., 2007. Role of random roughness on thermal performance of microfins. Journal of thermophysics and heat transfer, 21(1), pp.153-157.
[35]. Singh G., Natural convection heat transfer from modified 1degree 2 degree and 3 degree outward expansion of pin fins, International Journal of Engineering Science and Computing, 7, 2017, 14567-14570.
[36]. Farooq, S., Effect of Fin Inclinationson Natural Convection Heat Transfer by using CFD. International Journal of Engineering and Technology, ISSN (Print), pp.2319-8613.
[37]. Kadbhane, S.V. and Palande, D.D., 2016. Experimental study of natural convective heat transfer from vertical rectangular fin array at different angle of inclination. International Journal of Current Engineering and Technology E-ISSN, pp.2277-4106.
[38]. Sharma, D.E.E.W.A.K.A.R., Singh, P.P. and Garg, H.A.R.R.Y., 2013. Numerical analysis of trapezoidal shape double layer microchannel heat sink. Int. J. Mech. Ind. Eng, 3(1), pp.10-15.
[39]. Khan, A.A. and Kim, K.Y., 2016. Evaluation of various channel shapes of a microchannel heat sink. International Journal of Air-Conditioning and Refrigeration, 24(03), p.1650018.
[40]. Vinoth, R. and Kumar, D.S., 2018. Experimental investigation on heat transfer characteristics of an oblique finned microchannel heat sink with different channel cross sections. Heat and Mass Transfer, 54(12), pp.3809-3817.
[41]. Xia, G., Ma, D., Zhai, Y., Li, Y., Liu, R. and Du, M., 2015. Experimental and numerical study of fluid flow and heat transfer characteristics in microchannel heat sink with complex structure. Energy Conversion and Management, 105, pp.848-857.
[42]. Lin, L., Zhao, J., Lu, G., Wang, X.D. and Yan, W.M., 2017. Heat transfer enhancement in microchannel heat sink by wavy channel with changing wavelength/amplitude. International Journal of Thermal Sciences, 118, pp.423-434.
[43]. Kim, Y.H., Chun, W.C., Kim, J.T., Pak, B.C. and Baek, B.J., 1998. Forced air cooling by using manifold microchannel heat sinks. KSME International Journal, 12(4), pp.709-718.
[44]. Mohith, S., Karanth, P.N. and Kulkarni, S.M., 2019. Recent trends in mechanical micropumps and their applications: A review. Mechatronics, 60, pp.34-55.
[45]. Junaidi, M.A.R., Rao, R., Sadaq, S.I. and Ansari, M.M., 2014. Thermal analysis of splayed pin fin heat sink. International Journal of Modern Communication, Technological Research, IJMCTR, 2(4).
[46]. Vinodhan, V.L. and Rajan, K.S., 2014. Computational analysis of new microchannel heat sink configurations. Energy Conversion and Management, 86, pp.595-604.
[47]. Tuckerman, D.B. and Pease, R.F.W., 1981. High-performance heat sinking for VLSI. IEEE Electron device letters, 2(5), pp.126-129.
[48]. Peng, X.F. and Peterson, G.P., 1996. Convective heat transfer and flow friction for water flow in microchannel structures. International journal of heat and mass transfer, 39(12), pp.2599-2608.
[49]. Harms, T.M., Kazmierczak, M.J. and Gerner, F.M., 1999. Developing convective heat transfer in deep rectangular microchannels. International Journal of Heat and Fluid Flow, 20(2), pp.149-157.

[50]. Gunnasegaran, P., Mohammed, H.A., Shuaib, N.H. and Saidur, R., 2010. The effect of geometrical parameters on heat transfer characteristics of microchannels heat sink with different shapes. International communications in heat and mass transfer, 37(8), pp.1078-1086.
[51]. Wong, K.C. and Muezzin, F.N.A., 2013. Heat transfer of a parallel flow two-layered microchannel heat sink. International communications in heat and mass transfer, 49, pp.136-140.
[52]. Wu, J.M., Zhao, J.Y. and Tseng, K.J., 2014. Parametric study on the performance of double-layered microchannels heat sink. Energy conversion and management, 80, pp.550-560.
[53]. Lin, L., Chen, Y.Y., Zhang, X.X. and Wang, X.D., 2014. Optimization of geometry and flow rate distribution for double-layer microchannel heat sink. International Journal of Thermal Sciences, 78, pp.158-168.
[54]. Maji, A., Bhanja, D. and Patowari, P.K., 2017. Numerical investigation on heat transfer enhancement of heat sink using perforated pin fins with inline and staggered arrangement. Applied Thermal Engineering, 125, pp.596-616.
[55]. Muthuraja, C.S., Kumar, A. and Hanoca, P., 2015. Experimental study of the perforated rectangular fins by natural convection. International Journal of Advanced Technology in Engineering and Science, 3(1).
[56]. Sudheer, M., Shetty, A. and Somayaji, S., 2015. Finite element investigations of temperature distribution in fins with circular perforations. American Journal of Materials Science, 5(3).
[57]. Al-Essa, A.H. and Al-Hussien, F.M., 2004. The effect of orientation of square perforations on the heat transfer enhancement from a fin subjected to natural convection. Heat and mass transfer, 40(6), pp.509-515.
[58]. Awasarmol, U.V. and Pise, A.T., 2015. An experimental investigation of natural convection heat transfer enhancement from perforated rectangular fins array at different inclinations. Experimental Thermal and Fluid Science, 68, pp.145-154.
[59]. Kaushik, S., Sati, V., Gupta, A. and Puri, K., 2015. Experimental analysis between rectangular solid fins with different circular perforated rectangular fins under natural convection. International Journal of Engineering Research & Technology, 4(5).
[60]. Venkitaraj, K.P. and Siddikh, S., 2016, April. Natural Convection heat transfer enhancement from rectangular fin arrays with diverse geometrical perforations. In 2016 International Conference on Energy Efficient Technologies for Sustainability (ICEETS) (pp. 711-716). IEEE.
[61]. Al-Hamadani, A.A., Ogaili, K.S.J. and Al-Waaly, A.A., 2017. THE EFFECT OF finâ€™ S height and circular perforated on the natural convection of the vertical rectangular fins. Al-Qadisiyah Journal for Engineering Sciences, 10(4), pp.565-573.
[62]. Goshayeshi, H.R. and Ampofo, F., 2009. Heat transfer by natural convection from a vertical and horizontal surfaces using vertical fins. Energy and Power Engineering, 1(2), pp.85-89.
[63]. Prasad, L., Kumar, A. and Tewari, S., 2016. An experimental study of heat transfer enhancement in the perforated rectangular fin. Journal of Integrated Science and Technology, 4(1), pp.5-9.
[64]. Kaushik, S., Sati, V., Gupta, A. and Puri, K., 2015. Experimental analysis between rectangular solid fins with different circular perforated rectangular fins under natural convection. International Journal of Engineering Research & Technology, 4(5).
[65]. Tijani, A.S. and Jaffri, N.B., 2018. Thermal analysis of perforated pin-fins heat sink under forced convection condition. Procedia Manufacturing, 24, pp.290-298.
[66]. Al-Damook, A., Kapur, N., Summers, J.L. and Thompson, H.M., 2015. An experimental and computational investigation of thermal air flows through perforated pin heat sinks. Applied thermal engineering, 89, pp.365-376.
[67]. Shadlaghani, A., Tavakoli, M.R., Farzaneh, M. and Salimpour, M.R., 2016. Optimization of triangular fins with/without longitudinal perforate for thermal performance enhancement. Journal of Mechanical Science and Technology, 30(4), pp.1903-1910.
[68]. Chingulpitak, S., Ahn, H.S., Asirvatham, L.G. and Wongwises, S., 2019. Fluid flow and heat transfer characteristics of heat sinks with laterally perforated plate fins. International Journal of Heat and Mass Transfer, 138, pp.293-303.
[69]. Patil, M.H., Patil, S.V., Deore, E.R. and Chaudhari, G.A., 2016. Design & Analysis

of Perforated Rectangular Fin Array with Varying Percentage of Perforation. International Advanced Research Journal in Science, Engineering and Technology, 3(9), pp.26-31.

[70]. Maidin, S. and Azmi, N.F., 2015. Design and analysis of honeycomb structure cooling fin. Journal of Advanced Manufacturing Technology (JAMT), 9(1), pp.20-27.

[71]. Jassem, R.R., 2013. Effect the form of perforation on the heat transfer in the perforated fins. Academic Research International, 4(3), p.198.

[72]. Liu, Y., Luo, X., Liu, W. and Huang, Z., 2009, October. Thermal performance of the multilayered honeycomb microchannel heat sink. In 2009 International Conference on Energy and Environment Technology (Vol. 1, pp. 487-490). IEEE.

[73]. Liu, Y., Luo, X. and Liu, W., 2011. Experimental research on a honeycomb microchannel cooling system. IEEE Transactions on Components, Packaging and Manufacturing Technology, 1(9), pp.1378-1386.

[74]. Liu, Y., Luo, X. and Liu, W., 2009, January. Experimental study on a honeycomb micro channel cooling system. In International Conference on Nanochannels, Microchannels, and Minichannels (Vol. 43499, pp. 267-272).

[75]. Dafedar, M.A., Najeem, M., Fakruddin, Y. and Chirag, P., 2013. Heat Transfer Augmentation in Different Geometries of Dimpled Surface under Natural Convection an Experimental Approach. International Journal of Research in Engineering and Technology, 2, pp.937-940.

[76]. Chandra K. Anand K. S, Shailendra. S., 2019. Effect of Perforation Shapes on the Heat Transfer Characteristic of Perforated Fins. International Journal of Recent Technology and Engineering, 8(4), pp.1394-1400.

[77]. Wen, T., Tian, J., Lu, T.J., Queheillalt, D.T. and Wadley, H.N.G., 2006. Forced convection in metallic honeycomb structures. International Journal of Heat and Mass Transfer, 49(19-20), pp.3313-3324.

[78]. Lu, T.J., 1999. Heat transfer efficiency of metal honeycombs. International Journal of Heat and Mass Transfer, 42(11), pp.2031-2040.

[79]. Gu, S., Lu, T.J. and Evans, A.G., 2001. On the design of two-dimensional cellular metals for combined heat dissipation and structural load capacity. International Journal of Heat and Mass Transfer, 44(11), pp.2163-2175.

[80]. Kumar, R.S. and McDowell, D.L., 2004. Rapid preliminary design of rectangular linear cellular alloys for maximum heat transfer. AIAA journal, 42(8), pp.1652-1661.

[81]. Seepersad, C.C., Dempsey, B.M., Allen, J.K., Mistree, F. and McDowell, D.L., 2004. Design of multifunctional honeycomb materials. AIAA journal, 42(5), pp.1025-1033.

[82]. Dempsey, B.M., Eisele, S. and McDowell, D.L., 2005. Heat sink applications of extruded metal honeycombs. International journal of heat and mass transfer, 48(3-4), pp.527-535.

[83]. Bower, C., Ortega, A., Skandakumaran, P., Vaidyanathan, R. and Phillips, T., 2005. Heat transfer in water-cooled silicon carbide milli-channel heat sinks for high power electronic applications. J. Heat Transfer, 127(1), pp.59-65.

[84]. Liu, Y.L., Luo, X.B. and Liu, W., 2010. Cooling behavior in a novel heat sink based on multilayer staggered honeycomb structure. Journal of Energy and Power Engineering, 4(3).

[85]. Hodes, M., Weinstein, R.D., Pence, S.J., Piccini, J.M., Manzione, L. and Chen, C., 2002. Transient thermal management of a handset using phase change material (PCM). J. Electron. Packag., 124(4), pp.419-426.

[86]. Alawadhi, E.M. and Amon, C.H., 2003. PCM thermal control unit for portable electronic devices: experimental and numerical studies. IEEE Transactions on components and packaging technologies, 26(1), pp.116-125.

[87]. Tan, F.L. and Tso, C.P., 2004. Cooling of mobile electronic devices using phase change materials. Applied thermal engineering, 24(2-3), pp.159-169.

[88]. Kandasamy, R., Wang, X.Q. and Mujumdar, A.S., 2007. Application of phase change materials in thermal management of electronics. Applied Thermal Engineering, 27(17-18), pp.2822-2832.

[89]. Wang, X.Q., Mujumdar, A.S. and Yap, C., 2007. Effect of orientation for phase change material (PCM)-based heat sinks for transient thermal management of electric components. International Communications

in Heat and Mass Transfer, 34(7), pp.801-808.

[90]. Fok, S.C., Shen, W. and Tan, F.L., 2010. Cooling of portable hand-held electronic devices using phase change materials in finned heat sinks. International Journal of Thermal Sciences, 49(1), pp.109-117.

[91]. Arulmurugan, L., Ilangkumaran, M. and Prakash, K.V., Experimental Investigation on Thermal Performance and Effect of PCM based Heat Sink with Different Fins.

[92]. Guessab, A. and Aris, A., 2019. Numerical Analysis of CPU with Heat Sink base of Copper Core using CFD. International Journal of Mechanics, pp.144-148.

[93]. Zaidshah, S. and Yadav, V., Heat transfer from different types of fins with notches with varying materials to enhance rate of heat transfer a Review.