http://ijea.jctjournals.com/
ISSN(ONLINE):2320 – 0804
Volume-11, Issue-11, November, 2022
International Journal of Engineering Associates (IJEA)
Page Number: 01-10

An Experimental Study on The Performance of A Tree-Shaped Mini-Channel Liquid Cooling Heat Sink

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***Abstract*—A heat sink system is presented in this article :A heat sink is a passive heat exchanger that transfers heat. The heat sink is typically a metallic part which can be attached to a device releasing energy in the form of heat, with the aim of dissipating that heat to a surrounding fluid in order to prevent the device overheating. Heat sink is an electronic component or a device of an electronic circuit which disperses heat from other components (mainly from the power transistors) of a circuit into the surrounding medium and cools them for improving their performance, reliability and also avoids the premature failure of the components. The device transfers heat to the heat sink by conduction. The primary mechanism of heat transfer from the heat sink is convection, although radiation also has a minor influence. Here in this work, it review the different performance parameters of heat sink and also reviews the used of different use of heat sink..**

***Keywords*—Heat Sink, Review, Heat Transfer Performance Parameters., etc ……**

I. INTRODUCTION

A heat sink is a component that increases the heat flow away from a hot device. It accomplishes this task by increasing the device's working surface area and the amount of low-temperature fluid that moves across its enlarged surface area. Based on each device's configuration, we find a multitude of heat sink aesthetics, design, and ultimate capabilities. A heat sink (also commonly spelled heat sink) is a passive heat exchanger that transfers the heat generated by an electronic or a mechanical device to a fluid medium, often air or a liquid coolant, where it is dissipated away from the device, thereby allowing regulation of the device's temperature. In computers, heat sinks are used to cool CPUs, GPUs, and some chipsets and RAM modules. Heat sinks are used with high-power semiconductor devices such as power transistors and optoelectronics such as lasers and light-emitting diodes (LEDs), where the heat dissipation ability of the component itself is insufficient to moderate its temperature. Each heat sink is valuable in applications that may have varied: Heat sinks are one of the most common forms of thermal management in technology, machinery, and even in natural systems. These components are so ubiquitous that they're easy to overlook, even by those who are familiar with the technology. We'll address the basic working principles involved in heat sinks, introduce active and passive heat sink configurations, and discuss how some users implement heat sinks in their applications. A heat sink is designed to maximize its surface area in contact with the cooling medium surrounding it, such as the air. Air velocity, choice of material, protrusion design and surface treatment are factors that affect the performance of a heat sink. Heat sink attachment methods and thermal interface materials also affect the die temperature of the integrated circuit. Thermal adhesive or thermal paste improve the heat sink's performance by filling air gaps between the heat sink and the heat spreader on the device. A heat sink is usually made out of aluminium or copper.

In this part, a 3D conjugated heat transfer model for Nano-Encapsulated Phase Change Materials (NEPCMs) cooled Micro Pin Fin Heat Sink (MPFHS) is presented. The governing equations of flow and heat transfer are solved using a finite volume method based on collocated grid and validated by comparing results with the available data in the literature. The effect of nanoparticles volume fraction, inlet velocity, and bottom wall temperature are studied on Nusselt and Euler numbers as well as temperature contours in the system. The results indicate that considerable heat transfer enhancement is possible when using NEPCM slurry as a coolant and the degree of enhancement increases with increasing inlet velocity and volume fraction. However, with increasing bottom wall temperature, the Nusselt number first increases then decreases. The former is due to higher heat transfer capability of coolant at temperatures over the melting range of PCM particles due to partial melting of nanoparticles in this range and latent heat contribution effect into the heat transfer rate. While the latter phenomena are due to the lower capability of NEPCM particles and consequently coolant in absorbing heat at temperatures above the temperature correspond to fully melted NEPCM. It was observed that NEPCM slurry has a drastic effect on Euler number, and with increasing volume fraction and decreasing inlet velocity the enhancement in Euler number increases.

 ISSN(ONLINE):2320 – 0804

A. Plate Fin Heat Sink

Plate-fin heat sinks as implied by their name are heat sink geometries that have their extruded fins running across the entire length of the base in the form of a plate. These types of heat sinks are the most commonly used in electronic devices. Heat sinks with plate fins can be modelled in different shapes and can also be arranged in different forms to force the direction of flow. Plate-fin heat sinks usually cover a larger surface 2area across the base of the heat sink. Hence, generally has a larger area for heat transfer since there's an increase contact area between the working fluid(air) and the material surface.

B. Pin Fin Heat Sink

Heat sinks with pin fin extrusions are widely used based on the ability to increase their surface area through the increase in the number of pins. Pin fin extrusions are usually layered across the base of a heat sink in a specified order or pattern so as to enhance airflow. One advantage of using pin fins over plate fins is that the direction of flow does not necessarily need to be precisely defined since all sides could work as an inlet though or outlet. In most cases depending on geometry, there is a direction of flow inlet and outlet that increase the performance of the pin fin heat sink and should be taken into account when mounted on the object to be cooled.

C. Geometry Heat Sink

With improved methods of manufacturing, manufacturers and researchers are able to manufacture objects of different shapes and dimensions. With geometry being a factor that affects the performance of heat sinks, the ability to manufacture heat sinks of different exotic geometries enables both thermal engineering and researchers to optimize heat sinks based on geometry modification. In this study, different heat sink geometries are analysed under the same conditions and compared to each other based on their thermal performance and cost of operation. The exotic geometries in this study were modelled based on knowledge from fluid dynamics and heat transfer to better improve heat sink performance.

Fig.1 The geometry of Heat Sinks

As far as history goes, the field of electronics cooling does not have a very long past. A rather quick look through my personal reference material that is strictly geared towards cooling electronics had at the earliest some US Navy documents from the 1950s . Comparing the solution techniques available today to those available then shows that we have both much better tools and harder problems (although I still like to refer to the suggested heat transfer coefficient value of ~10 W/m2-K for natural convection when not much else is known). Perhaps because of the shorter history and the tendency of engineers working in this field always being exposed to the latest and greatest electronics, the electronics cooling community sometimes doesn't venture out and learn from related fields. When we start solving problems without doing significant research, we can live in a fairy tale world where we think that our problems are strictly unique to us. There can be a benefit of taking some time to examine the past and finding out that other smart engineers have often looked at similar problems and may have relevant information that would help us with understanding. The use of heat exchanges theory provides a good example where there is a possible benefit from thinking about the problems, we are solving from more than one viewpoint. Consider the simple illustration of a heat sink shown in Figure-2 Heat sink suppliers and designers, especially in air cooled electronics, like to use a thermal resistance type description such as Rth = 1/hA = (Tsurf - Tcool-in)/q

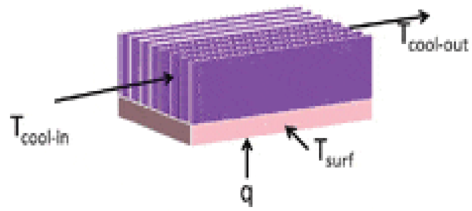

Fig.2 Simple heat sink

Since the resistance can vary with the coolant velocity, information about how Rth varies with velocity may be provided. The coolant temperature of reference is the inlet temperature. While this approach is convenient, there isn't much need to think about using a minimum amount of coolant and other constraints such as noise and prime power to move the coolant may dictate the flow rate. Engineers that come from an avionics background typically consider that the coolant will change temperature as the waste heat is added. Often, the coolant flow rate is specified in terms of flow rate per KW of heat such that the temperature rise of the coolant from inlet to exit is constant for different electronic assemblies.

D. Different Types of Heat Sink

- **The Source Generates Heat: -**This source may be any system that creates heat and requires the removal of said heat to function correctly, such as: Mechanical- Electrical- Chemical- Nuclear- Solar- Friction
- **Heat Transfers Away Fromthe Source: -**Heat pipes can also aid in this process, but. In direct heat sink-contact applications, heat moves into the heat sink and away from the source via natural conduction. The heat sink material's thermal conductivity directly impacts this process. That's why high thermal conductivity materials such as copper and aluminium are most common in the construction of heat sinks.
- **Heat Distributes Throughout the Heat Sink: -**Heat will naturally travel through the heat sink via natural conduction moving across the thermal gradient from a high temperature to a low-temperature environment. This ultimately means that the heat sink's thermal profile will not be consistent. As such, heat sinks will often be hotter towards the source and cooler towards the sink's extremities.

II. Literature Review

Mauro, A. W., et.al (2010), In this research work presented flow boiling saturated CHF data in a multi-micro channel copper heat sink have been collected with three HFC refrigerants: R134a, R236fa and R245fa. The test section was fed by a singular system with one central inlet and two outlets, called split flow, which provided much better performance in terms of CHF attainable compared with the single inlet/outlet system (and also reduced the pressure drop). For all the tests carried out, the saturated CHF increased with mass velocity. For R236fa and R134a, an increase of saturation temperature resulted in a slight decrease of CHF, while the inlet subcooling provided a moderate positive effect on CHF. For R245fa the effect of saturation temperature and inlet subcooling tended to be negligible. The highest CHF values have been reached with R134a (330 W/cm2 for G = 1500 kg/m2 s). With this fluid it was possible to achieve higher flow rates with the test facility, thanks to its lower two-phase pressure drop. On the other hand, making the comparison over the same range of mass velocity, R245fa yielded CHF values comparable with R134a. The experimental data were compared with five prediction methods, including one numerical method [1].

Koşar, et.al. (2010), In this research work presented unstable boiling was studied in three different micro-pin fin heat sinks. Pressure signals and flow images were acquired under unstable boiling conditions, which were accompanied by severe temperature fluctuations. The main conclusions drawn from this study are: Similar to parallel micro channel array, flow instabilities are of concern during flow boiling in micro-pin fin heat sinks. Onset of boiling was accompanied by considerable flow instabilities in all the tested micro-pin fin heat sinks with a corresponding increase in surface temperature. For water, the magnitude of the pressure drops fluctuations before and after unstable boiling was not significant regardless the shape of the pin fin. Peak to peak pressure drop fluctuations remain small compared to the time averaged pressure drop for all the devices For R-123, a drastic change is observed in the pressure signals with the initiation of unstable boiling, and a sharp increase in the magnitude peaks of the FFT profiles becomes apparent. Moreover, not only the spectrum peak increases significantly but the side-lobe energy also significantly increases after the inception of unstable boiling, which is an indicator of rapid bubble growth instability. For the devices operated with water (both circular and hydrofoil shaped micro-pin fin devices), no significant change is observed in the FFT profiles with unstable boiling. Upstream compressible volume instability rather than rapid bubble growth instability prevails under these unstable boiling conditions [2].

Dogruoz, et.al (2010), In this research work presented with the invention as well as implementation of advanced electronics, smaller, compact, low weight, and low-cost devices with aggressive thermal performances are demanded. In order to respond to this need, advanced thermal materials have been developed. Although these materials are relatively new, novel applications start to utilize them to meet certain design requirements. In this research work presented, four different advanced materials were studied as well as aluminium and copper as baseline materials. Authors developed a design of experiments for our simulations with 343 cases in total to understand conduction and convection resistances of extruded heat sinks in a natural convection environment. Simulations were carried out via commercially available CFD software by taking advantage of the tool's periodic boundary condition capability. In simulating the test cases, effect of the convection has also been studied by changing the heat sink base temperature. Pareto charts presented the relationships and strengths for both conductive and convective thermal resistances, as well as minimum fin temperatures [3].

Chein,, et.al (2010), In this research work presented copper foam fabricated using the electroforming technique was employed as the heat-sinking material. Because of the special flow characteristic of fluid flow in the copper foam and enlarged heat transfer area, the copper foam heat sink has better performance as compared with those of single-channel, plate-fin and pin-fin heat sinks. The measured results also indicated that the thermal resistance of copper-foam heat sink decreases with the decrease in porosity which can be controlled by the electroforming time [4].

Liu, et.al (2011), In this research work presented, two micro staggered square high pin fin heat sinks with different channel sizes were fabricated. Using deionized water as working fluid, the performance of pressure drop and heat transfer in staggered square long micro pin fins were experimentally studied. The main conclusions include:1) For both heat sinks, the pressure drop increased with the Rec number. The flow friction factor transition phenomenon appeared at Rec 300. 2) Both heat sinks exhibited huge heat dissipation capability. The experimental data showed that, for the type 2 heat sink, the heat dissipation could reach 2.83 106 W/m2 at the flow rate of 57.225 L/h and the surface temperature of 73.4 C, and, therefore, meet the demand of high-power heat removal. The heat dissipation increased with the flow rate for a fixed surface temperature while the increasing rate decreased with the flow rate. 3) The Nusselt number increased with the fin Reynolds number. For both heat sinks, the heat transfer was over predicted by the previous correlations. Therefore, we presented new correlations for the average Nusselt number prediction. The Nusselt number varies as Re0.61. 4) The heat resistance decreased with the pressure drop. The deceleration rate was faster for the small pressure drop and slower for the large pressure drop [5].

III. HEAT SINK DESIGN PRINCIPAL

A. Heat Transfer Principle

A heat sink transfers thermal energy from a higher-temperature device to a lower-temperature fluid medium. The fluid medium is frequently air, but can also be water, refrigerants or oil. If the fluid medium is water, the heat sink is frequently called a cold plate. In thermodynamics a heat sink is a heat reservoir that can absorb an arbitrary amount of heat without significantly changing temperature. Practical heat sinks for electronic devices must have a temperature higher than the surroundings to transfer heat by convection, radiation, and conduction. The power supplies of electronics are not absolutely efficient, so extra heat is produced that may be detrimental to the function of the device. As such, a heat sink is included in the design to disperse heat. Using the mean air temperature is an assumption that is valid for relatively short heat sinks. When compact heat exchangers are calculated, the logarithmic mean air temperature is used. Fourier's shows that when there is a temperature gradient in a body, heat will be transferred from the higher-temperature region to the lower-temperature region. The rate at which heat is transferred by conduction, , is proportional to the product of the temperature gradient and the cross-sectional area through which heat is transferred. When it is simplified to a one-dimensional form in the *x* direction, it can be expressed as:

$$\mathrm{qk} = -\mathrm{KA}\frac{\mathrm{dt}}{\mathrm{dx}} \quad (1)$$

Using the mean air temperature is an assumption that is valid for relatively short heat sinks. When compact heat exchangers are calculated, the logarithmic mean air temperature is used. The above equations show that:

When the air flow through the heat sink decreases, this results in an increase in the average air temperature. This in turn increases the heat-sink base temperature. And additionally, the thermal resistance of the heat sink will also increase. The net result is a higher heat-sink base temperature.

The increase in heat-sink thermal resistance with decrease in flow rate will be shown later in this article. The inlet air temperature relates strongly with the heat-sink base temperature. For example, if there is re circulation of air in a product, the inlet air temperature is not the ambient air temperature. The inlet air temperature of the heat sink is therefore higher, which also results in a higher heat-sink base temperature.

If there is no air flow around the heat sink, energy cannot be transferred. A heat sink is not a device with the "magical ability to absorb heat like a sponge and send it off to a parallel universe" Natural convection requires free flow of air over the heat sink. If fins are not aligned vertically, or if fins are too close together to allow sufficient air flow between them, the efficiency of the heat sink will decline.

B. Design factors

Thermal Resistance: -For semiconductor devices used in a variety of consumer and industrial electronics, the idea of thermal resistance simplifies the selection of heat sinks. The heat flow between the semiconductor die and ambient air is modelled as a series of resistances to heat flow; there is a resistance from the die to the device case, from the case to the heat sink, and from the heat sink to the ambient air. The sum of these resistances is the total thermal resistance from the die to the ambient air. Thermal resistance is defined as temperature rise per unit of power, analogous to electrical resistance, and is expressed in units of degrees Celsius per watt (°C/W). If the device dissipation in watts is known, and the total thermal resistance is calculated, the temperature rise of the die over the ambient air can be calculated.

The idea of thermal resistance of a semiconductor heat sink is an approximation. It does not take into account non-uniform distribution of heat over a device or heat sink. It only models a system in thermal equilibrium and does not take into account the change in temperatures with time. Nor does it reflect the non-linearity of radiation and convection with respect to temperature rise. However, manufacturers tabulate typical values of thermal resistance for heat sinks and semiconductor devices, which allows selection of commercially manufactured heat sinks to be simplified.

Commercial extruded aluminium heat sinks have a thermal resistance (heat sink to ambient air) ranging from 0.4 °C/W for a large sink meant for TO-3 devices, up to as high as 85 °C/W for a clip-on heat sink for a TO-92 small plastic case.[5] The popular 2N3055 power transistor in a TO-3 case has an internal thermal resistance from junction to case of 1.52 °C/W.[6] The contact between the device case and heat sink may have a thermal resistance between 0.5 and 1.7 °C/W, depending on the case size and use of grease or insulating mica washer.

C. **Material: -**The materials for heat sink applications should have high heat capacity and thermal conductivity in order to absorb more heat energy without shifting towards a very high temperature and transmit it to the environment for efficient cooling. The most common heat sink materials are aluminium alloys Aluminium alloy 1050 has one of the higher thermal conductivity values at 229 W/(m·K) and heat capacity of 922 J/(kg·K),[9] but is mechanically soft. Aluminium alloys 6060 (low-stress), 6061, and 6063 are commonly used, with thermal conductivity values of 166 and 201 W/(m·K) respectively. The values depend on the temper of the alloy. One-piece aluminium heat sinks can be made by extrusion, casting, skiving or milling. Copper has excellent heat-sink properties in terms of its thermal conductivity, corrosion resistance, bio fouling resistance, and antimicrobial resistance (see also Copper in heat ex changers). Copper has around twice the thermal conductivity of aluminium, around 400 W/(m·K) for pure copper. Its main applications are in industrial facilities, power plants, solar thermal water systems, HVAC systems, gas water heaters, forced air heating and cooling systems, geothermal heating and cooling, and electronic systems. Copper is three times as dense and more expensive than aluminium, and copper is less ductile than aluminium. One-piece copper heat sinks can be made by skiving or milling. Sheet-metal fins can be soldered onto a rectangular copper body.

D. **Fin Efficiency: -**Fin efficiency is one of the parameters that makes a higher-thermal-conductivity material important. A fin of a heat sink may be considered to be a flat plate with heat flowing in one end and being dissipated into the surrounding fluid as it travels to the other.[12] As heat flows through the fin, the combination of the thermal resistance of the heat sink impeding the flow and the heat lost due to convection, the temperature of the fin and, therefore, the heat transfer to the fluid, will decrease from the base to the end of the fin. Fin efficiency is defined as the actual heat transferred by the fin, divided by the heat transfer were the fin to be isothermal (hypothetically the fin having infinite thermal conductivity).

E. **Fin Arrangement: -**A pin-fin heat sink is a heat sink that has pins that extend from its base. The pins can be cylindrical, elliptical or square. A pin is one of the more common heat-sink types available on the market. A second type of heat-sink fin arrangement is the straight fin. These run the entire length of the heat sink. A variation on the straight-fin heat sink is a cross-cut heat sink. A straight-fin heat sink is cut at regular intervals. Free-convection flow around a pin-fin heat sink In general, the more surface area a heat sink has, the better it works However, this is not always true. The concept of a pin-fin heat sink is to try to pack as much surface area into a given volume as possible As well, it works well in any orientation. Kordyban has compared the performance of a pin-fin and a straight-fin heat sink of similar dimensions. Although the pin-fin has 194 cm2 surface area while the straight-fin has 58 cm2, the temperature difference between the heat-sink base and the ambient air for the pin-fin is 50 °C, but for the straight-fin it was 44 °C, or 6 °C better than the pin-fin. Pin-fin heat sink performance is significantly better than straight fins when used in their intended application where the fluid flows axially along the pins rather than only tangentially across the pins. Another configuration is the flared-fin heat sink; its fins are not parallel to each other, a. Flaring the fins decreases flow resistance and makes more air go through the heat-sink fin channel; otherwise, more air would bypass the fins. Slanting them keeps the overall dimensions the same, but offers longer fins. They found that for low air approach velocity, typically around 1 m/s, the thermal performance is at least 20% better than straight-fin heat sinks. also found that for the bypass configurations that they tested, the flared heat sink performed better than the other heat sinks tested.

IV. METHODOLOGY AND VALIDATION

A. Solid Model Of The Heat Sink

For making the solid model of heat sink as considered in karami et al. same geometric parameters was considered as mention in the paper. The geometric parameters considered for solid model of heat sink is mention in the below table.

Table.1 Geometric parameters considered for solid model of heat sink.

Parameter	Value (mm)
Length of the heat sink	100
Width of the heat sink	92
Height of heat sink	31
Length of the plate fins	25
Thickness of fins	2
Pitch of fins	8
Baffles dimension (width*thickness*height)	2*1*25

On the basis of above mention geometric conditions of plate fin heat sink solid model was made in Ansys design modular. The solid model of plate fin hear sink are shown in the below figure.

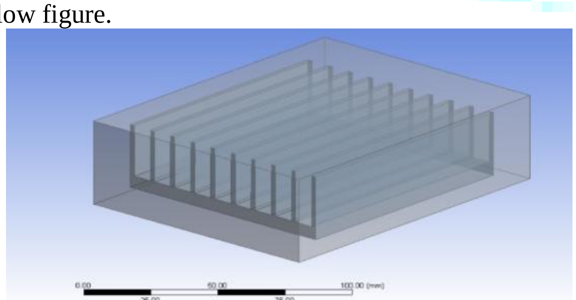

Fig.3 Geometry of plate fin heat sink considered during the initial case of CFD analysis

B. Meshing

For performing the numerical analysis of the heat sink, discretization of the heat sink intothe number of different elements was done. In order to check the grid independency, heat sink geometry was discretized with different numbers of elementsand calculated the heat transfer coefficient for Re – 1013. Through numerical analysis, it is found that with 231032 elements with 61566 numbers of nodes,the optimum result is coming. So, it is concluded that after increasing the number of elements to 231032, there is no such change was observed during the work. For further analysis, 2310 of elements was considered during this work. The meshing of the solid modelplate-fin heat sink without tabulators is shown in the below figure.

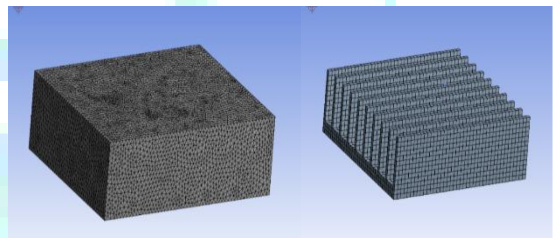

Fig.4 Mesh of the heat sink.

In this case, the hexahedral shape of element is used to do mesh of the heat sink. For the enhancement of result and better numerical analysis, it is necessary to have mesh refinement in critical zones of heat sink. Refinement was also done in the area of two different medium contact region. After mesh refinement name selection of different component of heat sink was done.

C. Name Selection

Different components of plate fin heat sink were selected and name was assigned on them.

- **Air -** In this case of analysis, air is flowing over the heat sink. The selection of air during the numerical analysis is shown in the below figure.
- **Heat sink-** it is place inside the channel of air, over which air flows throughout the section. The selection of heat sink body during the numerical analysis is shown in the below figure.
- **Air Inlet-** Surface from where air enters inside the channel, the selection of air inlet surface is shown in the below figure.
- **Air outlet**- Surface from where air exit the channel, the selection of air outlet surface is shown in the below figure.
- **Heat sink surface -** The selection of heat sink outer surface is shown in the below figure.

D. Boundary condition and Solution method

In order to validate the numerical analysis of heat sink, the same boundary conditions were considered as considered Saravana Kumar et al. at the inlet, the air inlet temperature is 300 K. whereas 80 W heat was considered during the numerical analysis. No-slip conditions were also considered at all inside the wall of the heat sink. Here it selects the coupled base second-order upwind methods for the CFD analysis of plate fins heat sink.

E. Plate Fin Heat Sink Without Baffles

For validation, numerical analysis of heat sink without baffles was done at different Reynolds number. For analysing the effect of change in Reynolds number four different number was consider during the work that is 1013, 1793, 2706 and 3309. According to Reynolds numbers velocity of air at the inlet heat sink was calculated, the velocity of air at the inlet for different Reynolds numbers is 0.822, 1.45, 2.19 and 2.68 m/s.

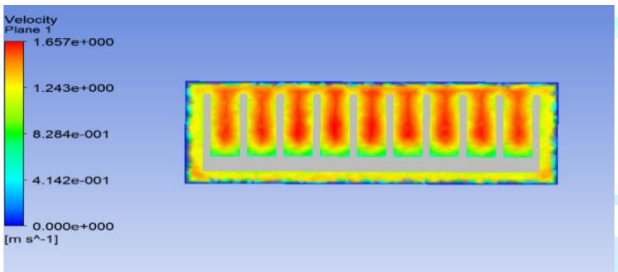

Fig.5variation of velocity in the transverse direction of heat sink Re- 1793

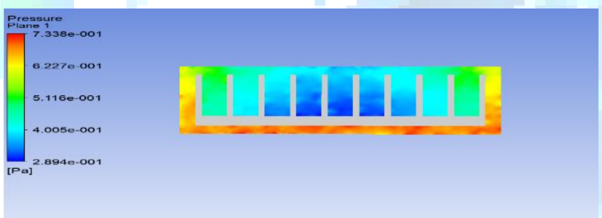

Fig.6 Contours of pressure in transverse plane of heat sinkRe -2706

Above figure shows the velocity variation at the central plane of the heat sink. From contour it was clearly observed that the velocity of air is maximum at the middle of the channel.

The value of Nusselt number and pressure drop for different Reynolds number calculated through numerical analysis is mention in the below table. Through table it was clearly found that with increase in Re number for simple plate fin heat sink the heat transfer gets increases. Whereas by increase the Re number pressure drop gets also increases.

Table.2 Value of Nusselt number and pressure drop

Reynolds number	Nusselt number	Pressure Drop (Pa)
1013	29.78	35
1793	48.78	38
2706	56.34	49.5
3308	62.39	50.2

F. Validation of Numerical Analysis of Plate-Fin Heat Sink Without Turbulator

After computing the significance of the Nusselt number and pressure drop for plate-fin heat sink at different Reynolds through CFD analysis, it is then compared with the experimental results performed by Saravana Kumar et.al (1). The comparison of different values was mention in the below table.

Table.3 Value of pressure drop for plate fin heat sink at different Reynolds number

Reynolds number	Pressure drop (Pa) through CFD analysis	Pressure Drop (Pa) through experiment performed by saravankumar et al.	Error (%)
1013	35	38	7.8
1793	38	40	5
2706	49.5	51.5	4.4
3308	50.2	53	5.2

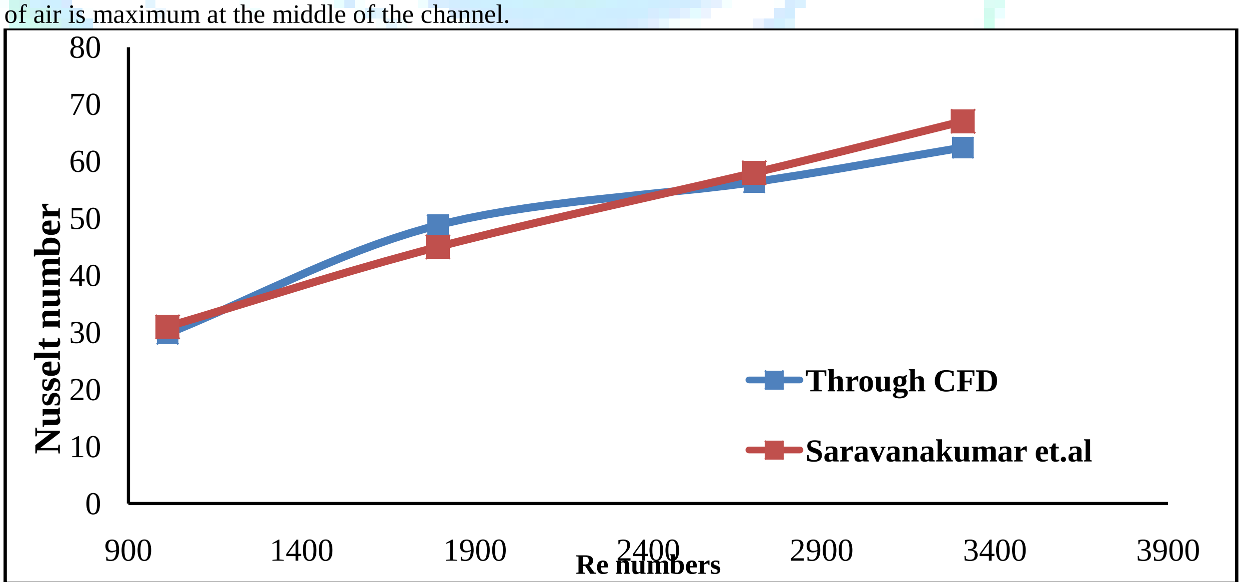

Fig.7 Comparison of the value of Nusselt number for numerical and experimental work

After comparing the value of the Nusselt number, the value of Pressure drop inside the heat sink was also analyzed and compared in the below table with the experimental result performed by Saravana Kumar et.al (1).Through comparison of pressure drop and Nusselt number it is found that the result obtained through CFD analysis is near to the values obtained through experimental analysis performed by Saravana Kumar et.al and it is coming to under 10% error to it is concluded the CFD analysis of Plate fins heat sink is correct. From the above graph, it is found that, the value of pressure drop inside the Plate fin heat sink without baffles at different Reynolds numbers is coming near to the values calculated through experimental analysis. The error in under 10% which shows the accuracy and correctness of the CFD analysis of plate fin heat sink without baffles. After validating the CFD analysis of heat sink, for the further enhancement of heat sink heat transfer, here in this work different shapes of turbulators were used in between plane fins.

V. RESULT AND DISCUSSION

A. Triangular shape of turbulator

In this case, equilateral triangular shape of turbulators was considered during the work, triangular shape turbulator with 4 mm^2 cross-sectional diameter. The solid model of plate-fin heat sink having equilateral triangular shape of turbulator is shown in the below figure.

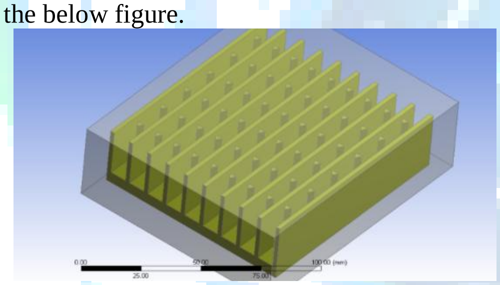

Fig.8 solid model of plate-fin heat sinks with the triangular shape of turbulator

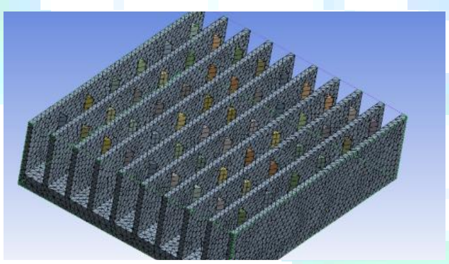

Fig. 9 Meshing of heat sink having triangular shape of turbulator

The pressure and velocity variation contour for this case of analysis at different Reynolds numbers is shown in the below section. The boundary and other geometric conditions will remain same as considered during the numerical analysis of plate-fin heat sink without turbulator. The variation of different parameters for 1013 Re number is shown in the below figure.This shows that with the use of turbulator the heat transfers from heat sink get enhanced. Also, the pressure variation inside the heat sink with the triangular shape of the turbulator is more intense as compared to without the turbulator heat sink.

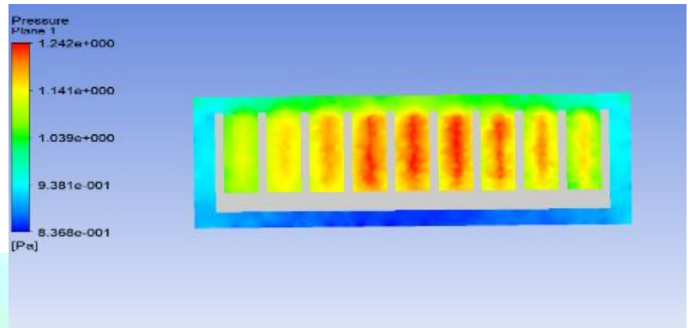

Fig. 10 Pressure variation in transverse plane of heat sink at Re-1013

Through CFD analysis the value of Nu number and pressure drop for plate-fin heat sink with the triangular shape of turbulator at different Re number was calculated and mentioned in the below table.

Table.4value of Nusselt number and pressure drop for the triangular shape of turbulator.

Reynolds number	Nusselt number	Pressure Drop (Pa)
1013	41.11	38.5
1793	60.74	61.4
2706	66.28	71.2
3308	73.16	78.4

Above table shows the value of Nu number and pressure drop for the different triangular shapes of turbulator. From table, it is found that with the increase in Re number the heat transfers and pressure drop inside the heat sink get increases which show the performance of the heat sink. Through table it is also found that at heat transfer for triangular shape of turbulator heat sink is more as compared to plat fin heat sink without turbulator.

B. The Square Shape of Turbulator

In this case, square shape of turbulators was considered during the work, square shape turbulator with 4 mm^2cross-sectionalarea. The solid model of the heat sink with a square shape turbulator is shown in the below table. The contours of pressure and velocity variation in transvers and longitudinal direction of square shape of turbulator. From above figures it is found that with triangular shape of turbulator the Nu number is mode as compared to Nu for a simple plate-fin heat sink. This shows that with the use of turbulator the heat transfers from heat sink get enhanced. Also, the pressure variation inside the heat sink with triangular shape of turbulator is more intense as compared to without turbulator heat sink. Through CFD analysis the value of Nu number and pressure drop for plate-fin heat sink with square shape of turbulator at different Re number was calculated.

Above table shows the value of Nu number and pressure drop for square shape of turbulator. From table it is found that with square shape of turbulator the heat transfer capacity of heat sink is more as compared to heat sink without turbulator and heat sink with triangular shape of turbulator.

C. Hexagonal Shape of Turbulator

In this case hexagonal shape of turbulators was considered during the work, hexagonal shape turbulator with 4 mm^2cross-sectionalarea. The solid model of plate fin heat sink having hexagonal shape of turbulator.it is found that with hexagonal shape of turbulator the Nu number is mode as compared to Nu for simple plate fin heat sink. This shows that with the use of turbulator the heat transfers from heat sink get enhanced. Also, the pressure variation inside the heat sink with hexagonal shape of turbulator is more intense as compared to without turbulator heat sink. Through CFD analysis the value of Nu number and pressure drop for plate fin heat sink with hexagonal shape of turbulator at different Re number was calculated and mention in the below table.

Table.5 value of Nusselt number and pressure drop for hexagonal shape of turbulator.

Reynolds number	Nusselt number	Pressure Drop (Pa)
1013	36.55	37.4
1793	57.40	59.64
2706	68.5	70.06
3308	74.8	76.84

Above table shows the value of Nu number and pressure drop for hexagonal shape of turbulator. From table it is found that with hexagonal shape of turbulator, the heat transfer capacity of heat sink is more as compared to heat sink without turbulator. Whereas it shows low heat transfer capacity as compared to triangular and square shape of turbulator.

D. Trapezoidal Shape Of Turbulator

In this case, trapezoidal shape of turbulators was considered during the work, trapezoidal shape turbulator with 4 mm^2 cross-sectional area. The solid model of plate-fin heat sink having trapezoidal shape of turbulator. From above figures it is found that with trapezoidal shape of turbulator, the Nu number is more as compared to Nu for simple plate-fin heat sink. This shows that with the use of turbulator, the heat transfers from heat sink get enhanced. Also, the pressure variation inside the heat sink with trapezoidal shape of turbulator is more intense as compared to without turbulator heat sink. Through CFD analysis the value of Nu number and pressure drop for plate fin heat sink with trapezoidal shape of turbulator at different Re number was calculated and mention in the below table.

Table.6 value of Nusselt number and pressure drop for trapezoidal shape of tabulator

The comparison of pressure drop for different shapes of turbulator is also mention in the below table.

Reynolds number	Nusselt number	Pressure Drop (Pa)
1013	47.78	40.21
1793	68.32	63.52
2706	73.21	72.84
3308	80.52	80.06

Comparison of different shapes of turbulators

After analysing the effect of different shapes of turbulators inside the plate-fin heat sink, comparison of different shapes of turbulators at different Re number was done. the comparison was mainly done on the basis of Nu number and pressure drop inside the heat sink for different turbulator geometry at different Re number. The comparison of value of Nu number for different Re number is shown in the below table.

Table.7 Value of Nu number for different shapes of turbulator at different Re number.

Reynolds number	Nusselt number for Without turbulator	Nusselt number for with triangular turbulator	Nusselt number for with square turbulator	Nusselt number for with hexagonal turbulator	Nusselt number for with trapezoidal turbulator
1013	29.78	41.11	51.75	36.55	47.78
1793	48.78	60.74	72.31	57.40	68.32
2706	56.34	66.28	77.5	68.5	73.21
3308	62.39	73.16	82.4	74.8	80.52

Table.8 Value of Nu number for different shapes of turbulator at different Re number

Reynolds number	Pressure dropfor Without turbulator	Pressure drop for with triangular turbulator	Pressure drop for with square turbulator	Pressure drop for with hexagonal turbulator	Pressure drop for with trapezoidal turbulator
1013	35	38.5	39.1	37.4	40.21
1793	38	61.4	62.4	59.64	63.52
2706	49.5	71.2	73.5	70.06	72.84
3308	50.2	78.4	80.43	76.84	80.06

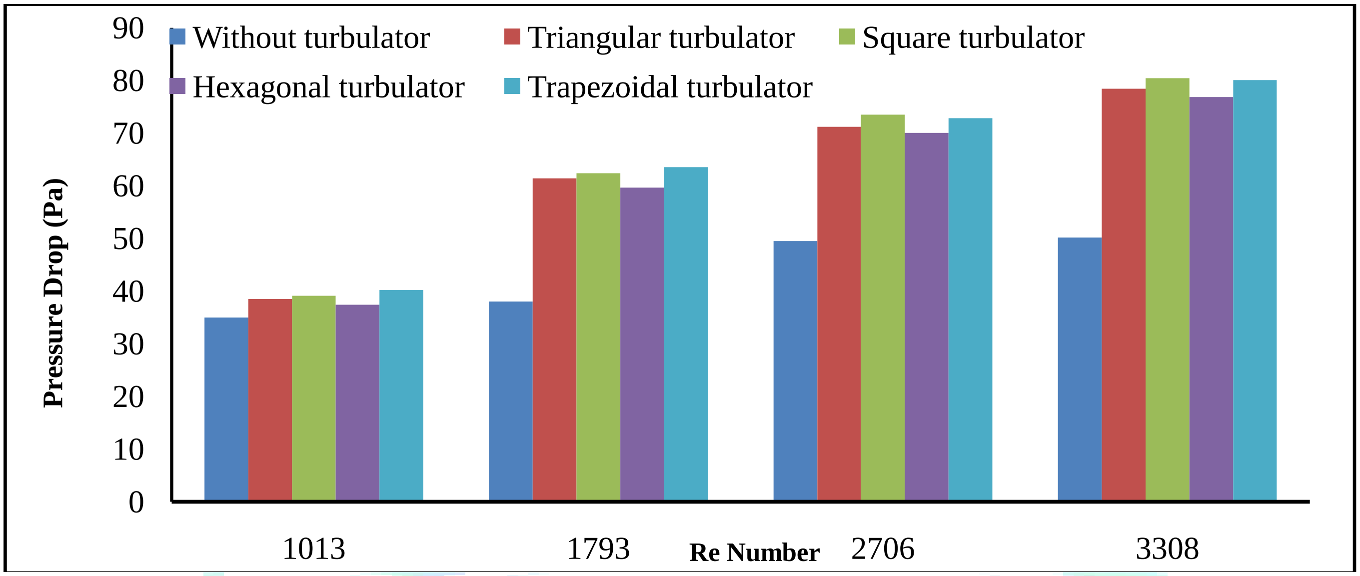

Fig.11 Comparison of value of Pressure Drop for different geometry of heat sink.

From above graph, it is found that heat sink with square shape of tabulator shows the maximum value of Nu number as compared to other shapes of turbulator for each case of Re number. From above graph it is found that with the use of turbulator, the pressure drop inside the heat sink is more as compared to without turbulator heat sink. But with the change in shape of turbulator there is a very marginal change in pressure drop for different shapes of turbulators.

VI. CONCLUSION

The overall goal of this research project was to generate a numerical method of testing different heatsink geometries using CFD software and also generate simple and exotic heatsink fin designs that improve the thermal performance of the heat-sink studied in this project. Some proposed models bother researchers in this field were tested for verification. The traditional rectangular plate fin heat sink widely used by thermal engineers for electronic cooling was set as the base of performance comparison since most researchers believe this model heatsink to be efficient both in performance and ease of manufacturability. The two performance evaluating parameters were thermal resistance and pressure drop. The thermal resistance and pressure drop values for the base case rectangular plate heat sink were 0.45 K/W and 33.27 Pa respectively. Thirteen models were simulated and compared to the rectangular plate fin heat sink. Considering the thermal resistance performance parameter four out of the thirteen models generated performed better.

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