CFD ANALYSIS AND DESIGN OPTIMIZATION OF PARALLEL PLATE HEAT SINKS FOR OIL IMMERSION COOLING

By

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ABSTRACT

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Air cooling is predominant cooling technique employed in most of the data centers. As the demand for High performance computing (HPC) which deploy large concentration of high-end servers (30 kW to 200 kW per rack) is increasing, it is becoming challenging to cool the systems using air cooling. Liquid cooling has significant advantages over air cooling techniques due to higher heat capacities of fluids. Liquid immersion cooling using dielectric and non-corrosive mineral oils is one of the potential alternative to air cooling methods for high density data centers.

In this work, we consider a third generation open compute server optimized for air cooling and find optimal heat sinks for immersion cooling. It is possible to use low profile heatsinks due to the thermal mass of the liquid vs air and thus reduce the server profile and potentially increase the server density in a rack. CFD is used to design the optimal heatsink.

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Chapter 1

INTRODUCTION

1.1 Data Center Cooling

Data centers are purpose-built facilities which house IT equipment which need to be running at most/all times. For instance, any activity that we perform on the internet, be it searching on Google, viewing videos on YouTube, or using Social Networking sites such as Facebook, LinkedIn, Instagram or literally anything that we view, post or download is obtained from data centers. All the information is stored in computers (aptly called servers) stacked in rows of several racks in a datacenter. Any command executed by us on our browser sends a request to these servers to access the information and thereafter the required information is relayed back to us. Now, if this information has to be accessed at any time of the day throughout the year, then the server has to be up and running at all times.

Now, when our personal computer is operating continuously for few hours it starts getting heated up and we can feel that by touch. Imagine the amount of heat liberated from servers which are operating continuously at all times. This heat generated is enormous and needs to be removed quickly in order to keep the servers operating. Therefore, Cooling becomes of paramount importance and needs to be supplied continuously.

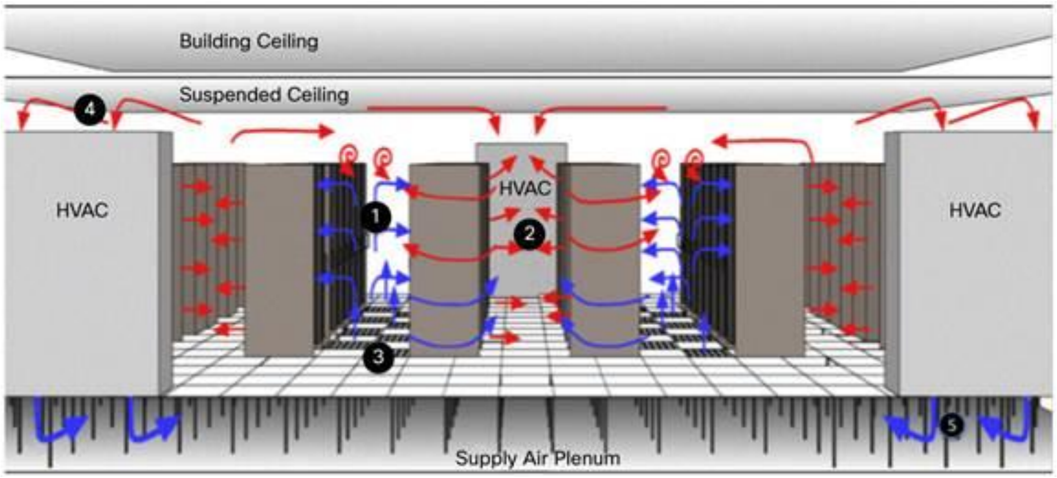


Figure 1.1 Data center air cooling method

There are different methods that are currently employed in data centers to cool their servers. We have Liquid Cooling, where water is circulated through tubes in server to collect and reject heat from the cold plate to the surrounding. Immersion Cooling practices immersion of the servers in a di-electric medium which is circulated through a heat exchanger to reject heat to the surrounding. But, Air Cooling is used widely because of less complexity and greater flexibility. Air Cooling has been in practice ever since the introduction of data centers.

1.2 High Density Data Center

With increasing demand on IT resources, data centers must grow to accommodate the needs of users. But adding more floor space is not an effective solution as it is an expensive, disruptive and sometimes unaffordable option. One possible solution is to increase the power density in the facility. This approach results increase in computing power density.

A number of different approaches to increasing power density have expanded the computing power per square foot of data center space. According to a Gartner press release (“Gartner Says More Than 50 Percent of Data Centers to Incorporate High-Density Zones by Year-End 2015”), “Traditional data centers built as recently as five years ago were designed to have a uniform energy distribution of around 2 kilowatts (kW) to 4kW per rack.” But the addition of high-density zones can increase this energy distribution several times over in certain areas of the facility. “Gartner defines a high-density zone as one where the energy needed is more than 10kW per rack for a given set of rows. A standard rack of industry-standard servers needs 30 square feet to be accommodated without supplemental cooling, and a rack that is 60 percent filled could have a power draw as high as 12kW. Any standard rack of blade servers that is more than 50 percent full will need to be in a high-density zone.”[1]

Chapter 2

OIL IMMERSION COOLING

Liquid immersion cooling is the diminishment of heat in gear through submersion in a dielectric liquid that is thermally conductive. One of the minimum complex outlines of liquid immersion cooling is taking a standard air-cooled PC's hardware and submerging it in mineral oil. Mineral, oil being nonconductive and noncapacitive, speaks to no danger to the equipment. PC fans on occasion use this procedure using standard aquariums to hold the hardware.

The fans continue turning, revolving around the oil over the glow sinks at a lower speed however with a more powerful fluid medium for cooling than air. This cools the parts, as the oil first absorbs the glow, then favorable circumstances from evaporative cooling. In any case, that procedure can't oversee high warmth loads and needs discontinuous energizing of the oil. More unpredictable frameworks for dousing cooling are used as a piece of magnum opus PCs, incorporated PCs, and datacenters.

These structures still consistently handle evaporative cooling and submerge the parts anyway they are every now and again a close system, more like a cream between standard liquid cooling, complete with pumps and external radiators, and submersion cooling. Their liquid is most typically a composed dielectric fluid with a lower limit than water. The liquid disperses, unites and streams back to the reason made a tank. This cycle diminishes the cost in a fluid, which is frequently prohibitive and excessive.

Figure 2-1 Submerging supercomputers into vats of liquid.

Distinctive focal points consolidate verging on the silent operation and less spotless in perspective of the diminishment in required wind stream. Water cooling can confine the flexibility of server ranch layout in light of the way that systems joined with funnels can't be easily patched up. The blend of electronic structures and water moreover obfuscates disaster recovery masterminding (DRP). Administrators need to know early how they will oversee potential issues, for instance, rust or spillage.

Immersion cooling with dielectric liquid encourages a substantial segment of these stresses and the general fear of merging electrical systems and water. The coolant can be creatively used to transport the glow where it is useful, inciting convincing speculation reserves on warmth moreover. Most server homestead immersion cooling plans are unreasonable to execute.[2]

2.1 Chemistry of Mineral Oil

Rough petroleum goes about as a wellspring of extraction of petroleum oil, which contains hydrocarbons alongside a little the extent of Sulfur and Nitrogen [3]. The particles of hydrocarbons are chiefly made out of Paraffin, Naphthenes, furthermore, Aromatics. Methane as a gas, ordinary butane and isobutane go under the gathering Paraffin while Naphthenes contain ring structures which can be either with 6 carbons particles inside of six-membered rings or 14 carbon molecules inside three-membered rings. Aromatics likewise fall under the class of six-membered ring structures, monoaromatic meaning single ring and polyaromatic which alludes to two or more rings.

On refining unrefined petroleum, helpful items like fuel, lamp oil, greasing up oils, LPG (fluid petroleum gas), thus on are gotten. In this procedure, different steps like Sulfuric corrosive extraction, specific dissolvable extraction, earth filtration, hydrogenation, re-refining, filtration, parchedness are taken after and this procedure additionally comprises of a vacuum refining unit.[4]

Chapter 3

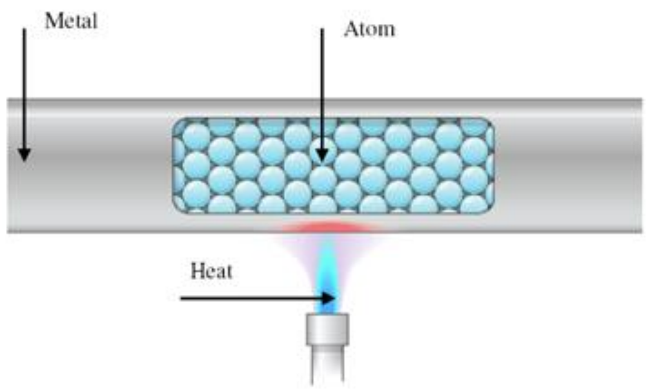
HEAT TRANSFER AND HEAT SINK

Heat transfer deals with the flow of heat from a body at higher temperature to a body at lower temperature. Heat cannot be stored and it is defined as the energy in transit due to the difference in the temperatures of the hot and cold bodies. The study of heat transfer not only explains how the heat energy transports but also predicts about the r Chemistry Of Mineral Oil ate of heat transfer. As we are dealing with the heating and cooling of materials in almost our all the processes, the heat transfer is an indispensable part of any of the industries. There are three different modes in which heat may pass from a hot body to a cold one. These modes are conduction, convention, and radiation. It should be noted that the heat transfer takes place in combination of two or three modes in any of the real engineering application.

3.1 Conduction

Conduction is the transfer of heat in a continuous substance without any observable motion of the matter. Thus, heat conduction is essentially the transmission of energy by molecular motion. Consider a metallic rod being heated at the end and the other end of the rod gets heated automatically. The heat is transported from one end to the other end by the conduction phenomenon. The molecules of the metallic rod get energy from the heating medium and collide with the neighboring molecules. This process transfers the energy from the more energetic molecules to the low energetic molecules. Therefore heat transfer requires a temperature gradient, and the heat energy transfer by conduction occurs in the direction of decreasing temperature. Figure 3.1

shows an illustration for the conduction, where the densely packed atoms of the rod get energized on heating and vibration effect transfers the heat as described in fig.3-1.



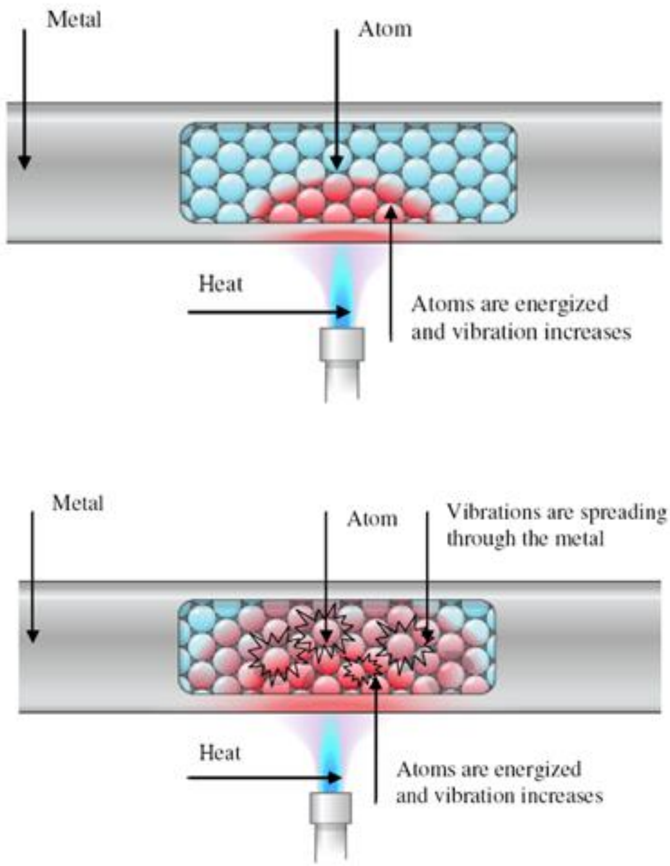


Figure 3-1 Different stages during conduction in a metallic rod

The Heat transfer in conduction is governed by the Fourier's law of heat conduction which is given by

$$Q = -KA\frac{dT}{dx}$$

Where Q = Heat transfer

K = Thermal conductivity

A = Surface Area

$\frac{dT}{dx}$ = Temperature gradient

3.2 Convection

When a macroscopic particle of a fluid moves from the region of hot to cold region, it carries with it a definite amount of enthalpy. Such a flow of enthalpy is known as convection. Convection may be natural or forced. In natural convection, the movement of the fluid particles is due to the buoyancy forces generated due to density difference of heated and colder region of the fluid as shown in the fig.3-2a. Whereas, in forced convection the movement of fluid particles from the heated region to colder region is assisted by some mechanical means too (eg. stirrer) as shown in fig.3-2b.

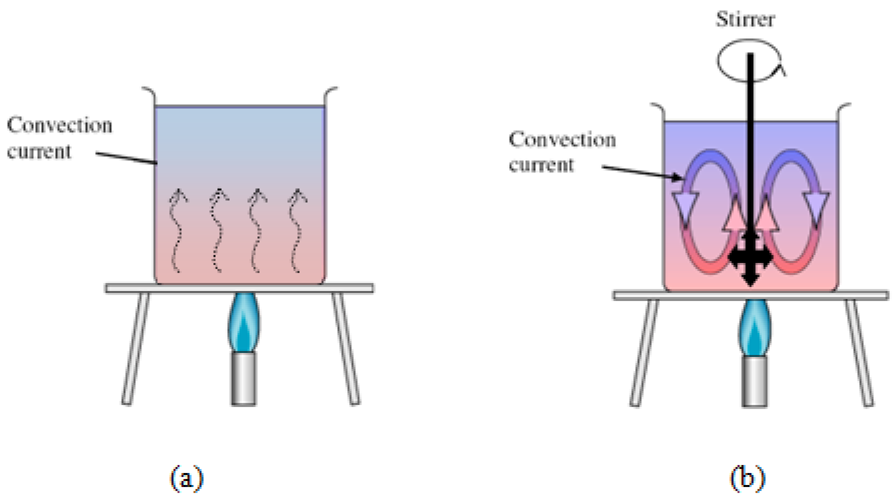


Figure 3-2 Heat transfer through convection (a) Natural (b) Forced

Convection is governed by Newton's law of cooling. The rate of heat transfer is given by

$$Q = hA(T_w - T_\infty)$$

Where h = heat transfer co-efficient

A = Surface area

T_w = Wall temperature

T_∞ = Temperature of the surroundings

3.3 Radiation

We have seen that a medium is required for the heat transfer in case of conduction and convection. However, in case of radiation, electromagnetic waves pass through the empty space. Electromagnetic waves travel at the velocity of light in vacuum. These waves are absorbed, reflected, and/or transmitted by the matter, which comes in the path of the wave. Thermal radiation is the term used to describe the electromagnetic radiation, which is observed to be emitted by the surface of the thermally excited body. The heat of the Sun is the most obvious example of thermal radiation.

There will be a continuous interchange of energy between two radiating bodies, with a net exchange of energy from the hotter to the colder body as shown in the fig.3-3

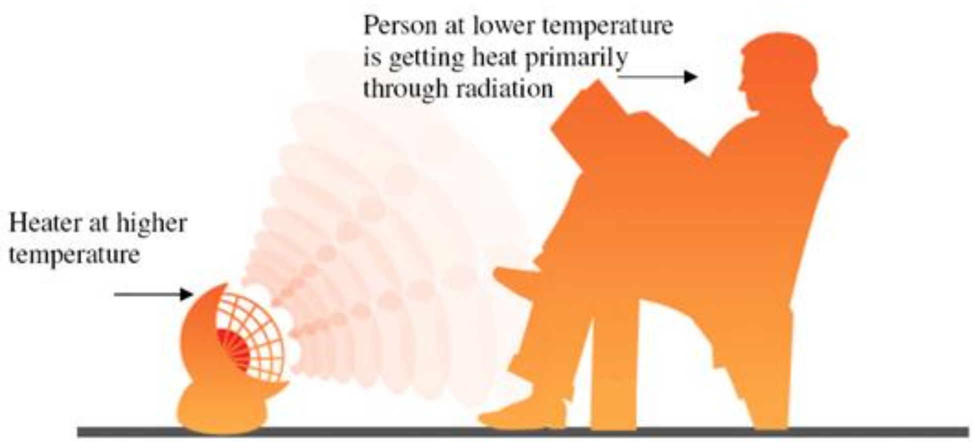


Figure 3-3 Heat transfer through radiation

The heat transfer in radiation is given by Stefan-Boltzmann law

$$Q \propto \sigma A T^4$$

Where $\sigma = 5.67*10^{-8}$ W $.m^{-2}.K^{-4}$ (Stefan- Boltzmann Constant)

A = Surface area of the radiating object

T = Temperature of the object

3.4 Heat Sink

A heat sink is nothing but a heat removal device which aids in heat transfer. Usually it is attached to an object or placed on the top of it so as to remove the heat from the objects in order to make the object work efficiently and keep the object below the peak working temperatures. With the increase in heat dissipation from microelectronics devices and the reduction in overall form factors, thermal management becomes a more a more important element of electronic product design.

Both the performance reliability and life expectancy of electronic equipment are inversely related to the component temperature of the equipment. The relationship between the reliability and the operating temperature of a typical silicon semi-conductor device shows that a reduction in the temperature corresponds to an exponential increase in the reliability and life expectancy of the device. Therefore, long life and reliable performance of a component may be achieved by effectively controlling the device operating temperature within the limits set by the device design engineers. The primary purpose of a heat sink is to maintain the device temperature below the maximum allowable temperature specified by the device manufacturers.

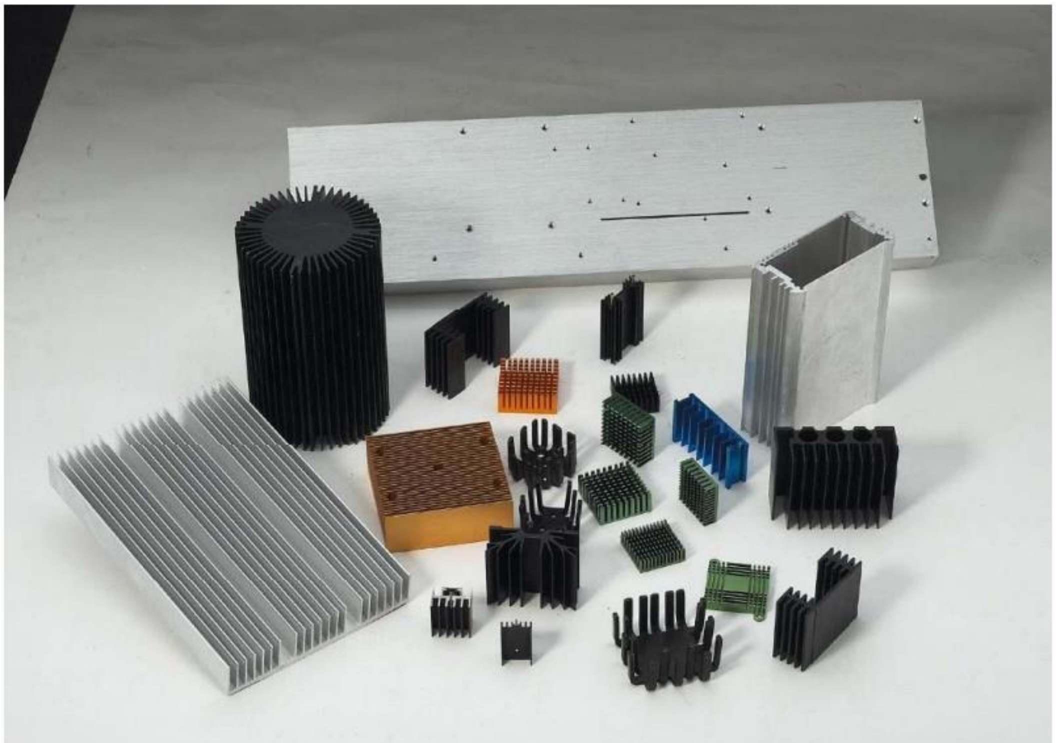


Figure 3-4 Heat sinks

3.4.1 Fins

Fins are extended surfaces that enhance the heat transfer by increasing the area for the heat transfer. Fins are thus used whenever the available surface area is found insufficient to transfer required quantity of heat with available temperature gradient and heat transfer coefficient. In the case of fins the direction of heat transfer by convection is perpendicular to the direction of conduction heat flow. Some of the examples of the use of extended surfaces are in cylinder heads of air cooled engines and compressors and on electric motor bodies. In radiators and air conditioners, tubes with circumferential fins are normally used to increase the heat flow. Electronic chips cannot function without using fins to dissipate heat generated. Fins with different shapes are in use.

3.4.2 Fin Performance

Evaluating the performance of fins is essential to achieve high heat transfer rate or minimum weight etc. Fin effectiveness, fin efficiency and total efficiency are some methods used for performance evaluation of fins.

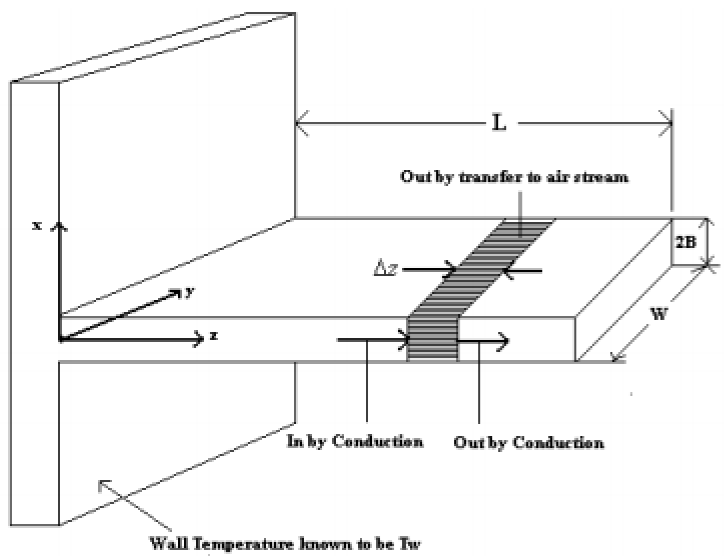


Figure 3-5 Rectangular fin

Fin efficiency, η

This quantity is more often used to determine the heat flow when variable area fins are used. Fin efficiency is defined as the ratio of heat dissipation by the fin to the heat dissipation takes place if the whole surface area of the fin is at the base temperature Tw.

$$\eta = \frac{\text{Actual heat dissipation}}{\text{Heat that would be dissipate if the fin surface was at } T_w \text{ everywhere}}$$

Then we can write

$$\eta = \frac{W\int_0^1 h\left(T\text{-}T_a\right)\, dz}{W\int_0^L h\left(T_w\text{-}T_a\right) dz} = \int_0^1 \theta \, dJ$$

<u>Fin Effectiveness, ε_f</u>

Fins are employed to increase the rate of heat transfer from a surface by increasing the effective surface area. In the absence of fins, the heat convected by the base area is given by Ah (T_w –T_a), where A is the base area. When the fins are present the heat transferred by the fin, Q_f can be calculated. Taking the ratios of these two quantities, we can express ε_f as

$$\varepsilon_f = \frac{Q_f}{hA\left(T_w\text{-}T_a\right)} = \frac{\sqrt{hPkA}\left(T_w\text{-}T_a\right)}{hA\left(T_w\text{-}T_a\right)}$$
$$= \left(\frac{kP}{hA}\right)^{1/2}$$

Where P is the perimeter of a fin

The effectiveness of the fin should be as large as possible for effective use of material used.

Conclusions on Fin Performance

1. Thermal conductivity of the fin material should be high to give large fin effectiveness. This leads to the choice of aluminum and its alloys.
2. The ratio $\frac{P}{A}$ should be as large as possible. This requirement can be achieved by the use of thinner fins. Use more thin fins of closer pitch than fewer thicker fins at longer pitch.
3. Effectiveness will be higher if heat transfer coefficient, h is lower. Generally convection in gas flow and heat flow under free convection lead to lower values of heat transfer coefficient, h. Hence fins are used on the gas side of heat exchangers.

3.5 Role of Fin Geometry in Heat sink Performance

While heat sinks are usually used in most electronics applications, the rationale for selecting a particular design of heat sink or more specifically a particular fin cross sectional profile remains somewhat uncertain. Most often these types of selection procedures are based exclusively on performance evaluations consisting of formulations for extended surface heat transfer found in most fundamental heat transfer text books. A careful review of the literature reveals that no theoretical study exist which compares the overall performance of the different fin geometries based on the thermal as well as the hydraulic resistance. Behnia et al. compared numerically the heat transfer performance of various commonly used fin geometries circular, square, rectangular, and elliptical. They fixed the fin cross-sectional area per unit base area, the wetted surface area per unit base area, and the flow passage area for all geometries. They found that circular pin fins outperform square pin fins and elliptical fins outperform plate fins. Also that the overall thermal resistance of the parallel plate fin was lower than the other two designs, whereas the heat transfer coefficient was highest for elliptical pin fins. They used cylindrical, square, and diamond shape cross section pin-fins and found that cylindrical pin-fins give the best overall fan-sink performance. Furthermore, the overall heat sink thermal resistance decreases with an increase in either applied pressure rise or fan power and fin height.

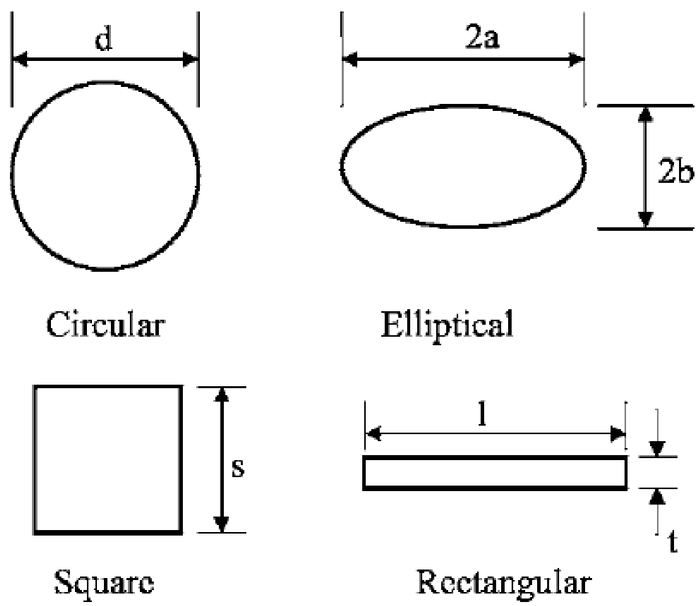


Figure 3-6 Different types of fin geometries

Chapter 4

DESIGN AND METHODOLOGY

The main objective is to design the 3D stacked die. The setup is designed using ANSYS Icepak 17. Our design consists of the following

1. Enclosure
2. PCB
3. RAM
4. Heat Source
5. Heat Sink

4.1 Enclosure

The enclosure is an environment where the entire setup is housed in. The enclosure we used in this is a JEDEC enclosure.

4.2 Printed Circuit Board (PCB)

Printed circuit board objects (PCBs) are two-dimensional rectangular objects representing printed circuit boards. You can specify PCBs either as single boards or as racks of identical boards.

To configure a PCB in the model, you must specify its locations and Dimensions. In addition, you must specify whether the PCB represents an individual board or rack of boards, and the spacing between boards in the rack. All most every electrical enclosures contain PCBs. PCBs are carriers of the traces and copper planes that form of circuitry. In ICEPAK it is easy to design a PCB we wish for.

4.3 RAM

RAM is acronym for Random Access Memory. As the name suggests it allows the data to be accessed randomly. Most of the RAM's are built in the form of integrated circuits. The two different types of RAM available are

1) DRAM (Dynamic Random Access Memory)

2) SRAM (Static Random Access Memory).

RAM is usually a volatile memory and requires power to keep the data accessible. Ram modules are usually installed into one of the memory slots on PCB

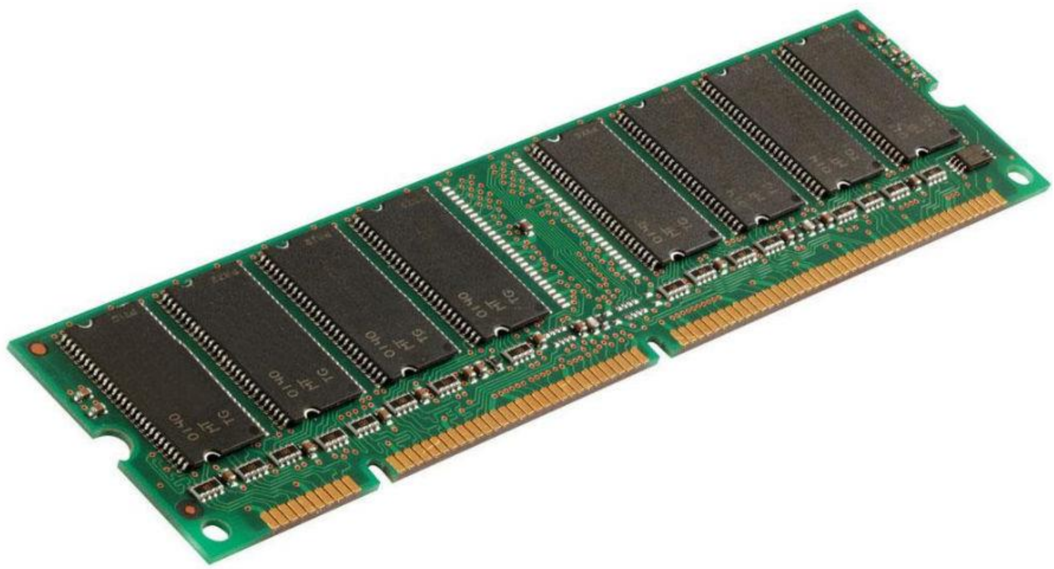


Figure 4-1 RAM Board

4.4 Heat Source

The blocks in ansys icepak used as heat sources with continuous heat supply the blocks. Usually Heat sinks are placed above the heat sources for immediate dissipation of heat from PCB board. Chip packages are the significant heat generating components on mother board.

4.5 Heat Sink

A heat sink is nothing but a heat removal device which aids in heat transfer. Usually it is attached to an object or placed on the top of it so as to remove the heat from the objects in order to make the object work efficiently and keep the object below the peak working temperatures. It is placed on the top of the mold to remove the heat from the Microprocessor. Three different types of fins are used in the computational analysis namely rectangular, cylindrical and conical.

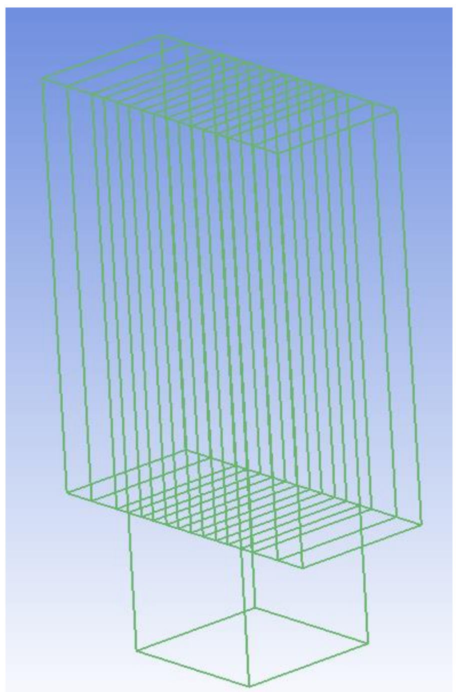


Figure 4-2 Rectangular Fins

4.6 Conditions and Parameters

All the conditions and parameters considered while modeling is mentioned in the table 4-1. Radiation is neglected during the entire process of the simulation. The Heat Transfer takes place only through conduction and convection. All the inlet conditions are ambient. The type of flow is turbulent. The convergence criterion is set to continuity of 10^{-6}.

Table 4-1 Conditions and Parameters

Type of Heat transfer	convection and conduction
Type of Convection	Forced convection
Type of Flow	Laminar
Enclosure	JEDEC
Ambient Temperature	30ºC
Ambient Temperature	1 atmosphere
Inlet Velocity	0.00115 m/s
Convergence Criteria	10^-6 continuity

4.7 Pumping Power

To drive air onto the components in an enclosure the air has to be pumped using a pump. The energy spent in pumping the air is called Pumping power. The flow rate depends on the air pumped in. We can increase or decrease the flow rate using the pump.

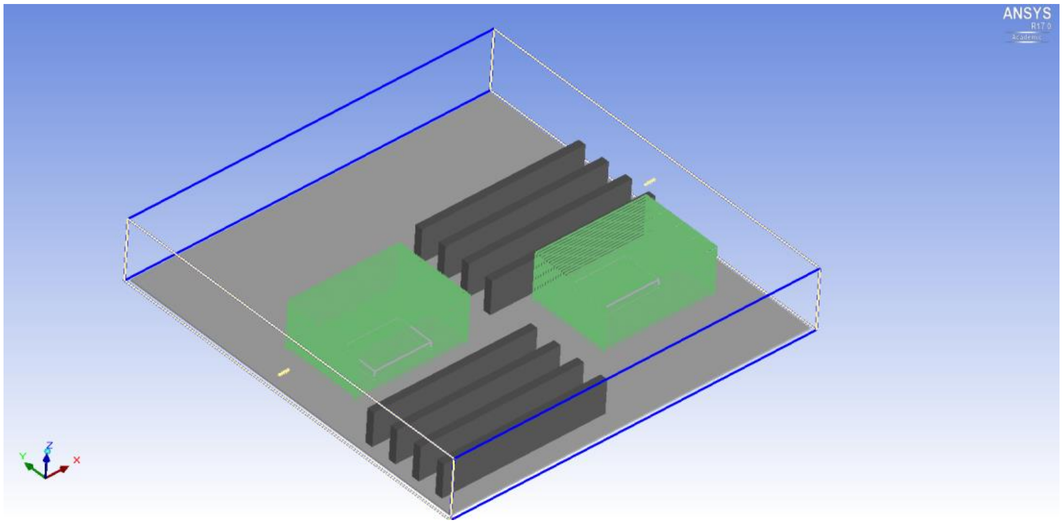


Figure 4-3 Model generated in the Icepak

4.8 Generating a Mesh

Once you have finished designing the model, you need to generate the computational mesh that is used as the basis of the solution procedure. The mesh consists of discrete elements located throughout the computational domain. Within each element, ANSYS Icepak solves the equations that govern the flow and heat transfer in the cabinet. A good computational mesh is an essential ingredient for a successful and accurate solution. If the overall mesh is too coarse, the resulting solution may be inaccurate. If the overall mesh is too fine, the computational cost may become prohibitive. In summary, the cost and accuracy of the solution are directly dependent on the quality of the mesh.

ANSYS Icepak automates the mesh generation procedure, but allows you to customize the meshing parameters in order to refine the mesh and optimize trade-offs between computational cost and solution accuracy.

Chapter 5

RESULTS AND DISCUSSIONS

The simulation is run and the solution for convergence is checked. The variation of temperature, velocity and their contours are obtained from the Post processor for different configurations and different geometry of the Heat sink. According to the standard procedures the results obtained are good if the junction temperatures of any device or the junction temperatures do not exceed 85ºC.

5.1 Parallel Plate Heat Sink at Constant Flow Rate

The graph of convergence for the Parallel Plate Heat Sink is shown in fig. 5-1. The yellow colored line represents the continuity. The convergence criterion is 10^{-6} for the continuity. It is observed that the continuity line decreases and follows a straight line after 250 iterations which is a good result.

The distribution of temperature along the heat sink and at the junctions of the devices is shown in the fig.5-2. The maximum temperature is recorded as 66.347ºC. The inlet velocity is 0.00115 m/s. Number of fins used are 37 and fin Height is 42.5 mm.

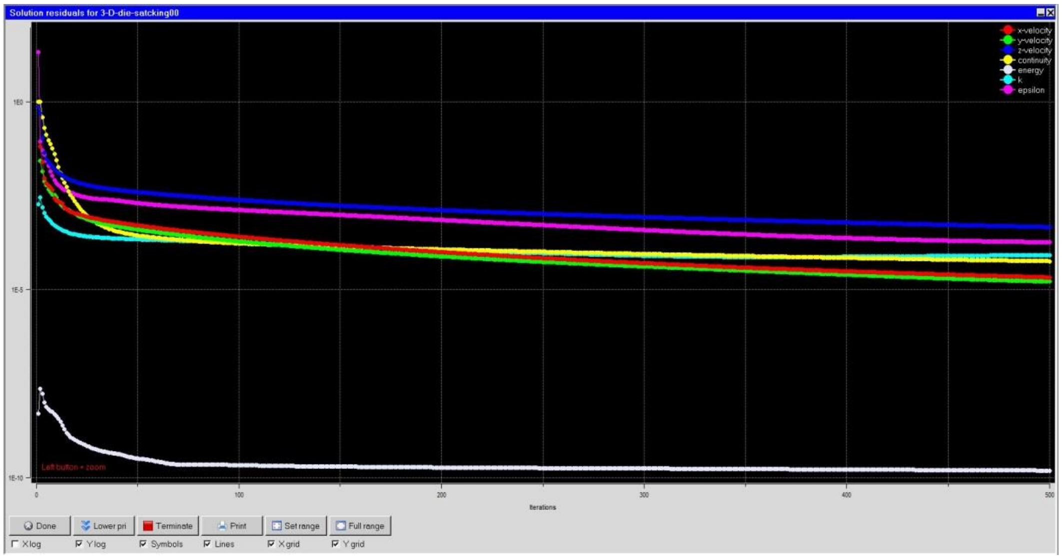


Figure 5-1 Convergence graph for Parallel Plate Heat sink

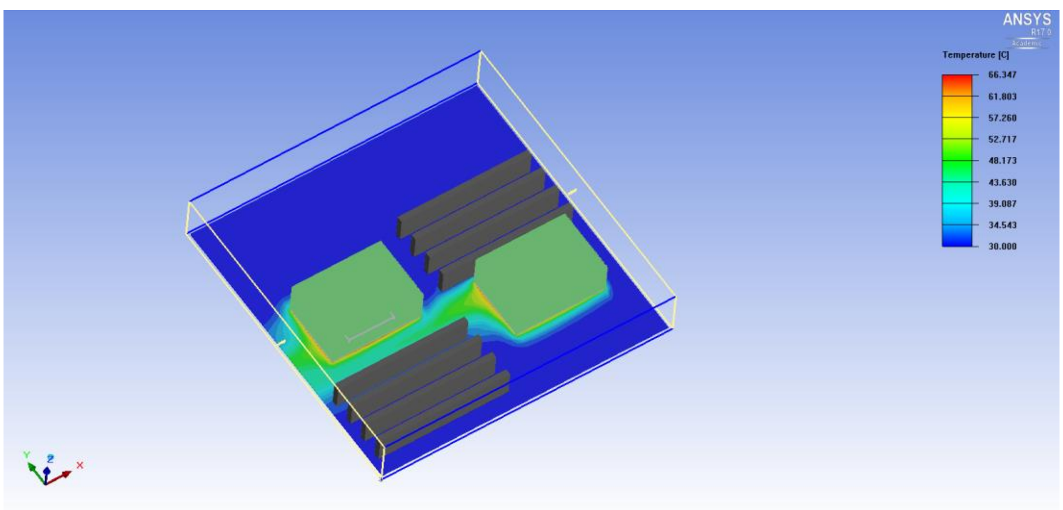


Figure 5-2 Temperature distributions for Parallel Plate Heat sink

5.2 Parallel Plate Heat Sink at Varying Flow rates

The distribution of temperature along the heat sink and at the junctions of the devices are shown in the Table.5-1. The maximum temperature is recorded as 73.36ºC when flow rate is 0.5 LPM. The flow rates observed are 0.5, 1.0, 1.5 and 2.0 litre per minute for which inlet velocity will be 0.00057, 0.00114, 0.00171. 00.00228 m/s respectively. Number of fins used were 37 and height of fins is 42.5mm which were optimized for air cooling methods.

Table 5-1: Temperature Distribution for Varying Flow rate

Temperature	No. of Fins	Flow Rate	Fin Height	Thermal Resistance
73.36	37	0.5 LPM	42.5	0.4564210526
71.02	37	1 LPM	42.5	0.4317894737
70.36	37	1.5 LPM	42.5	0.4248421053
69.94	37	2 LPM	42.5	0.4204210526

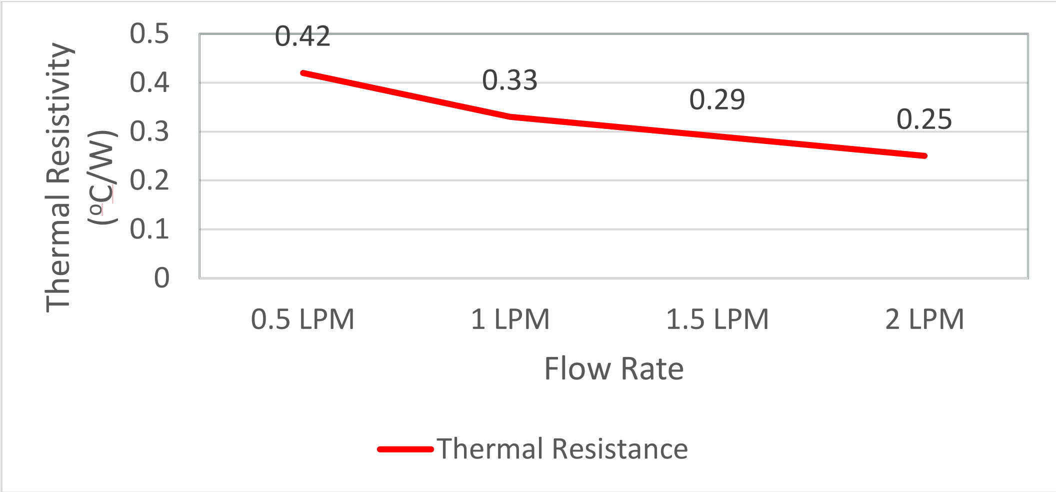


Figure 5-3 Thermal Resistance VS Flow Rate

As we can observe from the table the Thermal resistance is decreasing as the flow rate is increasing. The standard flow rate we consider for our analysis is 1LPM.

5.3 Parallel Plate Heat Sink with varying Number of fins

The distribution of temperature along the heat sink and at the junctions of the devices are shown in the Table.5-2.The maximum temperature is recorded as 80.03ºC when number of fins were 2. The inlet velocity applied is 1 LPM (0.00114m/s). Height of fins kept 42.5mm and by varying number of fins temperature distribution is observed. Heat Sink Base Height fixed 4.5 mm.

Table 5-2 Temperature distribution at varying number of fins

Temperature	No. of Fins	Flow Rate	Fin Height	Thermal Resistance
80.03	2	1 LPM	42.5	0.5266315789
63.66	4	1 LPM	42.5	0.3543157895
56.15	6	1 LPM	42.5	0.2752631579
52.95	8	1 LPM	42.5	0.2415789474
52.75	10	1 LPM	42.5	0.2394736842
54.32	12	1 LPM	42.5	0.256
55.9	14	1 LPM	42.5	0.2726315789
57.9	16	1 LPM	42.5	0.2936842105
60.32	18	1 LPM	42.5	0.3191578947

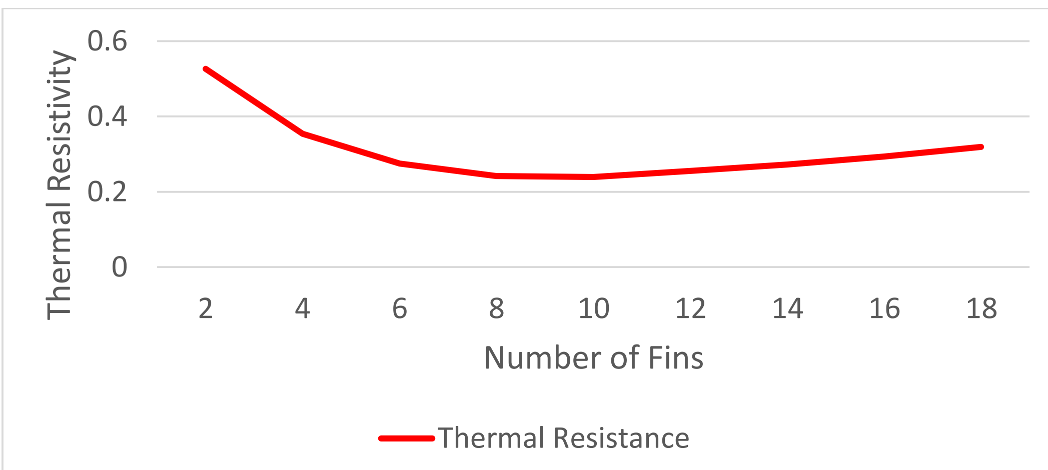


Figure 5-4 Thermal Resistance vs Number of fins

As we observe from the table thermal resistance of Heat Sink is decreasing as the number of fins decreasing until number of fins are 8.Optimum level of thermal resistance observed at 8 fins on heat sink.

5.4 Parallel Plate Heat Sink with Varying Fin Height

The distribution of temperature along the heat sink and at the junctions of the devices are shown in the Table.5-3. The inlet velocity applied is 1 LPM (0.00114m/s). Height of fins kept 42.5mm and by varying number of fins temperature distribution is observed. Heat Sink Base Height fixed 4.5 mm.

Table 5-3: Temperature Distribution for Varying Fin Height

Temperature	No. of Fins	Flow Rate	Fin Height	Thermal Resistance
94	18	1 LPM	15	0.6736842105
87.36	18	1 LPM	18	0.6037894737
79.99	18	1 LPM	22	0.5262105263
75.55	18	1 LPM	25	0.4794736842
70.89	18	1 LPM	29	0.4304210526
68.84	18	1 LPM	31	0.4088421053
66.9	18	1 LPM	33	0.3884210526
65.34	18	1 LPM	35	0.372
63.82	18	1 LPM	37	0.356
62.38	18	1 LPM	39	0.3408421053
61.28	18	1 LPM	41	0.3292631579

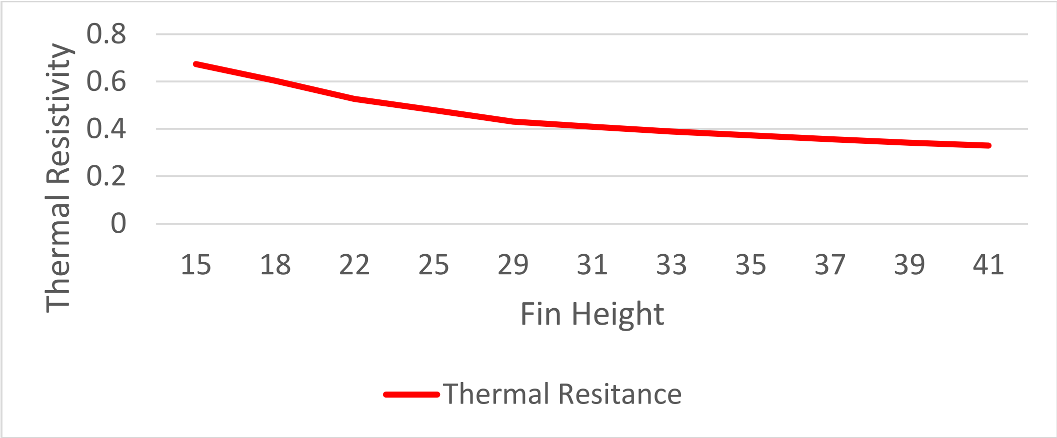


Figure 5-5 Thermal Resistance vs Fin Height

As we can observe from the table the Thermal Resistance of Heat Sink decreases as the height of fin increases. But we can see the change in thermal resistance is very insignificant after fin height increses from 31mm. So, the efficient fin height can be considered as 31mm.

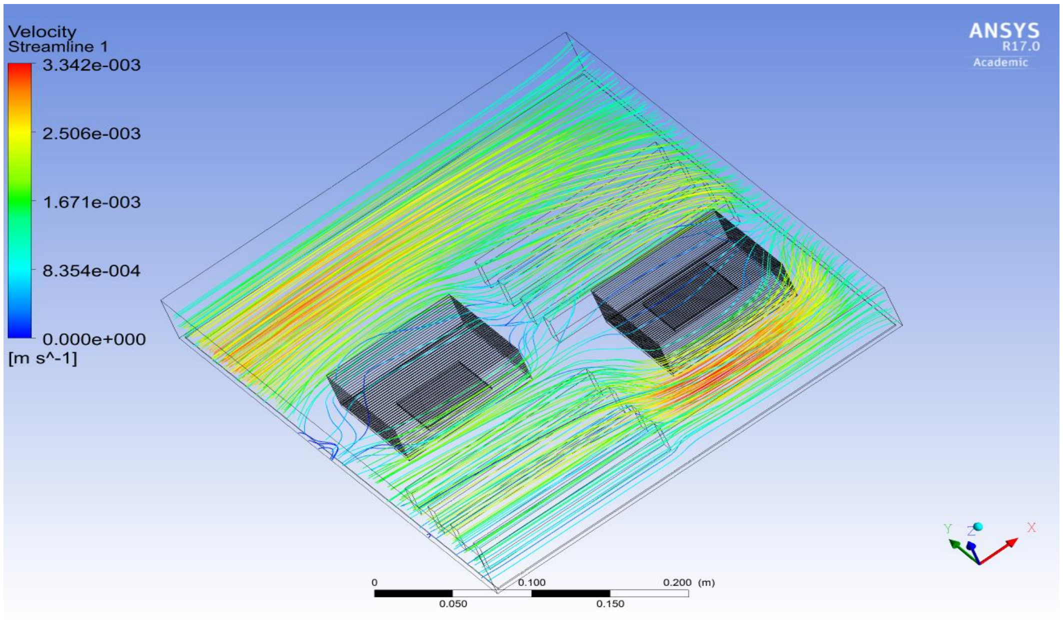


Figure 5-6 Particle Tracking in CFD Post

Chapter 6

CONCLUSION AND FUTURE WORK

6.1 Conclusions

From the obtained results Table 6-1 has been made. The Table shows the thermal resistance behavior for different parameters of Parallel Plate Heat .

Table 6-1 Thermal Resistance at Optimized Parameters

Temperature	**No.of Fins**	**Flow Rate**	**Fin Height**	**Thermal Resistance**
68.84	18	1 LPM	31	0.4088421053
66.9	18	1 LPM	33	0.3884210526
65.34	18	1 LPM	35	0.372

The following conclusions has been made from the results obtained

- ✓ The Parallel Plate Heat Sink optimized efficiency observed at 18 Number of fins on Heat Sink in Third Generation open compute server.
- ✓ Thermal Resistance of Parallel Plate heat sink decrease as the flow rate increases.
- ✓ Optimized Fin height for parallel Heat sink is 3 -3.4 cm for Third generation open compute server.
- ✓ Life of the equipment will increase and thus rise in reliability.

- ✓ Capitol cost can be cut-off highly at optimum number of fins and fin height.

6.2 Future work

The computational work can be experimentally tested and good results can be obtained. Also the effect turbulence on the devices can be done both computationally and experimentally. Further study can be conducted with fixed pumping power.

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