# 3D Conjugate Heat Transfer for Single Phase Immersion Cooling of CPU

by

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# ABSTRACT

This research aims to develop a single-phase immersion cooling system for CPU (Central Processing Unit) processors. To achieve this, a heat pipe with a dielectric liquid is designed to be used to cool the CPU, relying only on natural convection. A Tesla valve phenomenon is used to achieve the one-directional, recirculating system. A comparative study was conducted between two different single-phase dielectric fluids Mineral Oil and FC 3283 (Fluorocarbon), utilizing natural convection and Boussinesq correlations. ANSYS Fluent was used to conduct CFD (Computational Fluid Dynamics) analysis, demonstrating natural convection and recirculating flow in the heating direction. A comparison was made between the traditional cooling method of air and the developed immersion cooling system, with the results indicating that the system is capable of reducing the operating temperature of the CPU by 40 to 50 degrees Celsius, depending on the power consumption. The results of the experiment conducted showed that a processor cooled by Mineral oil would operate at 56 degrees Celsius, while a processor cooled by FC 3283 would operate at 47 degrees Celsius. By comparison, a processor cooled by the traditional air-cooled system would operate between 80 and 100 degrees Celsius. These results demonstrate that the Mineral oil and FC 3283 cooling systems are significantly more efficient than the traditional air-cooled system. This could prove to be a valuable asset in the development of more efficient cooling systems. Further research is necessary to evaluate the longevity, cost-effectiveness, and benefits of these systems in comparison to traditional air cooling.

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# INTRODUCTION

The Central Processing Unit (CPU) is generally regarded as the "brain" of a computer. It is an essential component responsible for executing the instructions given by the user, and is thus pivotal to the functioning of an entire machine. Since their introduction to the consumer market, CPU's have been growing increasingly powerful, as evidenced by Moore's Law, which states that the transistor count per square inch of a CPU doubles approximately every two years. This dramatic improvement in CPU performance, however, has come at the cost of higher power requirements. If these power requirements are not met, or if the cooling system is inadequate, then the cores of the CPU can become exposed to excessive temperatures, which can cause permanent damage to the hardware. To avoid such a scenario, it is important to ensure that the CPU cores do not exceed their maximum recommended temperatures, which can be done through the implementation of advanced cooling systems and efficient power management techniques. Research must be conducted to analyze the thermal loads associated with modern CPUs, and to develop solutions that can effectively combat overheating.

For decades, the primary cooling solution for consumer computers has been the combination of aluminium or copper heatsinks and fans. This approach has been successful in managing the temperature of the CPU, but it does have its disadvantages. As the wattage of the fans increases, their efficiency decreases, and if the fan reaches cavitation, its effectiveness drops significantly. In addition, a lower operating temperature can help to not only prolong the life of the CPU, but also to optimize its performance. This suggests that alternate cooling technologies should be explored, such as liquid cooling systems, vapor chambers, and thermoelectric cooling.

Research into these technologies could potentially provide a more efficient cooling solution that can help keep the CPU below its optimal operating temperature, while also providing other benefits such as noise reduction and improved system performance.

In recent years, Central Processing Units (CPUs) have become increasingly equipped with an integrated thermal throttling mechanism. This mechanism reduces the operating speed of the processor when its core temperature reaches a specific level, usually during a demanding task. The cooling system is essential to maintain the optimal performance of the CPU and to avoid thermal throttling. Additionally, many PC enthusiasts are interested in overclocking their CPU's, which is done by increasing the processor's clock speed beyond the factory settings. However, when attempting to overclock, the additional heat generated by the processor, as well as the increased power requirement, must be taken into account, and the cooling system must be able to adequately handle the increased load. Research is currently being conducted in order to determine the best methods for cooling CPUs when overclocking and to identify the most effective cooling solutions for different types of CPUs.

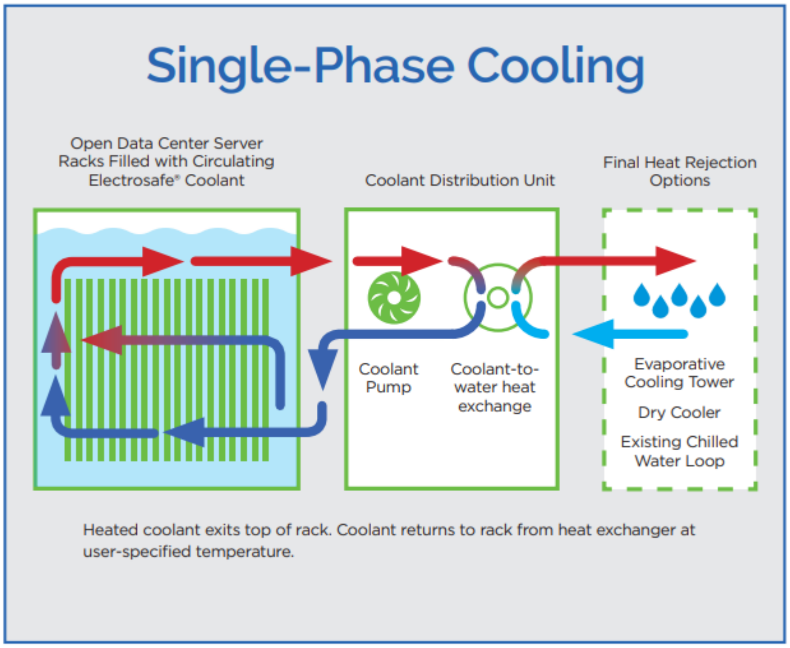
In order to meet the expanding need for cooling with modern CPUs, PC enthusiasts have developed two distinct solutions. The first is to mount an aluminium water block on the CPU, allowing water to flow through the water block and a cooling loop. This has been found to be significantly more efficient than traditional air cooling due to the superior capacity of water to promote forced convection. Unfortunately, this method is also much more hazardous, as any leak may lead to shortening of the system. The second concept is the new and developing method of immersion cooling, where the PC is submerged in a tank of mineral oil. This offers an alternative solution to air or water cooling, and although its effectiveness and reliability are yet to be thoroughly tested, preliminary evidence suggests that this could become a viable replacement for traditional cooling methods. Further research is required to better understand the potential applications of immersion cooling and to ensure its safety and reliability.

This research paper will explore the effectiveness of mineral oil as a dielectric fluid for cooling computer components. Mineral oil has the unique ability to insulate against the flow of electricity, thus removing the need for hermetic connectors, pressure vessels, seals and clamshells, which are typically associated with immersion cooling. Additionally, mineral oil eliminates the need for connectors, plumbing, pumps and cold plates, which are usually part of more traditional liquid cooling systems. This research will investigate the effectiveness of mineral oil for cooling computer components, and determine if it is a viable alternative to other cooling methods. A significant number of studies have been conducted to evaluate the potential of immersion cooling to improve the power density of data centers. These studies examined temperature measurements of CPUs, motherboard components, and bulk fluid, while keeping all other conditions constant, and compared them to results from traditional air cooling. The results of these studies indicated that mineral oil is a viable alternative for cooling data centers and could potentially increase power density. Nonetheless, further research is needed to consider the cost-effectiveness of immersion cooling and to explore the possibility of its implementation on a large scale in order to reduce energy consumption and operational costs.

The implementation of immersion cooling for data centers has been the focus of much research, due to its potential for cost savings. By using a liquid or refrigerant as a cooling medium, data centers can reduce their reliance on air conditioners, thereby reducing the amount of real estate needed for server racks and saving money on rent. Further research has shown that immersion cooling is at least marginally more efficient than air cooling for servers, leading to significant energy savings. Understanding the most effective and cost-efficient way to implement immersion cooling in a data center has become a priority for many researchers, due to the potential cost savings that could be achieved. To this end, various studies have investigated the technical and economic implications of immersion cooling and the best practices for its successful deployment.

This paper seeks to investigate whether immersion cooling is a viable alternative to traditional air cooling for high-performance computing systems. Specifically, it will analyze the potential cost savings, hardware requirements, and increased failure rate of immersion cooling in comparison to air cooling systems. Additionally, it will explore potential solutions to the issues associated with immersion cooling, such as specialized hardware and improved cooling liquids. This research will provide insight into whether immersion cooling is a viable alternative to traditional air cooling for high-performance computing systems, and the potential for it to be adopted more widely.

Exploring further into Immersion Cooling, two distinct models are employed in the industry, namely Single-Phase Immersion Cooling and Two-Phase Immersion Cooling. Single-phase immersion cooling involves immersing the heat-generating components, such as processors, in a fluid bath, usually a dielectric fluid. This fluid acts as a heat transfer medium, allowing the heat generated by the components to be efficiently dissipated and removed from the system. Two-phase immersion cooling involves immersing the components in a fluid bath which is maintained in a two-phase state, with a liquid and gas phase. In this system, the liquid phase transfers heat away from the components, which is then dissipated and removed by the gas phase.



Heated coolant exits top of rack. Coolant returns to rack from heat exchanger at user-specified temperature.

Figure 1: Single Phase Immersion Cooling

As shown in Figure 1. Single-phase immersion cooling is an increasingly popular concept for data center cooling, as it is seen to be more cost-effective, easier to maintain, and requires less floor space than traditional cooling methods. In this system, servers are submerged in a hydrocarbon-based dielectric fluid, such as mineral oil, which is then cooled via a heat exchanger or Cooling Distribution Unit (CDU). As the servers are completely submerged, they don't take up any additional space, making this an ideal cooling solution for data centers with limited floor space. This system does not involve boiling off the coolant, unlike two-phase immersion cooling, but instead keeps it in the liquid phase. This makes it much simpler to operate and maintain, and is a viable option for data centers with limited infrastructure and resources. [1]

This research paper will investigate the use of single phase cooling as a cost-effective and future-oriented approach for cooling processor units in computers. A comprehensive assessment and comparison of various single phase cooling media will be performed in the following chapter to determine the optimal cooling medium for the single phase immersion cooling system. The findings of this study will be utilized to guide the selection of the most suitable cooling medium for the intended cooling system.

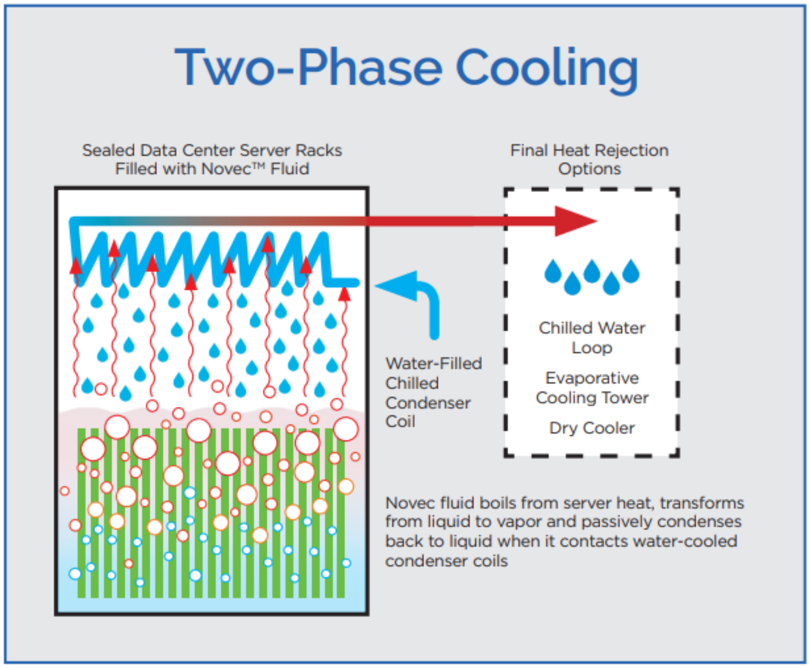


Figure 2: Two Phase Immersion Cooling

As shown in Figure 2. Two-phase immersion cooling is a sophisticated cooling method in which servers are encased in a bath of specially formulated fluorocarbon-based liquid. This liquid has a lower boiling point than water, typically below 50°C. As a result, heat from the servers can quickly boil the surrounding liquid, which undergoes a phase change from liquid to gas. The vapor is then condensed back to liquid form through water-cooled condenser coils built into the top of the rack. The condensed liquid then drips back into the bath to be recycled through the system. This type of cooling offers numerous advantages over traditional air-cooling systems, including increased system density, improved cooling efficiency, and lower noise output. Additionally, two-phase immersion cooling can potentially reduce the risk of fires, as the liquid bath quickly dissipates heat and can reduce the temperature of servers to below their maximum operating temperature. Two phase immersion cooling system requires a condenser coil to cool down the vapor and drips back into the bath, it also requires a cooling tower or other mechanism to cool the heated water in condenser. So, overall system consist a multiple components and required larger area which is a major disadvantage of this system and hence this paper mainly focuses towards the development of single phase immersion cooling system without any external devices or components. [1]

# COOLING MEDIUM SELECTION

When selecting a cooling medium for single phase immersion cooling, it is important to consider the thermal and physical properties of the cooling medium. It is also important to consider the application and its environmental conditions. Common cooling mediums used for single phase immersion cooling are water, ethylene glycol, and mineral oils. Water is the most commonly used because it is inexpensive and has a good thermal conductivity and high heat capacity. Ethylene glycol is used when the application needs to operate in very cold temperatures and when water may freeze. Mineral oils are used when the application needs to operate in extremely hot temperatures and water may boil. The choice of cooling medium should be based on the application's needs and the conditions in which it will be operating.

## a. Dielectric Strength

The ability of a fluid to resist the flow of electrical current is known as its dielectric strength. When selecting a cooling system for an electrical system, it is important to take into account the dielectric strength of the immersion coolant. This property indicates the effectiveness of the fluid in protecting against electric shorts and shocks. Fluids with higher dielectric strength are better able to withstand higher levels of electrical stress, making them suitable for use in high voltage applications. Investigating the dielectric strength of potential coolants is essential for selecting an appropriate and safe cooling system for an electrical system. The risk of an electrical short occurring in a circuit board due to its immersion in a fluid can be attributed to a phenomenon known as electrical breakdown. When the electrical potential difference between two points within a material reaches a high enough value, the insulating properties of the material fail, resulting in a rapid movement of electrons and causing a short circuit. This phenomenon is commonly observed in nature as lightning, wherein the potential difference between two points in the atmosphere reaches a sufficiently high value, causing a breakdown of the insulating properties of the air. Research has shown that when a fluid with a low dielectric strength is in contact with an electrical device, it can cause a short circuit, leading to system failure or damage. This is due to the low dielectric strength of the fluid causing an increase in current, which can overload the device.

In addition, the fluid can corrode or damage the electrical contacts, further exacerbating the problem. It is important to ensure that any electrical system that is in contact with a fluid with a low dielectric strength is adequately protected with fuses, circuit breakers, and other protective devices. Furthermore, it is important to regularly inspect and monitor the system to ensure that no damage has occurred due to the presence of the low dielectric strength fluid.

Thus, the selection of a cooling medium with higher dielectric strength has been shown to be a better choice for electronics cooling and immersion cooling systems. This is because it can provide better protection to the electronics, higher cooling efficiency and lower operating costs. Additionally, the use of a dielectric liquid with a higher dielectric strength can help to reduce the risk of electrical shock and short-circuiting, as it is non-conductive. Immersion cooling is a popular cooling system for electronics which involves immersing the components in a dielectric liquid, such as mineral oil or a fluorocarbon-based liquid. This type of cooling has many advantages over traditional air cooling techniques, such as higher heat transfer rates and better cooling efficiency. Therefore, the selection of a dielectric liquid with a higher dielectric strength is the preferable choice for electronics cooling and immersion cooling systems, as it can provide better protection for the electronics and improved cooling efficiency, as well as lower operating costs.

Immersion cooling has become an increasingly popular choice for organisations to cool their data centres due to the many advantages it provides. Amongst the various cooling mediums available in the market, Fluorinert FC 3283, Fluorinert FC 43, Fluorinert FC 60, Fluorinert FC 80, Silicone Oil 20, Silicone oil 50, and Soybean Oil 50 are some of the most widely used options for immersion cooling, with mineral oil and fluorocarbon-based liquids being the most popular choices [4]. As this research solely focuses on single phase immersion cooling systems, the selection of the appropriate cooling medium is of paramount importance, as it must be able to withstand the required temperature without reaching its boiling point. Research has indicated that the dielectric strength of mineral oil is significantly higher than that of air, with a difference of almost four times. the dielectric strength of air to be 3 kV/mm and that of mineral oil to be 11.8 kV/mm. This research reveals that when a CPU or computer board is operated in mineral oil, the risk of a short occurring is much lower than that of a short occurring in air. This finding illustrates why it is possible to successfully run a CPU immersed in mineral oil. Hence one of the suitable choices for single phase immersion cooling is Mineral Oil. Morito Matsuoka, Kazuhiro Matsuda, and Hideo Kubo conducted a case study entitled “Liquid Immersion Cooling Technology with Natural Convection in Data Center” [4] to evaluate the efficiency of various liquids as coolants in immersion cooling. The five liquids they tested were Fluorinert FC 3283, Fluorinert FC 43, Silicone Oil 20, Silicone oil 50, and Soybean Oil 50. According to their research, Fluorinert FC 3283 was the most efficient coolant for immersion cooling, with a temperature range of -65°C to 128°C [3]. Thus, Fluorinert FC 3283 is the second optimal choice for single phase immersion cooling. Also, The 3M™ Fluorinert™ Liquid FC-3283 is a dependable, non-conductive dielectric fluid that is suited for a range of thermal management purposes, including semiconductor wafer production, data center server immersion cooling, and other high-tech applications. This fluid is thermally and chemically stable, making it a great option for these types of applications.

| Fluid | Dielectric Strength |
|---|---|
| Air | 3 kV/mm |
| Mineral Oil | 11.8 kV/mm |
| FC 3283 | 40 kV/mm |

Table 1: Dielectric Strength of Air, Mineral Oil, FC-3283 [2],[3]

### b. Thermal Expansion Coefficient for Mineral Oil & FC 3283

This thermal expansion coefficient has been determined through numerous experiments, and has been found to be consistent across various materials. It is important to note that this coefficient may vary depending on the material being studied, as well as the temperature at which it is being studied. Consequently, it is important for researchers to accurately identify the thermal expansion coefficient of the material they are studying in order to ensure accurate results.

The equation for determining the thermal expansion coefficient, β, can be derived from this relationship.

$$\beta = \rho \frac{d(\rho^{-1})}{dT}$$

The values of density for Mineral Oil can be expressed as the following function. [2]

$$\rho = 872.5 - 0.625(T) \quad for\ 20°C \ \leq T \ \leq \ 60°C$$

Hence, Thermal expansion coefficient for Mineral Oil can be determined as,

$$\beta = \rho \frac{d(\rho^{-1})}{dT} = 1.6 \frac{872.5 - 0.625(T)}{(1396 - x)^2}$$

$$for\ 20°C \ \leq T \ \leq \ 60°C$$

At a theoretical operating temperature of 35°C, the thermal expansion coefficient for mineral oil is $7.3475 \times 10^{-4}\ [1/K]$, meaning that for every 1 Kelvin increase in temperature, the material will expand by $7.3475 \times 10^{-4}$. [2]

Same way for FC-3283 the density expression is given below [3],

$$\rho = 1878 - 2.455(T) \quad where\ T\ (°C) \ \text{ and } \rho_0 = 1816\ kg/m^3$$

calculating thermal expansion coefficient for FC-3283

$$\beta = \rho \frac{d(\rho^{-1})}{dT} = 1816 \frac{1878 - 2.455(T)}{dT}$$

Again, at a theoretical operating temperature of 35°C, the thermal expansion coefficient for FC 3283 is 0.0014[1/K]. [3]

| Cooling Medium | Thermal Expansion Coefficient |
|---|---|
| Mineral Oil | $7.3475 \times 10^{-4}\ [1/K]$ |
| FC-3283 | $0.0014\ [1/K]$ |

Table 2: Thermal Expansion Coefficient for Mineral Oil & FC-3283

### c. Other Material Properties

In order to accurately replicate a single-phase immersion cooling system in ANSYS Fluent numerical simulation, the values of specific material properties of the cooling medium must be obtained, including absolute viscosity, kinematic viscosity, thermal diffusivity, thermal conductivity, and specific heat capacity.

It is possible to deduce certain properties from other properties; for instance, thermal diffusivity can be determined from thermal conductivity, density, and specific heat capacity using the following equation,

$$Thermal\ diffusivity\ \ \alpha = \frac{k}{\rho \times Cp}$$

Kinematic Viscosity can be determined by measuring the absolute viscosity and density of the liquid used as a cooling medium.

$$Kinematic\ Viscosity\quad \nu = \frac{\mu}{\rho}$$

This study examines the means of achieving an equilibrium between two different working fluids, mineral oil and FC-3283, by interpolating their properties from a table. An iterative process was employed to identify the optimum plate temperature and the results of the process are displayed in a table that contains the plate temperature and the properties of the working fluids that achieved equilibrium.

| Properties | Mineral Oil | FC-3283 |
|---|---|---|
| Density ($\rho$)<br>$[kg/m^3]$ | $872.5 - 0.625(T)$ at 25°C856.04 $kg/m^3$ | $1878 - 2.455(T)$ at 25°C 1816 $kg/m^3$ |
| Specific Heat Capacity ($Cp$)<br>$[J/kg * K]$ | 1917.83 $[J/kg * K]$ | 1046.634 $[J/kg * K]$ |
| Absolute Viscosity ($\mu$)<br>$[N * m^2/s]$ | 0.02340 $[N * m^2/s]$ | 0.0014 $[N * m^2/s]$ |
| Thermal Conductivity($k$)<br>$[W/m * K]$ | 0.1488 $[W/m * K]$ | 0.063824 $[W/m * K]$ |
| Thermal Expansion Coefficient ($\beta$)<br>$[1/K]$ | $\beta = \rho \frac{d(\rho^{-1})}{dT} = 7.3475 \times 10^{-4}$<br>$[1/K]$ | $\beta = \rho \frac{d(\rho^{-1})}{dT} = 0.0014$<br>$[1/K]$ |
| Kinematic Viscosity ($\nu$)<br>$[m^2/s]$ | $2.8058 \times (10^{-5})$<br>$[m^2/s]$ | $7.5 \times (10^{-7})$<br>$[m^2/s]$ |
| Thermal Diffusivity ($\alpha$)<br>$[m^2/s]$ | $\alpha = \frac{k}{\rho \times Cp} = 9.08544 \times 10^{-8}$<br>$[m^2/s]$ | $\alpha = \frac{k}{\rho \times Cp} = 3.404 \times 10^{-8}$<br>$[m^2/s]$ |

Table 3: Material Properties of Mineral Oil and FC-3283 [2],[3]

Previous discussion exclusively focused on the fluid domain of a cooling system; however, the whole system consists of a CPU processor chip, a heat sink, and other solid domains that require cooling. Silicon is a suitable material for the processor chip, while copper is the preferred material for the other domains. The specific properties that these materials have to possess are outlined below.

| Properties | Silicon | Copper |
|---|---|---|
| Density ($\rho$) $[kg/m^3]$ | 2330 $kg/m^3$ | 8978 $kg/m^3$ |
| Specific Heat Capacity ($Cp$) $[J/kg * K]$ | 703.38 $[J/kg * K]$ | 381 $[J/kg * K]$ |
| Thermal Conductivity($k$) $[W/m * K]$ | 149 $[W/m * K]$ | 387.6 $[W/m * K]$ |

Table 4: Material Properties of Silicon and Copper

# CFD SIMULATIONS

The Ansys Fluent computational fluid dynamics (CFD) software was used to create a model of a single-phase immersion cooling system, in order to analyze the conduction-convection heat transfer processes and to simulate the conjugate heat transfer between the solid and fluid components.

## a. Natural convection and Boussinesq:

The design mainly depends on the natural convection and buoyancy effect in the fluid. The natural convection of fluids is a phenomenon that occurs in a variety of contexts, from industrial applications to planetary atmospheres. Its importance lies in its ability to transport heat and momentum, which can affect the flow of air, water, and other fluids. The Boussinesq equation is a mathematical model that describes the behavior of a fluid subject to natural convection. It describes the density, velocity, and pressure of the fluid and is used to predict the temperature and pressure of the fluid in a given system. The Boussinesq equation is useful for applications such as heating systems, cooling systems, and other industrial processes. For example, it can be used to predict the temperature profile of a fluid in a pipe or other closed system. In addition, the Boussinesq equation can be used to study the behavior of natural convection in the atmosphere, oceans, and other bodies of water. The equation can also be used to study the effects of gravity on a fluid and its role in natural convection. By understanding the behavior of natural convection, engineers can develop more efficient heating and cooling systems, and scientists can better understand the dynamics of Earth's atmosphere and oceans.

Natural convection is a common heat transfer mechanism in immersion cooling systems, which are used to cool electronic components. In these systems, the heat transfer fluid is heated by the components and then convected away due to the force of gravity. The efficiency of the convection process is largely determined by the physical properties of the heat transfer fluid, such as its thermal conductivity, viscosity, and density. The buoyancy force is the main driving force behind the convective process, causing hot fluid to rise and cold fluid to sink. In addition, the shape of the container and the orientation of the components will also have an influence on the convection process. Furthermore, the rate of heat transfer can be increased through the use of fans, pumps, or heat exchangers, which can improve the overall efficiency of the cooling system.

The Boussinesq approximation is a mathematical tool used to approximate the behaviour of a fluid in the presence of a temperature gradient. This approximation considers the changes in fluid density due to temperature differences and can be used to estimate convective heat transfer coefficients in an immersion cooling system. The Boussinesq approximation is capable of accurately predicting the convective heat transfer coefficients over a range of temperatures and can be employed to optimize the design of the heat transfer system. Furthermore, the Boussinesq approximation can be used to determine the appropriate locations of components in the cooling system, as well as the most suitable flow rate and type of heat transfer fluid to use. By making use of the Boussinesq approximation, engineers are able to create more efficient immersion cooling systems.

### b. CFD Model and Geometry for Design-1

For this research similar to the Intel Core i9-10900K processor was designed with a heat spreader and a silicon chip. The heat spreader was modeled as a 35 mm x 35 mm structure with a 2.59 mm height, while the silicon chip was modeled as a 22.4 mm x 9.2 mm structure with a 0.58 mm height. These dimensions were determined by previous studies [5]. In order to further investigate the heat dissipation of this processor, further research should be conducted to analyze the heat spreader and silicon chip combination in order to better understand how their dimensions affect the overall processor performance. [5]

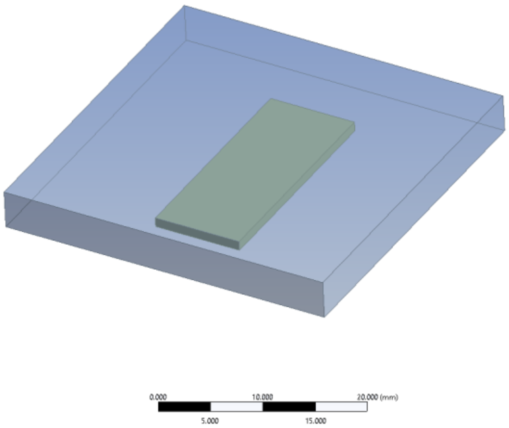
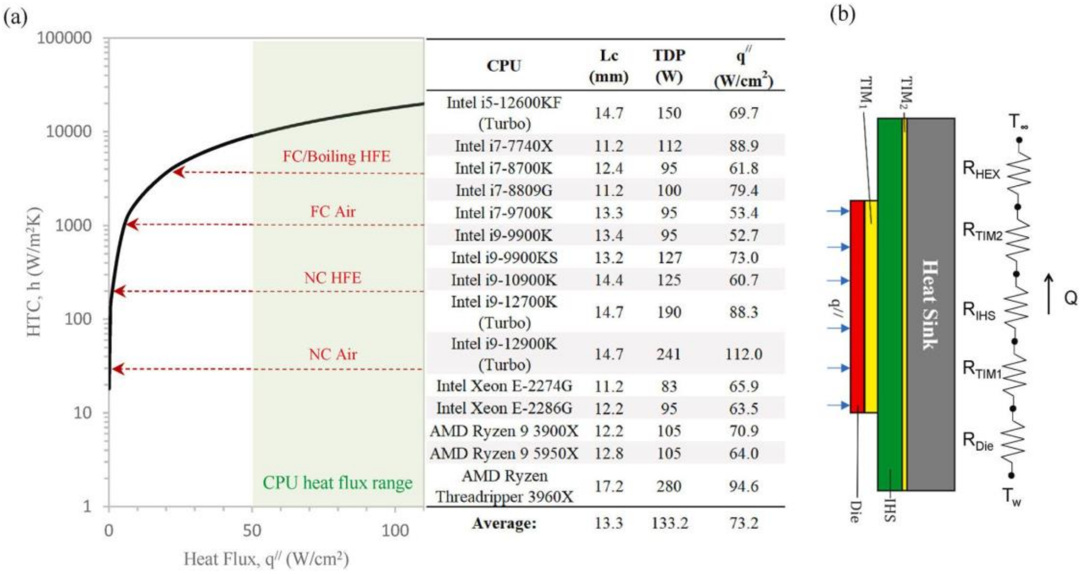


Figure 3: Silicon chip and Heat spreader CPU processor

The purpose of this research is to examine the impact of natural convection and the incorporation of a heat sink on the cooling of a CPU. To achieve this, CFD simulations will be conducted to evaluate the efficacy of air cooling the CPU with FC-3238 and mineral oil, in comparison to traditional air cooling. The output of the CFD simulations will be used to determine the advantages of utilizing natural convection and heat sink in the cooling of the CPU. The conclusions of this investigation may be useful for informing the design of cooling systems for CPUs, as well as other components that produce heat.

In order to accurately simulate the optimal working condition of Intel Core i9-10900K processor, heat was supplied to the bottom of the silicon chip at a rate of 112 W/cm2. This intensive heat application was necessary to recreate the conditions under which the processor operates in real-world applications.



| CPU | Lc (mm) | TDP (W) | $q''$ (W/cm$^2$) |
|---|---|---|---|
| Intel i5-12600KF (Turbo) | 14.7 | 150 | 69.7 |
| Intel i7-7740X | 11.2 | 112 | 88.9 |
| Intel i7-8700K | 12.4 | 95 | 61.8 |
| Intel i7-8809G | 11.2 | 100 | 79.4 |
| Intel i7-9700K | 13.3 | 95 | 53.4 |
| Intel i9-9900K | 13.4 | 95 | 52.7 |
| Intel i9-9900KS | 13.2 | 127 | 73.0 |
| Intel i9-10900K | 14.4 | 125 | 60.7 |
| Intel i9-12700K (Turbo) | 14.7 | 190 | 88.3 |
| Intel i9-12900K (Turbo) | 14.7 | 241 | 112.0 |
| Intel Xeon E-2274G | 11.2 | 83 | 65.9 |
| Intel Xeon E-2286G | 12.2 | 95 | 63.5 |
| AMD Ryzen 9 3900X | 12.2 | 105 | 70.9 |
| AMD Ryzen 9 5950X | 12.8 | 105 | 64.0 |
| AMD Ryzen Threadripper 3960X | 17.2 | 280 | 94.6 |
| **Average:** | 13.3 | 133.2 | 73.2 |

Figure 4: Heat Flux for different Processors [6]

The results of this simulation can be used to evaluate the performance of the processor and provide valuable insights into its energy efficiency and thermal properties. Therefore, a heat source with a power density of 112 W/cm2 was applied to the red zone in Figure 5 in order to assess the effects of heat flux. Figure (6) shows the heat spreader in the CPU processor. [6]

The results of this simulation can be used to evaluate the performance of the processor and provide valuable insights into its energy efficiency and thermal properties. Therefore, a heat source with a power density of 112 W/cm2 was applied to the red zone in Figure (5) in order to assess the effects of heat flux. Figure (5) also shows the heat spreader in the CPU processor. [6]

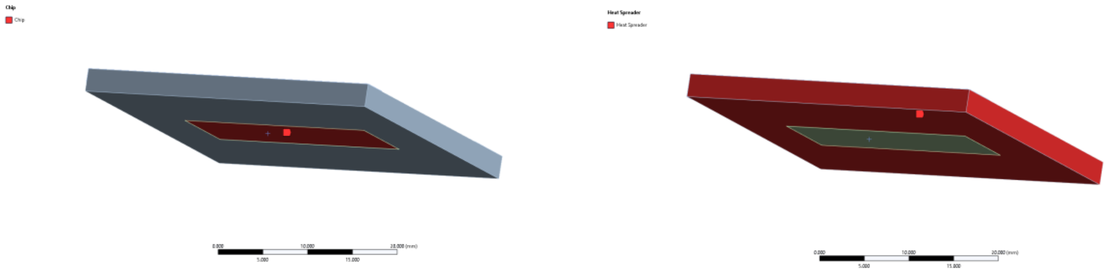


Figure 5: CPU chip and CPU heat Spreader

The single phase immersion cooling system was modeled with a recirculation and closed loop fluid domain. Specifically, the fluid domain was designed to exclude all components of the cooling system, including the pumps, radiators, and tanks necessary to enable the recirculation of the cooling fluid just based on natural convection and buoyancy effect. Furthermore, the fluid domain was validated with experimental tests to ensure that it accurately depicted the system's behavior. In conclusion, the recirculation and closed loop fluid domain for the single phase immersion cooling system was designed and validated so that it could be used to accurately model the system as shown in yellow portion Figure (6) below,

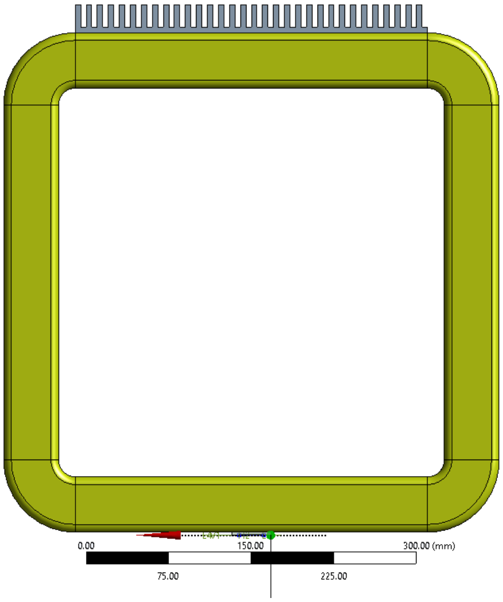


Figure 6: Fluid domain and Heat sink on Fluid Domain

This design employed two heat sinks in order to optimize the cooling of the heat spreader and the fluid domain. The first heat sink was placed directly above the heat spreader, providing an increased cooling power to the spreader. The second heat sink was placed atop the fluid domain, where the heated fluid, caused by the buoyancy effect, could be cooled by the heat sink before being recirculated back to the processor.

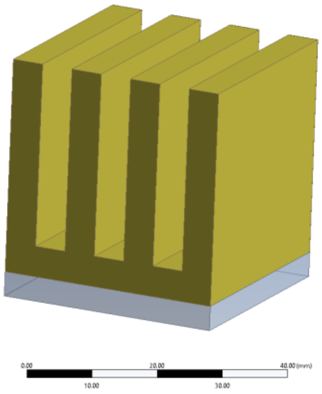


Figure 7: Heat sink on heat spreader

This enabled a more efficient cooling process, allowing for greater performance of the system. It is important to take into account that this research does not focus on the design and optimization of heat sinks.

c. <u>CFD Simulation setup and results for Design 1</u>

In order to accurately model the natural convection and buoyancy driven flow of the simulation, the commercial computational fluid dynamics (CFD) software Ansys Fluent was employed. The gravity force was turned on in order to replicate the effects of real-world gravity and a pressure solver was used to identify a steady state solution. To account for the effects of the density difference of the fluid driven by the temperature difference, the Energy equation was activated. Moreover, a turbulent K-Epsilon model was used to simulate the viscous effects of the fluid while double precision was utilized and 500 iterations were requested. Ultimately, by utilizing this setup, an accurate representation of the natural convection and buoyancy driven flow was achieved.

To accurately simulate the Boussinesq approximation in the cell zone condition, an operating temperature of 35°C and an operating density calculated from 1878-2.455(T) for FC-3283 was chosen, resulting in a density of 1794 kg/m3.

For the material selection, silicon was selected for the chip material, with the properties listed below. Copper was chosen for the heat spreader, heat sink on the processor and heatsink on the fluid domain. Finally, the fluid chosen for this design was FC-3283 for the single-phase immersion cooling system. Wall boundary conditions was applied to heat source and heat flux was given equivalent to $112\, W/cm^2$ using an expression and TUI command to give the expression "Flux

Value[$W$]/Area(“([Heat_Source])”)” which gives power supply equivalent to $241\ W\ and\ 112\ W/cm^2$.

Figure (8) displays a contour plot of the average temperature distribution over the centre plane of a processor cooled by a single-phase cooling system. The result of this system is a maximum temperature of 34°C, which is considerably lower than the CPU temperature of 98.4°C [2] when using conventional air cooling.

However, the results also suggest that the fluid is not recirculating properly as the temperature is rising symmetrically on both sides. This further implies that further research is necessary to fully understand why the single-phase immersion cooling system is not achieving optimal recirculation.

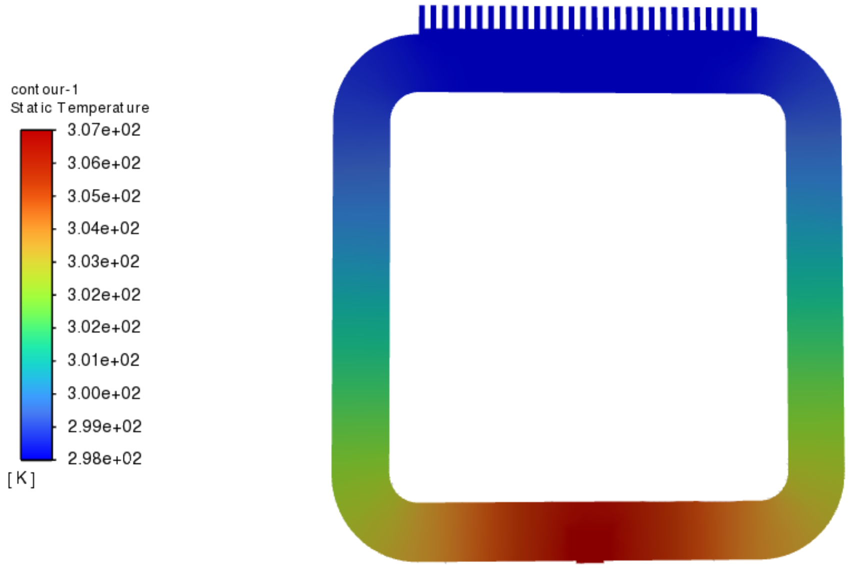


Figure 8: Temperature Plot of Design-1

Figure(9) justifies that the fluid is not recirculating and shows the contour plot of velocity magnitude over the centre plane of a processor cooled by a single phase cooling system. The results of a numerical simulation of a single-phase processor cooling system, depicted in Figure(9), demonstrate that the fluid is not recirculating.

The contour plot of velocity magnitude across the centre plane of the processor shows that the fluid is just rising in both directions without any recirculation with a very very low velocity of $4.55 \times 10^{-6}$, this is equivalent to no velocity at all. This indicates that the cooling system is working properly, but there is no evidence of fluid being recirculated. The results of this simulation are important for understanding the performance of the cooling system, and this information can be used to optimize the design of the processor.

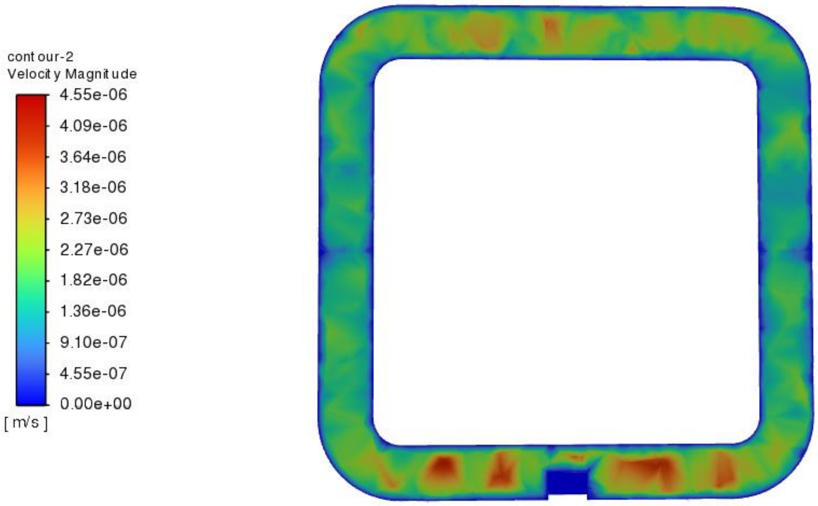


Figure 9: Velocity Contour plot Design-1

### d. CFD Model and Geometry for Design-2

The first design, Design-1, failed to successfully achieve recirculation for a single phase immersion cooling system, thus necessitating the development of Design-2. Design-2 utilized the same processor geometry as Design-1, but featured two key modifications in order to create the desired recirculating flow.

The first was an alteration of the design to introduce asymmetry via different cross sections, and the second was the removal of the heat sink from the fluid domain and the replacement of this with cooling conditions. These two modifications were made aiming towards successful achievement of recirculation in the single phase immersion cooling system.

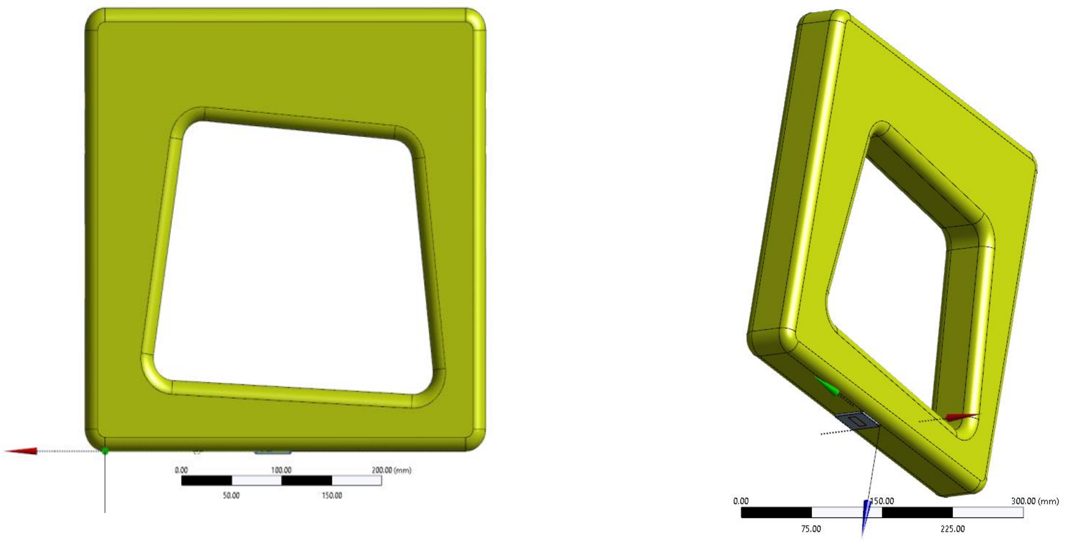


Figure 10: Asymmetric Fluid Domain Design-2

As shown in Figure (10) Asymmetric designs, which are characterized by varying cross sections, are often used for the purpose of recirculating and cooling liquid for single phase immersion systems. In particular, parts with converging designs are typically used to increase the flow rate, while divergence is employed to promote cooling through volumetric expansion. By using this technique, it is possible to achieve higher levels of efficiency and greater control over the cooling process in comparison to more traditional designs. Further research is needed to evaluate the potential of asymmetric design to improve the performance of recirculating and cooling systems.

Figure (10) illustrates the changing cross section when the width remains constant and the processor is situated beneath the area containing the fluid. This research paper will investigate how the varying cross section affects the flow of the fluid, and how the position of the processor influences the performance of the system. In this design processor is located offset from the centre axis to increase the asymmetric effects. By applying mathematical simulations, it was assumed to gain a recirculation with the cooling effect with the combination of a changing cross section and a processor located below the fluid domain.

### e. <u>CFD Simulation setup and results for Design 2</u>

A similar simulation was conducted with the same setup in Ansys Fluent to model natural convection and buoyancy-driven flow in a single-phase immersion cooling system. The gravity force was enabled to reflect the laws of physics, and a pressure solver was used to identify a steady state solution. The Energy equation was activated to consider the effects of the density difference of the fluid, and a turbulent K-Epsilon model with double precision and 500 iterations was employed to simulate the viscous effects of the fluid. The operating temperature and density of the fluid were chosen to accurately reflect the Boussinesq approximation, and Silicon and copper were selected as the chip and heat spreader materials, respectively. FC-3283 was chosen as the fluid, and a wall boundary condition was applied to the heat source, with a heat flux equivalent to 112 W/cm2. Since this design does not involve a second heat sink a constant temperature 298 K was applied to demonstrate the cooling of the fluid on the top portion of the design.

Figure (11) a contour of average temperature of the center plane of Design-2 reveals that the cooling system is more effective than the design that came before it, with a maximum temperature of 31°C, which is 3°C lower than the previous design. It outperforms the conventional air cooling system substantially. However the concern of recirculation is still unsolved. It is very clear that fluid is still rising from both sides.

Figure 11: Temperature contour for Design-2

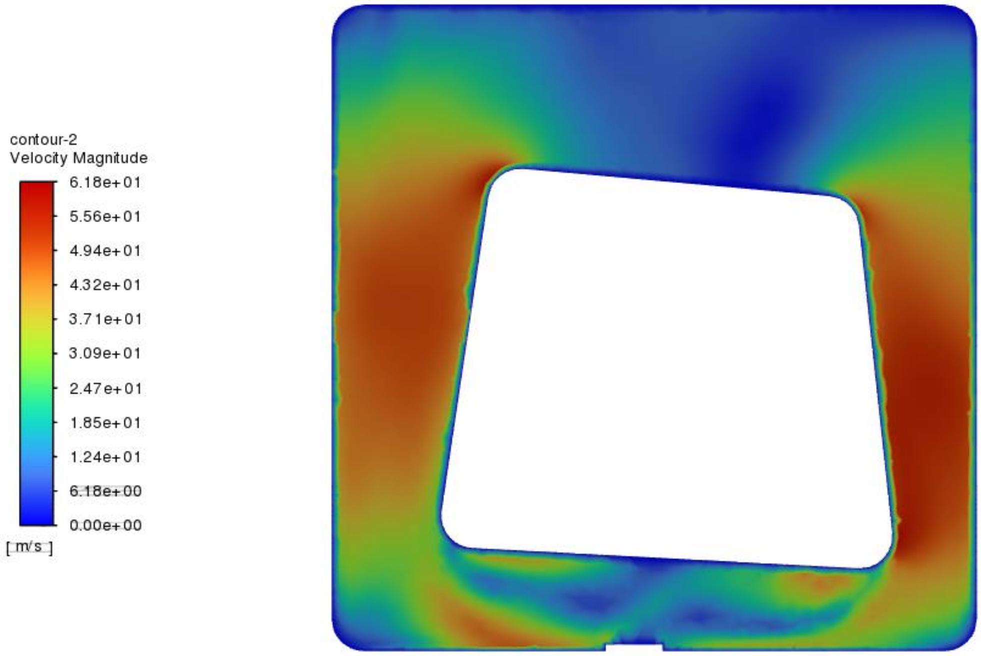


Figure 12: Velocity contour for Design-2

Design-2 is capable to achieve a very high velocity comparing the design-1, as shown in Figure (12) fluid has 6.18 $m/s$ a very high velocity. However, the fluid with high temperature and lower density is still moving to the top side from both sides. Despite achieving a higher cooling rate, the single-phase immersion cooling system has yet to accomplish asymmetric recirculation. This is a cause for concern, as in a practical situation the fluid could continue to receive heat from the CPU, leading to a decrease in the cooling effect and ultimately reducing the effectiveness of the system due to the lack of recirculation. This could have a detrimental impact on the overall performance of the system. Therefore, further research is needed to develop a method for achieving effective asymmetric recirculation, in order to ensure the maximum benefit from the single-phase immersion cooling system.

# CFD SIMULATIONS WITH TESLA VALVE

In the previous sections of this paper, Design-1 and Design-2 have been discussed and highlighted as being unsuccessful in achieving recirculating flow with efficient cooling for single phase immersion cooling systems. To achieve recirculation, the design of the system has to be engineered such that fluid can be directed to flow in a specific direction. This can be accomplished by incorporating a pump or blower, or an internal fan into the system; however, this research paper is specifically focused on devising a design that can generate a flow without any external or internal components. Therefore, the aim of this research study is to develop a design that can drive a flow using natural convection, buoyancy, and gravity.

An alternative approach to directing the flow of a fluid in a specific direction is to incorporate a one-way valve or to create a design that functions in a similar manner. While there are many types of one-way valves commercially available, they would not be suitable for this particular system since the flow rate and velocity generated by natural convection and boussinesq phenomena would not be sufficient to operate the available valves. Thus, an alternative design is proposed to achieve the desired flow direction. To achieve a unidirectional flow, the only viable solution is to produce a design that facilitates it. One effective approach is to use an asymmetric design that incorporates narrow sections and a converging diverging part. However, in some cases, such as with asymmetric design-2, achieving a unidirectional flow may not be feasible. Despite the challenges associated with achieving unidirectional flow in certain asymmetric designs, exploring alternative solutions is essential to ensure efficient and effective fluid dynamics in various applications. Therefore, further research is needed to develop innovative and practical approaches to overcome such limitations and enhance the performance of asymmetric designs in achieving unidirectional flow.

To overcome this problem the solution was found through one of Nicola Tesla's innovations. Nicola Tesla, the renowned Serbian-American inventor, electrical engineer, and mechanical engineer Nikola Tesla, and look into the Tesla valve, one of his lesser-known inventions. We will examine its principles, design, and potential applications for various industries, as the Tesla valve has recently gained attention in the field of fluid dynamics due to its ability to control fluid flow in an efficient manner. Tesla is well-known for his influential contributions to the field of physics and engineering, such as his ground-breaking work in developing the alternating current (AC) electrical system and wireless communication technology.

### a. Tesla Valve

A bit about the Tesla valve, The Tesla valve, also known as the "Tesla disk" or "Tesla pump," is a one-way fluid flow control valve that was invented by Nikola Tesla in 1920. The valve is made up of a series of circular disks, which are stacked together in a way that creates a labyrinth-like structure. The disks have rectangular or circular holes cut out of them, and the direction of these holes alternates from one disk to the next. When fluid flows through the valve in one direction, the disks allow it to pass through the holes in a smooth and efficient manner, with minimal turbulence. However, when the fluid tries to flow in the opposite direction, the holes become blocked, and the fluid is forced to travel through the narrow gaps between the disks, creating a series of vortices that generate resistance and prevent the flow from reversing. [11]

The Tesla valve's design is based on a series of circular disks stacked together to form a labyrinth-like structure with alternating holes that allow fluid to pass through in one direction while blocking flow in the opposite direction. The valve's complex geometry and intricate design allow for minimal turbulence and high flow efficiency, making it a promising solution to fluid flow control challenges. Additionally, the Tesla valve's simple and robust design makes it less prone to wear and tear, reducing the need for frequent maintenance and repairs. [11]

The Tesla valve's unique design offers several advantages over traditional valves, including its simplicity, low cost, and high efficiency. Because it has no moving parts, it is less prone to wear and tear and requires minimal maintenance. It is also highly efficient, with some studies suggesting that it can achieve up to 98% flow efficiency, which is significantly higher than most conventional valves. Additionally, the Tesla valve's ability to control fluid flow in one direction makes it well-suited for a range of applications, including controlling the flow of fuel in engines, regulating the flow of fluids in chemical processing plants, and facilitating blood flow in medical devices.

Despite its many benefits, the Tesla valve also has some limitations. For instance, the valve's performance can be affected by factors such as the fluid viscosity, the size and shape of the valve, and the orientation of the disks. Additionally, the valve's complex geometry can make it difficult to manufacture and optimize for specific applications. Nonetheless, ongoing research is exploring ways to overcome these limitations and to further enhance the performance and versatility of the Tesla valve in a range of fluid control applications. [11]

The Tesla valve has gained significant attention in recent years for its potential applications in various industries, such as automotive, aerospace, and biomedical.

For instance, the valve can be used in engines to improve fuel efficiency and reduce emissions by regulating fluid flow. It can also be used in medical devices to control fluid flow in a precise and efficient manner. As such, the Tesla valve presents a promising solution to fluid flow control challenges in various industries, and its continued research and development could lead to further innovations in the field of fluid dynamics. [7]

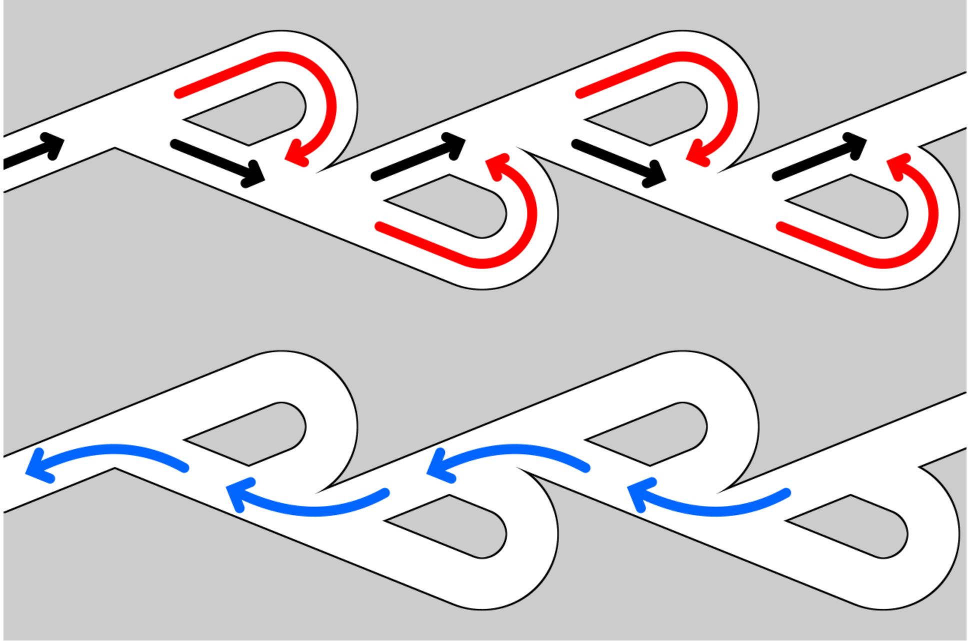


Figure 13: Tesla valve [10]

Figure (13) demonstrates the working principle behind the functioning of the Tesla valve. As demonstrated in the figure, when there is a right-to-left flow, the flow is unhindered, represented by blue lines. However, when the flow is left-to-right, the flow is impeded at each step, as indicated by the black and red lines.

This produces vorticity, which slows the flow down. As the flow progresses, it is further restricted, eventually preventing any flow from left to right. Ultimately, this illustrates how the Tesla valve works to control the flow direction within a system. [10]

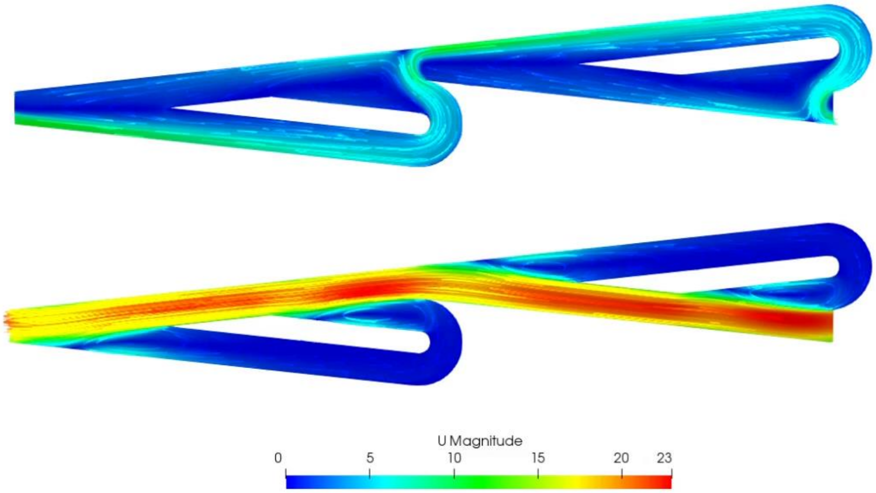


Figure 14: Tesla valve simulations [8]

Figure (14) Indicates the simulation results done in sim-flow to signify the results that if flow is moving from right to left then it has higher velocity magnitude rather than flow is moving from left to right. Which clearly shows that the tesla valve has capacity to generate one directional flow. [8]

### b. <u>CFD Model and Geometry for Design-3</u>

Design-3 includes a tesla valve to achieve a unidirectional flow. To demonstrate the CPU model same as previous geometry has been used however the design of heat sink on the heat spreader has been changed, the fins on sink are designed as they provide the path way to flow the fluid according to the tesla valve.

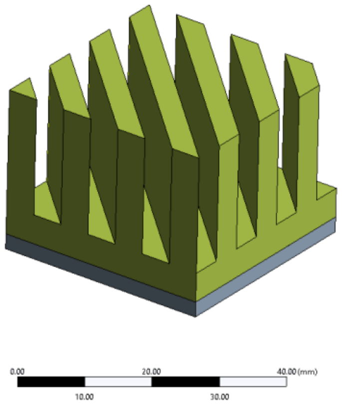


Figure 15: Heat sink for Design-3

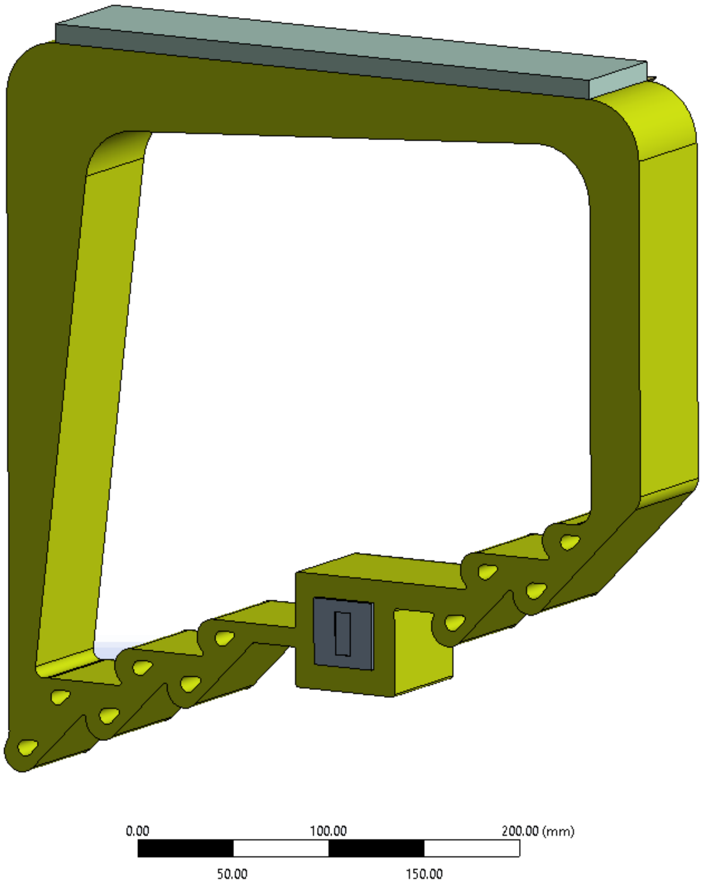


Figure 16: Fluid Domain for Design-3 with Tesla Valve

The fluid domain was designed such a way that it replicates the tesla valve to achieve unidirectional flow. The heat source is placed somewhere in between the tesla valve. However, to optimize the tesla valve efficiency it has been rotated about 45 degrees placing the CPU in the centre as shown in figure (16) while figure (17) shows the fluid domain and the heat sink where the fins are providing the path to flow the fluid.

In order to demonstrate the cooling effect of a fluid, two solid blocks were placed above the fluid in order to act as cooling heat sinks. Investigating and optimizing the design of these heat sinks is a separate field of research. As the fluid gains heat from the CPU, due to its lower gravity it rises to the top and then loses its heat to the cooling heat sinks, after which the cooled fluid circulates back to the CPU. Geometry with the two solids representing as cooling heat sink is given below,

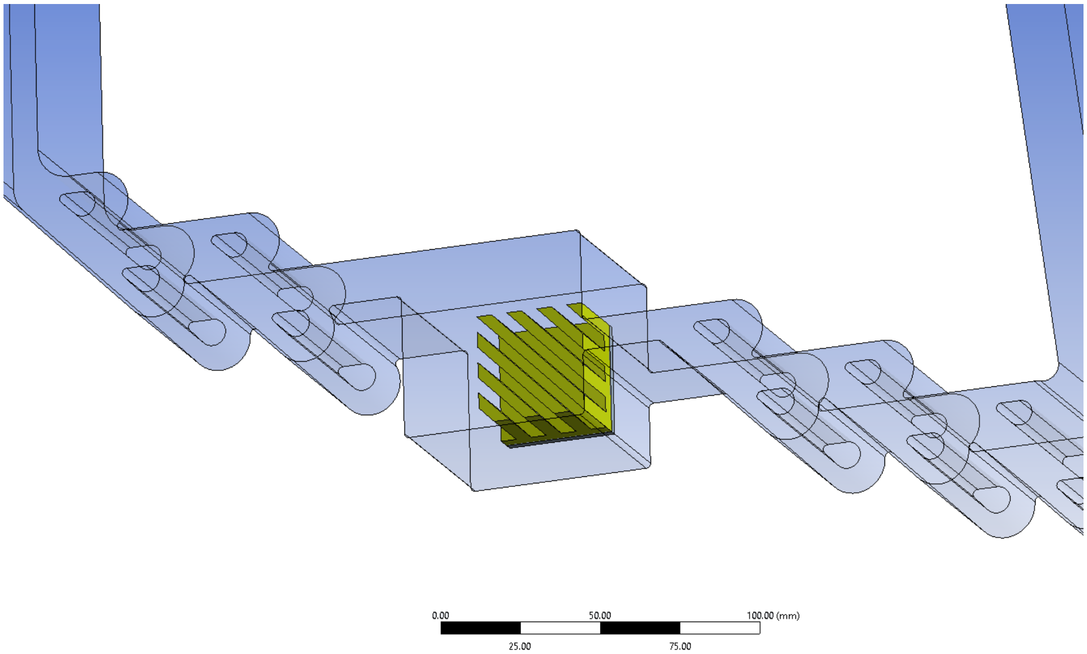


Figure 17: Heat sink with Fluid Domain

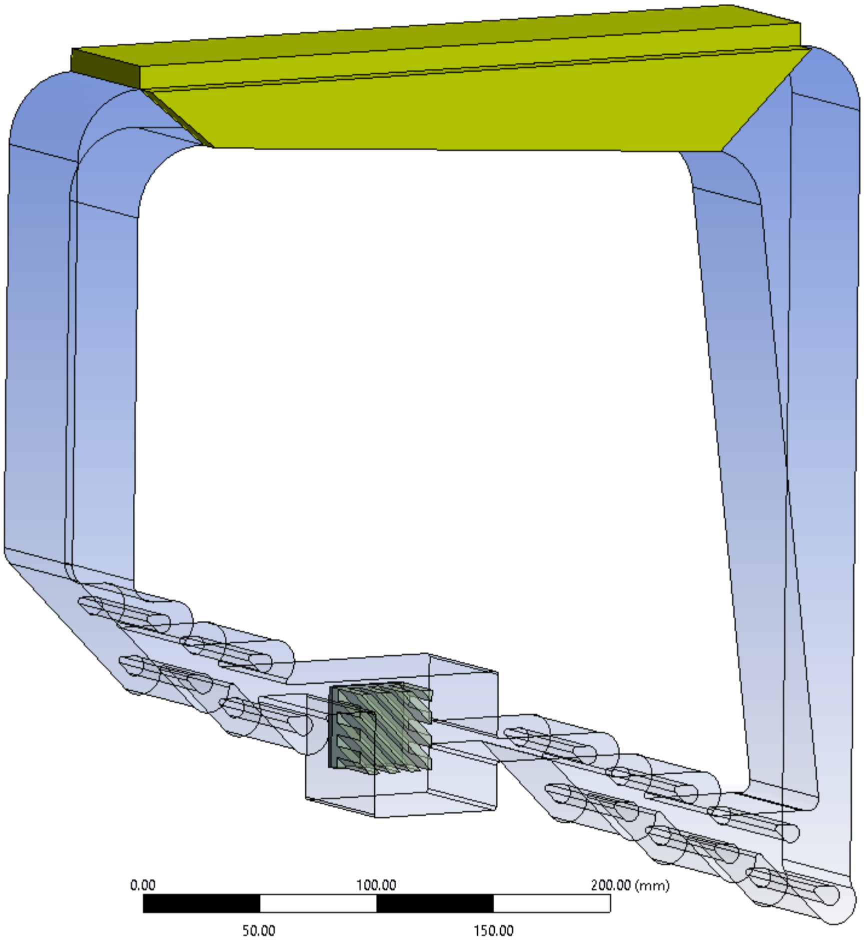


Figure 18: Solids as a Cooling Heat sinks

c. <u>CFD Simulation setup and results for Design 3</u>

In order to conduct the simulation for design 3 in Ansys Fluent, a Heat flux of 112 W/cm2 was input as an expression applied to heat source (Chip). The fluid domain chosen was FC-3283. Two solid blocks with copper material were used to simulate the cooling of the fluid, and a constant temperature of 298 K was applied for the boundary conduction. To account for both the turbulence and buoyancy effects, the Realizable K-epsilon model with enhanced wall treatment and full buoyancy effect were selected.

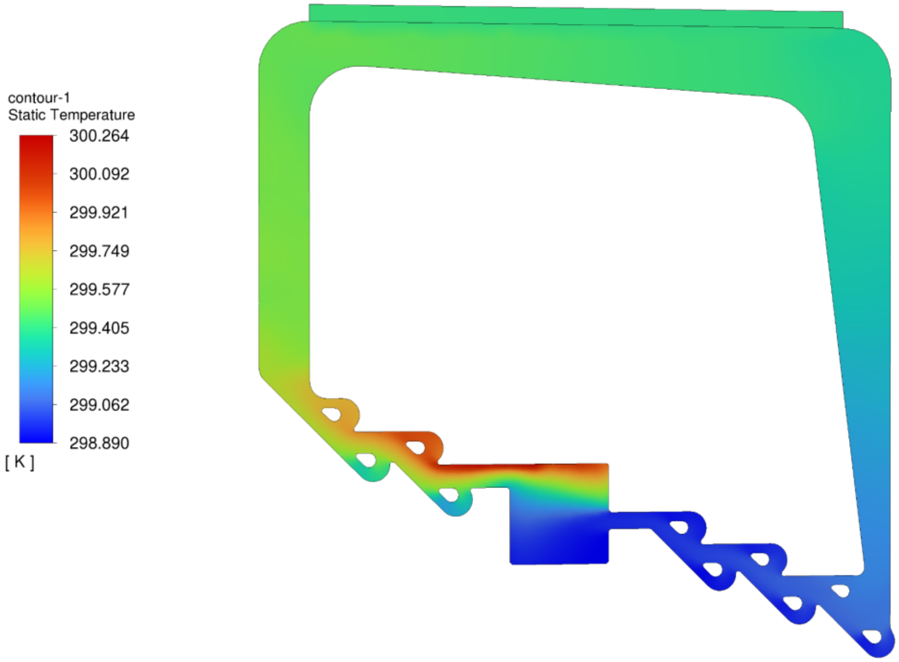


Figure 19: Temperature contour plot for Fluid Domain

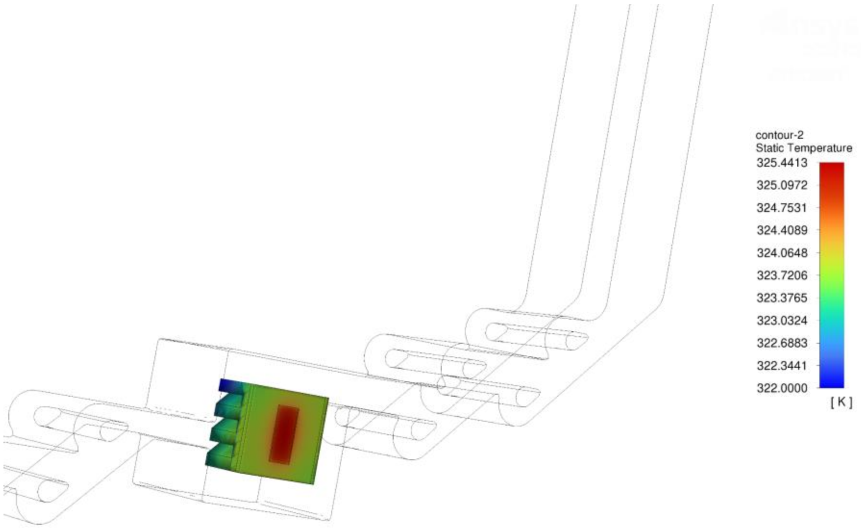


Figure 20: CPU Temperature plot for Design-3

Figure (19) clearly displays that fluid is rising from one side only which could lead to the suggestion that one directional flow may have been achieved by this design due to the effectiveness of the tesla valve. The cooling of the processor unit has been effective as evidenced by the maximum chip temperature of 325 Kelvin (K) –

approximately 40 K less than the conventional air-cooling method – despite a heat generation rate of 112 Watts per square centimetre (W/cm2) shown in Figure (20).

Design-3 is capable of providing a single direction of flow and cooling of the CPU. This can be seen in Figure (21), which shows the X-directional velocity plot for the centre plane of the design.

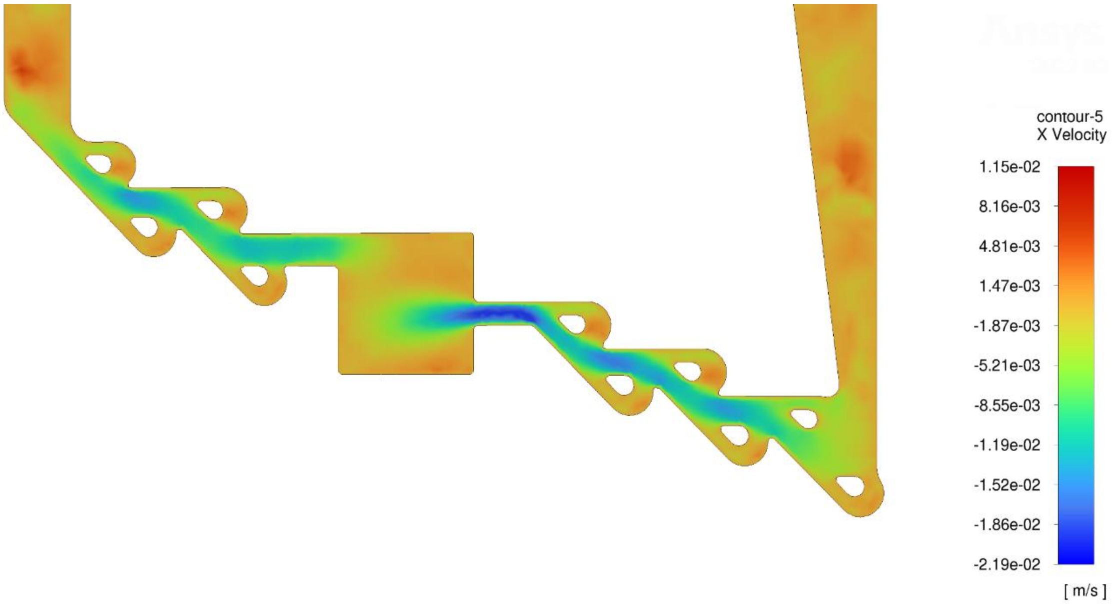


Figure 21: X-direction Velocity Contour plot

A velocity contour plot in the X-direction illustrates the flow of the blue colour in a leftwards direction, which is in agreement with and validates the vector plot which also indicates a negative X direction. Even though with the good results on achieving recirculation and effective cooling this design has some limitations such as applied cooling boundary conditions to the solid block represented as a cooling sinks 298 K constant temperature which could not be constant in experimental condition. Another limitation is that recirculation is not that sufficient that the majority of the portion has very less velocity magnitude that it could be considered as a “No velocity”. Also, in some portions due to large cross sectional area gravity dominates over the buoyancy effect and creates the vorticity hence fluid does not tend to rise and starts to move downwards figure (22) illustrate this limitation by demonstrating the Y-Direction velocity contour plot on left side of the system. Red portion shows the rising fluid while the blue portion shows the fluid moving downward.

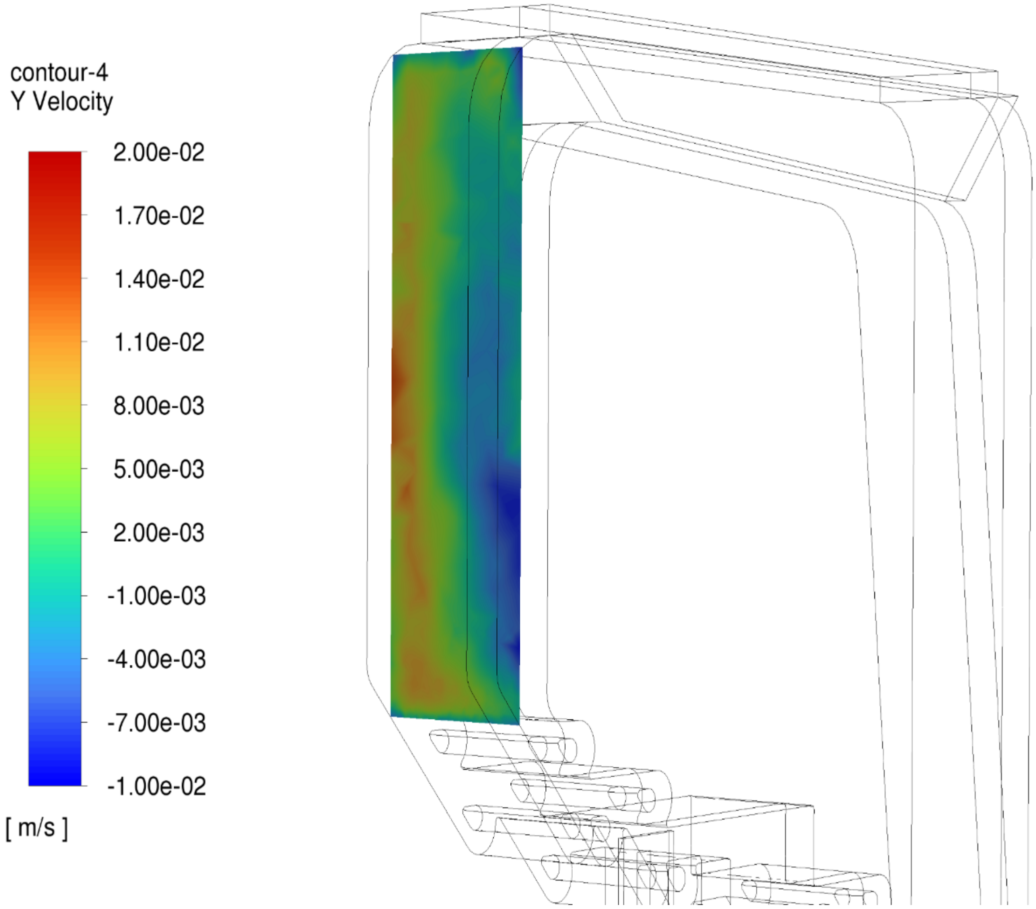


Figure 22: Y-Direction Velocity plot

### d. CFD Model and Geometry for Design-4 (Final Design)

In the previous section, the two main constraints of Design-3 were discussed: a hypothetical cooling condition in which two solid blocks are situated above a fluid domain, and the dominance of gravity over buoyancy, which leads to vorticity in areas with large cross-sectional areas. Additionally, the dominance of gravity over buoyancy can cause an increase in vorticity in larger cross-sectional area. To overcome both the constraints in the design of the single-phase immersion cooling system for CPU, the cross section of the heat pipe was narrowed down to optimize the design and maximize the flow rate. Where the fluid and solid are interacting, the cross section is around $30mm \times 60mm$ and for the rest of the heat pipe cross section is narrowed down to $5mm \times 10mm$ Additionally, in order to reduce hypothetical cooling, a radiator-like design was implemented with a certain number of plates. While the optimization of

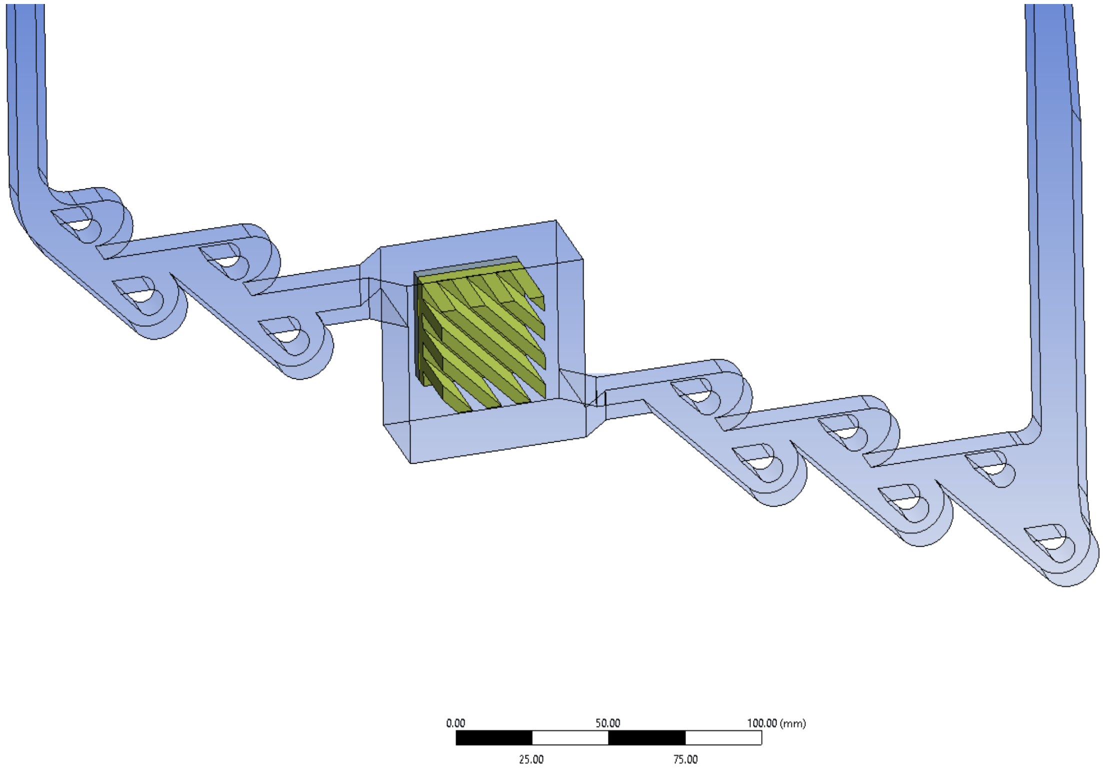


Figure 23: Design -4 Narrow section of Fluid domain

the radiator design was not the main focus, its implementation was expected to reduce the temperature of the heated fluid to 298 K before it was recirculated towards the CPU. Further research should be conducted to investigate the potential of optimizing the radiator design in order to increase the cooling efficiency of the single phase immersion cooling system for CPU Cross sections, thus creating more complex flow dynamics.

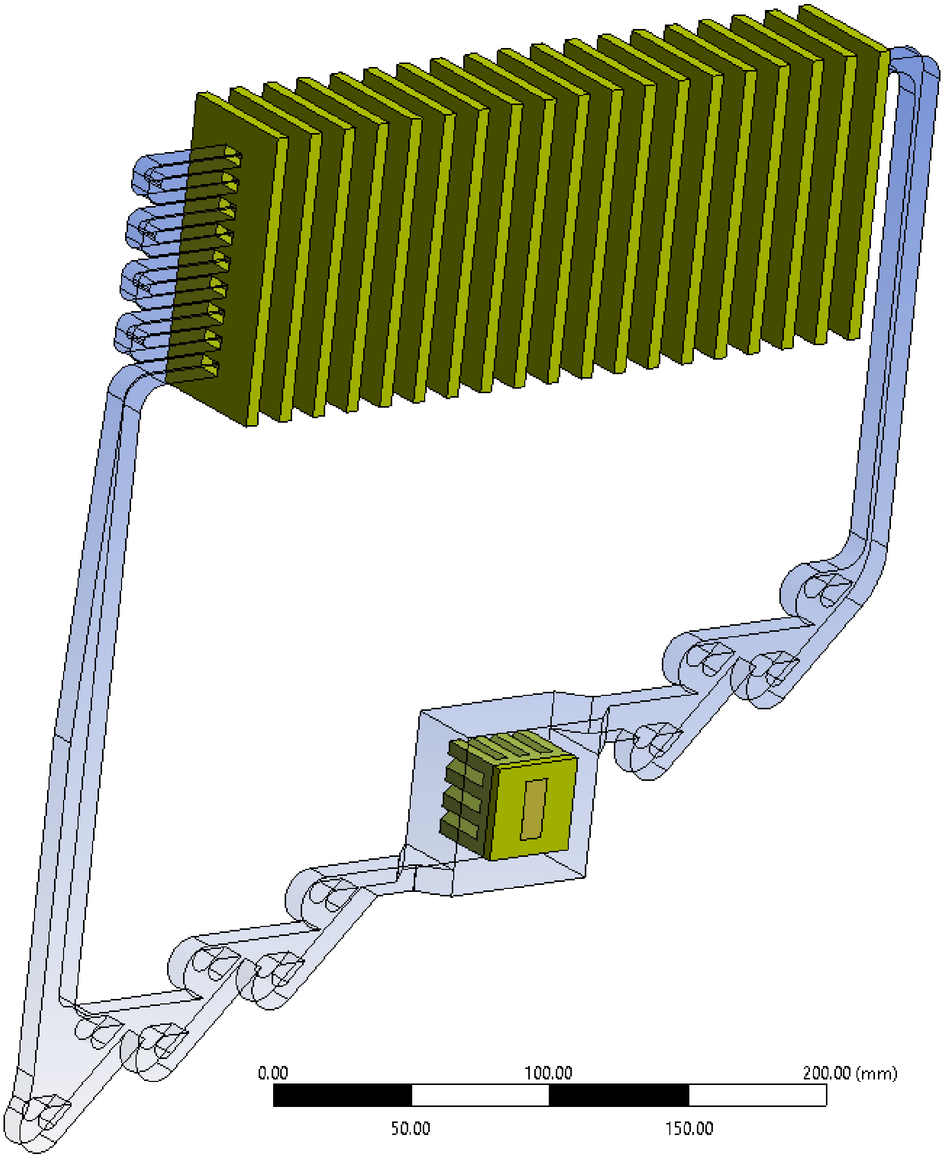


Figure 24: Design-4

Figure (23) demonstrates the modified section of a fluid domain and heat sink that are situated on the heat spreader with a series of fins, which direct the flow of the fluid in a direction specified by the Tesla valve. Figure (24) displays the finalized geometry of the design, which includes the Tesla valve to provide the direction and a radiator-style top to reduce the temperature of the fluid.

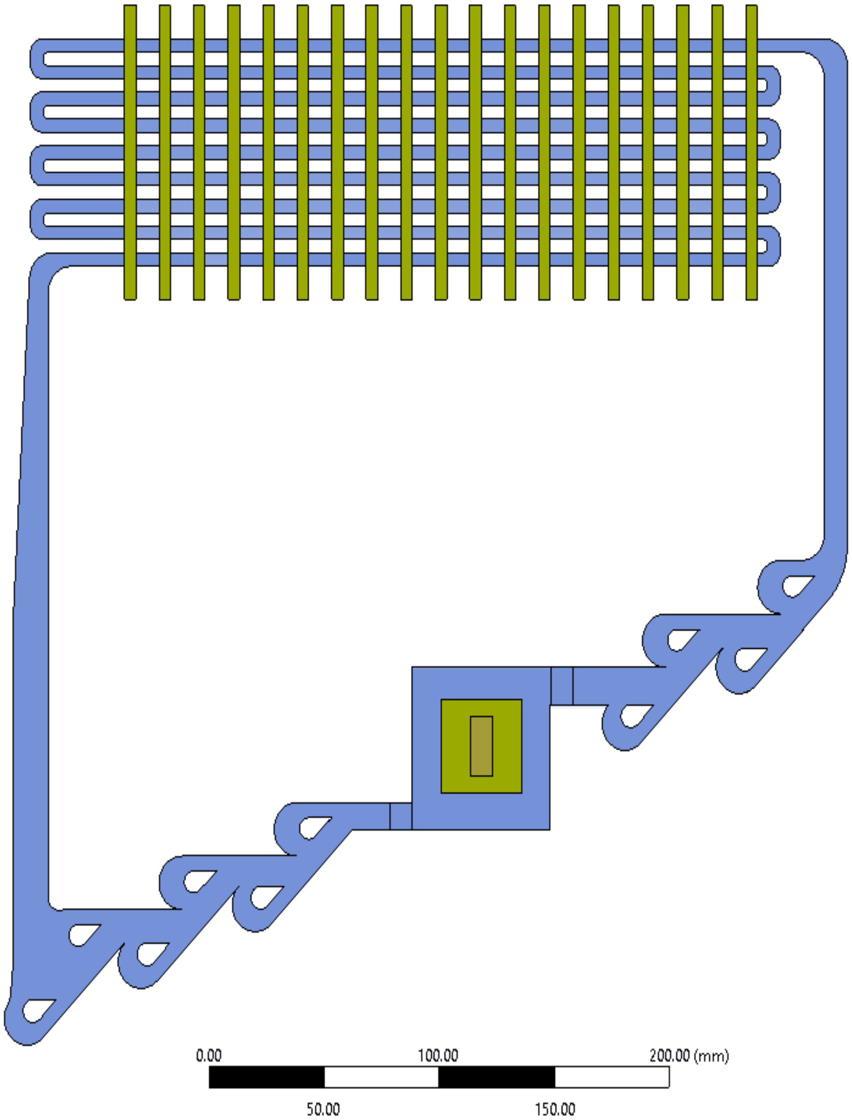


Figure 1: Front view of the Design-4

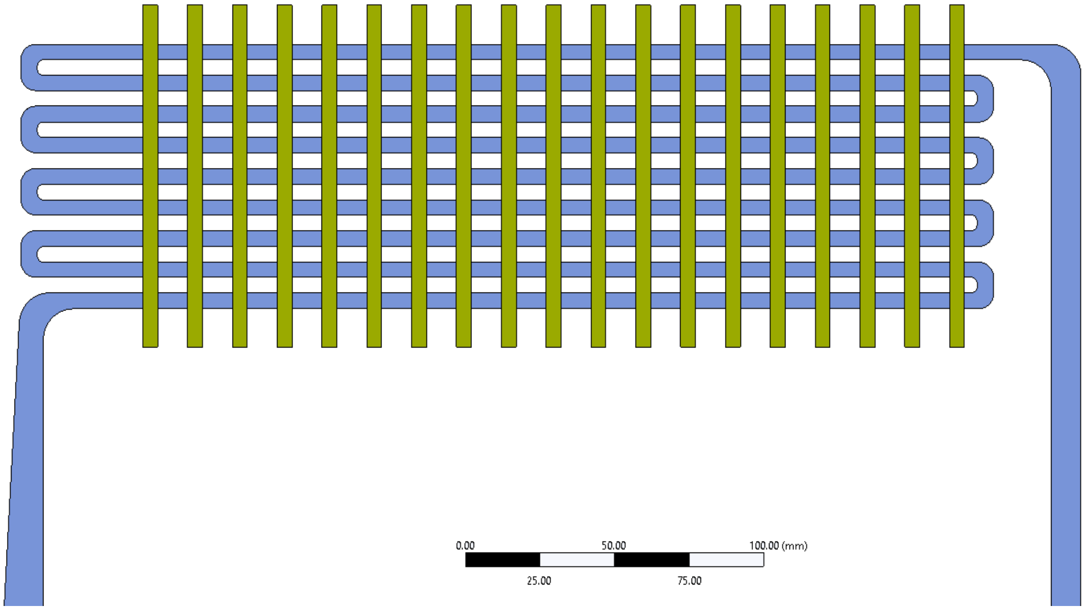


Figure 2: Radiator

As mentioned previously the hypothetical cooling condition was removed in this design and radiator like design was implemented to provide the cooling for the fluid which is further recirculated towards the heat source. While fluid enters in the radiator it starts losing the heat to the radiator plates and those plates are further cooled by air just like a conventional cooling method. As shown in Figure (26) fluid enters the radiator from the right top side and leaves on the left bottom side.

### e. CFD Simulation setup and results for Design 4

Design-4 was tested using a similar setup, wherein a silicon material was used for the CPU chip. For the immersion liquid, FC-3283 was selected as the fluid domain, and copper material was chosen for the heat spreader, heat sink and radiator plates. As opposed to hypothetical cooling conditions, the only input condition applied to the heat source plane on the chip of the processor was an equivalent heat flux of 112 W/cm2. An energy model was activated and the Realizable K-epsilon model with enhanced wall treatment and full buoyancy effect was selected in order to demonstrate the boussinesq, natural convection and buoyancy driven flow. For the operating temperature, the value of 308 K was used, and the equivalent operating density for FC-3283 was given as 1794 kg/m3. The simulation was conducted for approximately 500 iterations to determine the chip temperature.

When first heat flux was applied to the chip, conduction of heat occurred, flowing from the chip to the heat spreader and then further to the heat sink. This was followed by conjugate heat transfer between the solid and fluid domains, where the fluid gained the heat. Subsequently, because of natural convection the increase in temperature caused a decrease in the density of the fluid, leading to the buoyancy effect and Boussinesq phenomenon, resulting in the fluid rising. The Tesla valve design further facilitated this process, allowing the fluid to flow in one direction only. The hot fluid then reached the radiator, where it lost heat to the radiator plates. As the temperature of the fluid decreased, its density increased, resulting in the higher density fluid flowing towards the CPU due to the gravitational force, thus completing the closed loop cycle.

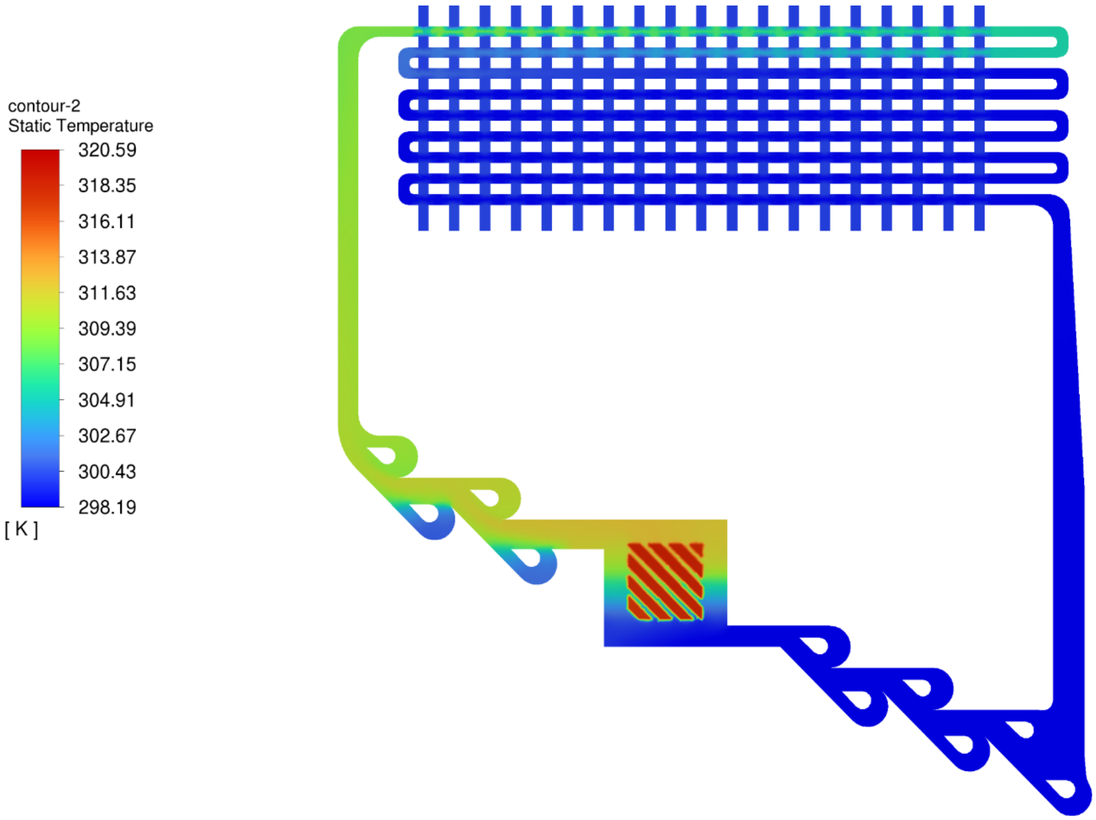


Figure 3: Temperature contour plot on centre plane of Design-4

Figures (27) and (28) demonstrate that, upon heating, the fluid rises in one direction only. The simulation results for 112 W/m2 of heat flux and 241 W of equivalent power confirmed that the maximum chip temperature increased to 320 K (46.96°C) - much lower than the temperature achieved with conventional air cooling. Figures (34) and (35) illustrate the temperature plots for the CPU chip, heat spreader and heat sink. Moreover, Figure (33) demonstrates that the fluid loses heat to the radiator plates and cooled fluid flows back to the CPU chip direction. These results clearly eliminate the first constraint of a hypothetical cooling condition for the previous design.

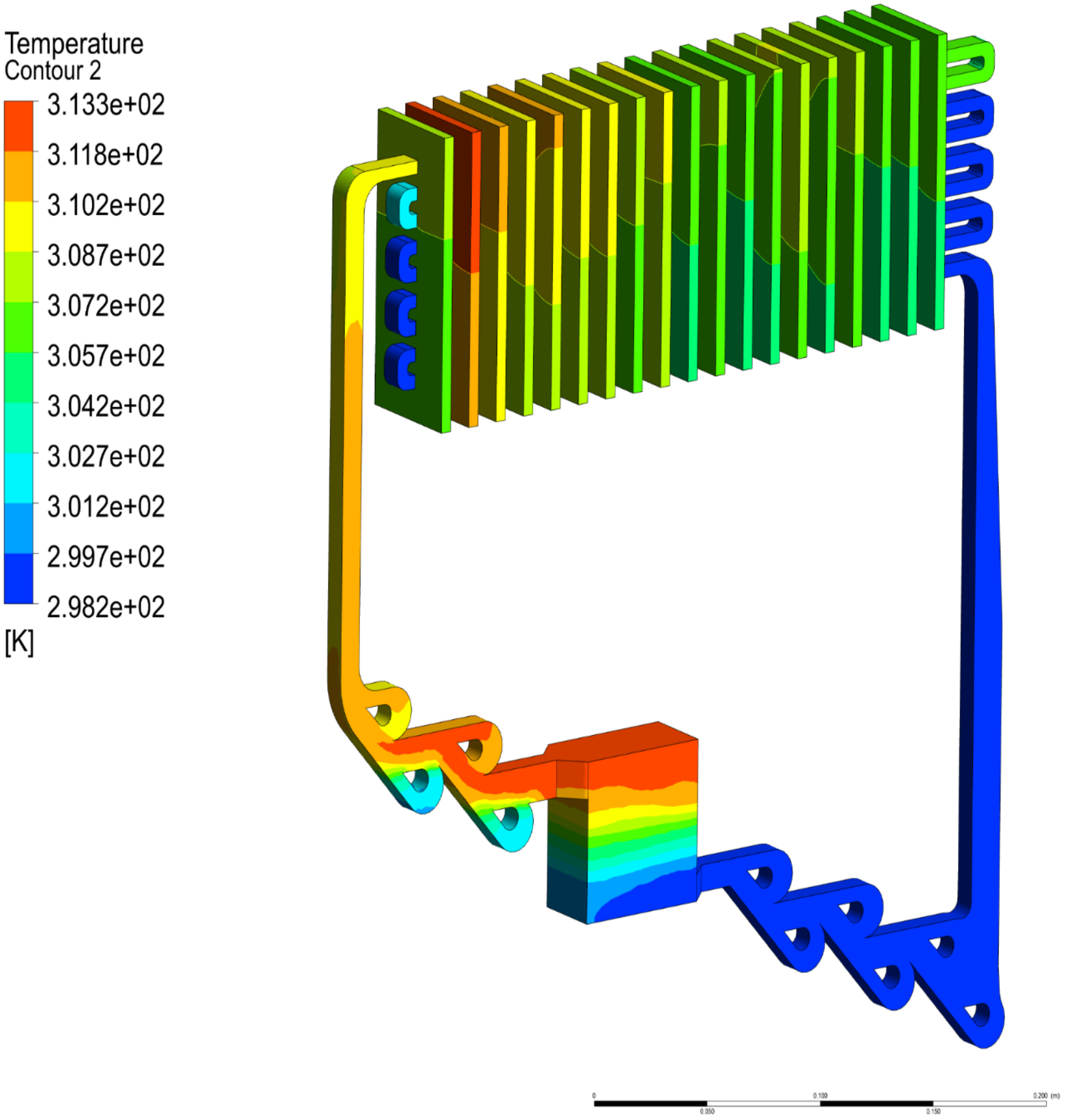


Figure (29)

Figure 4: Volume rendering of Temperature for Design-4

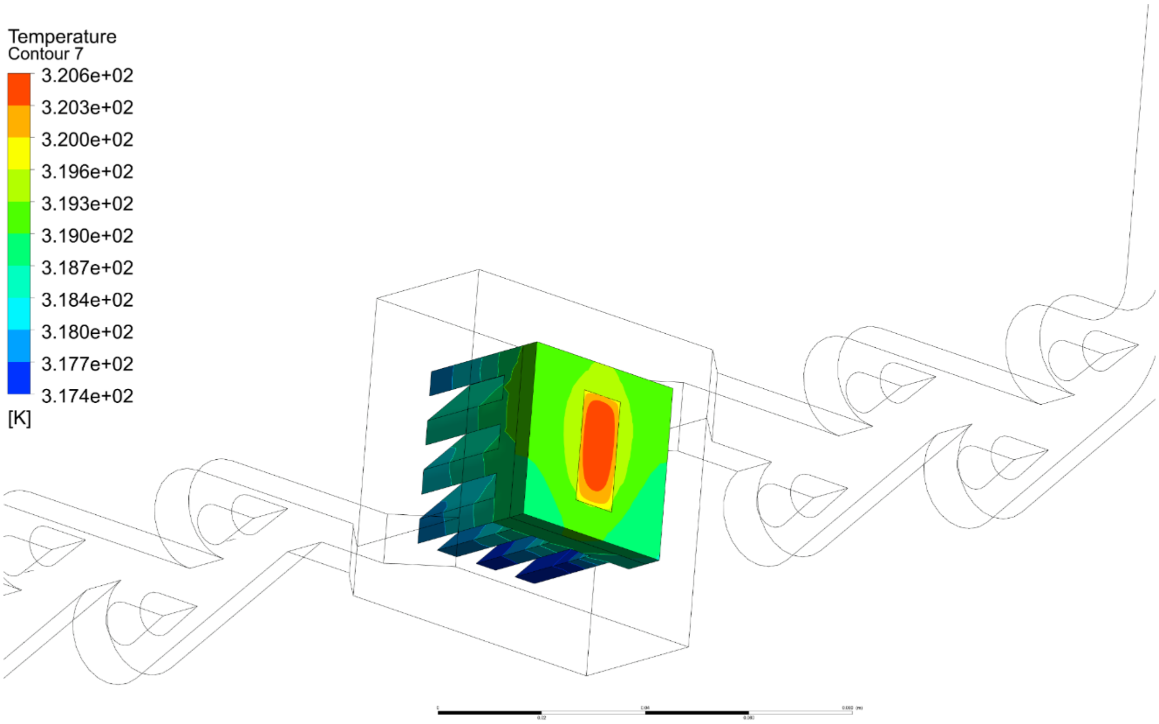


Figure 5: Temperature plot of CPU chip

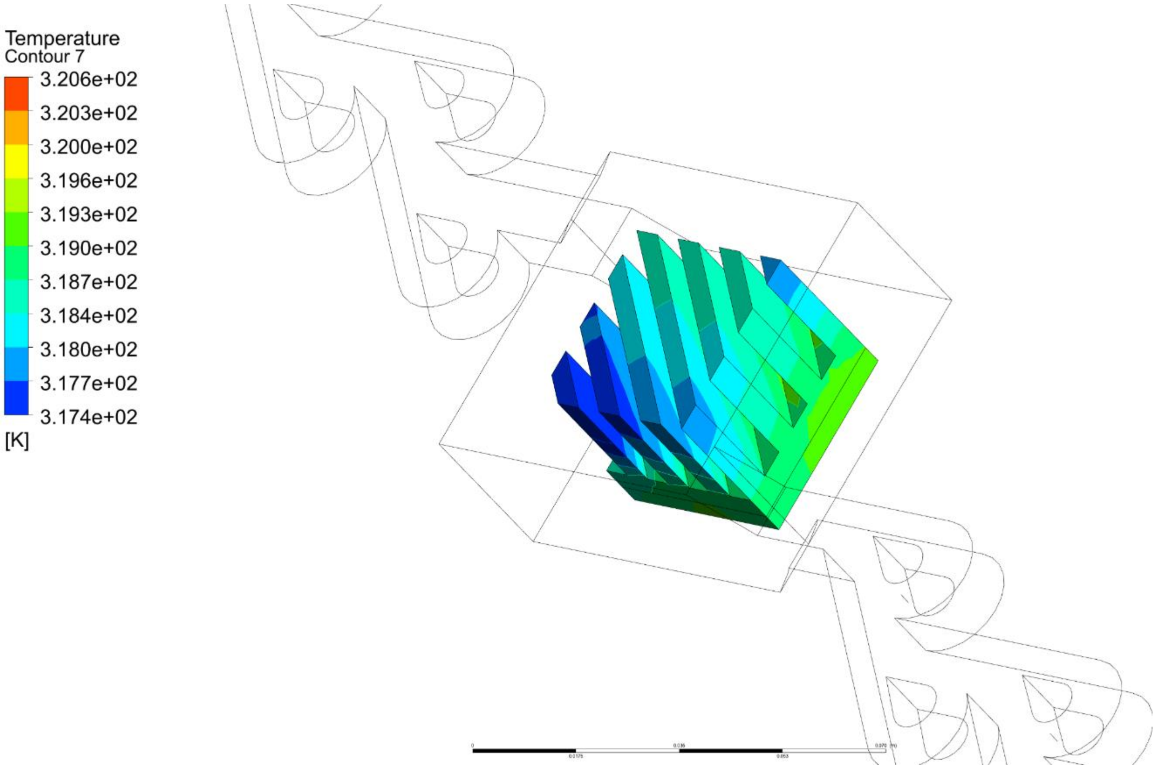


Figure 30: Temperature plot of Heat sink and Heat spreader

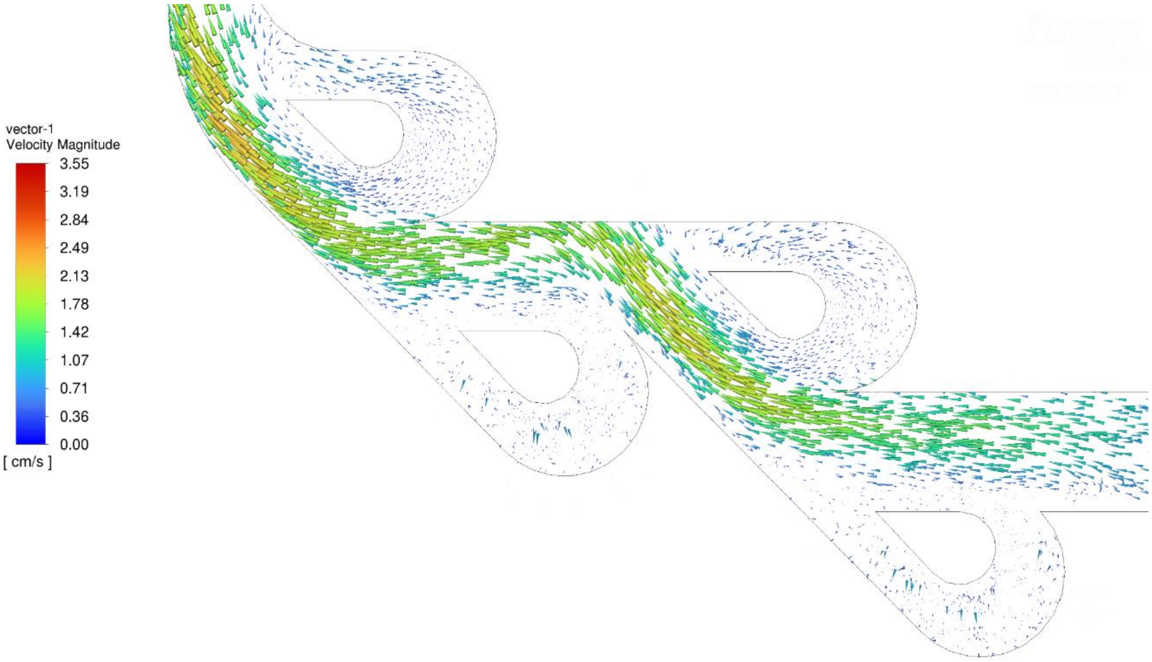


Figure 31: velocity vectors for Tesla Valve-1

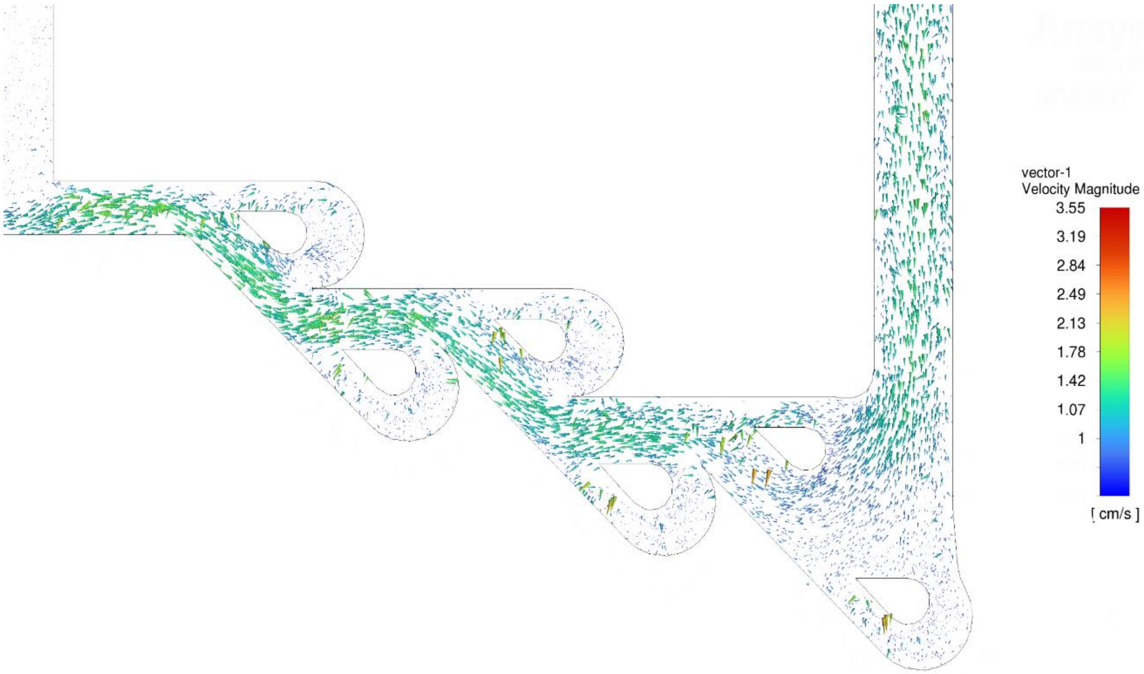


Figure 32: velocity vectors for Tesla Valve-2

Figures (31) and (32) illustrate the accomplishment of a unidirectional flow through the Tesla valve, with a higher flow rate than the previous design. The vector plot in the table shows that the maximum velocity magnitude is 3.55 $cm/s$, compared to the 2.4 $cm/s$ of the previous design. This suggests that narrowing down the fluid domain facilitates the acceleration of the fluid for the recirculation in a single-phase immersion cooling system.

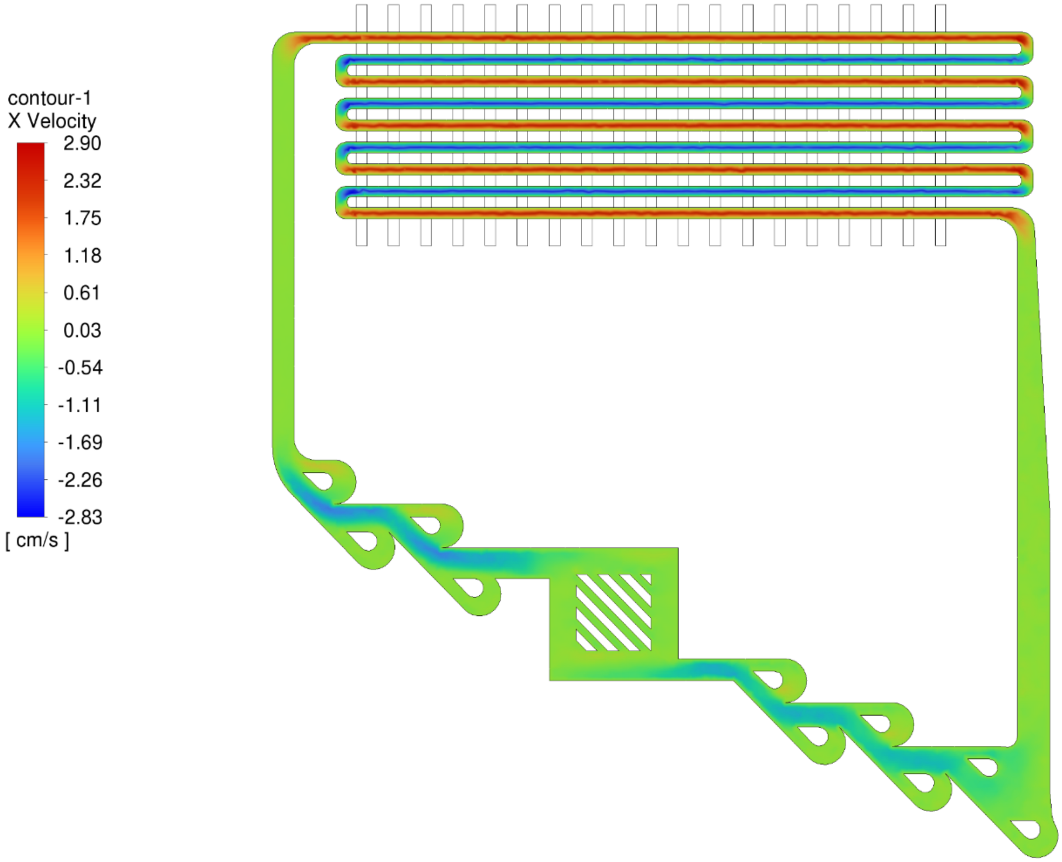


Figure 33: X direction velocity contour plot on centre plane of design-4

Since vector plots were only for the tesla valve portion Figure (38) validates that unidirectional flow has been achieved for all over the design. The negative blue region in the figure demonstrates flow going in negative X- direction means flowing from right to left direction and positive red region shows flow in positive X-direction means flow from left to right direction. From the image we can clearly depict that fluid is moving efficiently from the radiator plates. Furthermore, Figure (39) shows the Y-direction contour plots on two planes from the fluid domain which clearly concludes that there is no vorticity being generated in those regions eliminating the second constraint of previous design and it also demonstrates that the fluid is efficiently moving in positive Y-direction without vorticity with 1.87 $cm/s$ velocity and moving down from the radiator which again proves that the whole design has achieved unidirectional flow.

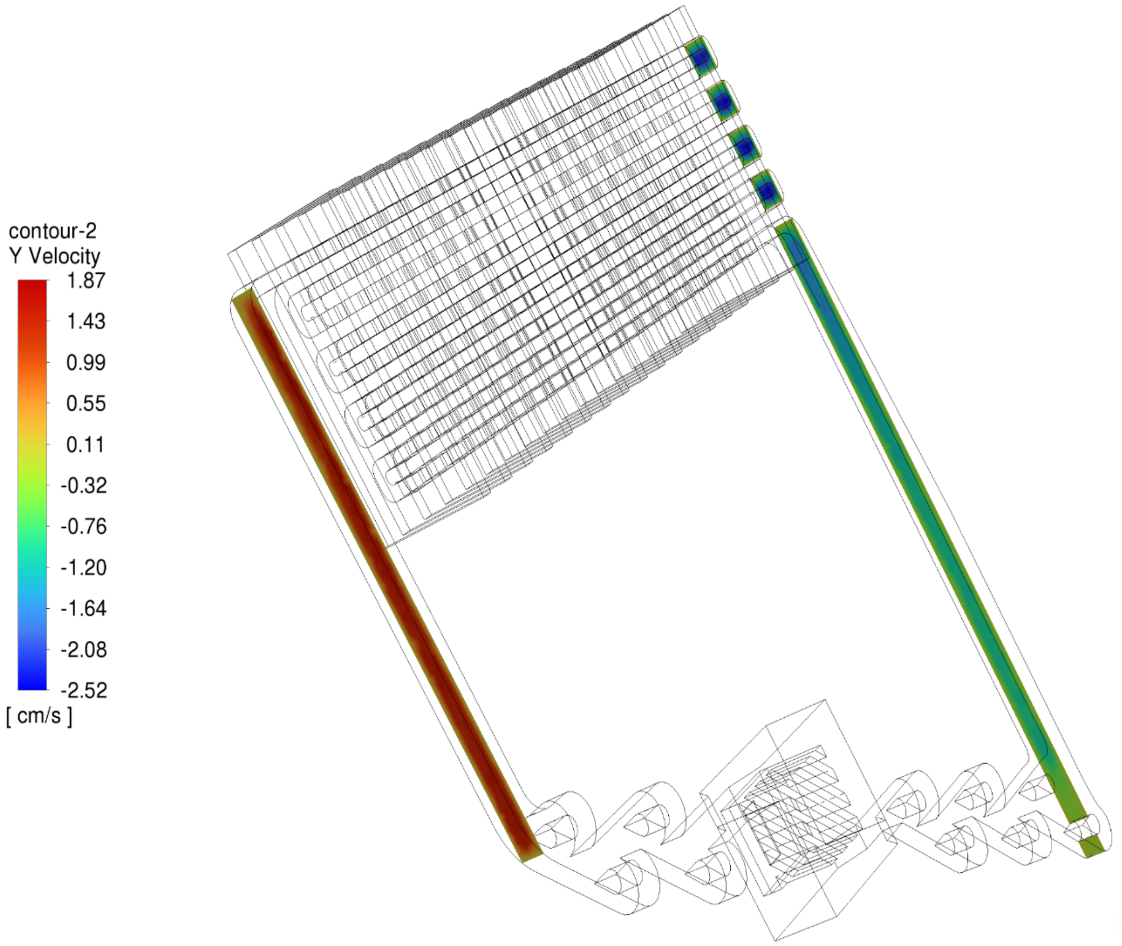


Figure 34: Y direction velocity contour plot for Design-4

Therefore, Design-4 has been shown to have the capacity to cool the CPU chip and also to generate directional flow for the single-phase immersion cooling system for the CPU. The maximum temperature achievable by Design-4, without the need for any external device to drive the flow, is 320 K (46.96°C), achieved through natural convection, boussinesq and a design based on the tesla valve. This is an impressive result, and one which could be used to facilitate more efficient and effective cooling of CPU chips in the future.

## COMPARATIVE STUDY FOR MINERAL OIL & FC-3283

It is essential for any research paper to validate its results in order to guarantee that the findings are accurate, reliable, and trustworthy. Validation helps to ensure that the results are consistent and are not affected by any bias or other factors, and that the conclusions drawn from the research are sound.

Moreover, the process of validation helps to ensure that the research is reproducible and can be replicated by other researchers. Furthermore, by validating the results of the research paper, a sense of trustworthiness and credibility is created, which is essential for gaining acceptance of the findings by the scientific community. Therefore, validating the results of a research paper is an important part of the research process that should not be overlooked and as a validation a comparative study was conducted for various heat fluxes for FC-3283 and changing a fluid domain to Mineral Oil.

In order to gain a comprehensive understanding of the behaviour of heat transfer in a CPU, two sets of simulations were conducted for the comparative study. The first set, which is similar to Design-4, was conducted with varying levels of heat flux ranging from 90 to 120 W/cm2. The second set of simulations involved changing the fluid domain from FC-3283 to Mineral Oil. This comparative study was conducted to gain further insight into the behaviour of heat transfer in a CPU, and it provides valuable information to the research. Results of all these simulations are listed below in the table (5).

| Heat Flux $[W/cm^2]$ | CPU temperature For FC-3283 $[K]$ | CPU temperature for Mineral Oil $[K]$ |
|---|---|---|
| 90 | 316.87 | 322.95 |
| 100 | 318.49 | 326.49 |
| 105 | 319.25 | 327.94 |
| 112 | 320.11 | 329.93 |
| 120 | 321.27 | 331.98 |

Table 5: Comparative study for FC-3283 & Mineral Oil

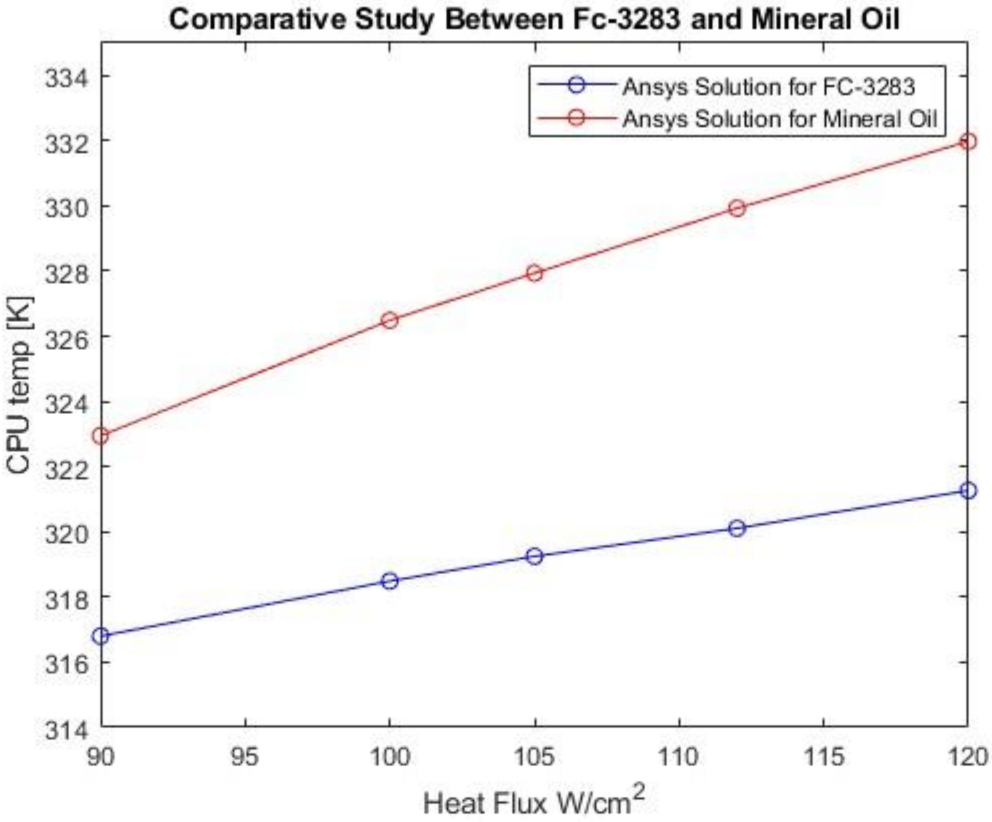


Figure 35: Comparative study between FC-3283 and Mineral oil

An in-depth comparison between the performance of FC-3283 and mineral oil as single-phase immersion coolants was conducted. The results demonstrated that FC-3283 was superior to mineral oil in terms of thermal conductivity, specific heat capacity, viscosity, and non-flammability. FC-3283 also had the advantage of being non-toxic and non-corrosive, making it a much safer option. Furthermore, FC-3283 showed better compatibility with electronic components and better thermal stability than mineral oil. These results showed that FC-3283 had a clear advantage over mineral oil for single phase immersion cooling applications.

# VALIDATION OF CFD RESULTS

Analytical calculations can be used to gain an understanding of the cooling performance of FC-3283 and mineral oil when used as working fluids in a natural convection system. In this study, the flat plate is assumed to represent a CPU and the goal is to compare the steady state temperature of the plate when FC-3283 and mineral oil are used as the working fluids. The derivation of these values were done in the MATLAB. Specifically, the convection correlations for natural convection are used to calculate the average temperature of the flat plate based on the heat transfer coefficient and the rate of heat removal. The results of these calculations are then compared to determine the difference in cooling performance between FC-3283 and mineral oil.

In order to validate the CFD results an analytical calculation was performed; a script was created in MATLAB to analyze the energy balance convergence of the FC-3283 system. An iterative study was conducted using an initial guess of a CPU temperature of 308 Kelvin, from which the Rayleigh number was calculated. Subsequently, The Nusselt number was then found in order to calculate the convective heat transfer coefficient and the Power. While performing the iterations the CPU temperature was increased by $0.01\,K$ for each iteration until the difference between the calculated power and the actual power of the CPU was less than 0.01. A similar study was conducted for mineral oil as well.

$$Ra = \frac{g \times \beta \times (T_{CPUchip} - T_{ambient})}{\upsilon \times \alpha}$$

$$Nu = 0.15 \times (Ra)^{\frac{1}{3}}$$

$$Nu = \frac{h \times L}{k}$$

$$h = Nu \times \frac{k}{L}$$

$$q = \ h \times Area \times (T_{CPUchip} - T_{ambient}) \qquad W \ in \ Watts$$

Results from the MATLAB for analytical energy balance calculation are listed below.

| Heat Flux $[W/cm^2]$ | CPU temperature For FC-3283 $[K]$ | CPU temperature for Mineral Oil $[K]$ |
|---|---|---|
| 90 | 313.9200 | 325.3400 |
| 100 | 315.4900 | 328.1300 |
| 105 | 316.1100 | 329.2400 |
| 112 | 316.4800 | 329.9000 |
| 120 | 319.4600 | 335.2500 |

Table 6: Analytical Energy Balance results

Then the result of the analytical solution and solution from the ANSYS were compared.

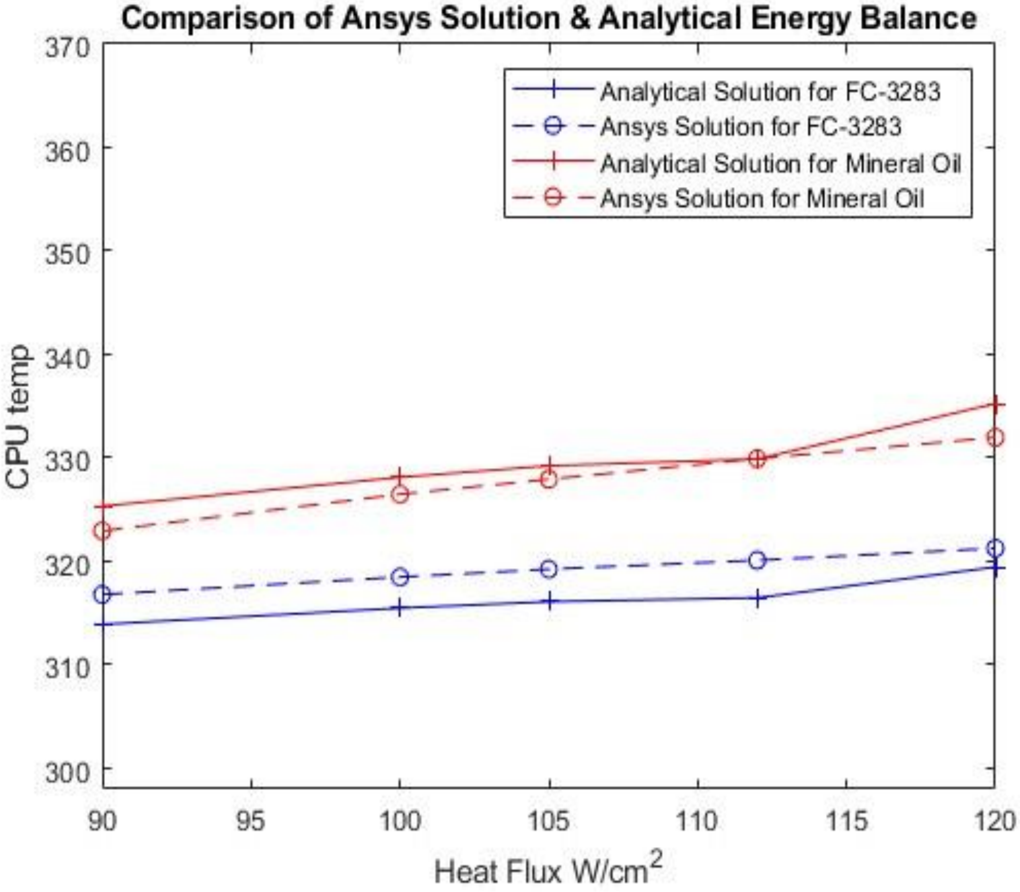


Figure 36: Comparison of Ansys Solution and Analytical Energy Balance

The analytical solution for a CPU chip and fluid interaction was found to be inaccurate when compared to the results from Ansys, which included the realistic conditions of recirculation of fluid, complex design, and cooling. Despite this, the analytical solution still serves as a useful tool to verify the results of the CFD simulations. This is because the analytical solution is not only quicker to obtain, but it can also be used to assess the accuracy of the CFD simulations and determine if they are providing reliable and sensible results. Moreover, the analytical solution may provide an additional insight into the physics of the CPU chip and fluid interaction, enabling researchers to better understand the complexities of the system. Therefore, the analytical solution still has its uses as a point of comparison when assessing the results of CFD simulations, and should not be disregarded in research on the CPU chip and fluid interaction.

# FUTURE ASPECTS OF DESIGN

The presented single phase immersion cooling system is a successful design which is able to produce unidirectional fluid flow without any additional components and provide adequate cooling to the CPU processor. Nonetheless, further research is necessary to identify potential modifications which may improve the system's efficiency and performance. Such modifications could include, but are not limited to, the study of different fluids, and their effects on system efficiency; the analysis of different pump designs and their effect on fluid flow; and the investigation of different cooling systems and their impact on CPU temperature. Additionally, the potential of using alternative materials for the construction of the system's components should be studied in order to identify further improvements. All of these aspects can contribute to further optimizing the design of the single-phase immersion cooling system. few future modifications could be possible are listed below

1. Efficient tesla valve Design

   The Tesla valve design has been used to achieve unidirectional flow, which can be modified to increase the flow rate, thereby enhancing natural convection. This improvement can be achieved by altering the geometry of the Tesla valve, such as decreasing the cross-sectional area of the valve, or changing the angle of the valve vanes. Additionally, the use of more efficient materials for the valve components can result in a higher flow rate, with improved thermal performance, as well as improved pressure stability. The potential benefits of this modification to the Tesla valve design for natural convection can be further explored through numerical simulations and experiments.

2. Modification in Radiator plates

   In order to achieve more efficient cooling, one can consider making modifications to the radiator design, such as increasing the number of radiator plates and expanding the surface area of the plates, as well as decreasing their thickness. Research has shown that these modifications can result in improved cooling efficiency, as more surface area is available for the heat to dissipate. Additionally, the thinner plates allow for a higher rate of heat transfer to the surrounding environment. By implementing these modifications to the radiator design, one can expect to achieve more efficient cooling.

3. Location of radiator like design

   Previous section has demonstrated that design-4, a radiator-like design situated in a vertical position, is effective in certain circumstances. However, this design has been found to be unsuitable when applied to a real computer's CPU due to the physical positioning of the chip on the motherboard. To address this issue, a horizontal radiator-like design may be more suitable for such cases, as the dimensions of the CPU are typically shorter in comparison. Further research is needed to investigate the efficiency of the horizontal radiator-like design in terms of its applicability to real-life computer CPUs, and to compare its efficacy with that of the vertical radiator-like design.

# CONCLUSION

In conclusion, this research has established that single-phase immersion cooling is an efficient cooling system compared to conventional technology. The results of the CFD simulations and analytical energy balance calculations demonstrated that FC-3283 is an exceptionally supercilious fluid for cooling compared to mineral oil and air (conventional cooling). The natural convection and boussinesq based CFD simulation showed that the FC-3283 fluid for single phase immersion cooling system outperformed the mineral oil (with the same design) cooling by 10 degrees Celsius, while the conventional air-cooling system by 50 degrees Celsius. Furthermore, the novel design of the single-phase immersion cooling system is capable of generating unidirectional flow rate without using any external components due to the buoyancy and boussinesq phenomenon. The invention of Nikola Tesla's 'valvular conduit' (also known as the Tesla valve) has proved to be instrumental in achieving the recirculation of fluid and generating one directional flow rate. Therefore, this research has provided evidence that single-phase immersion cooling is a viable and efficient option for cooling applications.

Despite the promising potential of single-phase immersion cooling systems, it is important to address the drawbacks that could limit their usefulness and adoption. For example, the system's reliance on a fluid-based cooling system makes it much heavier than an air-cooling CPU, and there is the possibility that the attachment system used to mount the system onto the processor chip could cause physical contact with other components of the motherboard, such as ICs and RAM. Nevertheless, these drawbacks are not so significant as to undermine the performance of the system or its potential for commercialization and implementation as an alternative to traditional air-cooling systems. Furthermore, since the FC-3283 fluid has a low boiling point, it does not require large amounts of energy for vaporization, thus making it an economical cooling option. In closing, the single-phase immersion cooling system with FC-3283 fluid material has proven to be a reliable, effective, and promising cooling system compared to two phase immersion cooling systems and traditional air-cooling systems. This system is highly efficient and has the potential to be utilized in future research endeavours.

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[14] MEASUREMENT OF THE THERMAL PERFORMANCE OF A SINGLE-PHASE IMMERSION COOLED SERVER AT ELEVATED TEMPERATURES FOR PROLONGED TIME Pratik V Bansode, Jimil M. Shah , Gautam Gupta , Dereje Agonafer , Harsh Patel , David Roe and Rick Tufty

[15]A critical review of traditional and emerging techniques and fluids for electronics cooling S M Sohel Murshed* and C A Nieto de Castro

# APPENDIX A

# MATLAB CODE FOR ANALYTICAL ENERGY BALANCE

```
clear all

clc

format short

%Comparative Study

%plot of comparative study of CFD results

Heat_Flux=[90 100 105 112 120];

FC3283_Temp = [316.8 318.49 319.25 320.11 321.27];        %CPU temp
for FC-3283 Ansys results

MinrOil_Temp = [322.95 326.49 327.94 329.93 331.98];      %CPU temp
for Mineral Oil Ansys results

figure(1)

plot(Heat_Flux,FC3283_Temp,"-ob",Heat_Flux,MinrOil_Temp,"-or")

legend("Ansys Solution for FC-3283","Ansys Solution for Mineral Oil")

xlabel('Heat Flux W/cm^2')

ylabel('CPU temp [K]')

title("Comparative Study Between Fc-3283 and Mineral Oil")

axis([90 120 314 335])

%Numerical Energy balance calculation for FC-3283

T_ref=25;           %ambient temperature

g=9.8;              %gravity

% v=7.5e-07;        %kinematic viscosity

% alpha=3.5e-08;    %thermal Diffusivity

L=0.00875;          %convection affected region interaction between
solid and fluid

k=0.063824;         %thermal conductivity

l=22.4/1000;        %length heat source

w=9.2/1000;         %width heat source

Area=l*w;

n=10000;                                %number of iteration
```

```
q_power=[200 225 235 241 290];        %power of CPU
q_f=[90 100 105 112 120];             %heat flux equivalent to power
for i=1:length(q_power)
   disp("iter       h           q        T_op    T_chip")
   T_chip_fc(i)=35;
   for j=1:n

       T_op=(T_ref+T_chip_fc(i))/2;
       rho=1878-(2.455*(T_op));                                  %Density
Calculation (T Degree Celsius)
       Cp=1046.634;                                              %Specific
heat Capacity
       u=0.0014;                                                 %absolute
Viscosity
       v=u/rho;                                                  %Kinematic
Viscosity
       alpha=k/(rho*Cp);                                         %Thermal
Diffusivity
       Ra=(g*(1/(T_op))*(T_chip_fc(i)-T_ref))/(v*alpha);  %Rayleigh
Number (T Degree Celsius)
       Nu=0.15*Ra^(1/3);                                         %Nusselt
Number
       h=Nu*k/L;                                                 %convective
heat transfer coefficient
       q_con_fc=h*Area*(T_chip_fc(i)-T_ref);                     %Power
Calculation
       fprintf("%3i    %7.4f  %7.4f  %7.4f  %7.4f\n",j,h,q_con_fc,T_op
,T_chip_fc(i))
       if abs(q_con_fc-q_power(i))<0.1
           disp("Solution converged")
           break
       else
```

```
           T_chip_fc(i)=T_chip_fc(i)+0.01;
       end
   end
end
%Numerical Energy balance calculation for Mineral Oil
% v1=2.8058e-05;           %kinematic viscosity
% alpha1=9.08544e-08;      %thermal Diffusivity
k1=0.1488;                 %thermal conductivity
for i=1:length(q_power)
   T_chip_m(i)=45;
   disp("iter      h        q       T_op   T_chip")
   for j=1:n
       T_op1=(T_ref+T_chip_m(i))/2;
       B=1/(T_op1);
       rho1=872.5-(0.625*(T_op1));                 %Density
Calculation (T Degree Celsius)
       Cp1=1917.83;                                %specific heat
capacity
       u1=0.0234;                                  %absolute viscosity
       v1=u1/rho1;                                 %Kinematic
Viscosity
       alpha1=k1/(rho1*Cp1);                       %Thermal
Diffusivity
       Ra1=(g*B*(T_chip_m(i)-T_ref))/(v1*alpha1);  %Rayleigh Number (T
Degree Celsius)
       Nu1=0.15*Ra1^(1/3);                         %Nusselt Number
       h1=Nu1*(k1/L);                              %Convective heat
transfer coefficient
       q_con_m=h1*Area*(T_chip_m(i) -T_ref);       %power calculation
       fprintf("%3i  %7.4f  %7.4f  %7.4f  %7.4f\n",j,h1,q_con_m,T_op1,
T_chip_m(i))
```

```
        if abs(-q_con_m+q_power(i))<0.1

            disp("Solution converged")

            break

        else

            T_chip_m(i)=T_chip_m(i)+0.01;

        end

    end

end

T_chip_fc=T_chip_fc+273.15                              %CPU chip temp
for fc 3283

T_fc=[316.8 318.49 319.25 320.11 321.27]  ;             % Ansys result
for chip temp for FC 3238

T_chip_m=T_chip_m+273.15                                %CPU chip temp
for Mineral oil

T_m=  [322.95 326.49 327.94 329.93 331.98];             % Ansys result
for chip temp for Mineral Oil

figure(2)

plot(q_f,T_chip_fc,"-b+",q_f,T_fc,"--bo",q_f,T_chip_m,"-r+",q_f,T_m,"-
-ro")

legend("Analytical Solution for FC-3283","Ansys Solution for FC-
3283","Analytical Solution for Mineral Oil","Ansys Solution for
Mineral Oil")

xlabel('Heat Flux W/cm^2')

ylabel('CPU temp')

title("Comparison of Ansys Solution & Analytical Energy Balance")

axis([90 120 298 370])
```