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Numerical Analysis for a Computer Immersion-Cooling System

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ABSTRACT

This study presents a unique forced flow and heat sink cooling system and technique for a single-phase immersed cooling system. Computer systems can use electricity more effectively if electronics cooling systems are done more appropriately. Computers and other electronic devices could be cooled via immersion cooling by immersing them in a thermally conductive liquid or coolant. The CPU surface is covered with a straight-fin heat sink, and the mainboard is immersed in NOVESC 3M 649, a designed fluid that can disperse heat while utilizing immersed cooling. The simulation software program results show that increasing the number of fins from 5 to 9 led to an increase in temperature, velocity, and pressure. However, the highest dissipated power was obtained when using eight fins; therefore, increasing the number of fins is considered ineffective due to the increasing temperature.

1. INTRODUCTION

Server power density rises directly to the demand because of data processing and storage. The temperature control of servers substantially affects the energy efficacy of data centers [1]. The most popular thermal management solution in data centers is air cooling. Due to powerful CPUs, air cooling has begun to hit its limits. Different dielectric fluids can be utilized in liquid immersion-cooling techniques to solve these drawbacks of air cooling in data centers [2]. The phenomenon known as "thermal shadowing" occurs when a cooling medium's temperature rises from absorbing heat from a single source and consequently loses some of its heat-carrying capacity as the in-between max junction and the temperature difference, temperatures of succeeding heat sinks and incoming fluids decrease [3, 4]. Both low-velocity oil flow cooling and air-cooling face difficulties from thermal shadowing. This study compares thermal shadowing effects in a 3rd generation public computing server utilizing different dielectric fluids. The heat sink dramatically influences the effectiveness of cooling at the server level. This method efficiently selects heat sinks in addition to the computational methods of 3rd generation public computing servers [5, 6]. Optimizing the heat sink allows high-power density servers to be successfully cooled for only one immersed cooling application. A parametric examination revealed a significant decrease in the vol. of such a heat sink [7].

Using the heat transfer technique of immersion cooling, a coolant is brought into close contact with a hot fluid. The most typical instance is when water is heated to a boil before being utilized to cool an engine [8]. Immersion cooling has been utilized for a long time, but high-performance computer systems are now beginning to employ it. Warm liquid is passed through one or more heating exchangers attached to a radiator or a fan to provide liquid immersion cooling. Air flows through the radiator, absorbing heating from the liquid and cooling as it does [9].

Using a thermally conductive but electrically insulating dielectric liquid or coolant, IT components and other electronics, including whole servers and storage devices, are immersed during immersion cooling [10]. Heating is removed from the system by moving relatively cold liquid into close contact with hot components and then moving this heated liquid via cooling heat exchangers. This method of cooling servers and IT gear eliminates the need for fans, and often, a heat exchanger is utilized to transfer heat from the heated coolant to the cold-water circuit. The temperature of the whole system is pre-set, which helps to maintain it within safe ranges [11].

By transitioning from conventional cooling methods to immersion cooling, data centers may efficiently prepare for future operating demands of high computing while controlling costs and environmental consequences. The liquid utilized should have a low enough electrical conductivity to prevent interfering with the computer's normal functioning. If the liquid is particularly electrically conductive, insulating certain regions of components susceptible to electromagnetic interference, including the CPU, could be essential. Therefore, it is ideal for the liquid to be dielectric [10].

Computer systems can use electricity more effectively if cooling electronics systems are done more appropriately. Computers and other electronics might be cooled via immersion cooling by immersing them in a thermally conductive liquid or coolant. The cooling structure and process of a single-phase immersion cooling system employing a heat sink and forced circulation were described by Cheng et al. [12]

in their publication. The CPU surface is covered with a straight-finned heat sink, and the whole mainboard is immersed in 3 M NOVEC 7100, a designed fluid that can disperse heat and is utilized in immersion-cooling applications. A simulation model created utilizing computer simulation software is tested experimentally to ensure accuracy. Three liquid coolant circulation rates and two distinct heat sink materials are utilized to investigate the cooling impact of a single-phase immersion-cooling system. Using a cross-sectional view and a 3-dimensional isothermal surface model, the heating distribution of the specified model was studied at varied liquid coolant and material flow rates. The simulation findings demonstrate that a cooler CPU might operate at a low temp if the liquid coolant moved more quickly.

Nevertheless, the coolant flow was impeded because of the decreased circulation speed. It also contributed to uneven heat distribution and higher temperature levels. The greatest temps were recorded, and it was found that the model's imbalanced heat distribution. The heat sink's composition only considerably impacts the findings. The system designer may utilize these results to boost power densification and ensure the secure functioning of the associated computer, server, and communication systems [13].

The system consumes approximately 40 percent of the energy needed to cool a standard information technology system. The three main subcategories of cooling systems are water, closed-loop liquid, and immersion-cooling systems. It was noted that immersion cooling is the newest development in cooling solutions for IT devices. The cooling process involves submerging the computer's parts in a dielectric coolant. Utilizing this immersion approach, Pambudi et al. [14] investigated the cooling procedure of the GPU. Due to its high dielectric strength, mineral oil is utilized as a medium fluid. Benchmarking software was then utilized to gauge the temperature variation between immersion cooling and fan usage. The outcome demonstrated that the GPU temp was lower with immersion cooling than with a traditional fan. When the immersion approach was utilized, the GPU's operating temp was 70 degrees centigrade, compared to 80 degrees centigrade when the traditional fan technique was utilized.

Since 46 percent of the world's population now uses the internet and creates up to 8 zettabytes of data flow daily, the value of the global internet is increasing. Due to this expansion, data center infrastructure has expanded as a communication system, storage, and processing in the digital world. The data center has already contributed 1.5 percent of the world's total power usage, and this percentage is anticipated to rise over time. Fifty-two percent of the energy required in the data center goes toward information technology (IT) devices, 38 percent to cooling, and 10% goes toward auxiliary equipment. The information technology (IT) cooling elements have been one of the issues these centers have had throughout the years. A cooling model with the potential to increase data center energy efficacy is described by Kuncoro et al. [15]. Many kinds of research were conducted, and one looks at using the immersion-cooling method since it promises to increase the energy efficacy of data centers by utilizing dielectric fluids with large heat capacities. This document identifies and discusses several fluids employed in this procedure.

One of the solutions for the problems with the present data center cooling system was the development of immersion cooling, as suggested by Kuncoro et al. [15]. Therefore, this work aimed to identify the variables influencing the performance of mineral oil immersion cooling. Creating an immersion-cooling unit and operating the server by loading the software were further steps in the experiment. The Technique with Orthogonal Array L8 was utilized to calculate the contribution and impact of each component. The CPU temp and Energy Usage are monitored, with the inlet-outlet position, flow rate, and cooling fan speed acting as the Taguchi parameters. The findings demonstrated that energy usage and cooling fan performance had a combined effect of 71.278 percent and 75.034 percent on CPU temp.

Server power density rises directly to the demand for data processing and storage. The temperature control of servers substantially affects the energy efficacy of data centers. The most popular thermal management solution in data centers is air cooling. Due to powerful CPUs, air cooling has begun to hit its limits. Different dielectric fluids can be utilized in liquid immersion-cooling techniques to solve these drawbacks of air cooling in data centers. The phenomenon known as "thermal shadowing" occurs when a cooling medium's temperature rises due to absorbing heat from a single source and consequently loses some of its heat-carrying capacity as the in between max junction and the temperature difference, temperatures of succeeding heat sinks and incoming fluids decreases. Both low velocity oil flow cooling and air-cooling face difficulties from thermal shadowing. The heat sink dramatically influences the effectiveness of cooling at the server level. By optimizing the heat sink, high-power density servers may be successfully cooled for only one immersed cooling application. A parametric examination revealed a significant decrease in the vol. of such a heat-sink. The current study aims to develop a simulated model utilizing the COMSUL program to validate the experiment's findings. The heat sink materials—Al and Cu—were selected to investigate the single-phase immersed cooling system's cooling effect when using different fins numbers on air velocity, temperature, and pressure.

2. MODEL SIMULATION

A three-dimensional model has been created via 3D modeling software to test the impact of the immersion cooling with flowing liquid and heat sink installed on the CPU surface of a computer (PC). The model has a flat-finned heating sink on top of the CPU, which generates most of the heating in a computer. The CPU measures 40 mm square in size. Copper and aluminum (Al) have been used for the heating sink (Cu). The PC box's top left corner served as the exit point for the liquid coolant, which entered the computer box from the bottom of the heating sink. The model has been predicated on a laminar, stable, incompressible flow [16]. The momentum formula is as follows:

$$\rho(\mathrm{DV}/\mathrm{Dt}) = -\nabla P + \rho \mathrm{g} + \mu \nabla^2 \mathrm{V} \tag{1}$$

A 3D model will be sufficient to depict the cooling for the project scope after it was decided to simulate only one rack since the flow was only going through the servers in one direction [17]. The fact that this choice will operate better with COMSUL Student's restricted meshing capabilities and the limited amount of available computing time at the institution was also seen as a benefit [18].

Even though three-dimensional modeling does not provide a complete view of everything in the data center, it would clearly illustrate what was occurring for the project. If further work was required based on promising findings, this could be accomplished within a three-dimensional model later as part of additional research.

2.1 Computer-aided design model

The integrated CAD program inside COMSUL Fluent has been used to produce the CAD model for the three-dimensional simulation, with the model parameters set to three-dimensional. Instead of modeling the space and rack for the three-dimensional COMSUL simulation, the fluid is modeled. Therefore, the proper boundary conditions were applied to this model during the meshing step. Figure 1 simulation of the 15kW air-cooled engine illustrates this concept. Figure 2 shows a meshed model.

The data center's floor and roof are the model's top and lower borders in the image above. The model's right edge has been designated as the exit, while the left side served as the inlet. The blanking panel and the cabinet top were modeled in the vast outdoor space, and the partition that emerged to the right of it served as the heated aisle containment area. The remaining gaps have been produced to simulate the servers, and the simulations' heat production has been placed to the margins of these gaps.

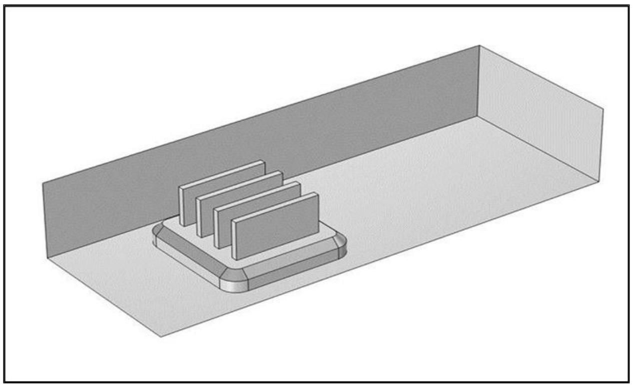


Figure 1. Three-dimensional AutoCAD model for air-cooling simulation

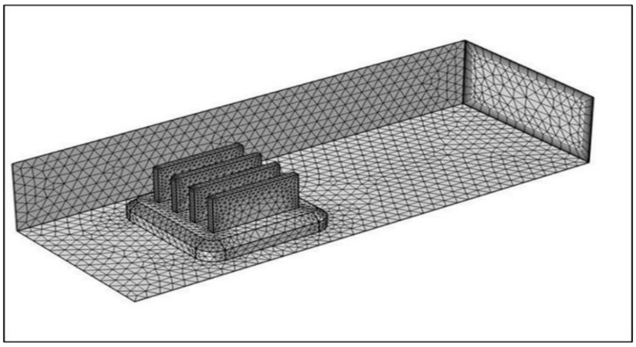


Figure 2. Air-cooling meshes (elements)

2.2 Simulation

Each simulation displays the overall temp in Kelvin inside the data centers with a steady state operation. The outlet and inlet variables were maintained constant and set, as shown in Table 1 for each simulation.

Table 1. Specifications and boundary conditions of forced air cooling with heat sink

Heat Sink Base		
Depth	3	cm
Length	3	cm
Thickness	5	mm
Corner fillet radius	2	mm
Chamfer length, angle 45°	2	mm
Box		
Inlet distance	2	cm
Outlet distance	6	cm
Lateral distance	0.5	cm
Top distance	0.5	cm
Heat Sink Fin		
Heat sink type	Straight	-
Hight	1	cm
Thickness	1.5	mm
Number of fins	5, 6, 7, 8, 9	-
Boundary Conditions		
Inlet velocity	1	m/s
Inlet temperature	22	℃
Heat source temperature	100	℃

2.3 Mathematical formulation

This rectangular cavity's flow is turbulent and is thought to be incompressible. In the Cartesian coordinates, the continuity formula is expressed by:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{2}$$

Applying the momentum formula in the X-axis with a Boussinesq buoyancy assumption [19]:

$$\begin{aligned}&\rho\frac{\partial u}{\partial t}+\rho\left[u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right]\\&=-\frac{\partial p}{\partial x}+\mu\left[\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right]+\rho g_x\beta(T-T_o)\end{aligned} \tag{3}$$

Y-axis:

$$\begin{aligned}&\rho\frac{\partial v}{\partial t}+\rho\left[u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right]\\&=-\frac{\partial p}{\partial y}+\mu\left[\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right]+\rho g_y\beta(T-T_o)\end{aligned} \tag{4}$$

Z- axis:

$$\begin{aligned}&\rho\frac{\partial w}{\partial t}+\rho\left[u\frac{\partial w}{\partial x}+u\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right]\\&=-\frac{\partial p}{\partial z}+\mu\left[\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right]+\rho g_z\beta(T-T_o)\end{aligned} \tag{5}$$

When the steady condition flow:

$$\frac{\partial u}{\partial t}=\frac{\partial v}{\partial t}=\frac{\partial w}{\partial t}=0$$
$$g_x=g_z=0$$

Since the absence of acceleration gravity in both the x and z-axis.

Therefore, the formula would be,

$$\rho\left[u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}\right]=-\frac{\partial p}{\partial y}+\mu\left[\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right] + \rho\,\underbrace{g_y\beta(T-T_o)}_{} \tag{6}$$

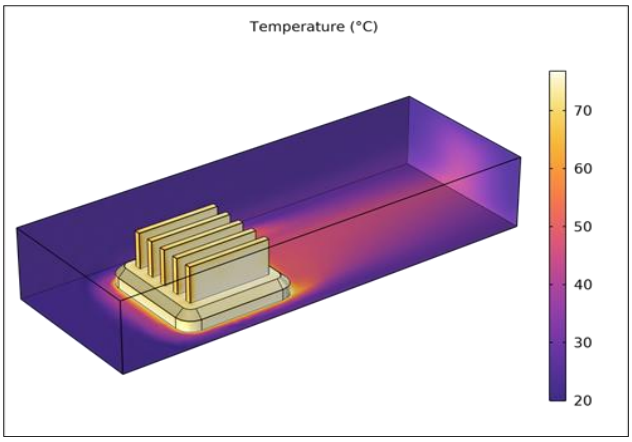
The energy formula:

$$\rho c_p\left[\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right]=k\left[\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}\right] \tag{7}$$

The following non-dimensional parameters are necessary for the non-dimensionalization of the governing formula.

3. RESULTS AND DISCUSSION

Heat sinks help heat transfer from a hot surface—often the housing for a heat-generating element—to a cooler environment, usually air. Heat exchangers are another name for heat sinks [20]. For the sake of the following discussions, it shall be assumed that the cooling medium is air. The system's least effective method of transferring heat occurs when a solid surface meets cooling air, which also serves as the greatest obstacle to heat dissipation. Most of the time, this is accurate [21]. A heat sink may assist in lowering this barrier since it increases the surface area directly in contact with the coolant, which increases the heat that can be dissipated and lowers the device's temperature [22]. The main goal of a heat sink is to maintain the device's temperature at or below the maximum temperature that is safe for operation, as established by the device's manufacturers. Hence, the following are the findings from the research on the impact of heat sink design.



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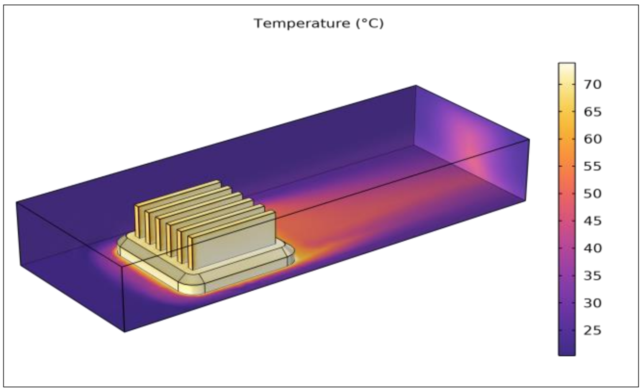

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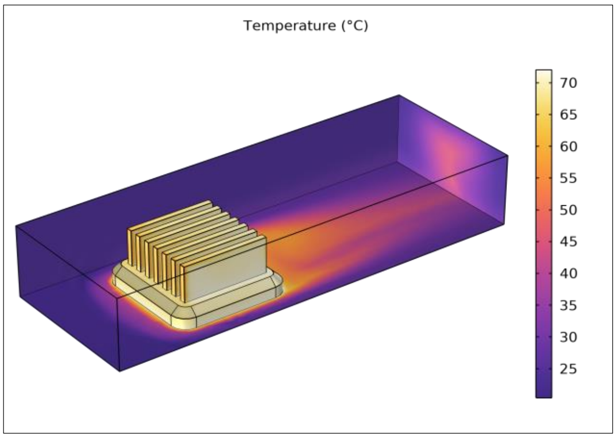

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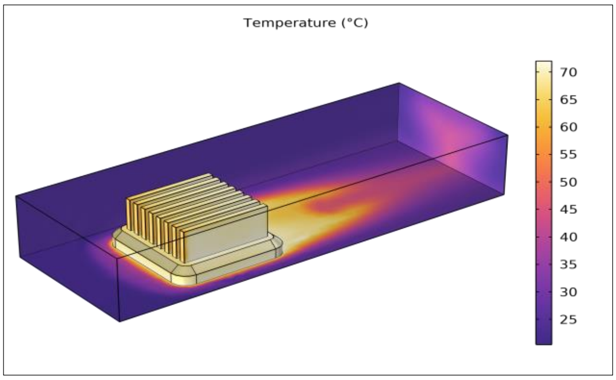

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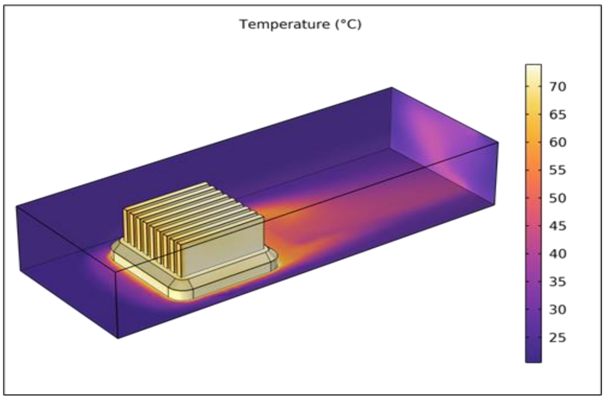

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Figure 3. Temperature profiles of the heat sink with multiple fin numbers (5, 6, 7, 8, and 9)

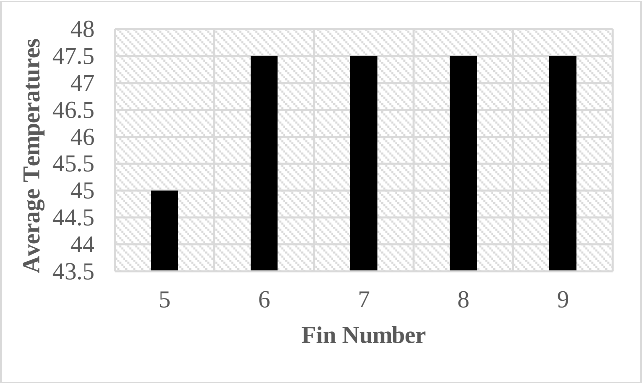


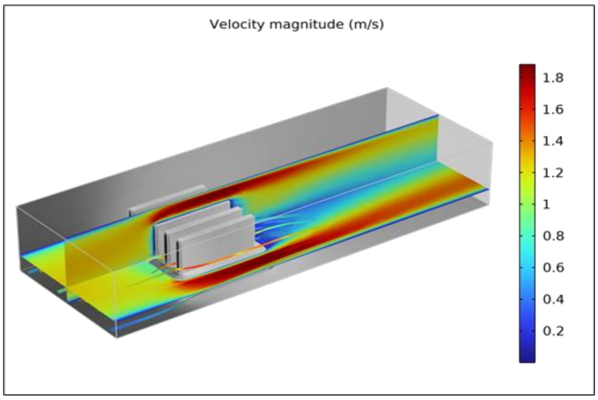
Figure 4. The effect of fins number on average temperature in immersion cooling system

3.1 Effect of fins number on the temperature of the heating sink

Cooling systems, particularly those involved in cooling the data center building, should be adjusted if the outside temp changes (for example, a hotter than typical summer day). "Work harder" to keep the temperature in the safe room. Working harder often results in more energy (and, hence, more money) being used to cool down. Nevertheless, it would be essential to throttle or shut down a portion of the data center in more severe situations. If trying harder to cool it does not work, that would influence the data center's performance and overall effectiveness. Based on the obtained results demonstrated in Figures 3 and 4, increasing the fins number for the heat sink from 5 to 6 reduces the system's cooling efficiency, where the temperature in the case of using five fins was 45 degrees centigrade. Increasing the number of fins by more than six led to an increase in the outlet temperature to 47.5 degrees centigrade [23]. The lowest temperature of the outlet heat sink is 20 degrees centigrade when using five fins, and the lowest heat sink temperature increased to 25 degrees centigrade when using six or more fins number [12].

3.2 Effect of fins number on velocity

The average velocity increased due to an increase in the fluid flow path, as demonstrated in Figures 5 and 6; increasing the number of fins for heat sinks from 5 to 6 increased the average velocity. Increasing the number of fins by more than eight does not affect the heat sink's average velocity due to reducing the path area resulting from the fins area [24]. The highest and lowest average velocity magnitude was changed based on the fins' numbers [25, 26]. In the case of using five fins, the highest velocity was 1.8 m/s, and the lowest velocity was 0.2 m/s. Moreover, using 6 and 7 fins have similar lowest and highest velocities, and using 8 and 9 fins have the same velocity in lower and upper cases.



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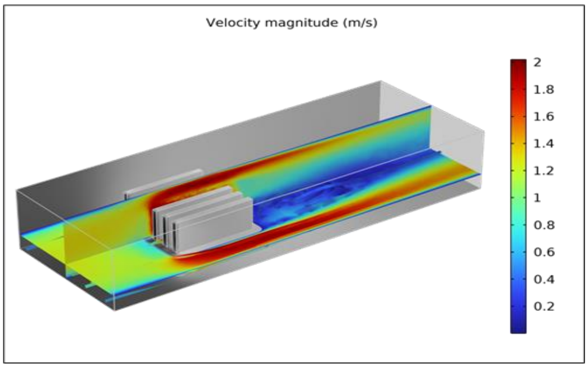

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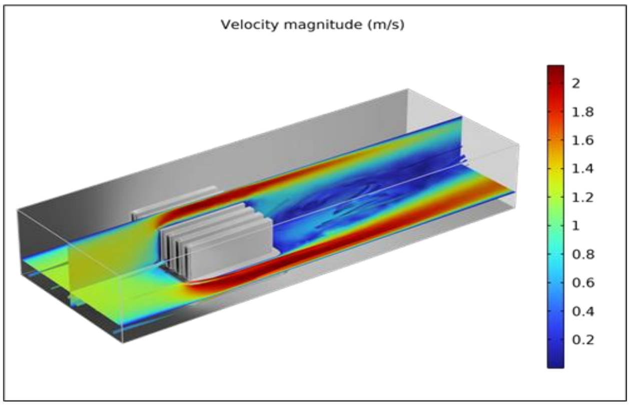

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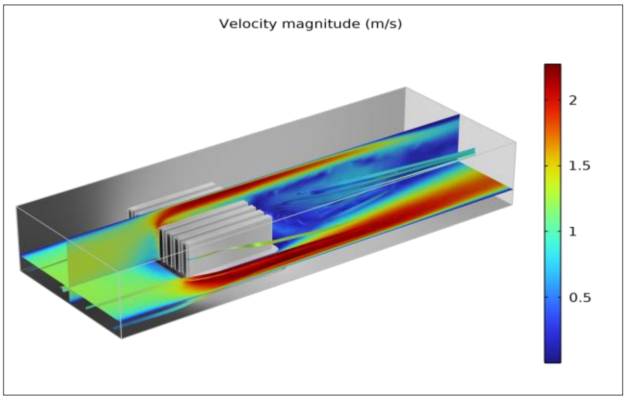

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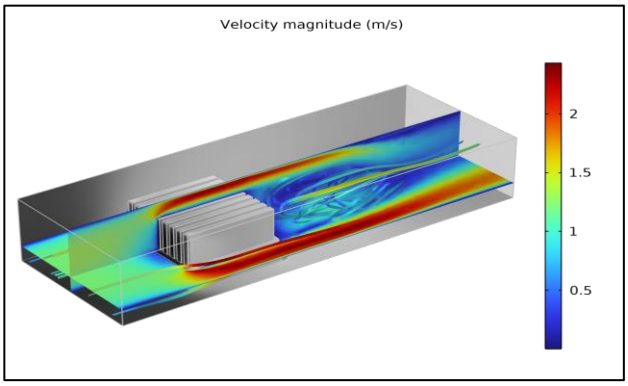

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Figure 5. Velocity profiles of a Heat sink with multiple fin numbers

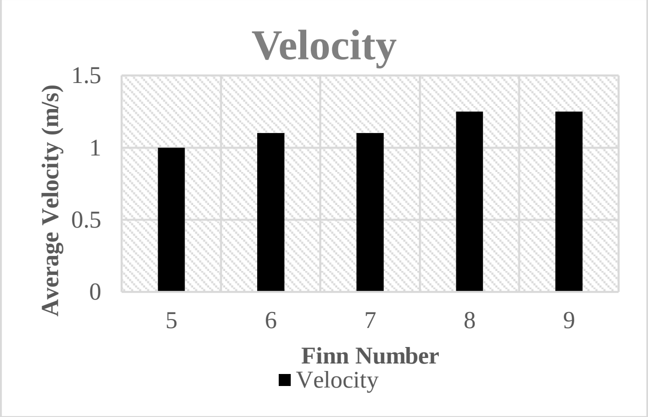
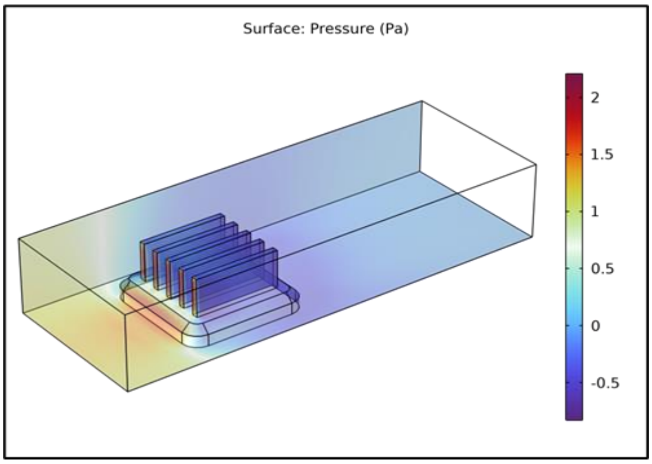


Figure 6. The effect of fins number on average velocity in immersion cooling system

3.3 Effect of fines number on pressure

Figure 7 shows that the pressure value and variation of pressure were changed based on fins number; when using five fins, the highest pressure value was 2 Pa, and the lowest value was -0.5 Pa. Increasing fins number to 6 and 7 led to an increase in the pressure variation value along with increasing the highest pressure value with similar lowest pressure value while increasing the fins number to 8 fins lead to increase the highest pressure value without any change on the lowest one that results in increasing the average pressure value as shown in Figure 8.



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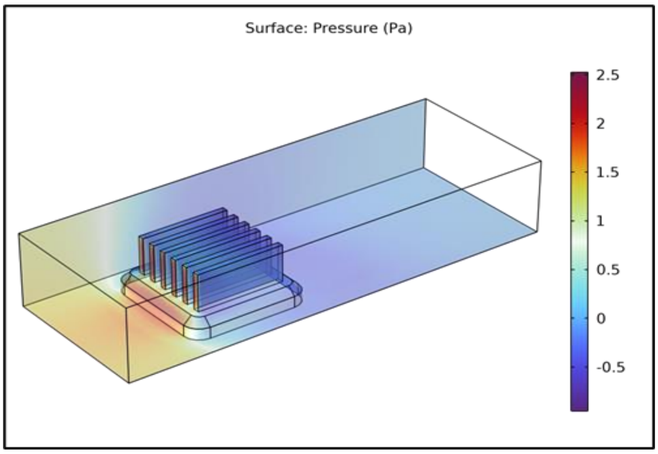

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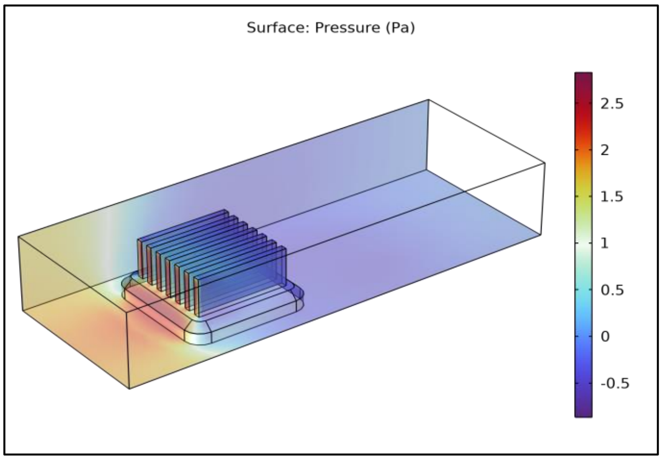

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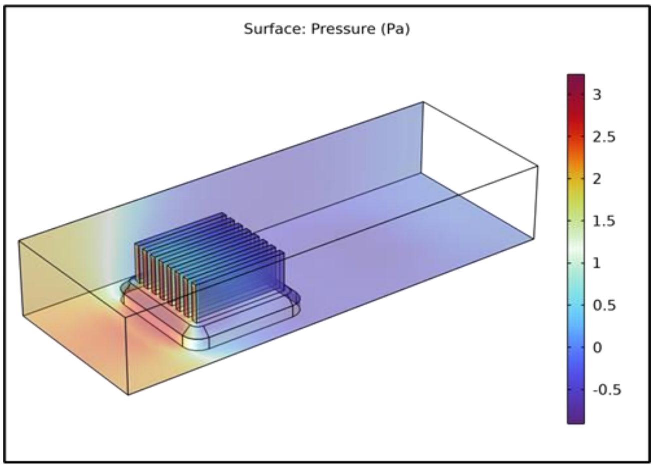

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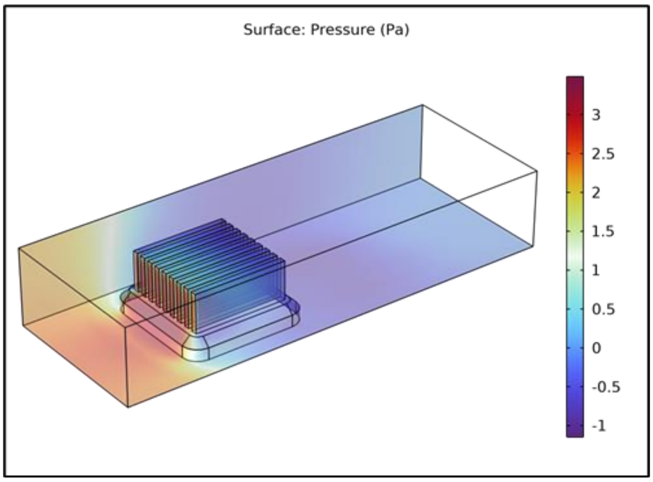

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Figure 7. Pressure profiles of the heat sink with multiple fin numbers

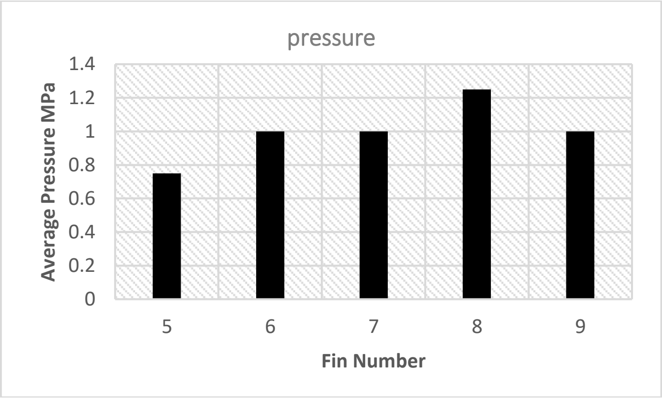

Figure 8. The effect of fins number on average pressure in immersion cooling system

Figure 9 shows the relationship between dissipated power and pressure drop for different fins. Increasing the number of fins leads to increased dissipated power, and the highest power dissipation has been obtained when using 7 and 8 fins. Increasing the pressure drop is compatible with increasing the number of fins (Table 2).

Table 2. Summary of obtained results

Number of Fins = 5	
Dissipated Power	6.311 W
Pressure drop	1.121 Pa
Number of Fins = 6	
Dissipated Power	7.0275 W
Pressure drop	1.3859 Pa
Number of Fins = 7	
Dissipated Power	7.5239 W
Pressure drop	1.757 Pa
Number of Fins = 8	
Dissipated Power	7.5334 W
Pressure drop	2.1011 Pa
Number of Fins = 9	
Dissipated Power	7.1887 W
Pressure drop	2.3696 Pa

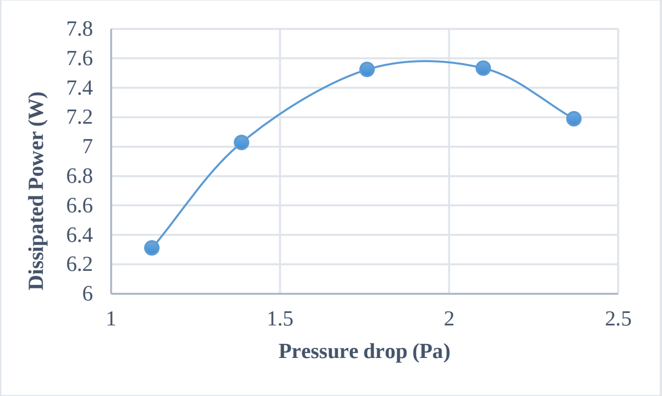

Figure 9. The relationship between dissipated power and pressure drops for different fin numbers

4. CONCLUSION

The choice of a specific heat sink type is greatly influenced by the thermal budget allotted for the heat sink as well as the environment in which the heat sink is located. The goal of the present study is to create heat sinks with various fins to determine the optimal models, such as the ones listed below:

1. Increasing inlet velocity reduces the components temp of heating generation, and the relation between temperature and inlet velocity is a negative linear relationship.
2. Increasing the number of fins from 5 to 9 increases the velocity and temperature of the heat sink in the immersion cooling system.
3. An increase in the number of fans leads to a decrease in released temperature significantly.
4. The pressure of the whole system improved when the heat sink was applied and increased the fin number, causing an increase in the pressure.
5. Based on the results, the heat sink with five fins is considered the best design with the lowest pressure and dissipated power.

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