Numerical Analysis of Hybrid Server Immersed in Synthetic Dielectric Fluid

By

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ABSTRACT

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In recent years there has been a phenomenal development in cloud computing, networking, virtualization, and storage, which has increased the demand for data centers. With this increase, there is a demand for higher CPU (Central Processing Unit) performance and an increase in the Thermal Design Power (TDP). Maintaining the CPU temperature within the specified parameters for air-cooled servers is a challenge in thermal engineering (due to performance). One of the components of the Data Centers with the largest energy consumption is the cooling system, which uses over 40% of the energy. Advancements in DRAMs and the increased support of CPUs (Central Processing Unit) led to higher power consumption up to 15 W per DRAM and supporting up to 12 DRAMs per CPU. This demands efficient cooling for the overall chassis. In single-phase immersion cooling, electronic components are typically submerged in a thermally conductive dielectric fluid allowing it to conduct heat away from all electrical parts. Therefore, the use of direct contact liquid cooling in data centers with high power dense components has recently been encouraged. In this paper we propose a numerical investigation of effects and improvements when attaching a cold plate to high heat flux components in an immersion cooled environment. Given their extremely low

thermal resistance, cold plates have been demonstrated to have higher heat dissipation rates, and it has been noted that they increase CPU/GPU clock rates (frequency/performance). In this study, the coolant used in the cold plate is PG25 (Dynalene Propylene Glycol) and the fluid used in the tank is a commercially available synthetic dielectric fluid EC-100. The model is built in such a way that only the CPU is cooled using cold plates and the remaining components are cooled by immersion cooling. A baseline CFD (Computational Fluid Dynamics) model using an air-cooled server with heat sinks is compared to the immersion cold server with cold plates attached to the CPU. Results discuss the impact on the temperatures of the components and predict the cooling capabilities of all the components in different test cases which can be used as a trend.

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CHAPTER 1
INTRODUCTION

1.1 Data Center: An Introduction

At its simplest, A data center is a facility that centralizes an organization's shared Information Technology operations and equipment for the purposes of storing, processing, and disseminating data and applications. The Switches, routers, firewalls, storage systems, servers, and controllers make up most of the data center's hardware [1]. As per 2018 study on total energy consumption, it is observed that there is a total energy consumption of 205 terawatt of energy consumed by the data centers which is 1% of energy consumption worldwide which is a total of 6% increase in energy consumption worldwide since 2010 [2].

It is crucial that the servers run continuously without any maintenance or stopping the entire data center as they must operate at optimal temperatures. As a result, the data center's cooling is crucial. The demand for better and more effective methods of cooling data centers has increased due to growing environmental concerns and an increase in electricity consumption. Energy production is a global concern, and it is critical to produce enough energy while continuing to cut back on unwelcome pollutant emissions [3,4]. There has been a renewed focus on the development of more efficient and environmentally friendly power generation systems because of current trends toward efficiency improvement and a global awareness of climate change brought on by CO_2 emissions into the atmosphere [5]. Researchers are working extremely hard to create energy more efficiently while keeping costs low in response to the rising need for its production [6]. Therefore, it is essential to construct energy-efficient data centers that are both effective and efficient for use.

1.2 Immersion Cooling Configuration

In the AI (Artificial Intelligence) era, deep Learning, machine learning, and big data need vast amounts of CPU (Central Processing Unit) power and computing resources. This implies that many high-performance processors, such as high-performance CPUs (Central Processing Unit) (Central Processing Unit) (Central Processing Unit) (Central Processing Unit), GPUs, FPGAs, and ASIC devices are required [7,8]. Due to the limitations of air cooling in dissipating growing power densities in servers, researchers have been driven to seek newer and more effective cooling alternatives. The next radical change in the thermal management of data centers is to shift from conventional cooling methods like air-cooling to direct liquid cooling (DLC) to deal with high thermal mass [9]. Immersion cooling is a thermal management technique, often applied as an IT (Information Technology) cooling practice, by which electronic devices and IT components, including complete servers and storage devices, are submerged in a thermally conductive but electrically insulating dielectric liquid or coolant. Submerging servers and IT equipment in a dielectric medium for cooling results in significant energy savings due to the high energy loads and density. Its heat capacity per volume is 1120–1400 times that of air [10]. Furthermore, the rack density as a function of Power Usage Effectiveness (PUE) shows that the rack power density for single-phase immersion cooling is three times greater than for air cooling. While a conventional air-cooled system has a PUE of about 1.5, immersion cooling has a PUE of about 1.07, meaning a 36% reduction in power usage when employing immersion cooling [11]. The single-phase immersion cooling uses a dielectric fluid that helps in dissipating much higher heat from the components of the server. Some of its advantages include a high heat transfer coefficient, stable hydrodynamic flow, and the ability to directly cool hot components using the fluid.

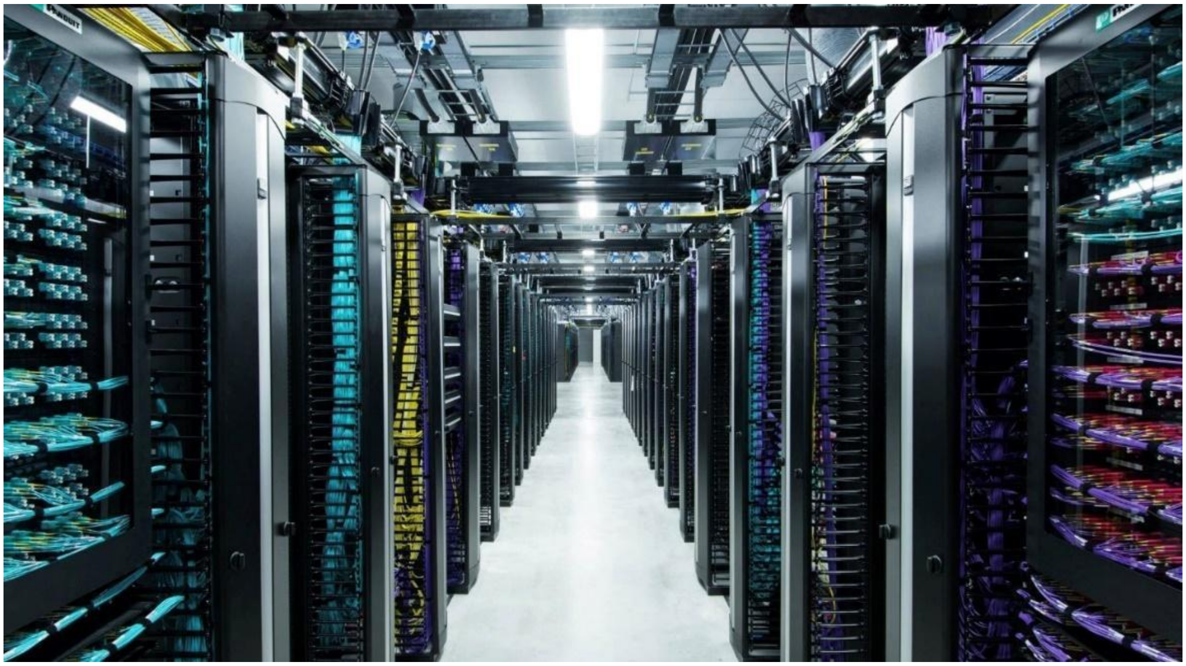

Figure 1.1: Typical Data Center Layout

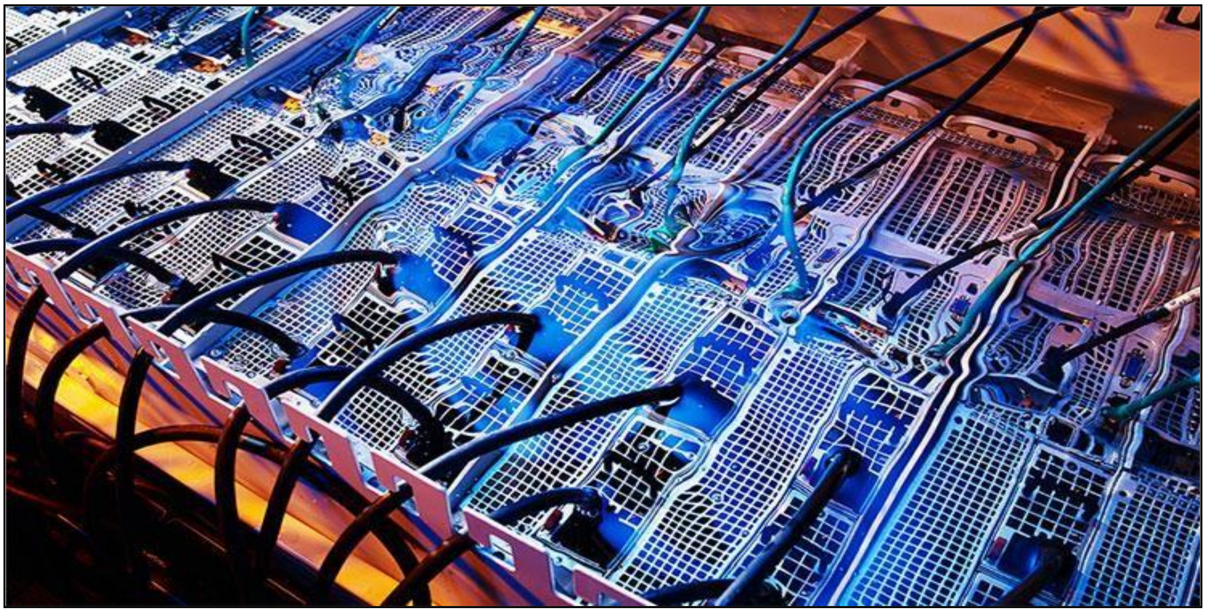

Figure 1.2 Typical Immersion Cooled Server

Over the years, Immersion Cooling has shown to be a reliable answer for high power requirements for a variety of uses. With CMOS technology developments, immersion cooling typically performs better than air cooling. Chip makers are currently increasing the number of transistors with the same chip area in order to compensate for the disappearance of Dennard's scaling and produce higher performance. Since fluids are a nearly 1200 times more efficient conductor of heat than air, they can disperse more heat than air, increasing the power density. Single-phase immersion cooling has a PUE of 1.03. Since there are fewer moving parts in immersion cooling than in air cooling, electricity consumption is significantly reduced. Additionally, system dependability rises as the number of moving parts is reduced. The main advantage that immersion cooling has over air cooling is that it allows us to enhance the data center's power density while still using the same amount of space. Fans used for air cooling adhere to a 20% power consumption limit. Immersion cooling is among the easiest types of cooling because it does not require parts like air handling systems, humidity controls, or fans. The IT components (servers) are sealed off from the external environment size and are submerged in dielectric immersion pods which decreases the reliability failure issues as seen in the contamination of air in air cooled data centers [12- 16].

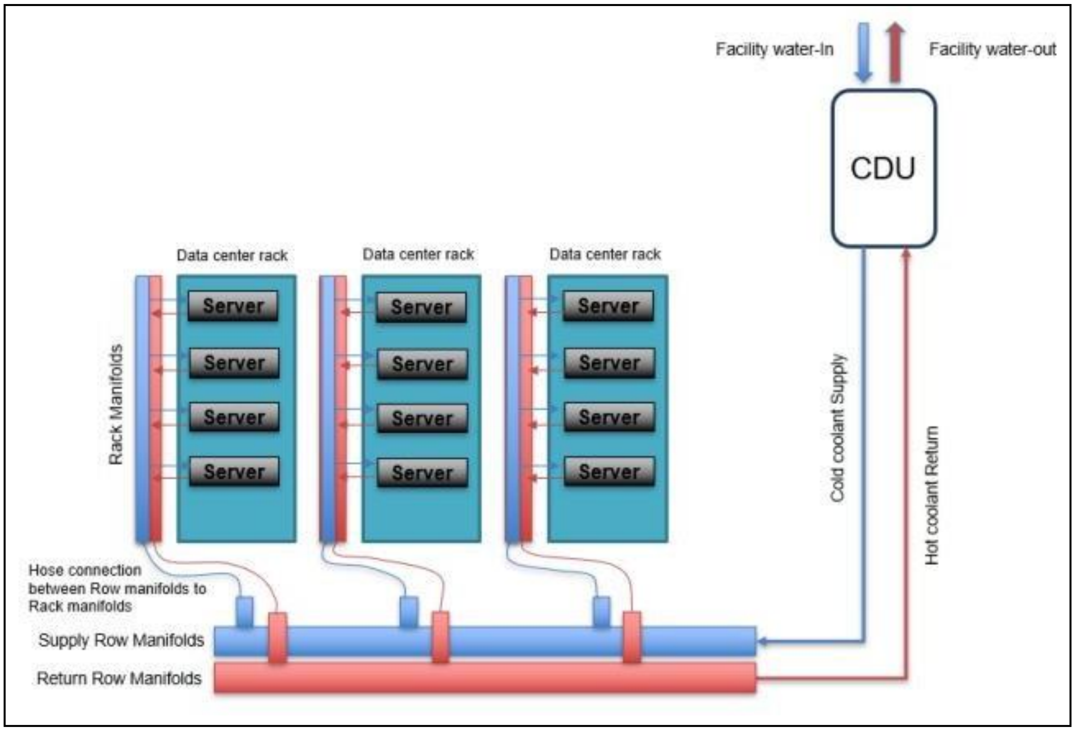

Figure 1.3 Schematic Diagram of Liquid Cooled Data Center

1.3 Thermal Management of Data centers

The equipment inside the Data Centers consumes a lot of power and thus dissipates a large amount. This requires the cooling of equipment to operate at optimum temperature. Shah et al. studied the reliability considerations for oil immersion-cooled data centers [17]. In order to achieve optimum temperature and cooling of these equipment, it is crucial to provide sufficient airflow. For optimum cooling and designing purposes of these data centers American Society of Heating, Refrigerating and Air-Conditioning Engineers. (ASHRAE) TC 9.9 [18] have developed standard guidelines to operate, design, maintain and run data centers at efficient energy consumption. ASRAE TC 9.9 has provided 4 inlet temperature zones as shown in figure 1.4.

Classes (a)	Equipment Environmental Specifications							
	Product Operations (b)(c)					Product Power Off (c) (d)		
	Dry-Bulb Temperature (˚C) (e) (g)	HumidityRange, non-Condensing (h) (i)	Maximum Dew Point (˚C)	Maximum Elevation (m)	Maximum Rate of Change(˚C/hr) (f)	Dry-Bulb Temperature (˚C)	Relative Humidity (%)	Maximum Dew Point (˚C)
Recommended (applies to all A classes, evaluate ITE metrics in this paper for conditions outside this range)								
A1 to A4	18 to 27	5.5ºC DP to 60% RH and 15ºC DP						
Allowable								
A1	15 to 32	20% to 80% RH	17	3050	5/20	5 to 45	8 to 80	27
A2	10 to 35	20% to 80% RH	21	3050	5/20	5 to 45	8 to 80	27
A3	5 to 40	-12˚C DP & 8% RH to 85% RH	24	3050	5/20	5 to 45	8 to 85	27
A4	5 to 45	-12˚C DP & 8% RH to 90% RH	24	3050	5/20	5 to 45	8 to 90	27
B	5 to 35	8% RH to 80% RH	28	3050	NA	5 to 45	8 to 80	29
C	5 to 40	8% RH to 80% RH	28	3050	NA	5 to 45	8 to 80	29

Figure 1.4: Summary of ASHRAE 2011 Thermal Guideline classes

1.4 Motivation

The infrastructure houses a number of components and servers. Tushar er al. studied the effect of thermal aging and thermal cycling on the thermal interface materials and found that thermal expansion decreased from approximately 2.5% to 1.2% and after 1000 thermal cycles delamination and major cracks were observed in samples [19]. Misrak et al. studied the impact of aging on mechanical properties of thermally conductive gap fillers [20]. Mugdha et al. performed reliability assessment of BGA Solder Joints on different Printed Circuit Boards and found that Megtron PCBs (Printed Circuit Boards) perform better than FR-4 which is a major component electronic equipment [21]. Rahangdale et al. performed solder ball reliability assessment of WLCSP — Power cycling versus thermal cycling [18, 19]. It is observed in numerous studies that a small percentage increase in cooling performance at server level can have a large- scale improvement on cooling of the whole data center. An energy logic model by Emerson Network Power, reported that one watt of power saved at the server level extrapolated to as much as 2.84 watts at the facility level [22]. In this study we will be focusing on the improvement of the cooling capability of the server by improving the server design by attaching the cold plates to immersion cooled hybrid servers. The main objective of the study is to study the chassis level structural modifications to convert an air-cooled server to immersion environment and study the effects of air and immersion fluid as the medium of heat transfer at server level. This work involves Numerical analysis and thermal analysis of high heat generation components and associated components like DIMMs (Dual Inline Memory Module) (Dual Inline Memory Module) and Chipsets and establish that Immersion Hybrid cooling has better impact on all component temperatures while keeping power consumption minimum compared to air hybrid cooling.

CHAPTER 2
SERVER UNDER STUDY

2.1 Server Description

The system considered for study is Cisco M220 M3 rack server designed for performance and density over a wide range of business workloads from web serving to distributed database. The data server has a 1U form factor with height 1.75in, width 16.92 and depth of 28.5in. The server consists of two CPUs of Intel Xeon E5-M2600 vs ME5-2600 processor with a thermal design power (TDP) of 135 Watts. It has 16 DIMMs, up to 8 drives and 2 x 1 GbE LAN-on-motherboard (LOM) ports delivering outstanding levels of density and performance in a compact 1U package.

Figure 2.1: Front view and Rear view of Cisco M220 [3]

The below table and figure show a schematic representation of the components and their location inside the server.

1	Drives (hot-swappable, accessed through front panel)	10	Trusted platform module socket on motherboard
2	Drive backplane	11	Standard-profile PCIe riser (PCIe slot 1)
3	Super Cap backup unit mounting location	12	Low-profile PCIe riser (PCIe slot 2)
4	Cooling fans (five)	13	Cisco Flexible Flash SD socket SD2 on PCIe riser 2
5	SCU upgrade ROM header (RAID key)	14	Cisco Flexible Flash SD socket SD1 on PCIe riser 2
6	DIMM (Dual Inline Memory Module) slots on motherboard (16)	15	Internal USB port
7	CPUs and Heatsinks (two)	16	Power supplies (two, hot-swappable access through rear panel)

8	Integrated RAID on motherboard, and mini-SAS connectors	17	RTC battery on motherboard
9	Mezzanine RAID card, mini-SAS connectors SAS1 and SAS2	18	Software RAID 5 header (RAID key)

Table 2.1: Component location in Schematic Representation

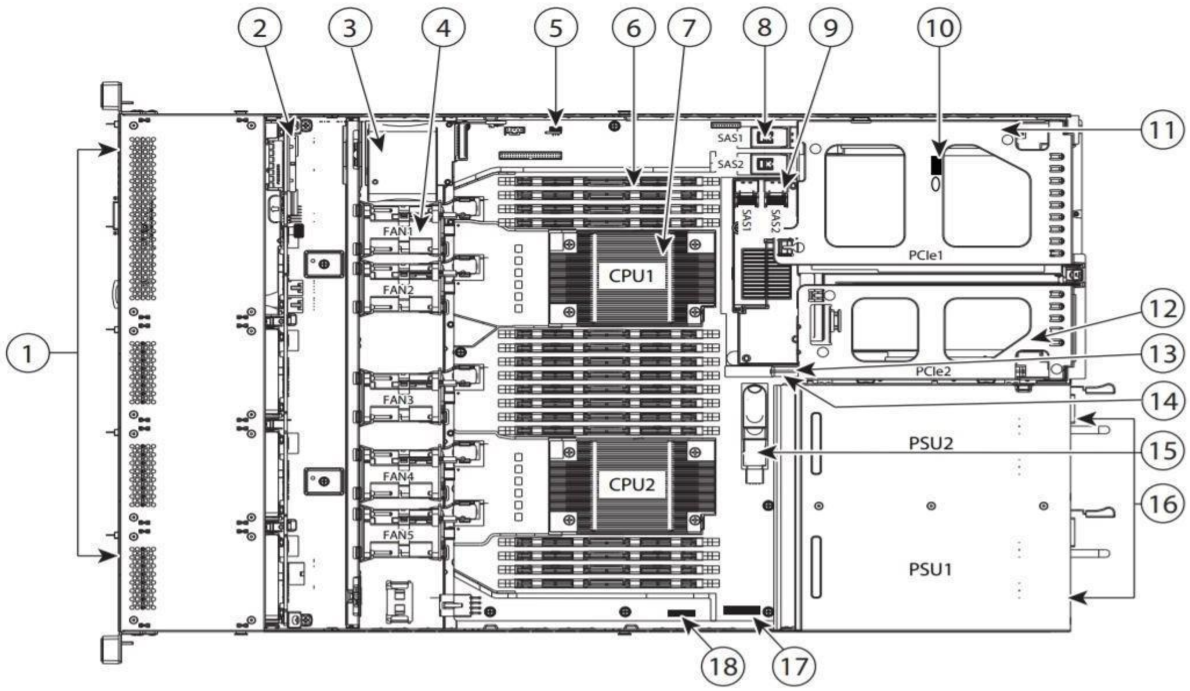

Figure 2.2: Schematic Representation of server [3]

The server is usually provided with five fans but to change the air-cooled hybrid environment to immersion cooled environment the fans were uninstalled. The CPUs in an immersion cooled environment were provided with cold plates. In immersion cooling the electronic components, servers, storage devices are completely submerged in a thermally conductive dielectric fluid and the Heat is removed through natural and forced convection from the components in the server. The schematic diagram of the Immersion cooled server is shown in figure 2.3

Figure 2.3: Immersion cooled server with cold plates

Immersion cooled systems use optimized heat sinks to dissipate heat from high power consuming components such as CPUs and GPUs based on the fluids. The rise in power density over the years, heat sinks do not satisfy the relative power dissipation from the electronics as well as the desired form factor of the servers. Associated components such as DIMMs, HDDs and other chipsets like Platform Control Hub (PCH) consume proportionally higher power which poses a challenge for air cooling systems to work efficiently. Hence, the server is modified by adding cold plates to the immersion cooled server and a thermal analysis is made to compare between air cooled and immersion cooled server.

CHAPTER 3

COMPUTATIONAL FLUID DYNAMICS (CFD) ANALYSIS

3.1 Detailed Model of the Baseline Model

This chapter showcases the CFD model and mesh sensitivity analysis to calibrate it. It is important to calibrate the CFD model to get accurate results. A detailed CFD model of the server is shown in figure 3.1. The CFD model contains all the heat generating and flow impeding components including CPUs, DIMMs, Chipsets and cold plates. A computational model was set up using commercially available software, 6SigmaET - Cadence. For the baseline study, an air-cooled hybrid server was modeled to compare with an immersion cooled hybrid server. A commercially available synthetic dielectric fluid EC-100 compatible for immersion cooling was used as the coolant; it has good heat transfer properties with no/minimal risk of corrosion. A water-based coolant, PG25 (25% Propylene Glycol in water) was used for the cold plate as the heat transfer medium. Thermal analysis and comparison were done on % heat transfer and cooling capability for both cases. Numerical inverse analysis is used to predict properties of heat generating material by measuring temperature at outer boundary. Accuracy and efficiency of the method is enhanced by using accurate sensitivity information by use of Semi-Analytical Complex Variable Method (CVSAM). Sensitivity information is beneficial in determining reliability of the system like ball grid array package. In addition, machine learning can be used to predict temperature of heat generating bodies [1-5]

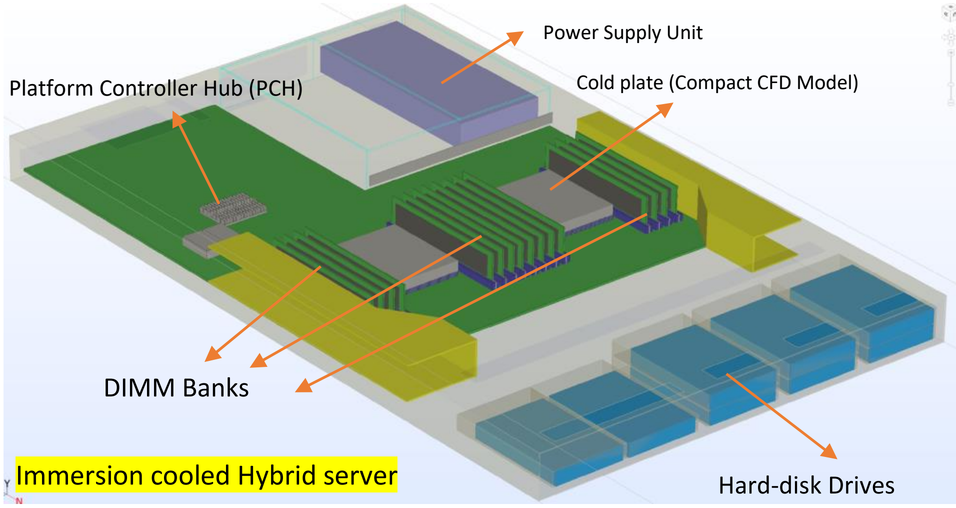

Figure 3.1: Isometric View of CFD Model of Immersion Hybrid cooled server

The thermal design power (TDP) of heat generating components inside the server are shown in table 3.1

Components	Quantity	Values
CPU	2	115W
DIMMs	16	4W
Hard Disk	8	1.5W
Platform Controller Hub (PCH)	1	7W

Table 3.1: Thermal Design Power of the component

3.2 Synthetic Fluid EC- 100

A commercially available synthetic dielectric fluid EC-100 compatible for immersion cooling was used as the coolant. EC-100 fluid properties are shown in table 3.2. For this study we used Electro Cool 100, a dielectric synthetic fluid from Engineered Fluids. The major reason to use EC – 100 was that model validation could be done since the experimental test on the server was performed using EC – 100 [14]. Also, the fluid is suitable for general electronics cooling, has excellent material compatibility, high dielectric strength, good heat transfer and is biodegradable.

EC100				
Temperature	Dynamic Viscosity	Density	Thermal conductivity	Specific Heat
ºC	Kg/m-sec	Kg/m^3	W/m/K	KJ/kg-K
20	0.02193	845.86	0.1389	2.1317
25	0.01763	842.56	0.13853	2.1499
30	0.01439	839.26	0.13815	2.1683
35	0.01191	835.96	0.13778	2.1868
40	0.00998	832.66	0.1374	2.209
45	0.00847	828.7	0.13703	2.2243
50	0.00725	826.06	0.13665	2.2433

Table 3.2: EC-100 fluid properties

3.3 Water Based Coolant PG25 (25% Propylene Glycol in water)

A water-based coolant, PG25 (25% Propylene Glycol in water) was used for the cold plate as the heat transfer medium. PG-25 fluid properties are given in table 3.3. In order to suit your application, Dynalene Propylene Glycol mixes can be made with USP (food grade) propylene glycol or premium industrial grade (PGI) propylene glycol. There are several applications for corrosion inhibitors, including those for common metals like carbon steel, cast iron, copper, brass, and stainless steel. For aluminum exposed to temperatures above 50ºC, a specific formulation (PG-A1) is advised.

PG25				
Temperature	Dynamic Viscosity	Density	Thermal conductivity	Specific Heat
ºC	mPa s	Kg/m^3	W/m K	KJ/Kg K
20	2.54	1024.85	0.457	3.9105
25	2.155	1022.65	0.4625	3.9225
30	1.855	1020.4	0.4675	3.9345
35	1.61	1017.95	0.4725	3.947
40	1.405	1015.45	0.4775	3.9595
45	1.245	1012.8	0.481	3.972
50	1.105	1009.95	0.4855	3.984

Table 3.3: PG-25 Fluid properties

3.4 Mesh Sensitivity Analysis

Mesh Sensitivity analysis is performed to ensure that the model is independent of the grid count. Since the system resistance is done with turning the fans off, sensitivity analysis is also done keeping the fans turned off. The analysis is done at different grid counts keeping the inlet flow rate constant. The grid count considered are 17, 27, 46 and at 57 million grid counts with the inlet flow rate at 35 CFM and 25C temperature and keeping the rear end open to the environment.

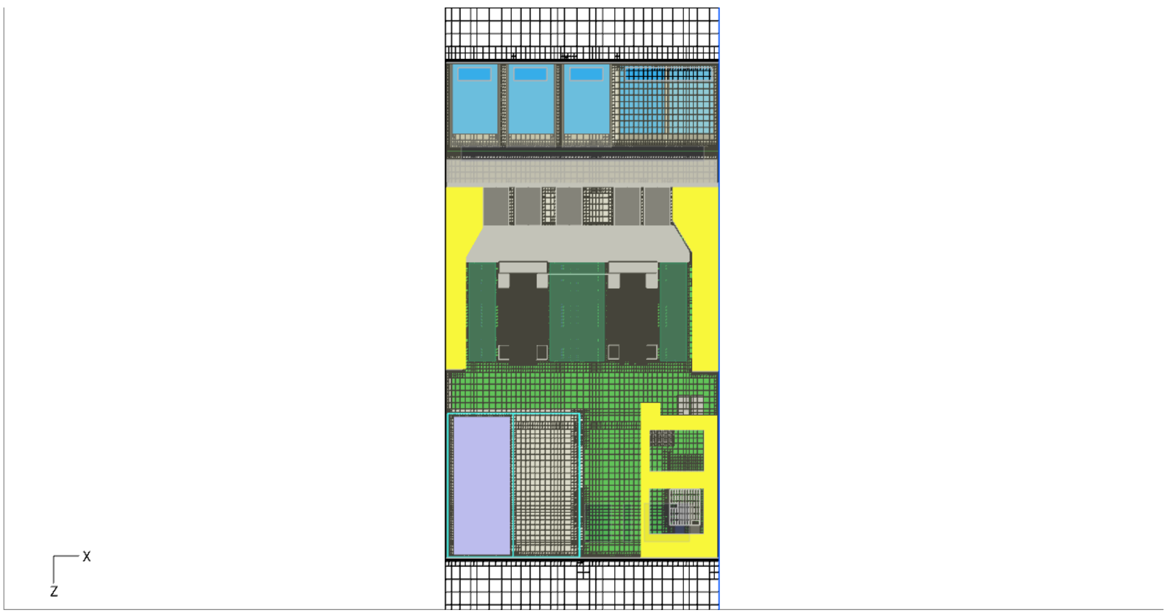

Figure 3.2: Model with 17M Grid Count

3.5 Computational Model Validation of Hybrid cooled server

Computational model is validated with an already existing experimental setup.

3.5.1 Model Validation

Experimental study of third generation open compute servers for single-phase immersion cooling was performed by previous master's student Trevor McWilliams [26]. The computational model server was validated by performing simulation for fluid inlet temperatures of 25ºC 35ºC and 45ºC at 115 W of TDP (100% use) at various flow rates and comparing their average junction temperatures. Figures 3.3,3.4 and 3.5 show the CFD model validation

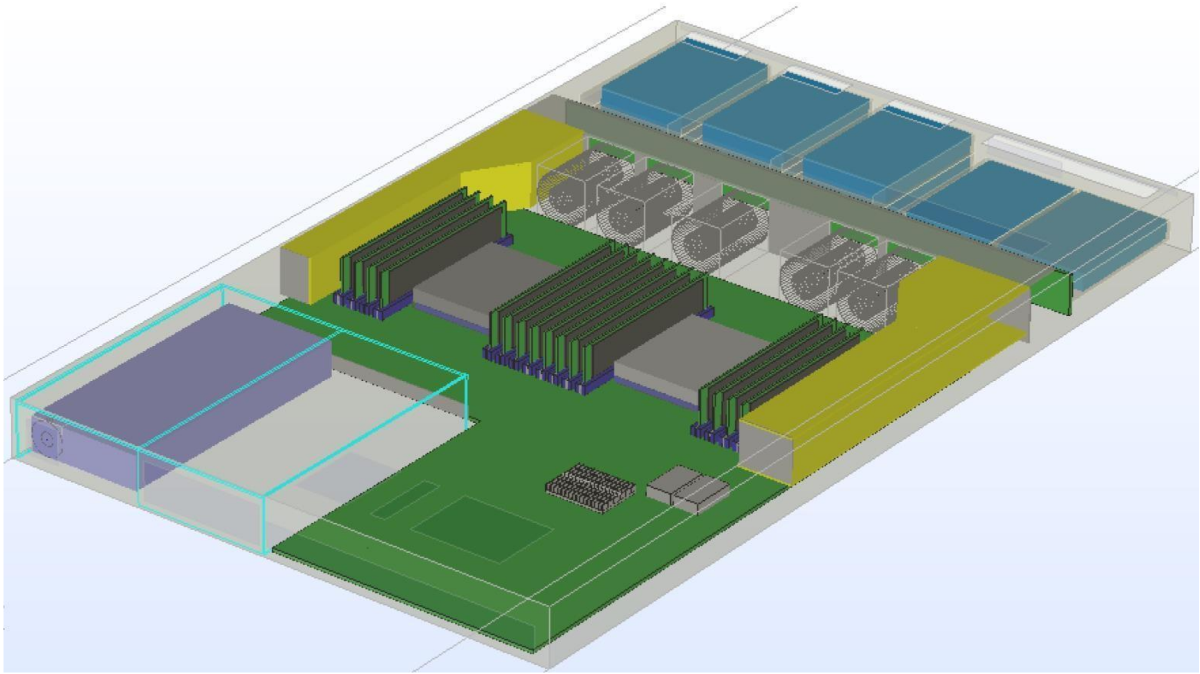

Figure 3.3: Schematic Diagram of the server used for validation

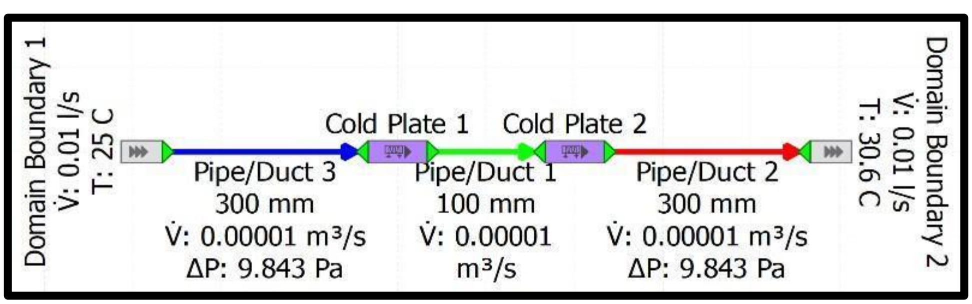

Figure 3.4: Validated of the CFD model with Flow network

		Experimental	*CFD*
		Air & coolant inlet temp 25°C	
Coolant flowrate	Air flowrate (CFM)	80	80
0.4 lpm	CPU1 exit Temp (°C)	28.37	29.1
	CPU2 exit Temp(°C)	30.77	31.4
	Avg. air exit Temp (°C)	27.6	27.87
0.6 lpm	CPU1 exit Temp (°C)	28.16	27.8
	CPU2 exit Temp (°C)	29.84	30.5
	Avg. air exit Temp (°C)	28.4	27.81

Figure 3.5 Validated values for the CFD Model

3.5.2 Cold plate thermal and flow resistance (Experimental)

As discussed above the fluid used in the cold plate is PG-25, Pressure drop across the cold plate was measured experimentally using calibrated pressure sensors and Thermal Resistance at various coolant inlet temperatures are calculated using the formula given below, Figures 3.6 and 3.7 show the thermal and flow resistant curves.

Thermal Resistance at various coolant inlet temperatures:

$Thermal\ Resistance\ (Rth)$ = (CPU surface temperature – Coolant Inlet temperature)/CPU Power or

Thermal Resistance = (Junction Temperature – Inlet Fluid Temperature) / Heat Dissipation

Thermal Resistance = (Tj – Ta) (ºC) / Power (W)

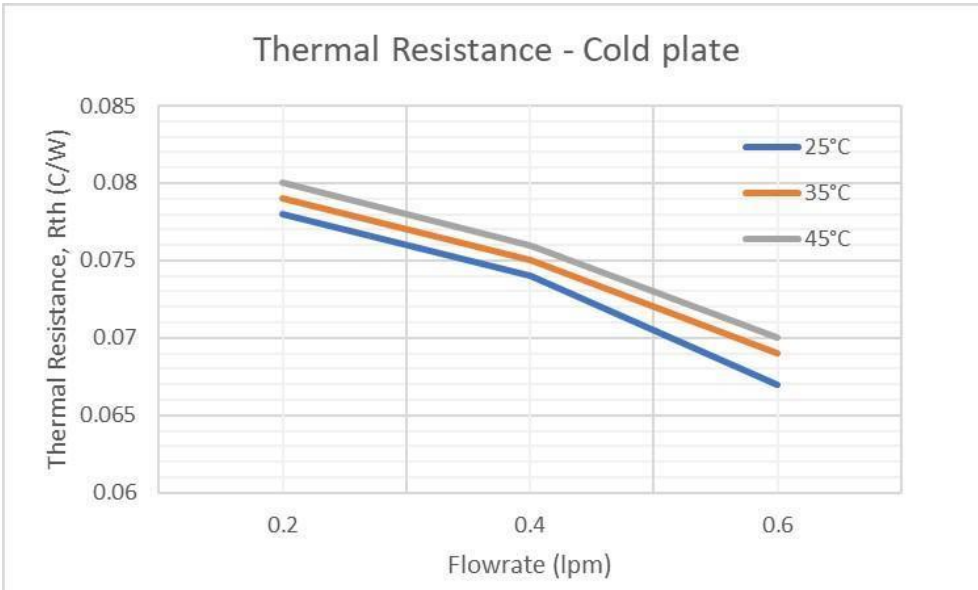

Figure 3.6: Thermal Resistance curve

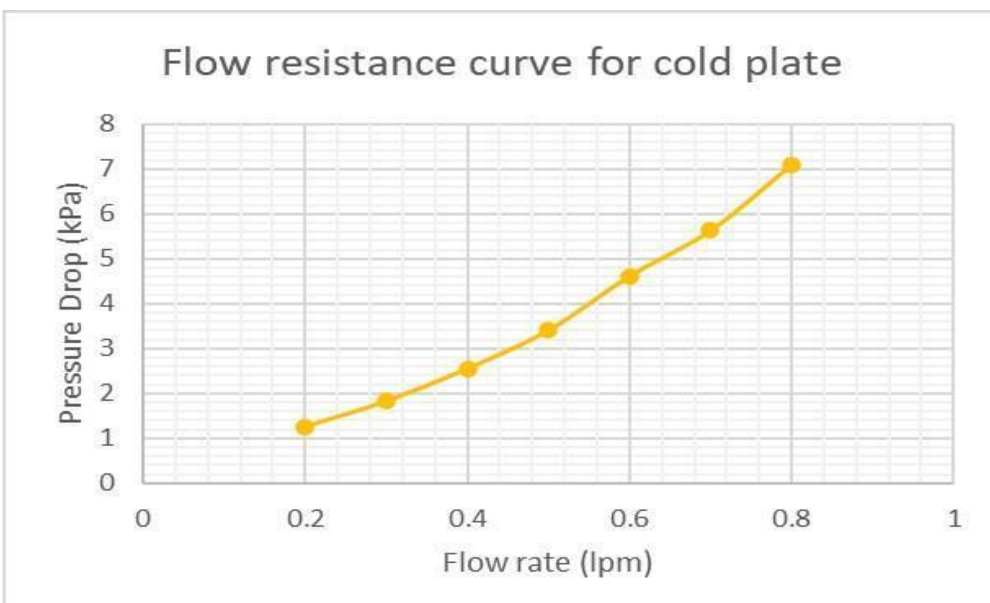

Figure 3.7: Flow Resistance Curve

CHAPTER 4

TEST CASES AND MODIFICATIONS

4.1 Test Cases

Several test cases were run at different flow rates at different environments and with component modifications to do a comparison study to determine the cooling capability at component level such as CPU, PCH and DIMMs.

4.1.1 Air Hybrid Cooling Model

Simulations were run with different air inlet temperatures at fixed flow rates and the environment has forced convection heat transfer. Later calculations were carried out to determine CPU, PCH and DIMM cooling capability.

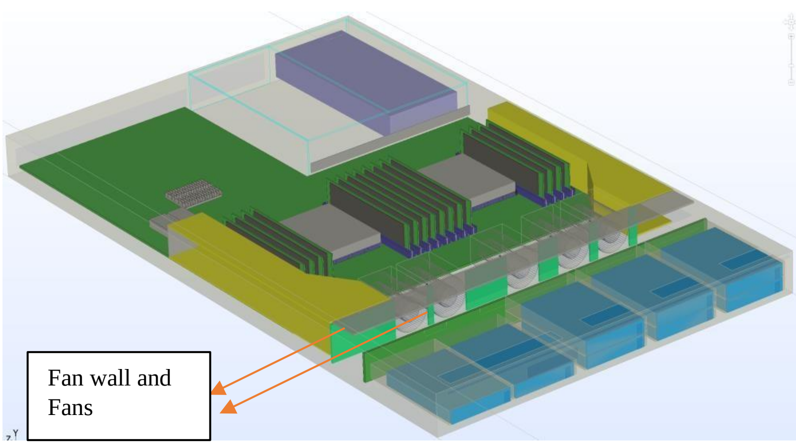

Figure 4.1 Air hybrid cooling model

This test case has a cold plate installed on the CPU, Fan and Fan case installed while running the simulations. There are five fans installed and each Fan power was set to 25W/fan. The server is placed Horizontally hence, the gravity is acting in negative Y direction.

4.1.2 Immersion Hybrid Cooling model

In this case the fans and fan wall were uninstalled to change the environment from air cooled server to Immersion cooled server Simulations were run with EC100 at different temperatures like 25ºC, 35ºC, 45ºC in a natural convection environment. The cold plates were installed on both the CPUs which had varying temperatures 25ºC, 35ºC, 45ºC at fixed flow rate at 0.5 LPM and forced convection heat transfer.

Later the percentage convection happening at cold plate in immersion cooled server is compared to air cooled server for conducting a comparison study and calculations were made to evaluate the cooling capability at CPU, PCH and DIMMs.

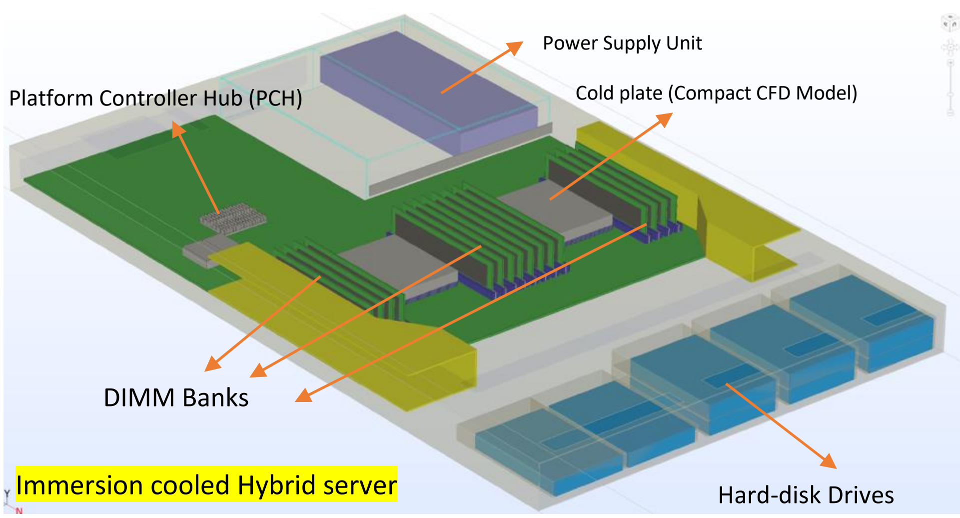

Figure 4.2: Immersion cooled hybrid server

The server is placed in vertical direction hence the gravity is acting in negative Z direction which enhances natural convection for immersion cooling.

4.1.3 Immersion with heat sink sever (Typical)

Usually, a typical Immersion cooled server has heatsink installed in them, to do a comparison study the previously installed cold plates were uninstalled and heat sinks are installed on the CPUs in this model and has a complete natural convection heat transfer in the server. The server is analyzed for natural convection and the heatsink is optimized for natural convection. The boundary condition for natural convection is as follows; the inlet and outlet of the server are set as openings. There is no volumetric flow rate set since this is a case of natural convection. The flow is gravity/buoyancy based. The fluid temperature is set at 25^{o},35^{o}C and 45^{o}. The TDP for each CPU is set at 115 W. Gravity is acting in the negative Z direction.

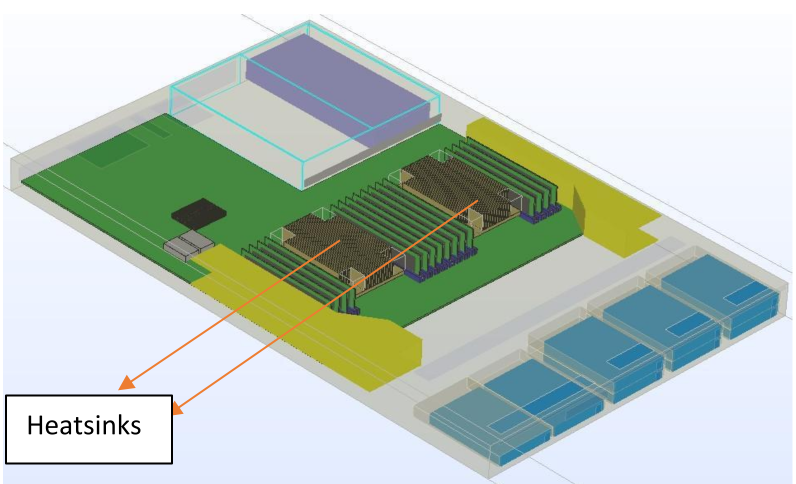

Figure 4.3: Immersion with heatsinks installed

A comparison study with air cooled and Immersion cooled with cold plates is made and calculations are done to evaluate the cooling capability at CPU, PCH and DIMMs.

4.1.4 Chassis and server component modifications

As discussed above fan and fan wall are removed or uninstalled in immersion cooled hybrid server, the size of vent openings was changed and placed on both front and back of the server.

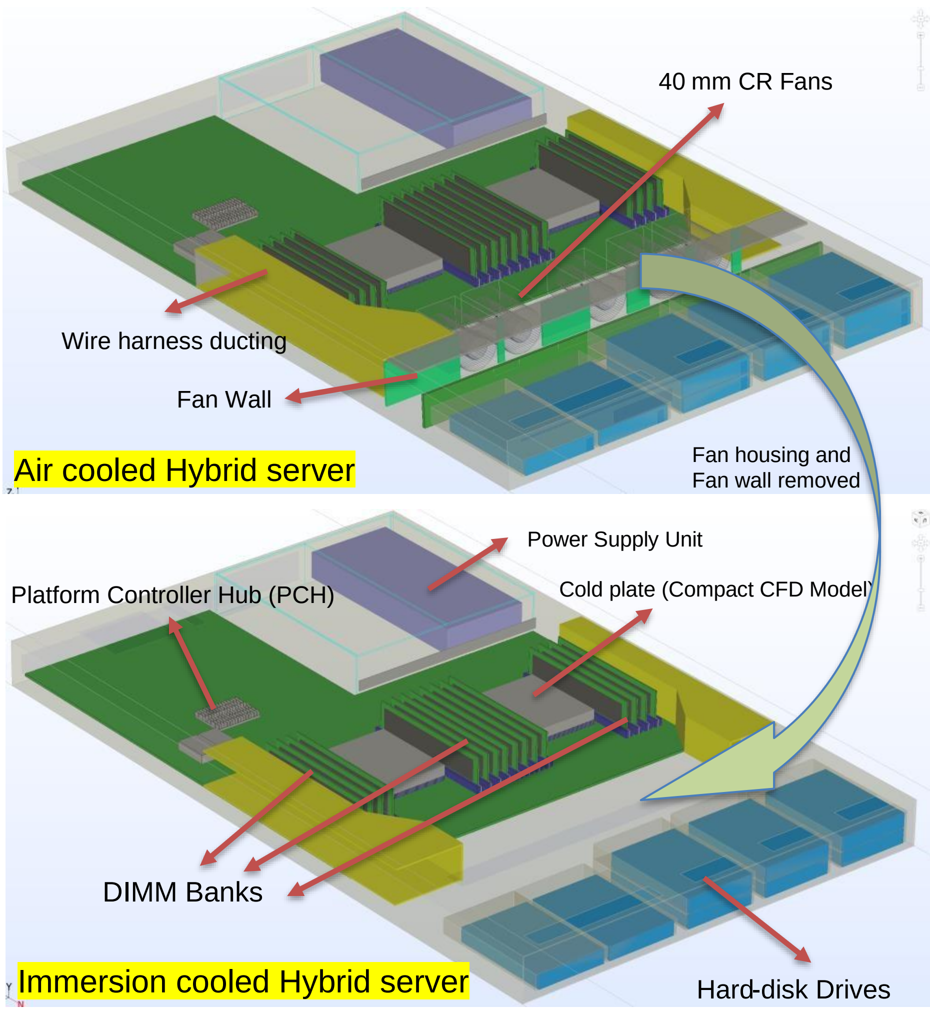

Figure 4.4: Chassis and components modified server

4.2 Boundary Conditions

Simulations were run in sets of 3 keeping the air inlet temperature constant and varying cold plate coolant inlet temperature, air flow rate across the servers were kept constant and maximum speed throughout all tests. The coolant flow rate used for cold plates is also fixed at 0.5 LPM throughout all the various test cases.

Parameters	**Values**
Air Inlet Temperature	25ºC, 35ºC, 45ºC
Air Flow Rate	80 CFM (max.)
PG-25 Inlet Temperature	25ºC, 35ºC, 45ºC
Cold Plate liquid Flow Rate	0.5 lpm (fixed)
EC100 Immersion Inlet Temperature	25ºC, 35ºC, 45ºC

Table 4.1: Boundary conditions for all test cases

4.3 Flow Pattern

Various flow patterns are observed as shown below for Air hybrid cooling and Immersion Hybrid Cooling when set to different inlet temperatures and fixed boundary conditions.

4.3.1 Air Hybrid Cooling

As discussed in test cases the Air flow is set to max fan speed which is 25W per fan (total 5 fans), the server is placed horizontally hence the gravity is acting in negative Y direction.

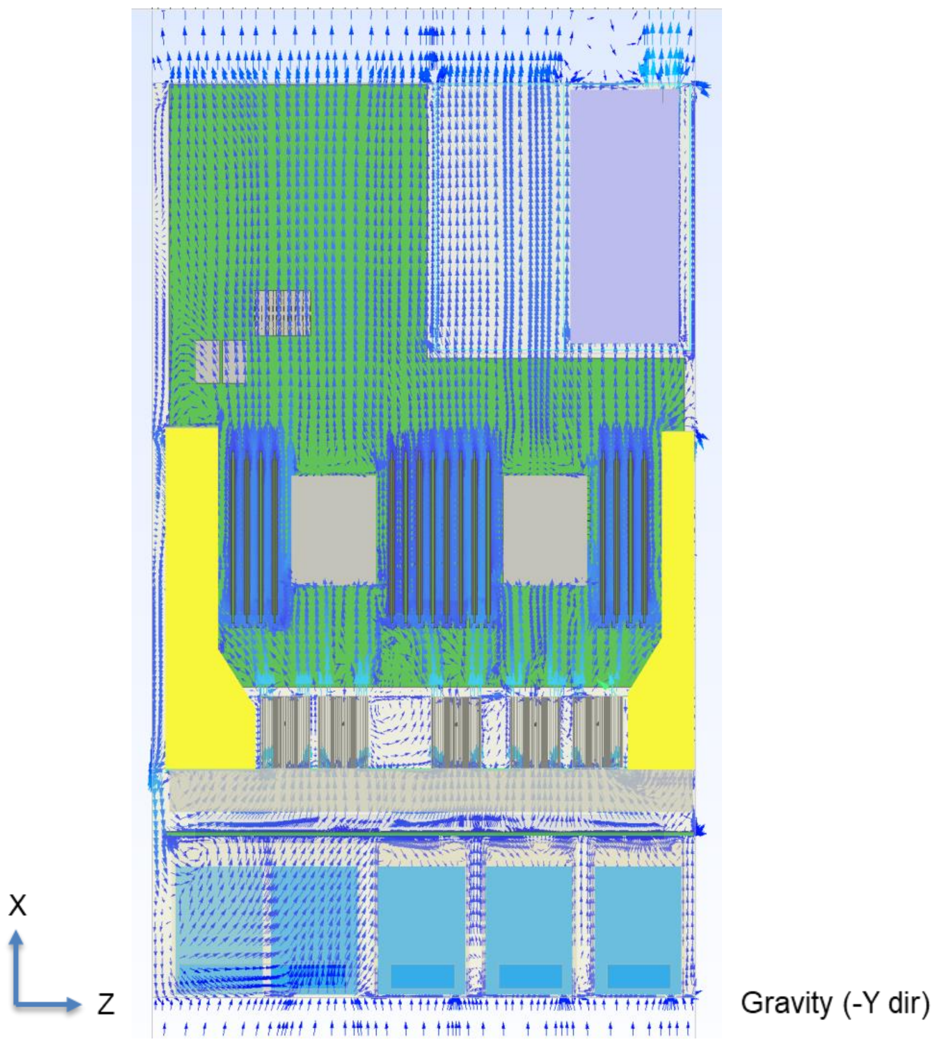

Figure 4.5 Air hybrid cooling flow pattern

In Air hybrid cooling there is forced convection heat transfer.

4.3.2 Immersion hybrid cooling

As discussed in test conditions the immersion fluid which in our case is EC100 is maintained at set temperatures in the tank to provide the set approach temperatures. The flow pattern observed was a natural convection heat transfer and the gravity is acting in negative Z direction as the server is placed vertically.

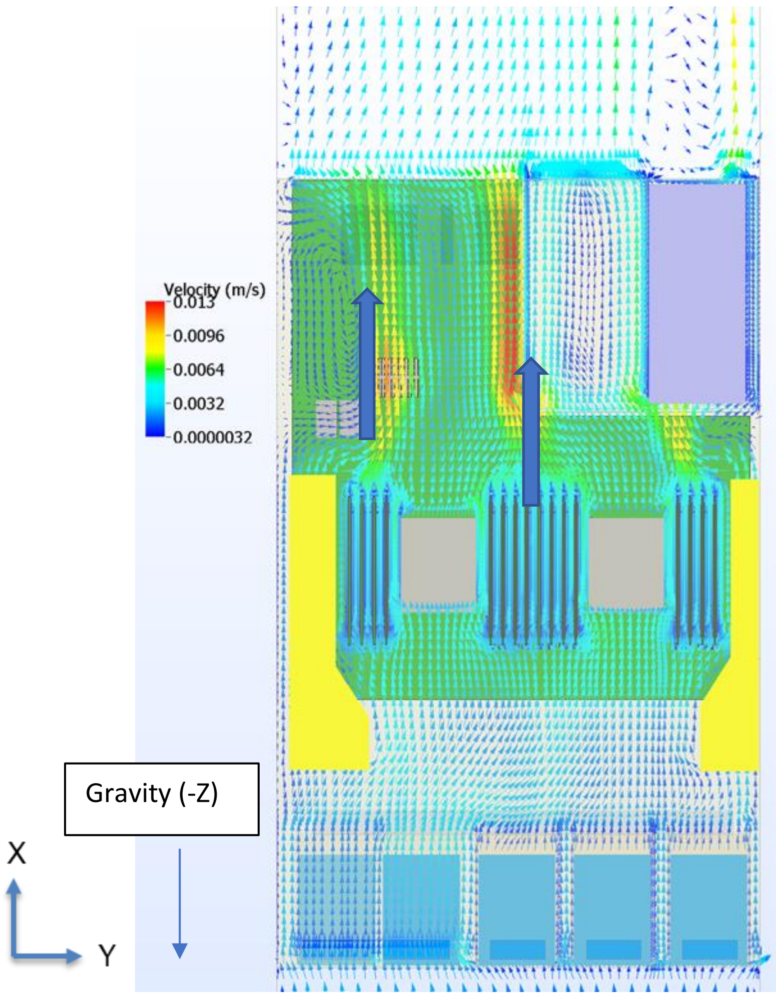

Figure 4.6 Immersion hybrid cooling flow pattern

Chapter 5

Results and Observations

5.1 Mesh Sensitivity Analysis

In order to make sure that the model is grid independent to achieve accurate results, it is necessary to do mesh sensitivity analysis. The simulations have been carried out at different grid counts keeping the inlet temperature fixed at 25°C and flow rate fixed at 35 CFM and the model is grid independent at 27 million grid count.

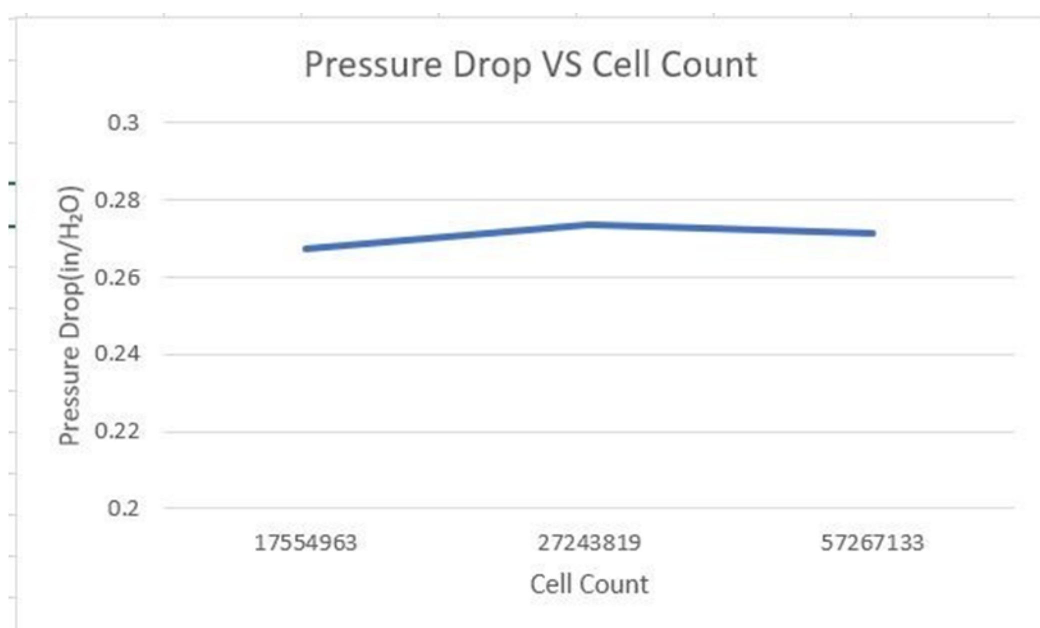

Figure 5.1: Grid Independence of study of static pressure

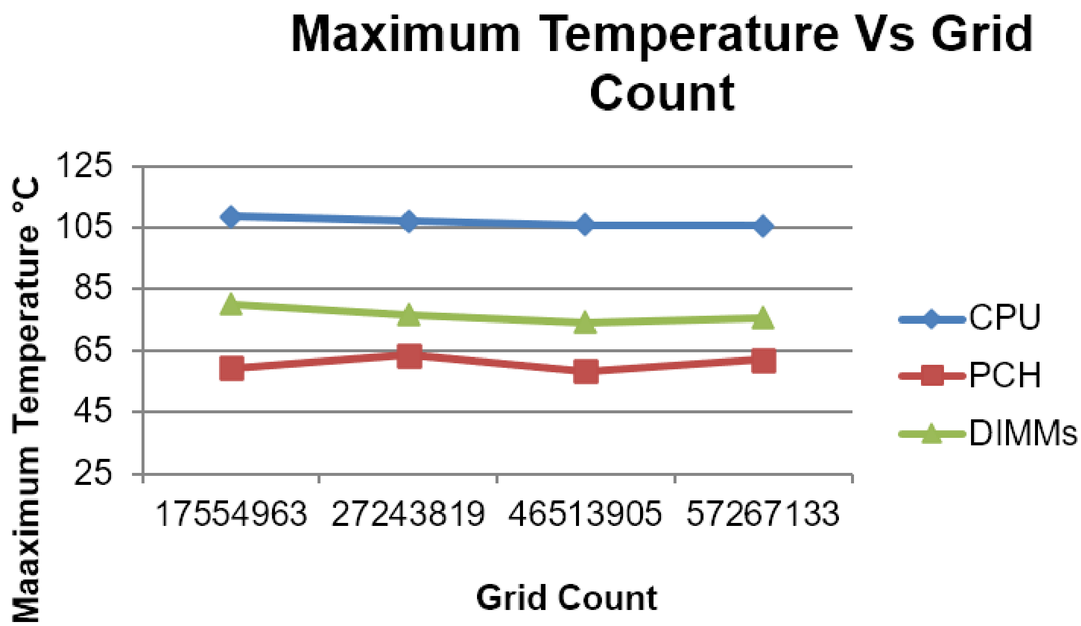

Figure 5.2: Grid Independence study of Component Temperature

5.2 System Resistance Curve

The pump head needed to convey fluid through a piping system at various flow rates is represented graphically by a system curve, as seen in Figure 5.3. The system curve aids in determining how much resistance there is in a system as a result of friction and elevation change for various flows. The system resistance curve of the new design is compared with the baseline model to see if there is increase or decrease in resistance. Adjusting the flow rate (intersection point) across the system can be done in one of the following ways: putting in a control valve that raises the pipeline's resistance. Changing the pump speed changes the pump curve's form.

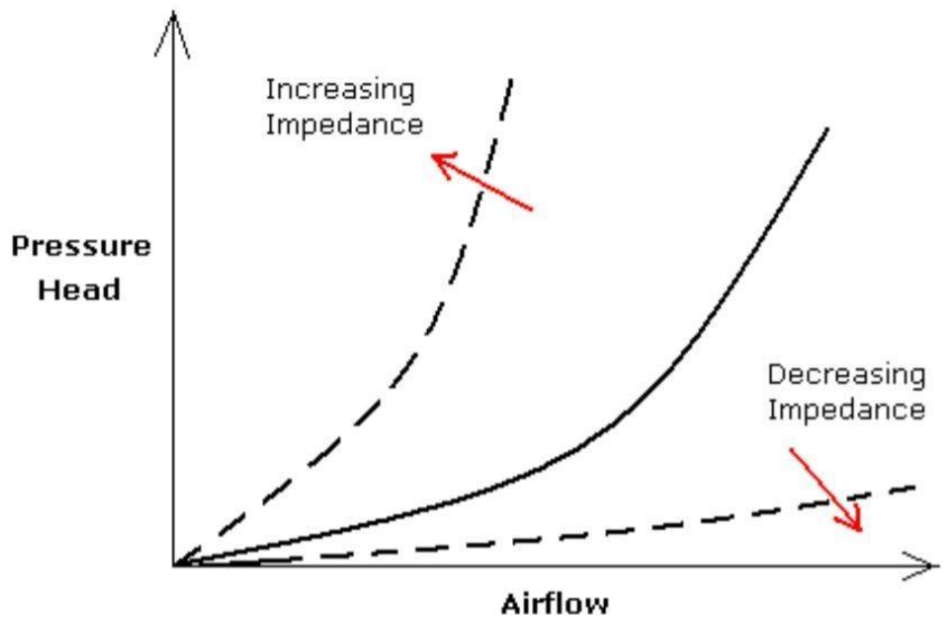

Figure 5.3: General representation of system resistance curve

It can be seen that the improved design helps in reducing the system resistance as the pressure drop is decreasing with increasing flow rate.

5.3 Observations in Temperatures

A comparison was made between the observed temperatures for all the components such as PCH, DIMMs, CPUs at both Air environment and Immersion environments to see how the temperature is varying.

5.3.1 Observation in PCH Temperature

An observation was made in PCH Temperature for Both air and immersion environment and the results showed that in Air environment the PCH temperatures are high when compared to immersion fluid environment. Even when there is a change in cold plate inlet temperature the PCH temperature remains consistent in the Immersion fluid environment, whereas in the Air environment we see at least a 1° or 2°C difference in temperature.

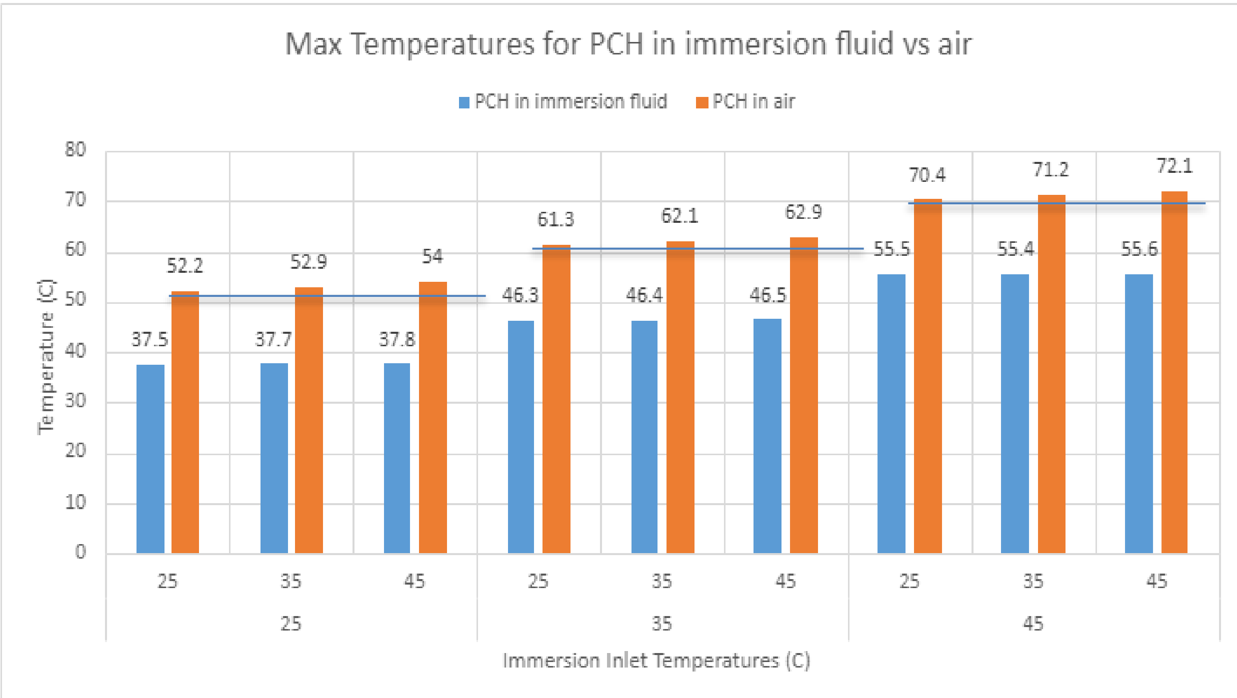

Figure 5.4: Comparison between Max Temperature for PCH in Immersion fluid vs air

5.3.2 Observations in DIMM Temperature

An observation was made in DIMM Temperature for both air and immersion environment and the results showed that in Air environment the DIMM temperatures are high when compared to immersion fluid environment. Even when there is a change in cold plate inlet temperature the DIMM temperature remains consistent in the Immersion fluid environment, whereas in Air environment we see at least a 1°C difference in temperature.

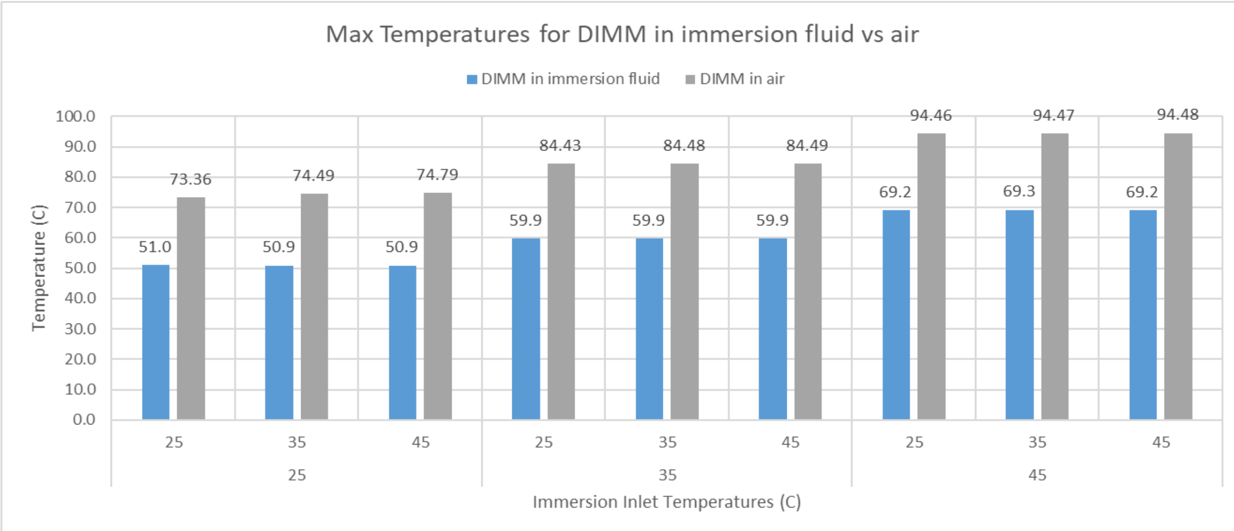

Figure 5.5: *Comparison between Max Temperature for DIMMs in Immersion fluid vs air*

5.3.3 Observations in CPU Temperature

An observation was made in CPU Temperature for both air and immersion environment and since we are using cold plates in both the environments, we see increase in CPU temperatures in both the cases based on cold plate inlet temperature (proportionally), but there is a slight temperature drop of about 3°C to 4°C at the CPUs in case of immersion environment since % of convection at the cold plate surface is higher compared to air.

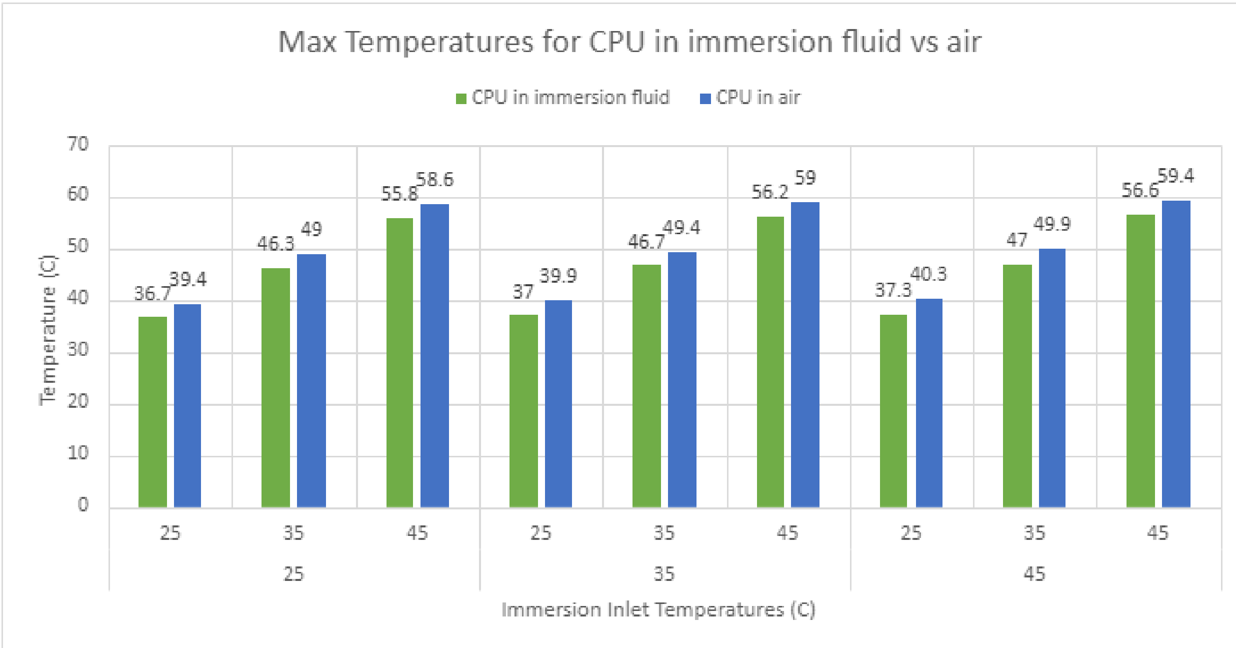

Figure 5.6 Comparison between Max Temperature for CPU in Immersion fluid vs air

5.4 Cooling Capability Calculations

To maintain computer components within acceptable working temperature ranges, computer cooling is necessary to remove the waste heat generated by the components. Overheating can cause integrated circuits including central processing units (CPUs), chipsets, graphics cards, and hard disk drives to temporarily malfunction or permanently die. Upon calculating the thermal resistance based on results from the simulation and calculating the cooling capability based on throttling temperature of the component we have made a trend prediction.

Calculations used:

- $Thermal\ Resistance$

$$\frac{(T\_component - T\_inlet)}{Q\_heat\ dissipation\ or\ power}$$

➤ *Cooling Capability* (Q)

$$\frac{(T_{throttle temperature} - T_{inlet fluid\ temperature})}{Thermal\ resistance\ (Rth)}$$

Immersion tank model				
Immersion tank Temperature (°C)	Cold plate inlet temp (°C)	CPU temp (°C)	PCH temperature (°C)	DIMM temperature (°C)
25	25	36.7	37.5	51.0
	35	46.3	37.7	50.9
	45	55.8	37.8	50.9
35	25	37	46.3	59.9
	35	46.7	46.4	59.9
	45	56.2	46.5	59.9
45	25	37.3	55.5	69.2
	35	47	55.4	69.3
	45	56.6	55.6	69.2

Table 5.1 Temperature values of the components in immersion environment

Components	Thermal Throttling Limit (°C)
CPU	~ 90 - 100
PCH	~ 70 - 80
DIMM	~ 80 - 90

Table 5.2 Thermal Throttling limit of the components

5.5 Cooling capability Predictions

	Cooling Capability using in immersion hybrid set up			Cooling Capability using in Air-hybrid set up			Cooling Capability in Immersion with heat sink		
Immersion tank temp (°C)	PCH Power (W)	DIMM Power (W)	CPU Power (W)	PCH Power (W)	DIMM Power (W)	CPU Power (W)	PCH Power (W)	DIMM Power (W)	CPU Power (W)
25	27.6	9.3	688.0 610.6 532.4	12.5	4.9	559.0 492.9 422.8	46.1	13.6	347.4
35	24.6	8.0	670.8 589.7 513.4	10.3	4.1	540.3 479.2 410.7	32.2	9.7	291.0
45	20.0	6.6	654.5 575 495.7	8.0	3.2	526.1 463.1 399.3	17.5	7.5	241.0

25°C cold plate inlet
35°C cold plate inlet
45°C cold plate inlet

Table 5.3 Cooling capability predictions for all the components in all the test cases

There are certain limitations for these predictions made above:

- The form factor of the server must be same
- The cold plate thermal resistance and pressure drop are not considered

Hence these predictions can be followed as trends for further calculations.

From the above calculations made we predicted the amount of cooling/power consumption that can be provided to the components for the same form factor for the same fluid properties, it is observed that for all the components the immersion cooling environment has the best cooling capability prediction values when compared to air cooling environment for all the components.

5.5.1 Cooling Capability Prediction visual representation for all the components

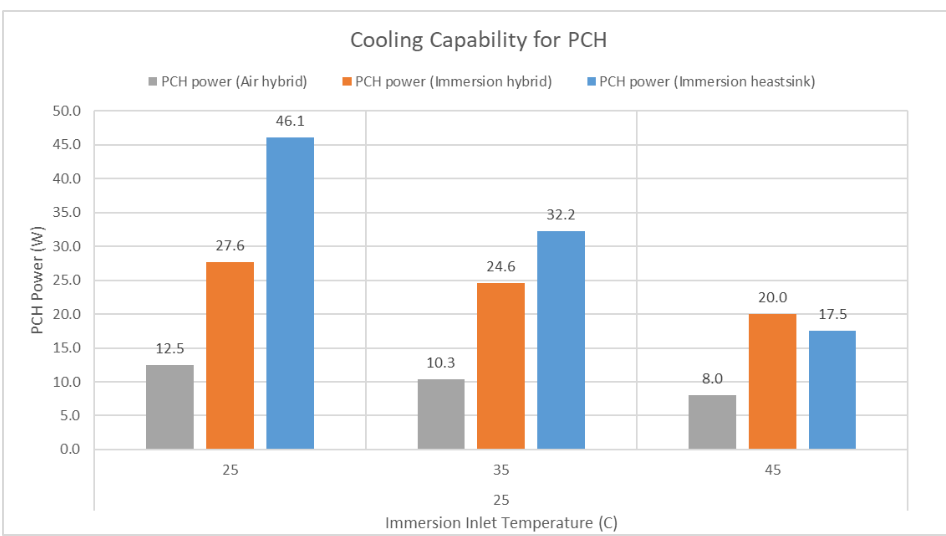

Figure 5.7 Visual representation of cooling capability for PCH in all the test cases

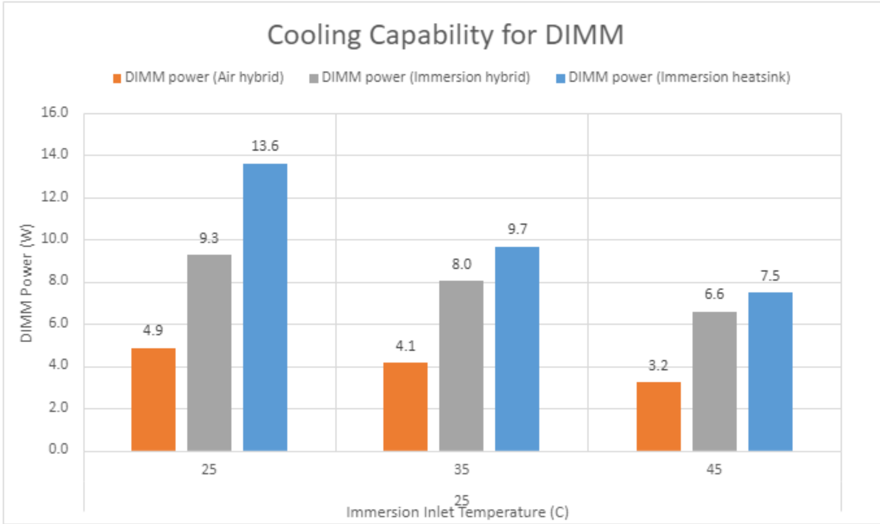

Figure 5.8 Visual representation of cooling capability for DIMMs in all the test cases

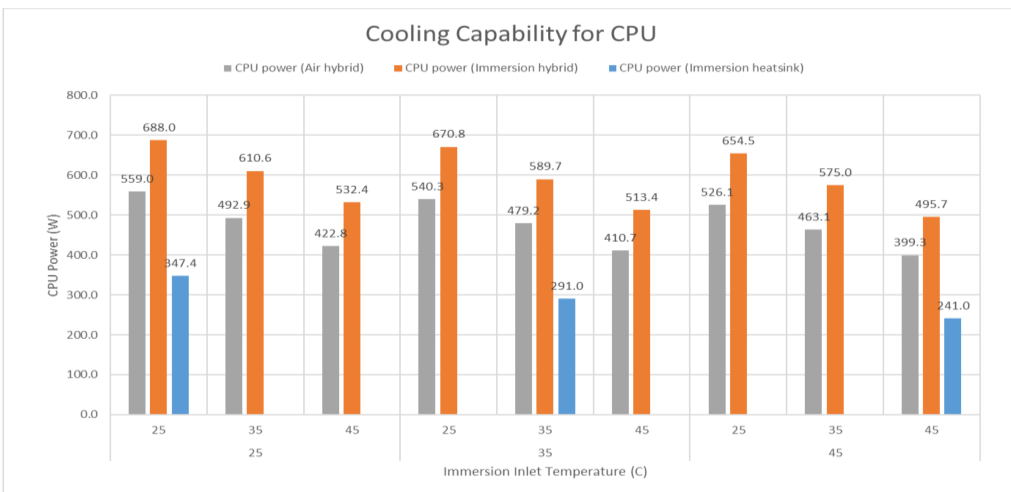

Figure 5.9 Visual representation of cooling capability for CPU in all the test cases

5.6 Targeted Liquid delivery control

In the case of targeted liquid delivery without temperature control CPU temperatures are lower in cold plate-based models compared to heat sink models, even when both tank and cold plate inlet temperatures are the same. Close observation on CPU temperature shows 2°C to 9°C temperature variations when comparing heatsink based and cold plate immersion cooling model obviously due to higher heat transfer due through forced convection at the cold plates.

Comparison of targeted liquid delivery without temperature control		
Immersion tank & Cold plate Inlet temp (°C)	Immersion heatsink model CPU temperature (°C)	Immersion cold plate model CPU temperature (°C)
25	38.7	36.7
35	51.3	46.7
45	65.5	56.6

Table 5.4 Comparison of targeted liquid delivery without temperature control

In the case of targeted liquid delivery with temperature control CPU temperatures can individually be optimized based on coolant inlet temperature Opens opportunity/Potential for precision control using cold plates in high performance computing systems.

Comparison of targeted liquid delivery with temperature control			
Immersion Inlet temp	Immersion heatsink model CPU temperature (°C)	Immersion cold plate model CPU temperature (°C)	Cold plate Inlet temp (°C)
25	38.7	36.7	25
		46.3	35
		55.8	45
35	51.3	37	25
		46.7	35
		56.2	45
45	65.5	37.3	25
		47	35
		56.6	45

Table 5.5 Comparison of targeted liquid delivery with temperature control

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 Conclusion

Single-phase immersion cooling of servers using forced convection and natural convection has been studied and researched previously. Single-phase immersion cooling has proved more efficient than air cooling of data centers. In addition to being more efficient than air cooling, many moving parts such as fans are obsolete in immersion cooling. The servers are cut-off from the external environment and air contamination as seen in air cooling is completely taken aback. Hence, the reliability issues in immersion cooling are lesser. The power density of the data centers can be increased by reducing the form factor of the server using immersion cooling techniques. In this study, mesh sensitivity analysis is performed to calibrate the CFD model and Numerical study on cooling capability is done. It is observed that Immersion Hybrid cooling has a better impact on all the component temperatures while keeping the power consumption minimum compared to air hybrid cooling (fans – steady increase in power). Cooling capability predictions are made and it shows the amount of cooling/power consumption that can be provided to the components for the same form factor for the same fluid properties.

6.2 Future work

In the case of targeted liquid delivery with and without temperature control CPU temperatures can individually be optimized based on coolant inlet temperature. It Opens opportunity/Potential for precision control using cold plates in high performance computing systems.

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