COMPUTATIONAL STUDY OF FORM FACTOR OF 3RD GENERATION OPEN COMPUTE SERVERS USING DIFFERENT DIELECTRIC FLUIDS FOR SINGLE-PHASE IMMERSION COOLING

by

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Abstract

COMPUTATIONAL STUDY OF FORM FACTOR OF 3RD GENERATION OPEN COMPUTE SERVERS USING DIFFERENT DIELECTRIC FLUIDS FOR SINGLE-PHASE IMMERSION COOLING

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Computer system dependency has been increased in the modern world and that has encouraged the rapid growth of data centers in leading business units like banking, education, transportation, social media and many more. Data center is a facility that incorporates an organisation's IT operations and equipment, as well as where it stores, processes, and manages the data. To fulfil the demands of data storage and data processing, corresponding increase in power density of servers are needed. The data center energy efficiency largely depends on the thermal management of servers. Currently, air cooling is the most widely used thermal management technique in data centers. But air cooling has started to reach its limitations due to high powered microprocessors and packaging. Therefore, industries are looking for single-phase immersion cooling using different dielectric fluids which reduces operational and cooling costs by enhancing the thermal management of servers.

Form factor study of 3rd generation open compute server is another area of research in which impact of form factor (geometry of different Open Rack Units) on maximum junction temperature and thermal resistance at the server level is documented. This work is to provide an insight to increase the rack density by reducing form factor of an existing server. This work could open to more heat load per rack. A computational study is conducted in operational range of temperatures and the thermal efficiency has been optimized. A parametric study is conducted by changing the velocities and inlet temperatures of cooling liquid for different heights of the open compute 3rd generation server. The comparative study was carried out for white mineral oil and synthetic fluid(EC100). The results show an enhancement in thermal management for synthetic fluid when compared to mineral oil for the same inlet temperatures. This study clearly indicates that the single-phase immersion cooling is efficient and capable to accommodate high thermal mass.

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CHAPTER 1

INTRODUCTION

1.1 Introduction to Data Center

Data center is a facility that incorporates an organisation's IT operations and equipment, as well as where it stores, processes and manages the data. In a data center, the servers are mounted in racks. In the present networking world, the demand for the data centers has been increasing remarkably. Increasing demands of processing and storage of data causes corresponding increase in power density of servers. To ensure the reliability and efficient working characteristics of the server components, servers must be cooled continuously and efficiently. The thermal management of the servers depends wholly on the thermal efficiency of the servers. So it is important to enhance the cooling systems every day.

1.2 Data Center Cooling Methods

Cooling is a critical part of a data center's infrastructure, and a few approaches are available to maintain the necessary temperatures. At present two major cooling techniques are used for maintaining the permissible range of temperatures in the data center. They are as follows:

1. Air cooled servers
2. Liquid cooled servers

1. Air Cooled Servers

The sole purpose of cooling in a data center is to remove the heat dissipated by the servers. Air cooling is one of the most widely used cooling techniques. In this technique, the heat generated is removed by the forced convection of air over the heat transfer component called heat sink. Fans are provided to manage the airflow from inlet to outlet and are controlled according to the change in the temperature of server components.

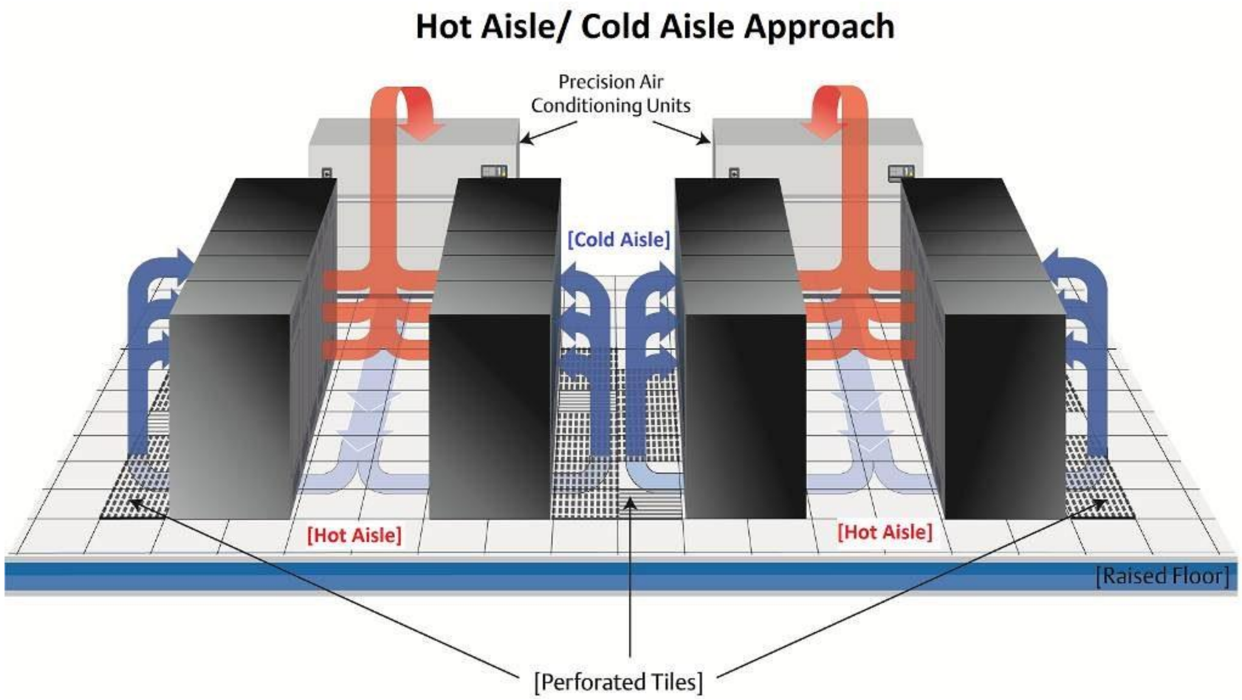

Figure 1 Hot Aisle/ Cold Aisle Approach

Air cooling involves the use of computer room air conditioners (CRACs) to convert warm air to cool air by removing heat to the outside. CRACs can be used in several basic configurations that focus on cooling the entire room, just a row or just a rack. The air after cooled down is again supplied to the cold aisle of the cooling system for further cooling. The process of air cooling can be seen in the Fig1.

1. Liquid Cooled servers

Though air cooling is a widely used technique, it has started to reach its limitations due to high powered microprocessors and packaging. Due to the poor conductivity of heat, in air cooling we need to provide fins for increasing the heat dissipation rate. The ducting system and fans used for managing the airflow also occupies a large space. To overcome all these limitations, industries are looking towards liquid cooling methods. Generally we use water or oil for cooling the servers either by flowing the fluid over the servers or immersing them in the fluid. The liquid cooling methods can be subdivided into:

A. Water Cooled servers

B. Oil Cooled serve

A. Water Cooled Servers

In water cooling technique, we cannot allow the water to come in direct contact with the components as water conducts electricity. So we use a passive heat transfer device call Cold plate. Cold plate bottom is made up of copper and it is placed on the heat producing components.

Figure 2 . Top view of the Cold Plate

The water is made to flow over the cold plate. Here the heat is transferred to cold plate from the components through conduction and cold plate to water through convection. Later the water is sent to the chillers for cooling and recycled. The advantage of using cold plate over the heat sink is it makes the server design compact and uses less power than the air cooling technique.

B. Oil Cooled Servers

It is the practice of submerging servers in a thermally, but not electrically, conductive liquid (dielectric coolant). The heat is transferred directly from the heat source to the cooling fluid. The flow of the fluid is maintained using a flowmeter. Most frequently used cooling liquids are white mineral oil, electrical cooling liquids and non-purpose oils. The immersion cooling can be classified as:

I. Single-phase immersion cooling
II. Two-phase immersion cooling

I. Single-Phase Immersion Cooling

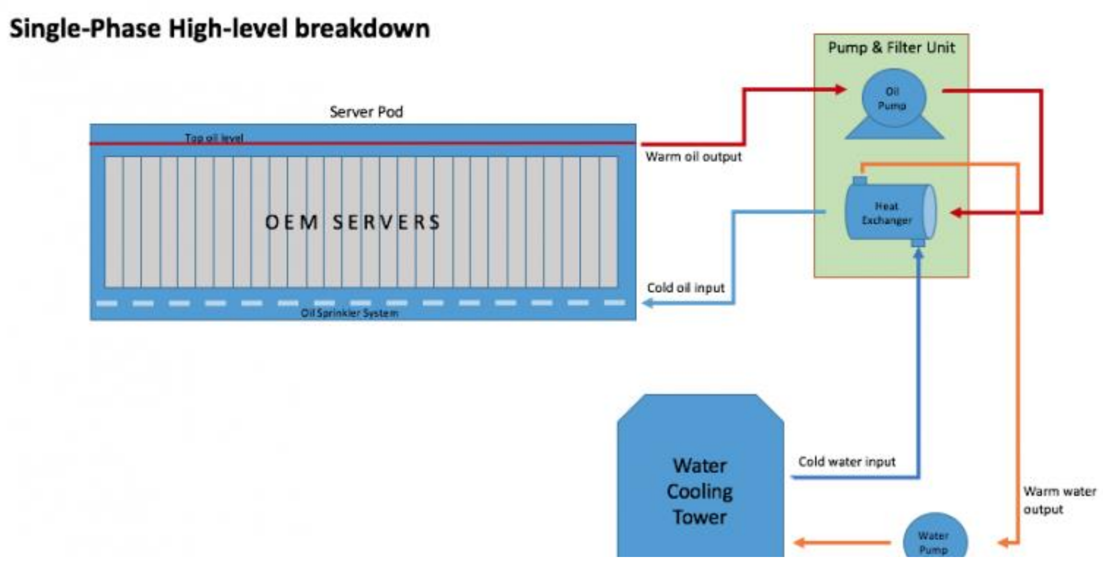

Figure 3 Single Phase Immersion Cooling

Single Phase coolant never changes state, it never boils or freezes and always remains in a liquid form. The coolant gets pumped to a heat-exchanger where heat is transferred to a cooler water-circuit. This technique uses *open baths*, as there's little (or no) risk of the coolant evaporating.

II. Two-Phase Immersion Cooling

In two phase cooling the working fluid boils and thus exists in both a liquid and gas phase. It is also called as evaporative cooling or flow boiling. The system takes advantage of a concept known as "latent heat" which is the heat (thermal energy) required to change the phase of a fluid. The working fluid is only cooled by boiling and thus remains at the boiling point. Energy is transferred from the heat source into the working fluid will cause a portion of it to boil off into a gas. The gas rises above the fluid pool where it contacts a condenser which is cooler than the saturation temperature. This causes the fluid to condense back into a liquid and fall (rain) back into the pool. This immersion cooling method required semi-open baths. It means that when the system operates it is sealed to avoid the

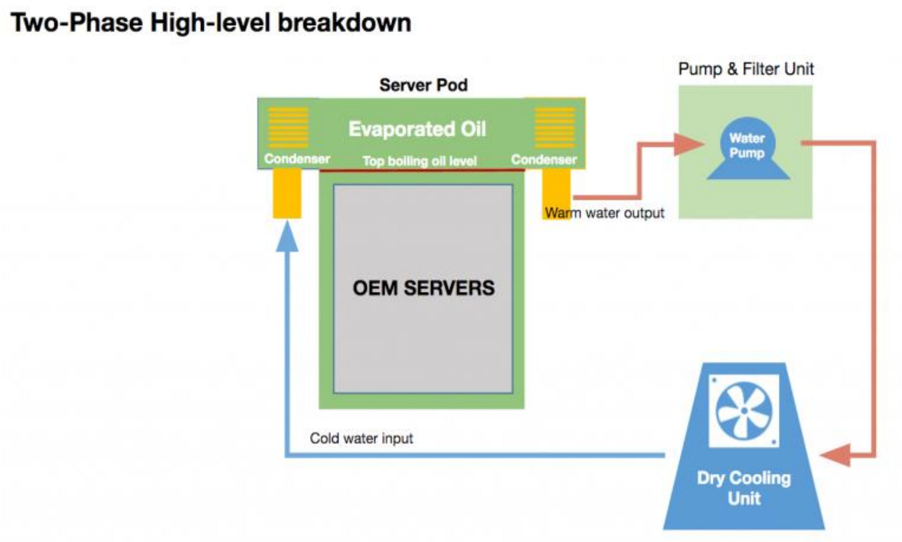

Figure 4 Two Phase Immersion Cooling

evaporation or coolant.

In this study, we have used white mineral oil and synthetic fluid Electro Cool 100 (EC-100). The physical properties of different types of fluids are compared for this study.

Type of Fluid	Heat Capacity (KJ/Kg K)	Density (Kg/m^3)	Kinematic viscosity (X 10^{-6} m^2/s)	Heat Conductivity (W/m K)
Air	1.01	1.225	0.016	0.02
Water	4.19	1000	0.66	0.58
White Mineral Oil	1.67	849.3	16.02	0.13
Synthetic fluid (EC-100)	2.165	803.78	13.22	0.1378

Table 1 Properties of different fluids

It is clear from the Table1 that the Thermal mass (Density x Heat Capacity) of Di-Electric liquids is high compared to air. Although the thermal mass of water is the highest, the efficiency of heat dissipation is less as it is a passive heat transfer medium.

1.3 Motivation of the Study

Air cooling has reached its limitations due to high powered microprocessors and packaging. Single phase immersion cooling enhances the thermal management of servers. It helps to remove the ducting system and fans and increase the rack density in the open compute 3rd generation servers.

CHAPTER 2

SPECIFICATION OF THE SERVER

1.4 Server Description

The server considered for the study is a “Third Generation Open Compute Server”. It comprises of four DIM blocks each having four DIMMS of 8GB memory. It consists of two microprocessors with design power density of 115 W each. It has two CPU’s each having a dimension of 50mm X 50mm. The length and width of the chassis are 166.2mm and 511mm, and the height varies for different form factors are as follows.

	RACK UNIT	**OPEN RACK UNIT**
1U	44.5	48
1.5U	66.5	72
2U	89	96

Table 2 Height of the chassis for rack unit and open rack unit

The Open Compute Server taken under study has a form factor of 2 Open rack unit and with the dimensions of 166.2mm x 511mm x 96mm. The server is enclosed with a top cover on the chassis body. The top view of the server is as shown in the figure.

Figure 5 Top view of Open Compute Server

1.5 Baseline Air Cooled Server Specifications

The baseline air cooled server has the same dimensions as considered for the study. But the power of each CPU is 95W instead of 115W. Ducting system is provided at the top of the server to manage the air flow.

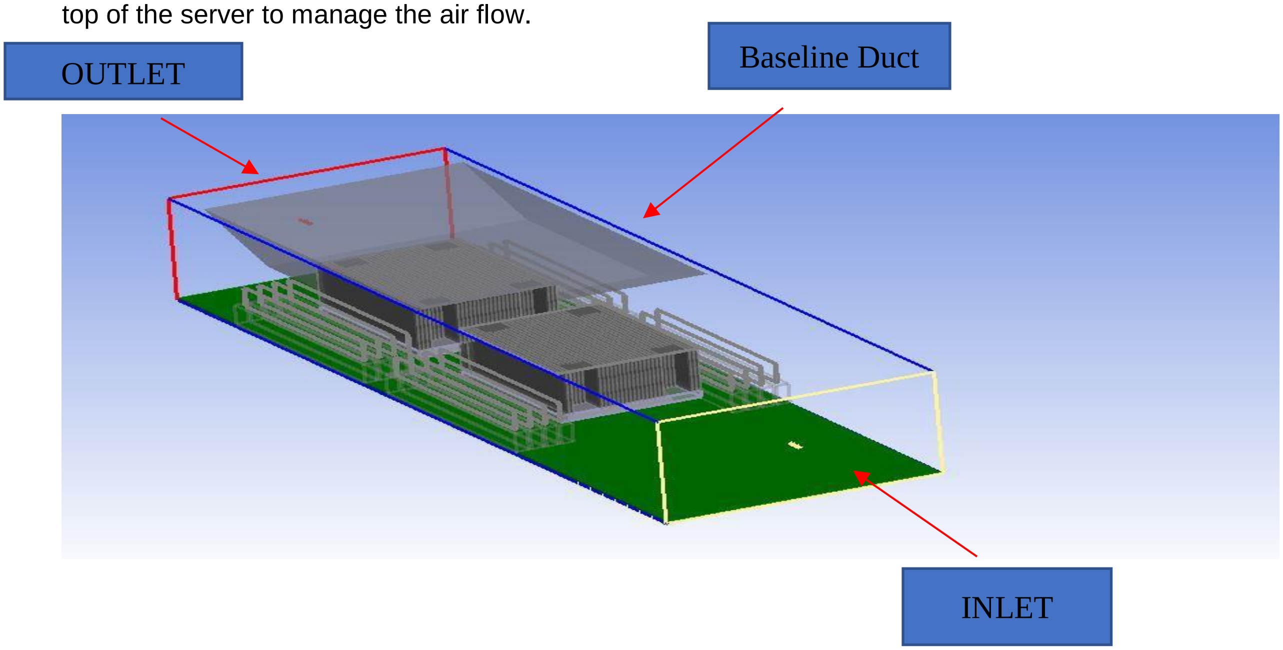

Figure 6 CFD model of Baseline Air Cooled Server

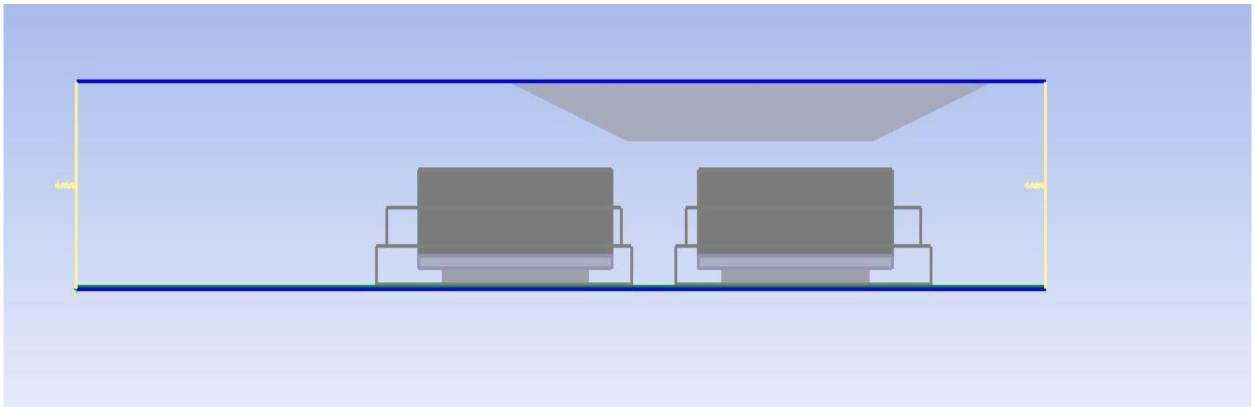

Figure 7 Sideview of Baseline Air Cooled Server

The CFD model has been developed using the Computational tool called ANSYS ICEPAK 17.0 and duct geometry has been imported from the modelling tool SOLIDWORKS. The baseline duct is made of aluminium. From the Fig 2.2. we can see that one end is considered as inlet and the other as outlet. Experiment on air cooling was performed by previous master's student Divya Mani. She had connected the server inlet with airflow bench. The desired air quantity is supplied using airflow bench and data of pressure drop and temperature had been documented. Thermocouples are placed at critical positions inside the server and are connected by DAQ units.

The baseline single server had been tested at various inlet velocity and varying the processor usage.

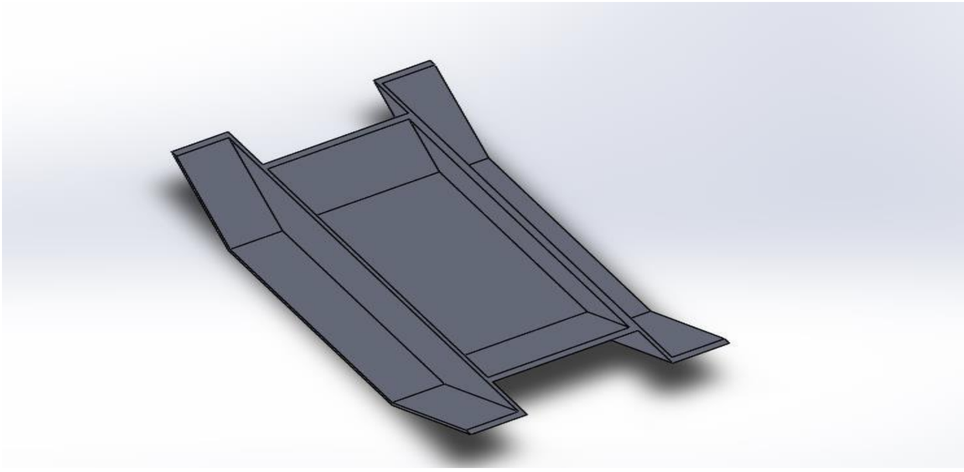

Figure 8 Baseline Duct

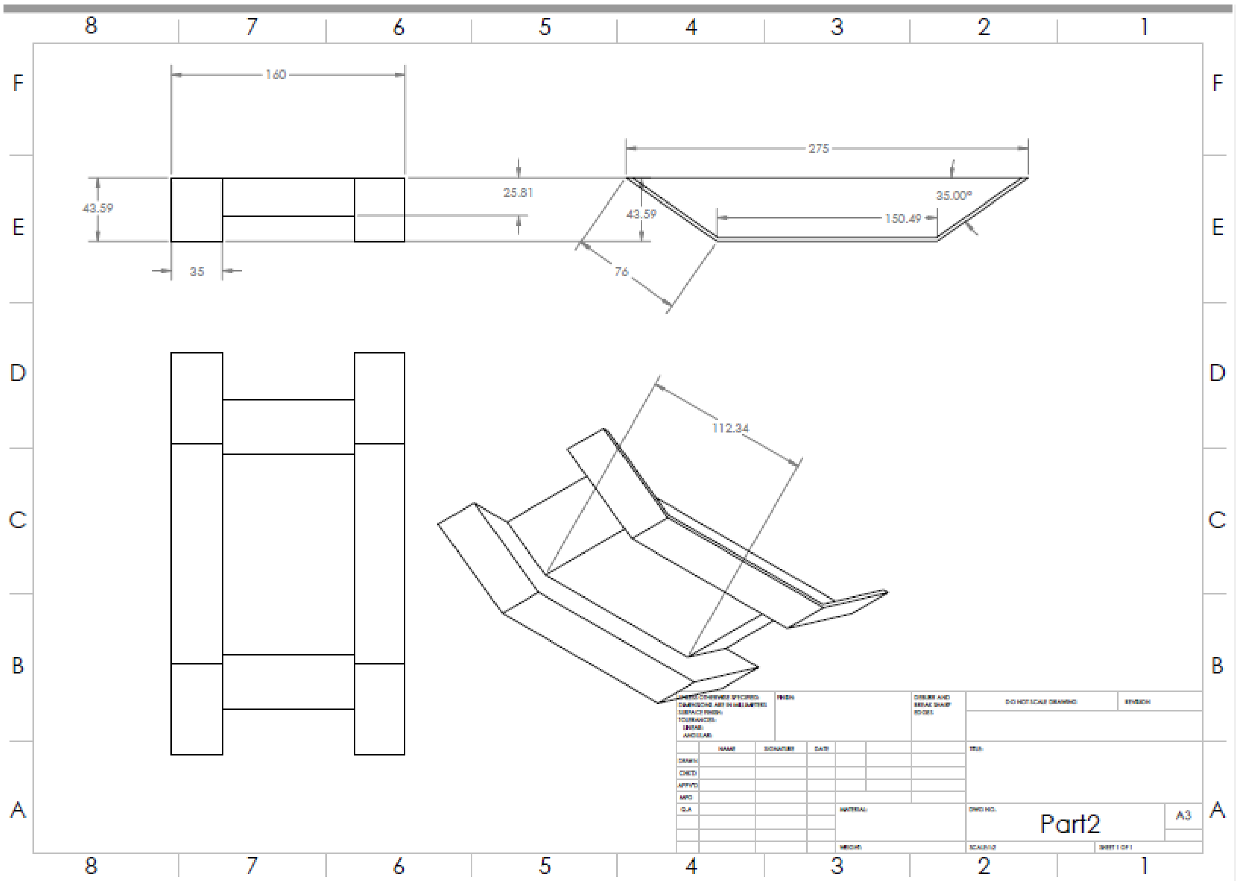

Figure 9 Dimensions of baseline duct

1.6 Baseline Oil Cooled Server

The baseline oil cooled server has been developed using the computational tool ANSYS ICEPAK 18.0. Server dimensions are kept same as the baseline server except the duct and fans has been removed. In this geometry, Cabinet max y is the inlet and min y is the outlet for the flow of fluid.

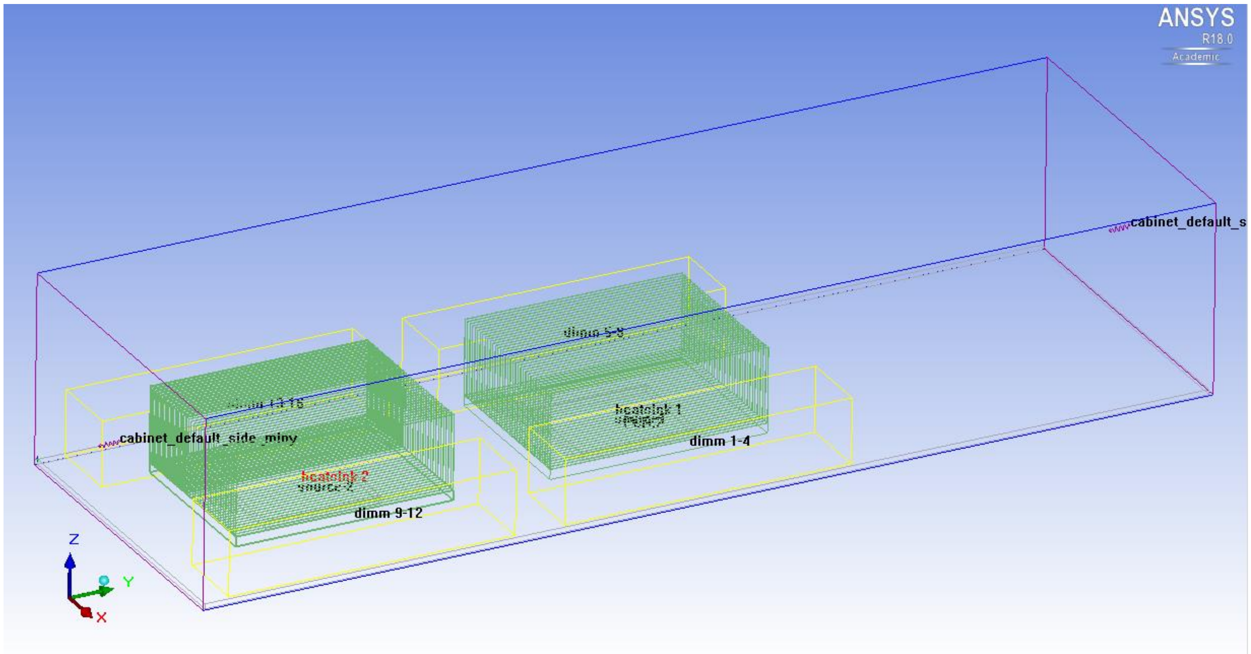

Figure 10 CFD model of a Baseline Oil Cooled Server

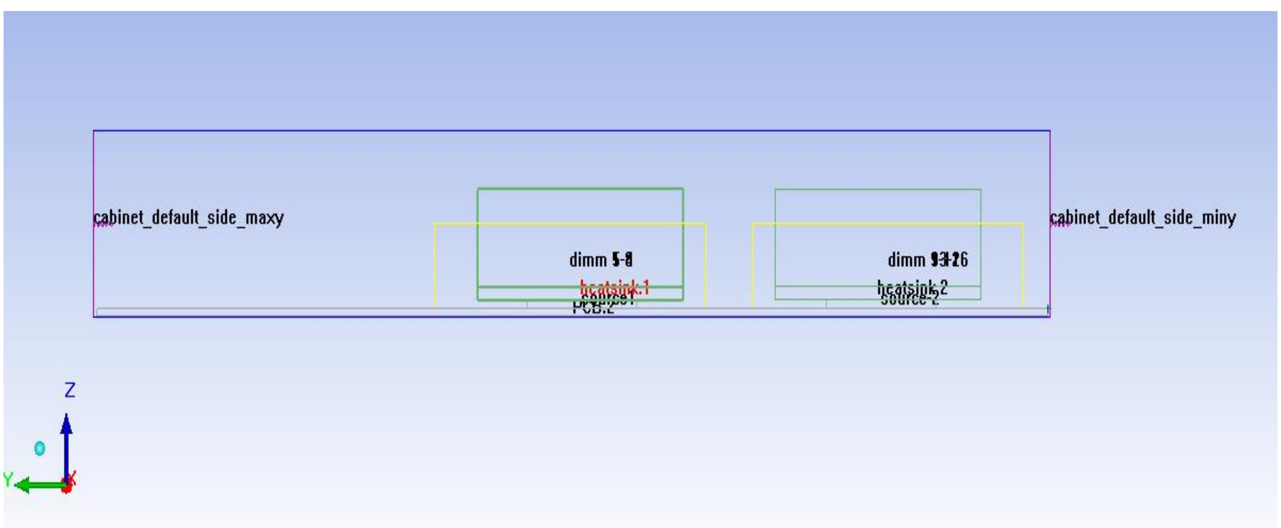

Figure 11 Orientation of serve in the Positive X-Directio

1.7 Area Calculation for Different Form Factors

The area for the different open rack unit servers has been calculated by using the following formula: Area = Length x Height …………… (Eqn 1)

The dimensions and the areas calculated for the different open rack unit servers has been tabulated as below:

Open Rack Unit Server	Length (mm)	Width(mm)	Height(mm)	Area(m^2)
1 ORU	166.2	511	48	7977.6 X 10^{-6}
1.5 ORU	166.2	511	72	11966.4 X 10^{-6}
2 ORU	166.2	511	96	15955.2 X 10^{-6}

Table 3 Area calculation

1.8 Volumetric Flow Rate Conversion

In this study we consider volumetric flow rate of 0.5 Litres Per Minute (LPM) to 2 LPM.

These values in m^3/sec are tabulated as follows:

LPM	$\mathrm{m^3/sec}$
0.5	8.33 x 10^{-6}
1	1.6667 x 10^{-5}
1.5	2.5 x 10^{-5}
2	3.333 x 10^{-5}
2.5	4.1667 x 10^{-5}

Table 4 Volumetric Flowrate conversion

1.9 Velocity Calculation

The velocity of the fluid changes whenever the volumetric flow rate and cross-sectional area changes. So we need to change the velocity while running simulations for different flow rates. It can be calculated using the formula

Volume flow rate = Area x Velocity ……………….. (Eqn 2)

i.e, Velocity (V) = Volume flow rate / Area

LPM	$\mathbf{m^3/sec}$	**1 Open Rack Unit**	**1.5 Open Rack Unit**	**2 Open Rack Unit**
0.5	8.33×10^{-6}	0.0010442	0.00069639	0.00052209
1	1.6667×10^{-5}	0.0020896	0.0013928	0.0010448
1.5	2.5×10^{-5}	0.0031337	0.002089	0.00156689
2	3.333×10^{-5}	0.00417795	0.002785	0.0020889
2.5	4.1667×10^{-5}	0.005223	0.003482	0.0026115

Table 5 Velocity Calculation

CHAPTER 3

GRID INDEPENDENT STUDY AND CALCULATIONS

3.1. Validation and Grid Independent Study of an Air-Cooled Server

Validation of the CFD model with actual experimental data and previously developed CFD model in other computational tool is mandatory for an accurate and precise results of future simulations. As mentioned earlier, Ansys ICEPAK has been used as a computational analysis tool for this study. To validate the model boundary condition is very important. Boundary condition should be kept same as used for an experiment.

Boundary condition used for validation as inlet air temperature (T=24.5℃) and relative humidity is in range of ASHRE defined recommended range[1]. Figure 3.1. shows the allowable and recommended zones for air cooling method.

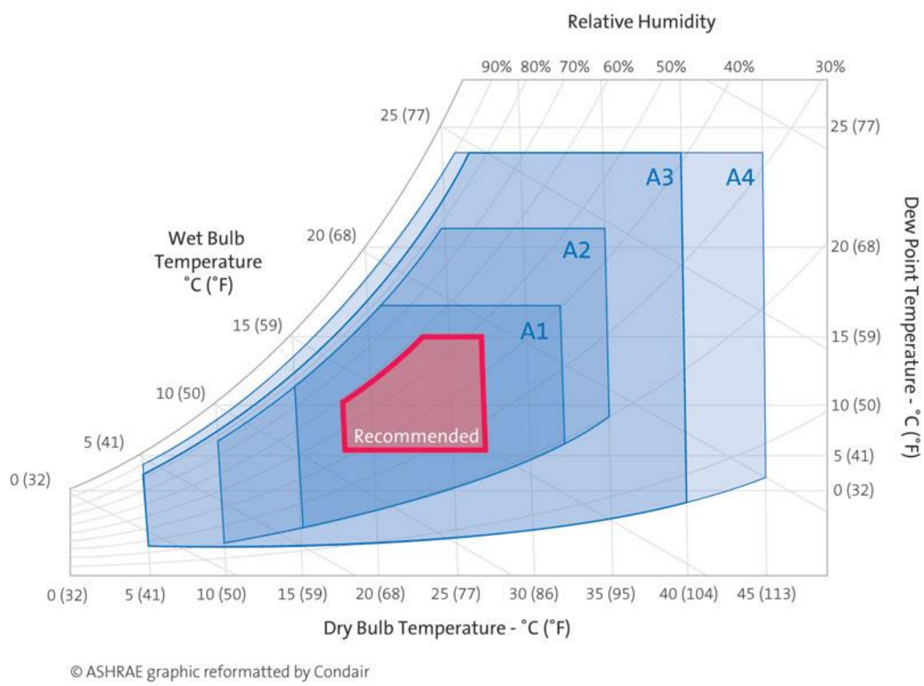

Figure 12 . ASHRE Recommended zones for Data center cooling

Temperature and pressure drop has been obtained keeping the same boundary condition used for an experiment and compared with the previously documented CFD results. For validation purpose power density of each server is kept as 95W and base line ducting system has been incorporated.

Once the boundary condition is applied and exact environment has been created, the next and very important stage of the process is simulations. ICEPAK basically runs the solver according to boundary condition and solves the naiver-stokes equation on each node and up to predefined number of equations. Here, for an air- cooled server CFM had been varied from 0 to 100 with an interval of 20. To decide that which model is used for the simulation process, Reynolds number is very important dimension less number. For an air-cooled server, it came out as Re ≥ 4000 for selected inlet CFM range. To justify the condition, turbulent model with zero equation has been used. Pressure drop has been noted and compared with the previous results. It has come out with the maximum of ±10 % error with the actual results.

Flow Rate (LPM)	Previous CFD Pressure Drop (in/H_2O)	ICEPAK CFD Pressure Drop (in/H_2O)	Error Percentage
0	0	0	0
20	0.034	0.038	10.52
40	0.106	0.104	-1.88
60	0.214	0.218	1.834
100	0.549	0.556	1.3

Table 6 Pressure Drop of CFD Model

For the accuracy of the model grid independent study has been carried out for an air-cooled server. For the grid independent study, processor power is kept as 95W each, inlet air temperature is taken as 24.5℃ and inlet air velocity is kept constant as 1m/s.

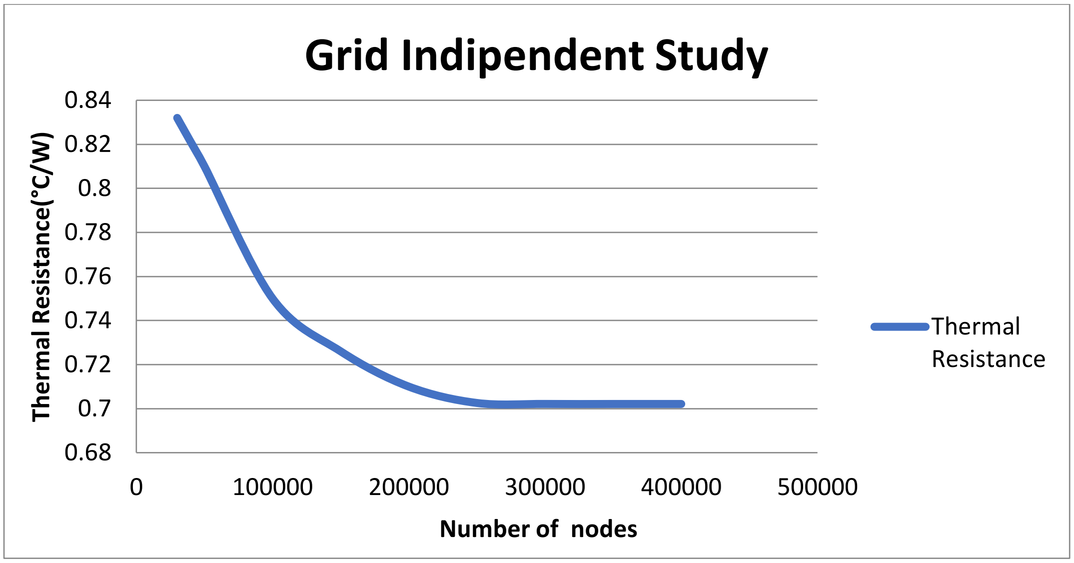

Figure 13 Grid Independent Study

It is clear from the above graph that the thermal resistance decreases as we increase the number of nodes in the server and there isn't major variation after number of nodes exceeds 250000. For the rest of the research, total number of nodes is taken in the range of 250000 to 400000. The grid independent study for air cooled server is done by the previous master's student Chinmay Hemanth Kumar Bhatt[5]. As we have considered same model for studying the form factor using different dielectric fluids, we have considered same nodal values.

3.2. Validation and Grid Independent Study of Oil Cooled Server

For validation of the oil cooled server, some material properties must be specified. The material property of the server component will remain same as an air-cooled server, but fluid properties must be changed in place of air. There are different types of Di-Electric Fluids, but in this study White Mineral Oil and Synthetic Fluid EC100 are used by considering cost factors and High temperature cooling applications.

Flow condition is kept same as that of an actual experiment. Inlet oil temperature is taken as 30˚C, volume flow rate is kept constant of 1 LPM. 2 Open Rack Unit Server cross section in this case is considered as 511mm x 166.2mm x 96mm. The formula below can calculate Hydraulic Diameter,

$D=\frac{2\,b\,h}{(b+h)}$ ………………… (Eqn 4)

Where,

b= channel width = 511 mm

h= channel height = 96 mm

D = (2 x 511 x 96) / (511 +96)

= 161.6 mm

= 0.1616 m

3.2.1 Reynolds number calculation for White Mineral Oil

There are some physical properties of white mineral oil that should be considered for computational analysis.

Density – 851.515 Kg/m^3

Thermal conductivity – 0.13 W/m K

Specific heat – 1680 J/kg k

Thermal Diffusivity – 9.166E-8 m^2/s

Molecular Weight–150 Kg/ K Mol

Over all heat transfer co-efficient – 50-30 W/ $m^2\ K$

At 30℃, the Dynamic Viscosity (μ) of White mineral oil is 0.01405 Kg/m s

The Kinematic Viscosity (v) is 1.65E-05 m^2/s

Reynolds number can be calculated using the below formula

Re=$\frac{V\,D}{\nu}$ ………………. (Eqn 5)

Where Re is the Reynolds number,

V is the Velocity,

D is the Hydraulic Diameter,

v is the Kinematic Viscosity.

Substituting Hydraulic Diameter, Velocity and Kinematic Viscosity in eq 5,

Re= (0.0010448 x 0.1616) / (1.65E-05)

Re = 10.23

Prandtl number can be calculated using the below formula

P= $\frac{\mu\,C_P}{\lambda}$ = (0.01405 X 1670) / 0.13

P= 180.488

Temperature (℃)	Dynamic Viscosity (kg-m/s)	Kinematic Viscosity (m^2/s)	Reynold's Number	Prandtl Number
30	0.01405	1.65E-05	10.23	180.488
40	0.01046	1.23E-05	13.72	134.37
45	0..00909	1.07E-05	15.77	116.77
50	0.00794	9.35E-06	18.05	101.99

Table 7 Change in properties of White Mineral Oil due to Temperature

3.2.2 Reynolds number calculation for Synthetic Fluid

The properties that must be considered for the calculation of Reynold's number for synthetic fluid are as follows:

Density – 803.78 Kg/m^3

Thermal conductivity – 0.1378 W/m K

Specific heat – 2165.9 J/kg k

Molecular Weight–350 Kg/ K Mol

At 30℃, the Dynamic Viscosity (μ) of Synthetic Fluid is 0.01062 Kg/m s

The Kinematic Viscosity (v) is 1.322E-05 m^2/s

Re=$\frac{V\,D}{\nu}$

Re = (0.0010448 x 0.1616) / 1.322E-05

Re = 12.77

Prandtl number can be calculated using the below formula

P= $\frac{\mu\, C_P}{\lambda}$ = (0.01062 X 2165.9) / 0.13787

P= 166.837

Temperature (℃)	Dynamic Viscosity (kg-m/s)	Kinematic Viscosity (m^2/s)	Density (kg/m^3)	Specific Heat (J/kg-K)	Thermal Conductivity (W/m-K)	Reynold's Number	Prandtl Number
30	0.01062	1.322E-05	803.78	2165.9	0.13789	12.77	166.837
40	0.00767	9.63E-06	796.98	2203.2	0.13730	17.53	123.077
45	0.00662	8.34E-06	793.58	2221.9	0.13702	20.24	107.349
50	0.00576	7.29E-06	790.18	2240.5	0.13673	23.16	94.385

Table 8 Change in properties of Synthetic Fluid due to Temperature

Reynolds number is less than 2000 for both White Mineral Oil and Synthetic Fluid. So Laminar model is used to solve the naiver stoke equation. CFD results documented by Chinmay Bhatt are compared with the experimental results documented by Trevor Mc.Williams for Validation[10].

Flow Rate (LPM)	Experimental Results	CFD Results	Error Percentage
0.3	70	71.23	1.72
0.4	68.74	68.86	0.174
0.5	67.43	66.87	-0.83

Table 9 Validation of an Oil Cooled CFD Model

3.3. Thermal Resistance Calculation

Thermal resistance is the key factor for designing a cooling system. It is one of the major parameter that needs to be carefully designed and optimized. Thermal resistance is calculated for the heat transfer components. Thermal resistance can be calculated using the below mentioned formula.

Thermal Resistance = (T_j – T_a) / Heat Dissipation

Where,

T_j = Junction Temperature

T_a = Incoming fluid temperature

Heat dissipation from processor is taken in watts.

CHAPTER 4

FORM FACTOR STUDY

4.1. Definition of Form Factor

In Computers, the form factor is the size, configuration or physical arrangement of a computing device, a computer case or chassis or one of its internal components. When used to refer to the size of a free-standing computer or other device, its close in meaning to footprint. Here, Form factor defines the height of the server. In the data center industry, U is considered as standard rack unit, but we are considering the open rack unit for our study. It has the value of 48mm.

4.2. Rack unit and Open Rack Unit

A rack unit is a unit of measure defined as 44.50mm. It is most frequently used as a measurement of the overall height of 19in or 23in rack frames, as well as the height of equipment that mounts in these frames, whereby the height of the frame or equipment is expressed as multiples of rack units. A typically full-size rack size is 42U high while equipment is typically 1U, 2U, 3U or 4U high.

Open rack is a mounting system designed by the Facebook's open compute project that has the same outside dimension as typical 19inch racks. It has 21inches out of the 24inches available for 87.5% space efficiency.

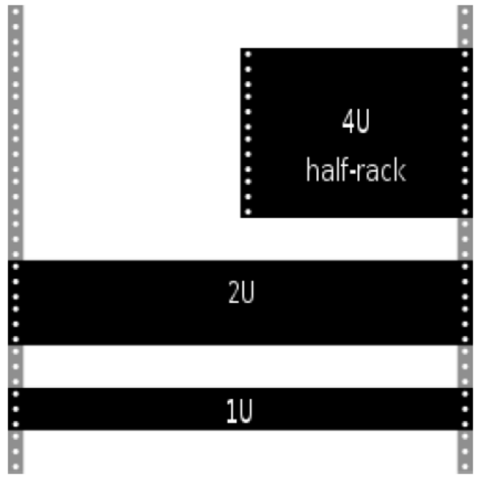

Figure 14 Rack Unit Comparsion

4.3. Parametric Study of Form Factors

The server is basically designed for air cooling application and it has by default form factor as 2U. Ansys ICEPAK has the provision to change the parameters and solve the naiver stoke equations. Two major parameters have been considered are inlet oil temperature and oil flow rate. Inlet oil temperature has been varied from 30℃ to 50℃. This range has been selected from the previous research experiment carried out on oil immersion cooling. [7] Volume flow range for an incoming oil is kept from 0.3 lpm to 2.5 lpm. Maximum value of Reynold's number for this study is 656 obtained at the volume flow rate of an oil as 2.5 lpm. It can be concluded that even at maximum volume flow rate of 2.5 lpm Reynold's number does not exceed 2000 hence, laminar model is used for solution of parametric trails.

Similar procedure repeated for form factor 1.5U and 1U. The Cabinet height is changed according the value of form factor. The major purpose of the study is to get an insight to increase the existing rack density by reducing its form factor. This study is very useful to predict the behaviour of cooling fluid at various form factor. Small improvement at server level cooling can be useful for a significant amount of savings at the facility level.

CHAPTER 5

RESULTS AND CONCLUSIONS

5.1. Form Factor study of 2U server

A series of simulations has been performed by changing the properties depending on the temperature and velocities when height of the server is changed. Form Factor study of Facebook’s third generation open compute server includes comparison of thermal resistance and maximum junction temperature of 2U,1.5U and 1U for low velocity oil cooled severs. This study shows the change in trend of thermal performance the server with variation in inlet boundary condition. Purpose of this study is to analyses the change in maximum junction temperature and thermal resistance when form factor of the server is reduced. The simulation run for the 2 open rack unit server using mineral oil can be seen in the following figure,

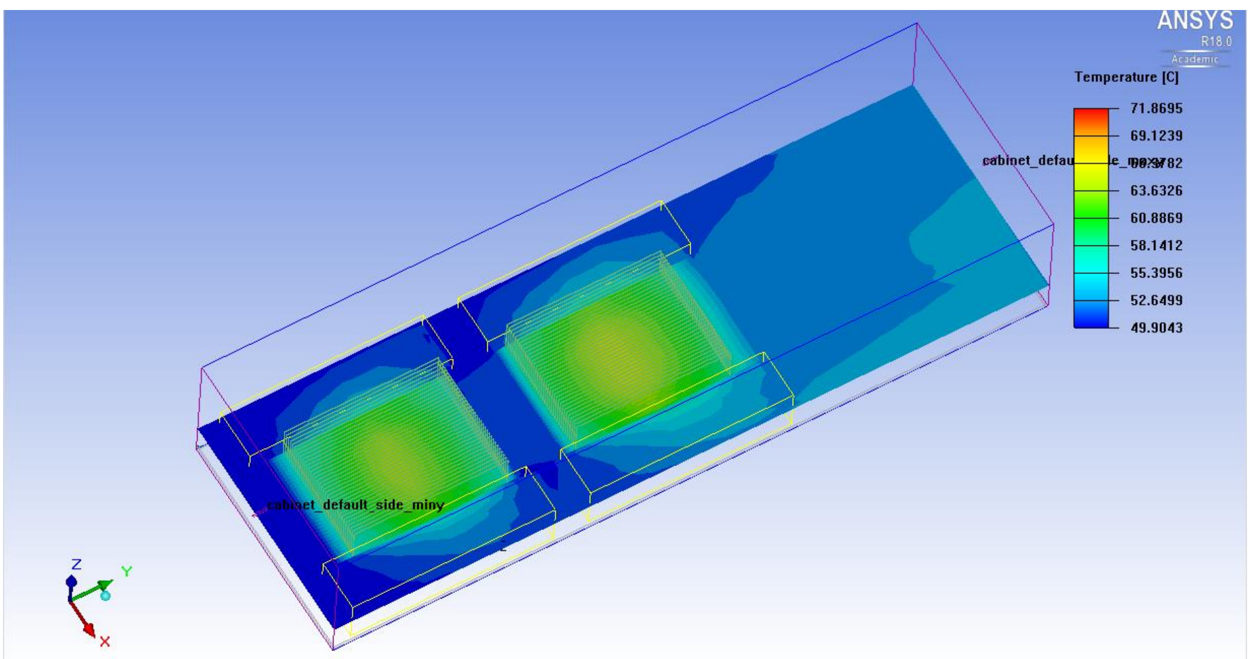

Figure 15 Open Rack Unit Server with mineral oil as cooling fluid

The data obtained through the simulations has been tabulated for white mineral oil and EC100. A comparison of the thermal efficiency has been done between white mineral oil and synthetic fluid. The thermal properties are changed depending on the fluid used and the inlet conditions.

Similarly, we can see the simulation of the 1.5 open compute server @30℃

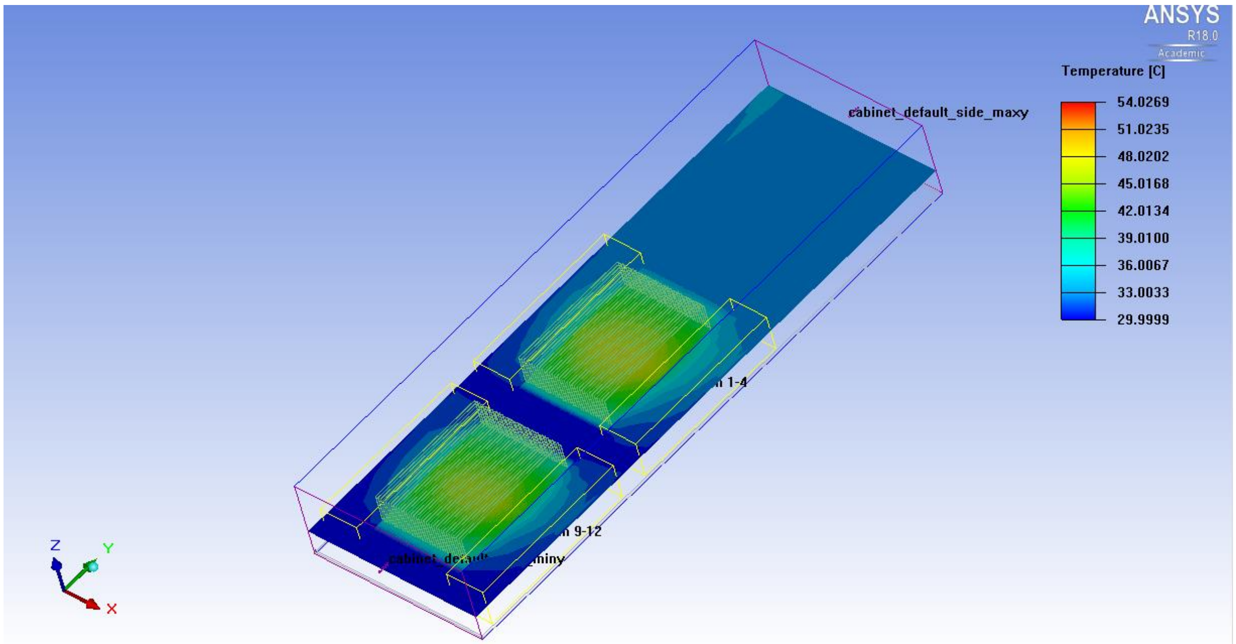

Figure 16 1.5 Open Compute Server @30

5.2. Comparison of Mineral oil and Synthetic Fluid For 1 Open Rack unit server

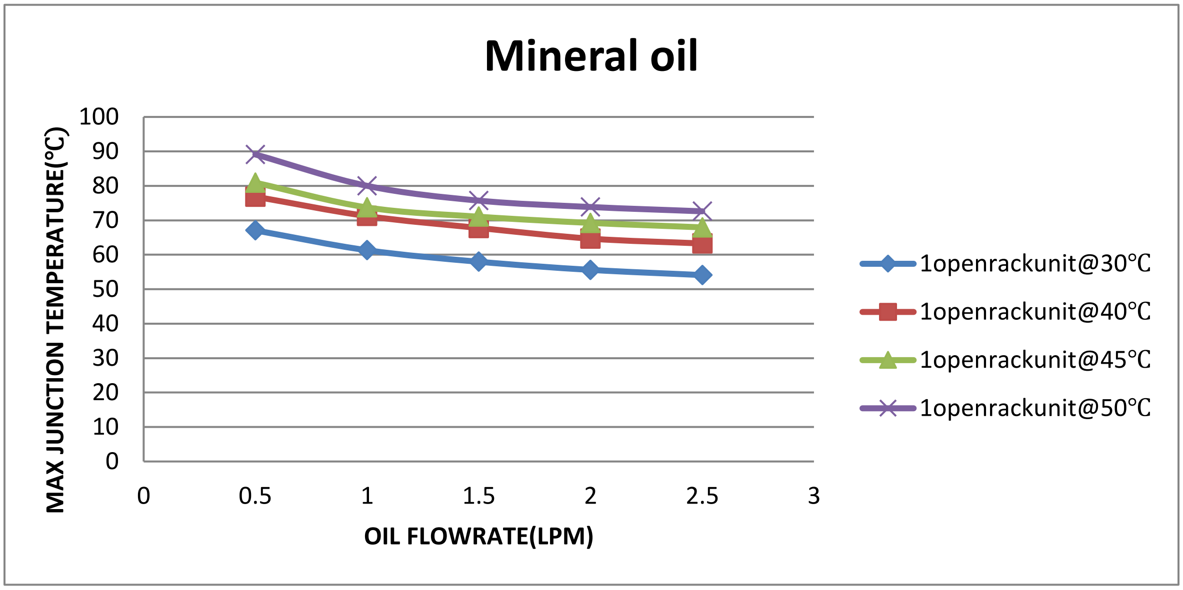

Figure 18 Max Junction Temp Vs Oil Flow rate at source 2

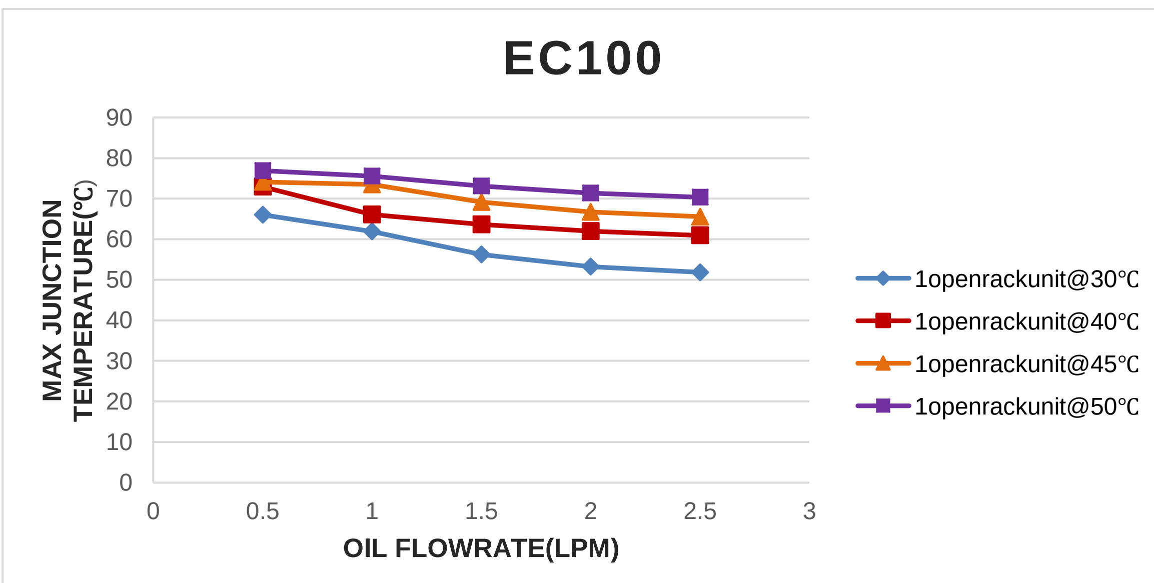

Figure 17 Max Junction Temp Vs Oil Flow rate at source 2

We can see from the both the graphs that the temperatures for the source 2 is less when synthetic fluid is used as cooling liquid rather than the mineral oil

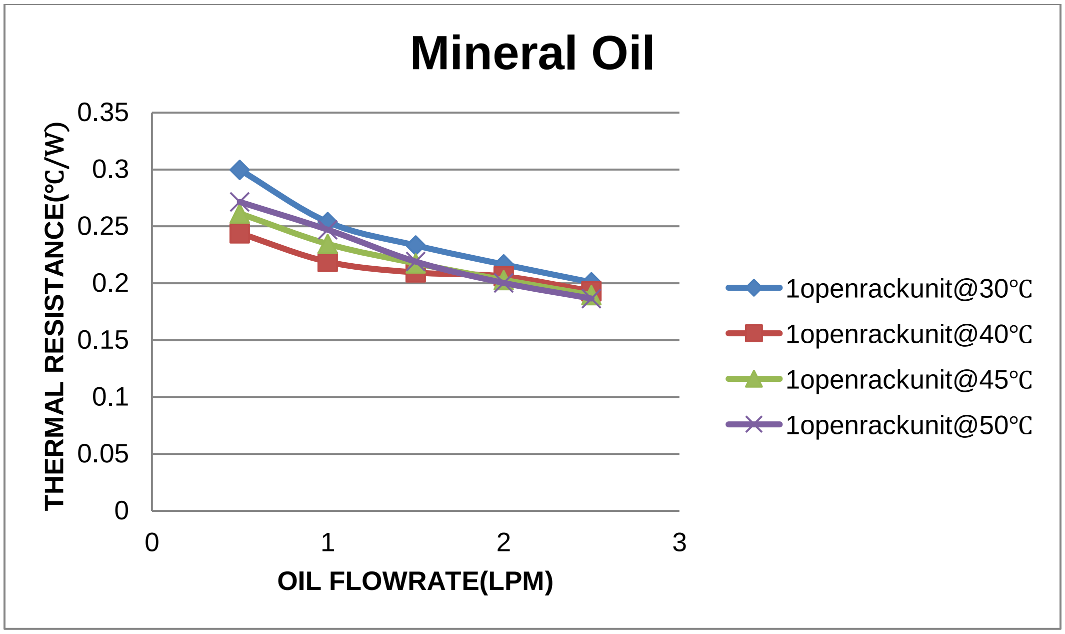

Figure 19 Thermal Resistance Vs Oil Flow rate at source 2

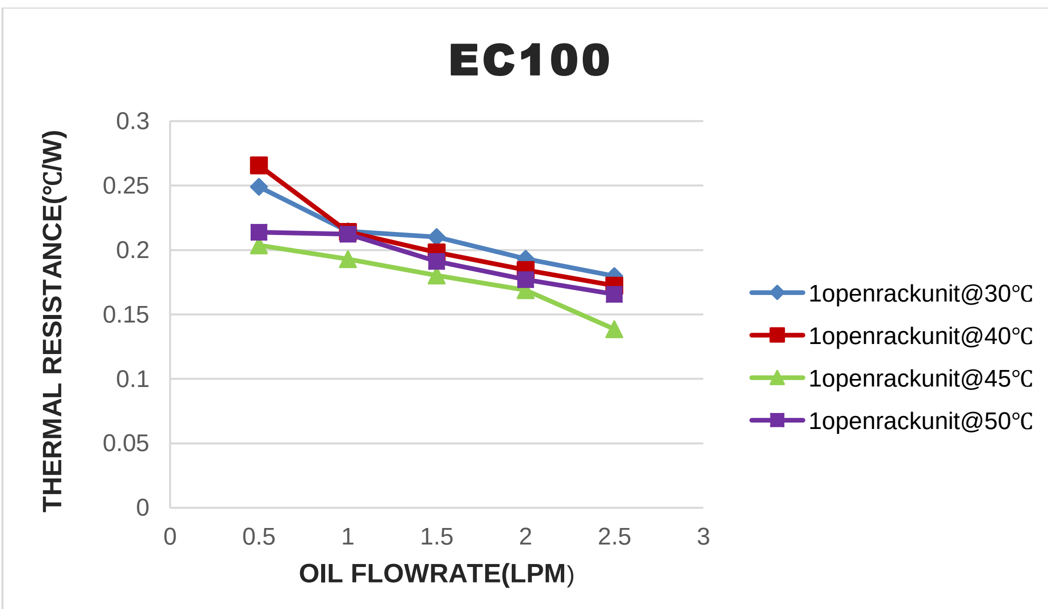

Figure 20 Thermal Resistance Vs Oil Flow rate at source 2

Here also we can see that there is an noticeable change in the values of thermal resistance.

5.3. Comparison of Mineral oil and Synthetic Fluid For 1.5 Open Rack unit server

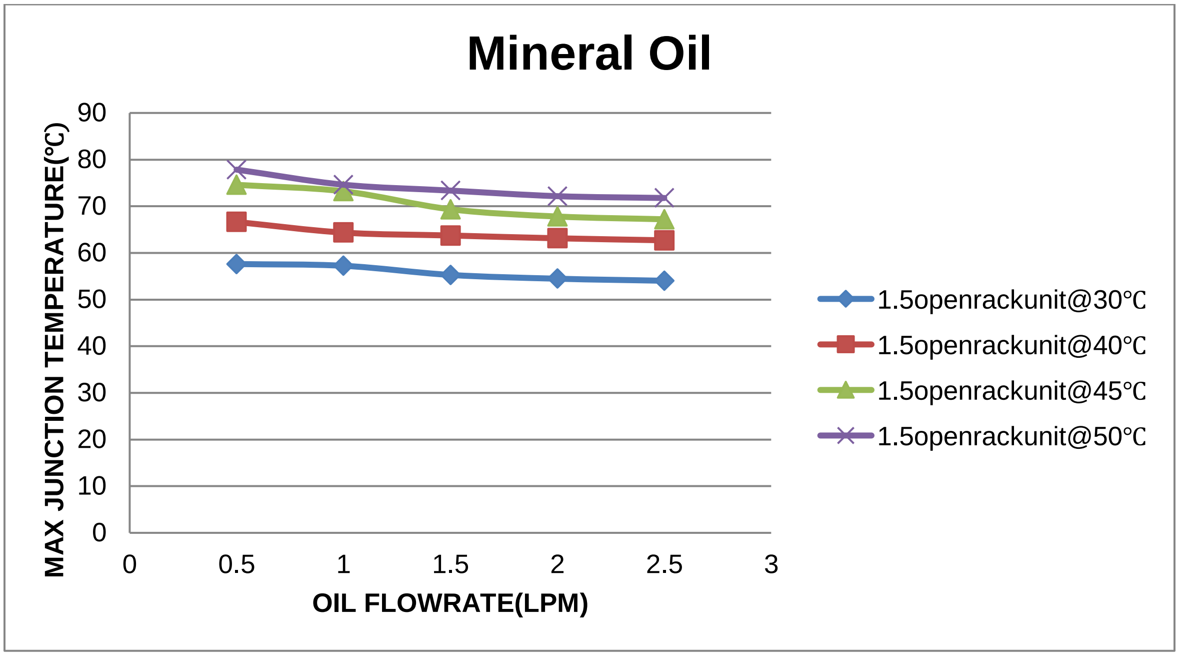

Figure 21 Max Junction Temp Vs Oil Flow rate at source 2

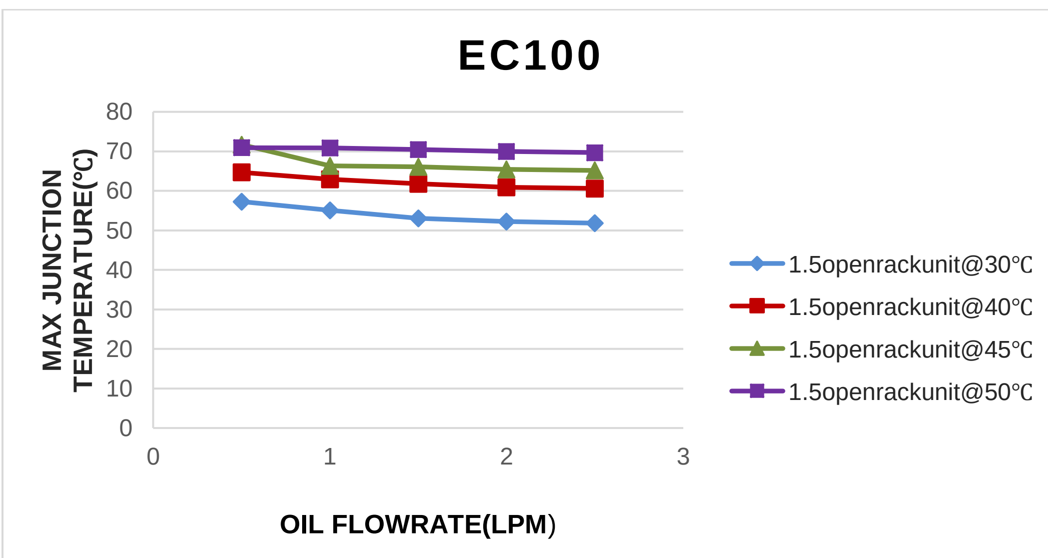

Figure 22 Max Junction Temp Vs Oil Flow rate at source 2

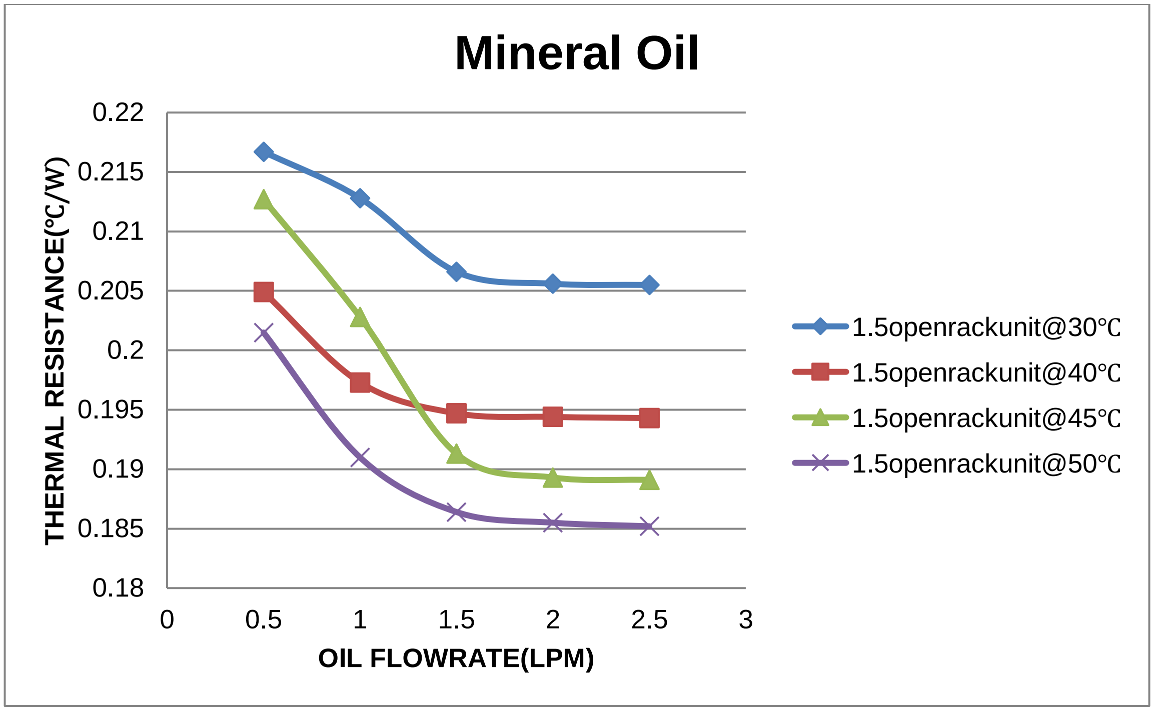

Figure 23 Thermal Resistance Vs Oil Flow rate at source 2

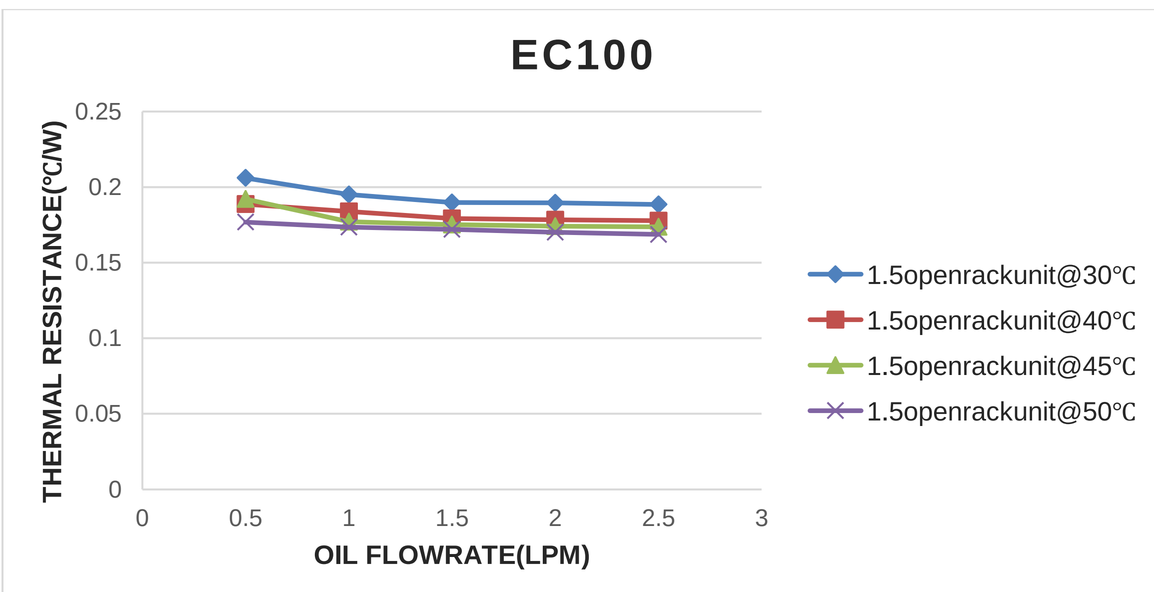

Figure 24 Thermal Resistance Vs Oil Flow rate at source 2

5.4. Comparison of Mineral oil and Synthetic Fluid For 2 Open Rack unit server

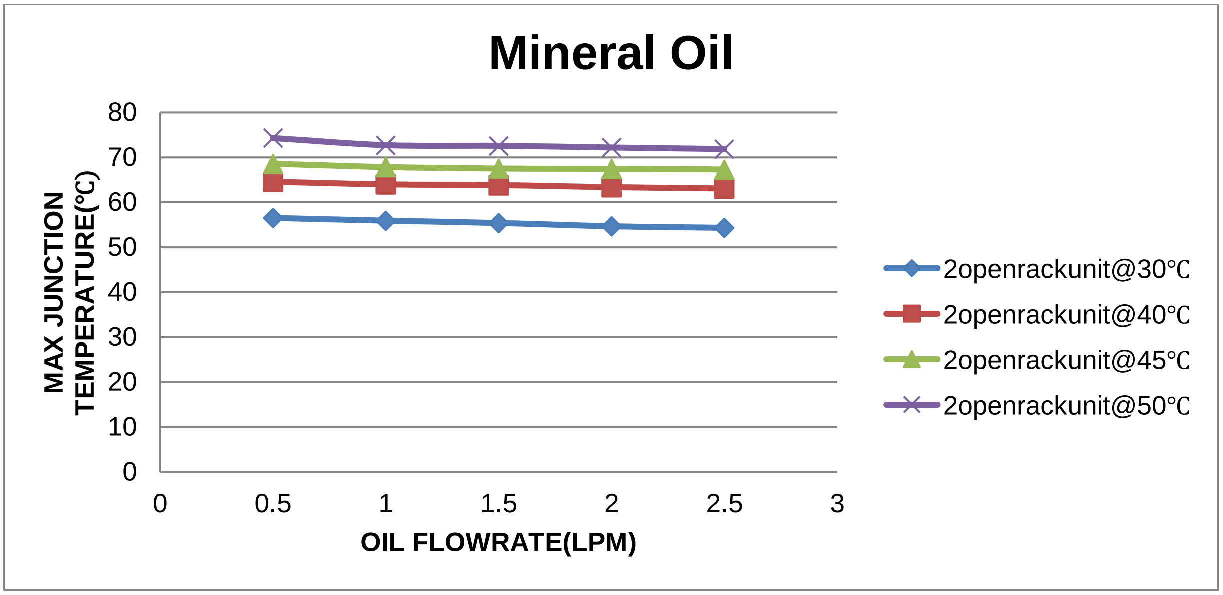

Figure 25 Max Junction Temp Vs Oil Flow rate at source2

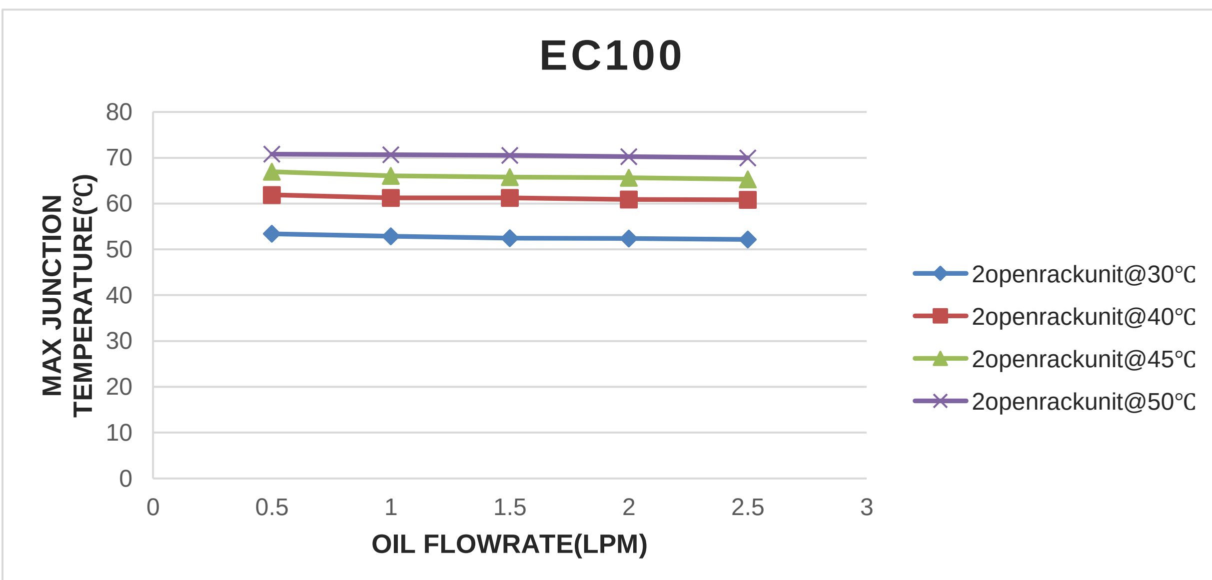

Figure 26 Max Junction Temp Vs Oil Flow rate at source2

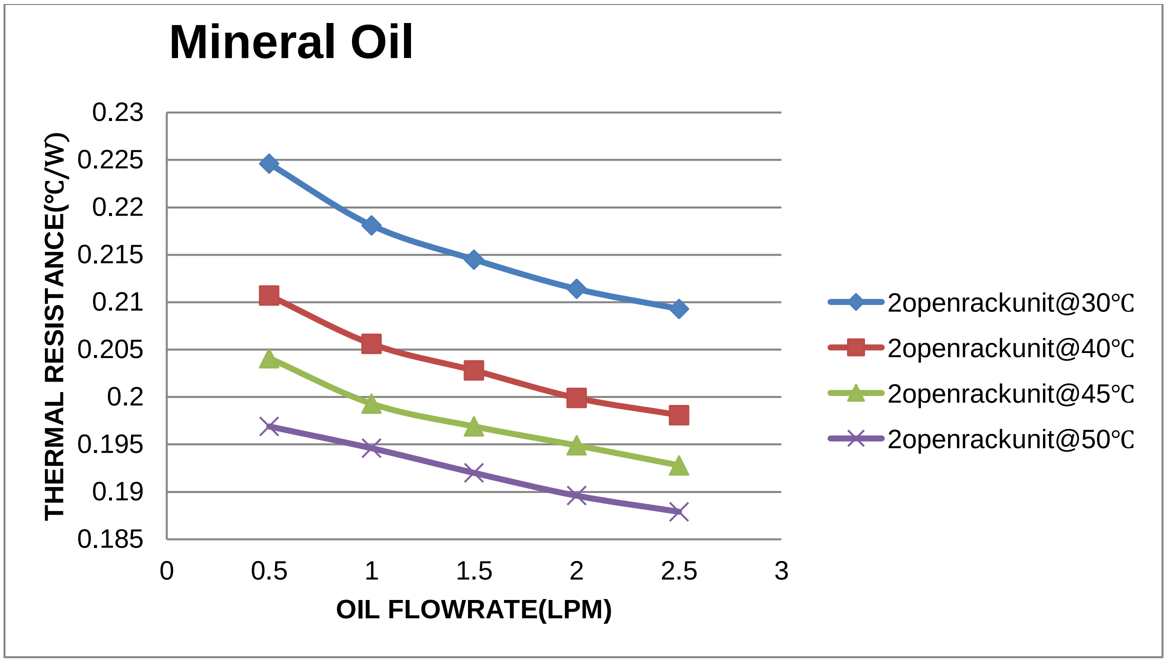

Figure 27 Thermal Resistance Vs Oil flow rate at source2

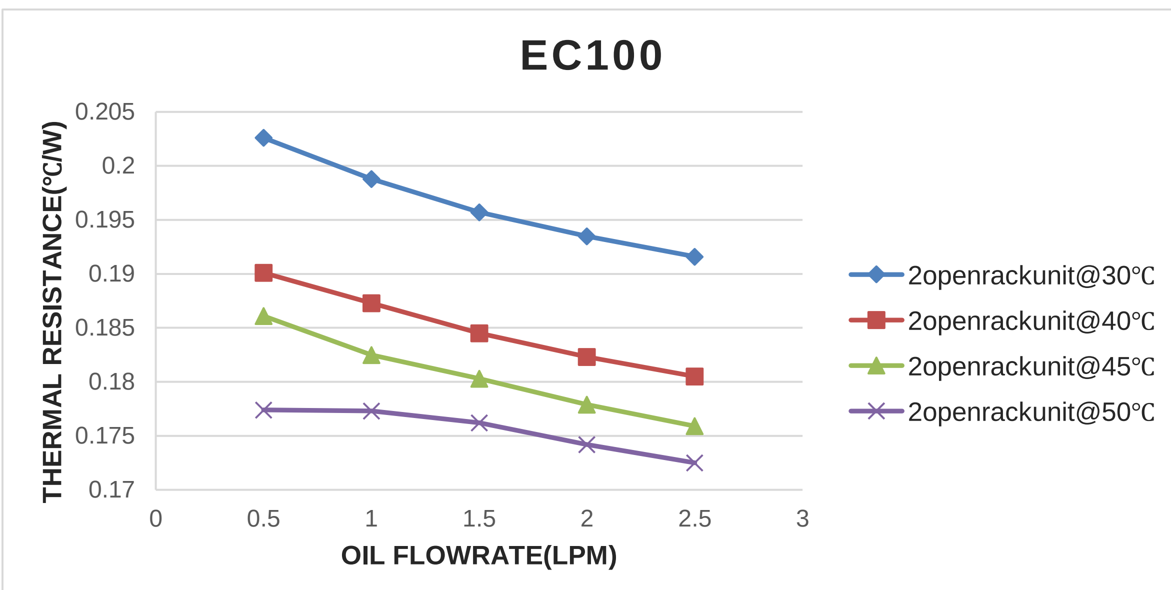

Figure 28 Thermal Resistance Vs Oil flow rate at source2

As the size of the server is high and also the inlet temperatures, we can see a lot of difference between the maximum junction temperature and thermal resistance values.

5.5. Best Result

Of all the simulations run on the server for different inlet temperatures, we have obtained the best results for 1.5 Open rack unit server @40℃ and a flowrate of 1LPM using synthetic fluid(EC100). It is advisable to keep the oil flow rate in the range of 1 to 2.5 lpm for effective cooling of servers especially with 1.5 Open rack unit server form factor.

1.5openrackunit@40℃	
Temperature	Thermal resistance
60.68	0.2256
60.23	0.2086
59.7	0.199
59.6	0.1906
59.54	0.1875

Table 10 For Source 1 @40℃

1.5openrackunit@40℃	
Temperature	Thermal resistance
64.69	0.1887
62.9	0.1838
61.84	0.1792
60.94	0.1783
60.63	0.1778

Table 11 For Source 2@40℃

5.6. Conclusions

- Ducting system can be removed completely as the fluid flow need not be guided to the second heatsink.
- The comparative study carried out for white mineral oil and synthetic fluid shows an enhancement in thermal management for synthetic fluid (EC100) mineral oil for the same inlet temperatures.
- This study clearly indicates that the single-phase immersion cooling is efficient and capable to accommodate high thermal mass.
- By using single phase immersion cooling we can cool the server at low flowrate and high inlet temperatures.

CHAPTER 6

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Biographical Information

Pranavi Rachamreddy was born in Andhra Pradesh, India. She received her Bachelor of Engineering in Mechanical Engineering with an excellent grade of 4 GPA from G. Pulla Reddy Engineering College, Andhra Pradesh, India in the year 2016. She started her Master of Science from University of Texas at Arlington in Fall 2016. During her master's program she conducted her research in the field of thermal management under Dr. Dereje Agonafer. She has indulged herself in various industry collaborated projects and gained extensive experience working in laboratory environment. She has worked with computational characterization of rack mount servers. Pranavi Rachamreddy received her Master of Science in Mechanical Engineering from University of Texas at Arlington in May2018