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MEASUREMENT OF THE THERMAL PERFORMANCE OF A SINGLE-PHASE IMMERSION COOLED SERVER AT ELEVATED TEMPERATURES FOR PROLONGED TIME

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ABSTRACT

Fully immersion of servers in electrically nonconductive (dielectric) fluid has recently become a promising technique for minimizing cooling energy consumption in data centers. The improved thermal properties of these dielectric fluids facilitate considerable savings in both upfront and operating cost over traditional air-cooling. This technology provides an opportunity for accommodating increased power densities. It also minimizes the common operational issues of air cooling technique like overheating and temperature swing in the system, fan failures, dust, air quality, and corrosion. This paper presents various data about the thermal performance of a fully single-phase dielectric fluid immersed server over wide temperature ranges (environment temperatures) from 25°C to 55°C for prolonged periods in an environmental chamber. This work explores the effects of high temperatures on the performance of a server and other components like pump, along with potential issues associated with extreme climatic conditions. The experimental data serves as a means to determine failure criteria for the server and pump by subjecting the system to accelerated thermal aging conditions i.e. around 55°C, consequently simulating the most extreme environmental condition that the server may encounter. Connector seals are inspected for expected degradation upon temperature cycling typically at such extreme conditions. Throttling limit for the server and pump power draw for different temperatures was determined to assess pump performance. Determining the relations between component behavior and operating temperature provides an accurate measure of lifetime of a server. The scope of this paper can be expanded by reviewing the effects of low temperatures on server and component performance. Changes to various performance parameters like power draw of pump and server at the higher and the lower operating temperatures and an understanding of issues like condensation can be used to quantify upper and lower limits for pump and server performance.

INTRODUCTION

In this fast-growing world, millions of individual users along with many large and medium enterprises access and store online content on the World Wide Web. Because of this ever-increasing demand, the data center cooling costs are constantly on the rise. Cooling typically accounts for 40% of a data center's total energy bill [1]. Removing heat constantly from the data centers is the one of the biggest concerns as with increase in heat densities of electronic components and densities at the rack level; air becomes less capable of efficient cooling. Due to this inadequacy of traditional air-cooling, many discussions are focused on the new immersion technology. Submerging servers and IT equipment in a dielectric medium for cooling provides substantial energy savings as it accommodates heavy energy loads and density [1], [2].

There are many benefits of the immersion cooling: it helps keep the temperature constant irrespective of changes in server workload. This is because its heat capacity by volume is 1120-1400 times greater than air [1], [2]. The server is in a good isothermal environment. Another advantage is server hygiene. In traditional air-cooling, some dust and dirt particles enter the facility. These dirt and dust particles get accumulated inside the chassis with the computers and lead towards the mechanical failure.

Immersion cooling also minimizes common operational issues and eliminates the causes of failure like solder joint failures. It provides benefits like even operating temperature for PCB components, prevention of oxidation or corrosion of electrical contacts, no moving parts like fans, no sensitivity to humidity or any temperature condition. Operating expense of this equipment is exceptionally low [2]. Single-phase immersion cooled servers are simple, easy to manufacture and inexpensive.

Figure 1, shows the flow path of immersion cooling system. The low temperature dielectric fluid is pumped into the server system. The dielectric fluid absorbs the heat from the system and exits at higher temperature. The fluid is cooled in a heat exchanger and is pumped back into the system. The server used here for the study has a pump inside the chassis.

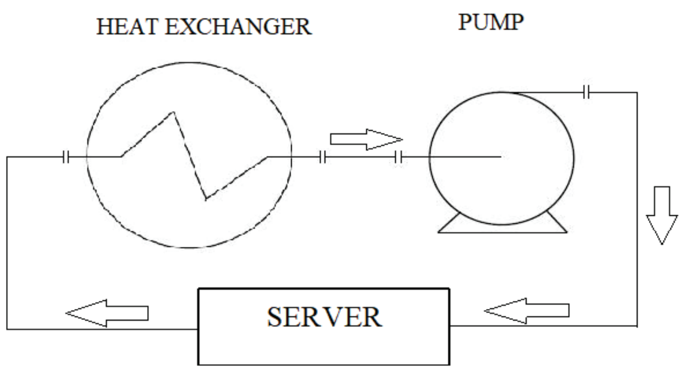

Figure 1: Schematic diagram of immersion cooling system

Most of electronic failures happen due to thermally induced stresses and strains caused by excessive differences in coefficients of thermal expansion (CTE) across materials. This experiment is based on thermal cycling and thermal aging process. It reviews the effects of high temperatures on the single-phase dielectric fluid submerged server, which provides a helping hand to validate the ruggedness and robustness of the server. The performance of a server and other components like pump and connectors sealing were observed at different temperature cycles typically between 25°C to 55°C (higher temperatures than the operating temperatures typically found in air cooling based on ASHRAE Thermal Guidelines) at 50% RH. Some additional relations and properties of different components, examined like power draw vs temperature. This research helps to determine the threshold limit of a server with the higher temperature and qualifies the robustness of the system for its reliability and performance.

SERVER CONFIGURATION

In this experiment, a server, which is fully, immersed in a single-phase dielectric fluid is used. The server comprises a computer system and an internal pump, which circulates cooling medium i.e. dielectric fluid through the system. Two passive heat exchangers transfer heat from the system to the surrounding environment. Rugged hoses conduct the cooling liquid between the enclosure and the heat exchanger. Specifications of the server and the fluid are as follows:

Server dimensions: 2.3”(H)x8.1”(W)x15.3”(L).

Server Specification: Windows i7 5thGen with Quad core processor.

Storage: NVME SSD, 1 x mSATA III SSD, SATA SSD

Pump Specification:

- Dimensions (WxDxH) of the pump are 90x62x38mm.
- Motor have electronically commuted ball bearing.
- Nominal voltage and power consumption: 12V DC and 18W.
- Maximum flow rate and system temperature: >900 l/h and 60°C.
- Materials in contact with the coolant: Stainless steel 1.4571, PPS-GF40, EPDM O-Rings, Aluminum oxide.

Pump in the server is maintained at its maximum rpm, which is 6000 rpm. Pumps rpm did not change with the load of the server. Server have rugged seal enclosure and waterproof I/O connectors, which is IP67 Rated. Electronics are protected from air particulates, moisture contaminants and other contaminants [8]. Customized heat sink is used in the server. It is EKWPs vertical impingement heat sink where fluid can flow in both directions.

Software used:

Prime 95:

Prime95 is one of the most popular CPU stress-testing program. It tests the computer for stability issues by stressing CPU to its maximum limit. Prime95 runs Lucas-Lehmer iteration indefinitely and only terminates a stress test when it encounters an error and informs the user that the system may be unstable. Prime95's stress test feature can be configured to test various system components by changing the Fast Fourier Transform (FFT) size. There are three pre-set configurations available. First, one is Small FFTs primarily tests FPU and CPU caches. Second is In-Place FFTs gives maximum power consumption and tests FPU and CPU caches, some part of RAM and the last one Blend which tests everything including RAM. In this experiment small FFTs option is been used since it tests FPU at maximum stress and system operates in more stable condition [11].

Core temp:

Core Temp is a compact program to monitor CPU temperature. It can show the temperature of each individual core in each processor. It shows real time core temperature when the load of the server varies. Core Temp is completely motherboard independent. The temperature readings are very accurate as the software is collecting the data directly from a Digital Thermal Sensor (or **DTS**). DTS is located near the hottest part of each core. This sensor does not rely on an external circuit located to report temperature, all core temperature values is stored in the processor. Core temp software can access and provide real time reading. This method eliminates any kind of inaccuracies [4].

Dielectric fluid:

The server is fully submerged in a single-phase dielectric fluid. The properties of the dielectric fluid (Opticool 872552) are given in the Table (1). Flash point of the dielectric fluid is 185°C. Dielectric fluid provides great cooling efficiency, safety and thermal stability at a low cost. It is designed to use in circulating systems, which includes both heating and cooling systems of electrical applications [9].

Table 1: Property Table

Temp °C	Kinematic Viscosity (cSt)	Dynamic Viscosity (poise)	Specific Heat (kw-s/kg-K) (J/g/K)	Thermal Conductivity (W/m/K)
0	18.8	0.1519	2.054	0.1381
10	12.5	0.1002	2.092	0.1375
20	8.82	0.0701	2.129	0.1369
30	6.52	0.0514	2.167	0.1364
40	5.00	0.0397	2.204	0.1358
50	3.96	0.0307	2.242	0.1352
60	3.22	0.0247	2.280	0.1346
70	2.69	0.0205	2.2317	0.1341
80	2.27	0.0171	2.355	0.1335
90	1.95	0.0146	2.392	0.1329
100	1.70	0.0126	2.430	0.1323

EXPERIMENTAL SETUP

Environmental chamber:

Thermatron SE-600-10-10 environmental chambers provide versatility in testing environments. In other words, Thermotron Environmental chamber provides the user to change its environment as per user fed values, i.e. user can control the humidity and temperature values as they wish. In this experiment, the server is kept inside a Thermotron SE 600 Environmental chamber, and the thermocouples were attached at various locations on the server. Temperatures ranges from -70°C to 180°C (-94°F to 356°F) and humidity ranges from 10% to 98%.

Thermocouple:

In the experiment T-Type thermocouples were used. The Type T is a very stable thermocouple and is often used in extremely low temperature applications such as cryogenics or ultra-low freezers [5]. The type T has excellent repeatability between –380°F to 392°F. Temperature Range of Type T is from -454°F to 700°F (-270°C to 370°C) and Standard Accuracy is +/- 1.0C or +/- 0.75% [5].

DAQ and Multiplexer:

In this experiment, Agilent 34972A DAQ system was used to log the temperatures of the thermocouples. DAQ's capability of combining the precision measurement with various signal connections makes this instrument very versatile and reliable. It also has three module slots into the rear of the instrument to accept any combination of data acquisition component or multiplexer (MUX). All the data were recorded directly in the through its pre-installed Agilent 34901A software in the system. This software gives more flexibility for logging data as user desire [12].

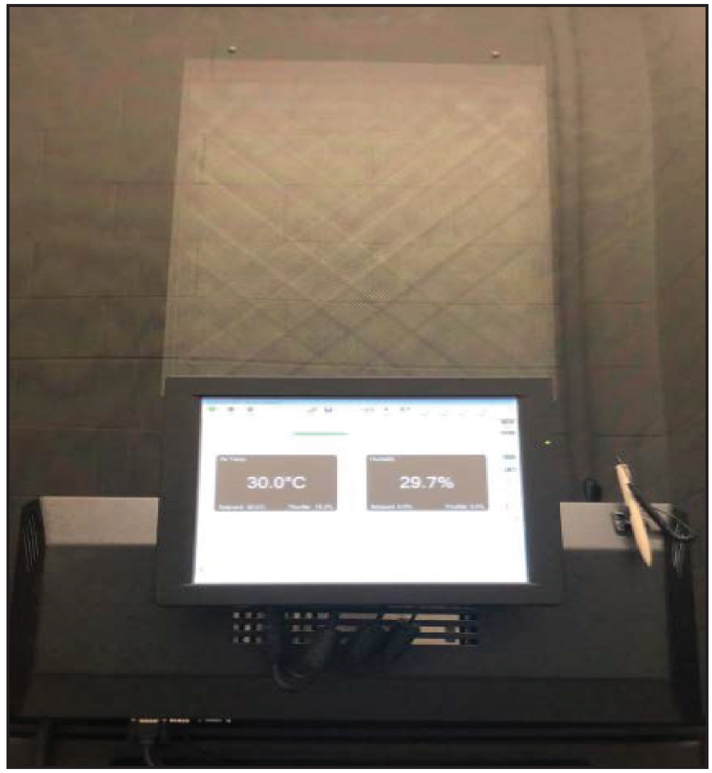

Figure 2: Thermatron SE-600-10-10 Environmental Chamber

Power meter:

The Power meter used in this experiment was Watts Up Pro (Figure 3). It is one of the efficient, precise, and accurate power measuring devices. This device logs data at any interval defined by the user. It measures total server power and not only power but also voltage, current, cost, watt-hour, power factors, duty and power cycle etc.

Figure 3: Power meter

METHODOLOGY:

Positions of thermocouples:

T-type thermocouples attached on the server at eight different locations. Figures (4 and 5) show the precise locations of the thermocouples on the server. Nomenclatures are as follows:

- Ch-1: Top of the server
- Ch-2: Left of the server
- Ch-3: Right of the server
- Ch-4: Inlet of the server
- Ch-5: Outlet of the server
- Ch-6: Connector of two radiators
- Ch-7: Calibrator Front (Air)
- Ch-8: Calibrator Back (Air)

Calibration of thermocouples:

After attaching all the thermocouples, the server was placed in the environmental chamber. Before starting the actual experiments, the thermocouples were calibrated. Calibration was done in following order:

1. After attaching one end of all the thermocouple on server, the other end was installed in the Agilent 34901A 20 Channel Multiplexer Module.
2. The server was placed in the middle of the environmental chamber as shown in Fig 6. Multiplexer module was then inserted in the Agilent 34972A DAQ system. Connectivity of the thermocouples were checked when the Agilent system was switched on.
3. Environmental chamber was taken online and was allowed to set at temperature (25°C).
4. Once temperature was set, the thermocouples were checked through the DAQ systems. The variation between the thermocouple measured temperatures and the temperature in the environmental chamber was only -/+ 1 °C.

After calibration of the thermocouples, the server was started and 100% load was given by Prime 95 software. The temperature of the chamber was set to 25°C with 50% RH. The experiment was performed for 4 hours. The voltage, current, power and all four core temperatures were logged at the interval of 15 minutes by the power meter and software Core Temp respectively. Temperatures of the thermocouples were logged manually from DAQ display.

After 4 hours, the chamber was stopped and opened. Inspection was done on the server to check for any leakage from the connectors, abnormal noise, and condensation on the radiators. After inspection, the server was kept idle for 4 hours allowing it to reach to its normal state and the next experiment was performed. This procedure was repeated for the different chamber temperatures of 30°C, 35°C, 40°C with 50% RH and all the parameters were recorded. For 45°C, 50°C and 55°C same experiment was performed but for longer period of time i.e. for 8 hours with 50% RH. Temperatures of thermocouples and core were recorded at every 30 minutes by the systems. After above experiments, server was tested at 45°C for 144 hours. This experiment was done to perform the detailed analysis of server performance. Core temperature were recorded at every 2 hours of interval, inlet and outlet temperature of the fluid and power was recorded at every 4 hours of interval. Longer duration experiments were performed at higher temperature to check the reliability and performance issues of the server.

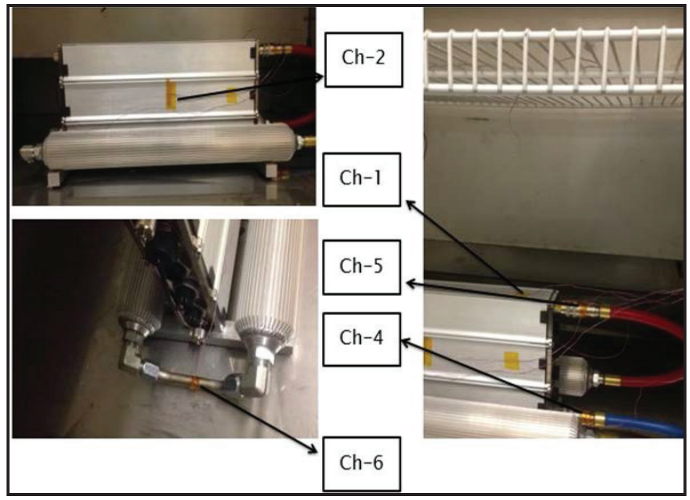

Figure 4: Front side of the server

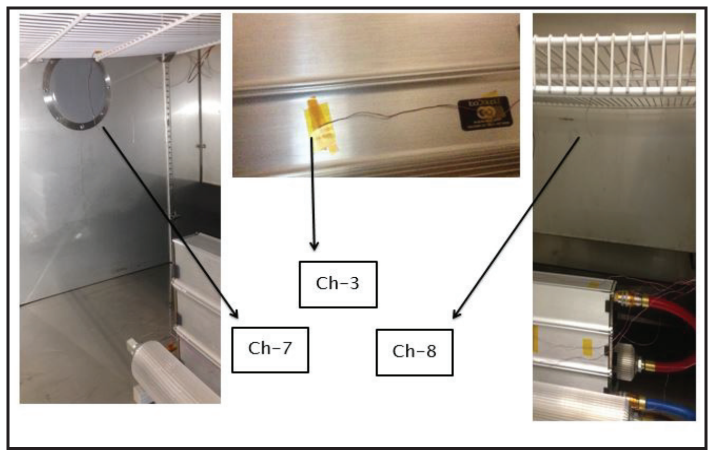

Figure 5: Backside of the server

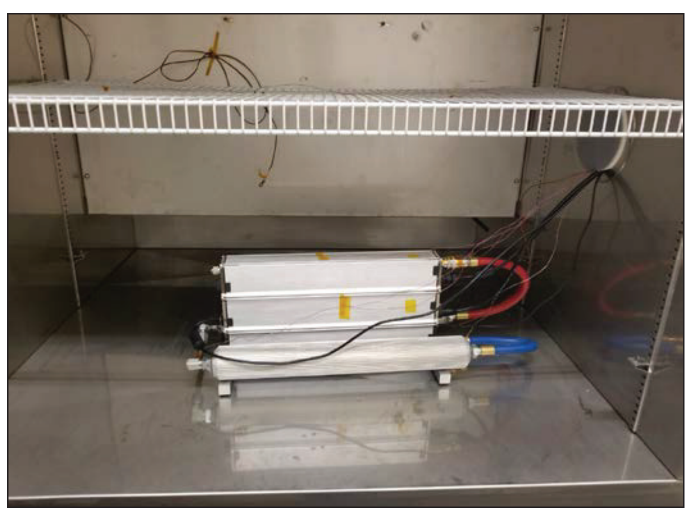
Figure 6: Experimental Setup in the environmental chamber

RESULTS

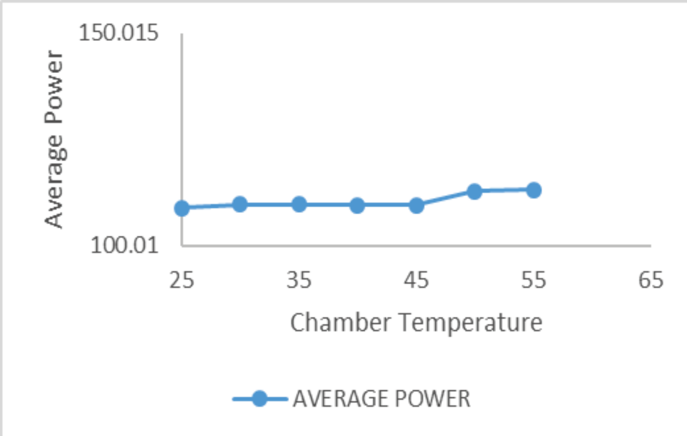

Figure 7: Average power (W) vs Temperatures (°C) graph

Figure 7 shows the variation of average power with respect to environmental chamber temperature. At 25°C the power consumption of the server is 109.1 Watts, which steps up to 109.6 Watts at 30°C and remains constant until 45°C. After 45°C, it rises to 112.8 Watts and 113.2 Watts for 50°C and 55°C respectively. This power increase at the higher temperature is due to decreasing pump power and increasing leakage current of the pump. This is because of the low viscosity of the fluid at the higher temperature.

Figure 8 shows the average core temperature of server with respect to the changing chamber temperature. At 25°C, all core temperatures were below 65°C. It is noticeable that average core temperature is increasing drastically with the rising chamber temperature. At 55°C, core 0 temperature almost reached the Maximum Junction Temperature (T_j) of the system. The set junction temperature of the system is 92°C. Same pattern observed for all other core temperatures.

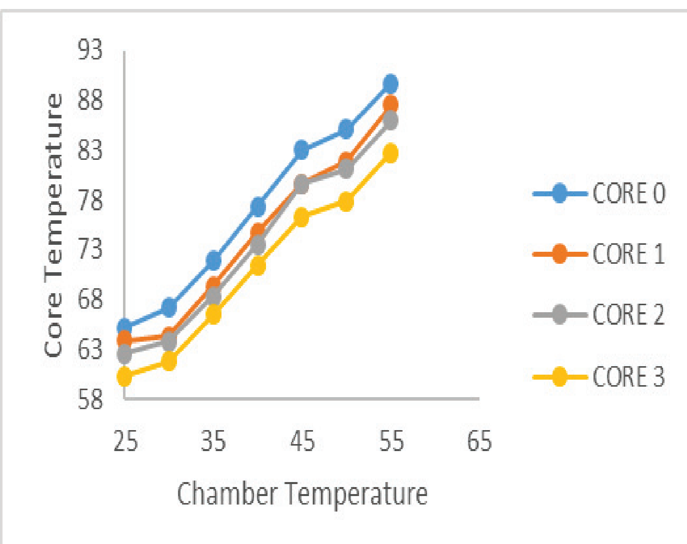

Figure 8: Average Core temperature (°C) vs Chamber temperature (°C)

Figure 9 shows average Inlet/Outlet temperatures of the server with respect to the environmental chamber temperature. It is evident that there is almost 1°C difference between inlet and outlet temperature of the server. Inlet and outlet temperature is the temperature of coolant entering and exiting the server respectively as shown in Figure 4.

Figure 10, 11, 12 are the results of the experiment which was performed at 45°C for 144 hours. At every 2 hours of interval core temperature reading was recorded. Similarly, inlet and outlet temperature of fluid and power was recorded at every 4 hours of interval.

Figure 10 shows core temperature of the server with respect to time. Server core temperatures was almost constant in the cycle. Maximum range of temperature for the all core is around 4 °C. It is evident that the average core temperature of each core is almost same as shown in Figure 8.

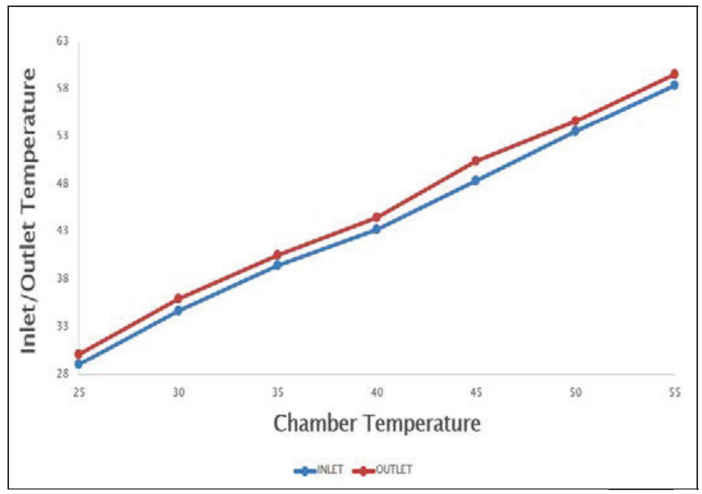

Figure 9: Average Inlet and Outlet temperatures (°C) vs Chamber temperatures (°C)

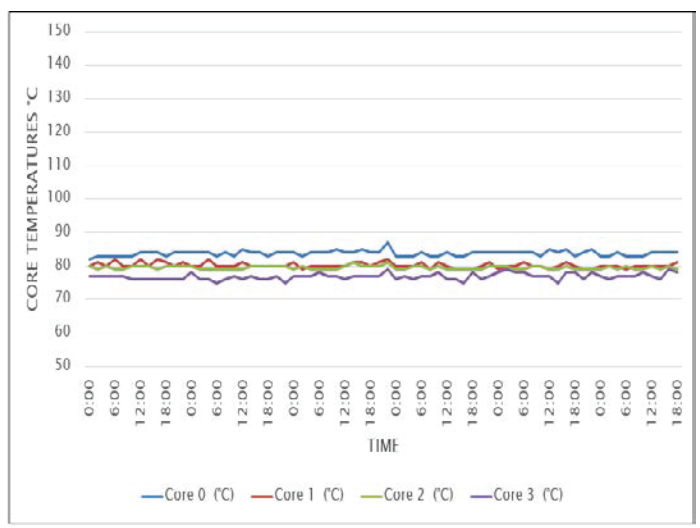

Figure 10: Core temperature (°C) vs Time (Hours)

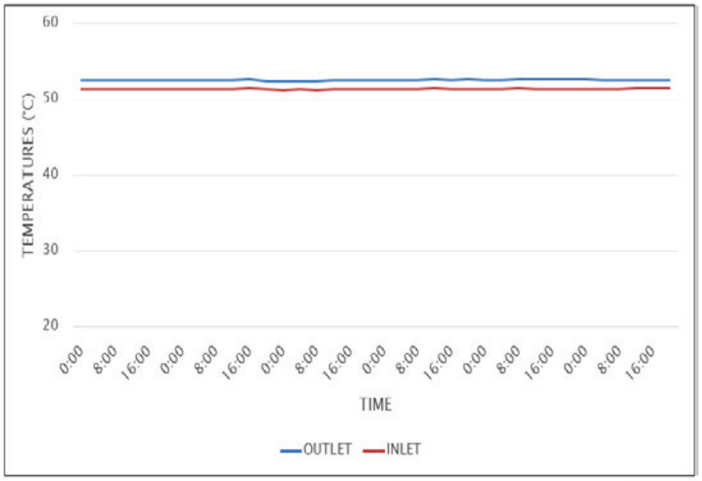

Figure 11: Inlet/Outlet Temperature (°C) vs Time (Hours)

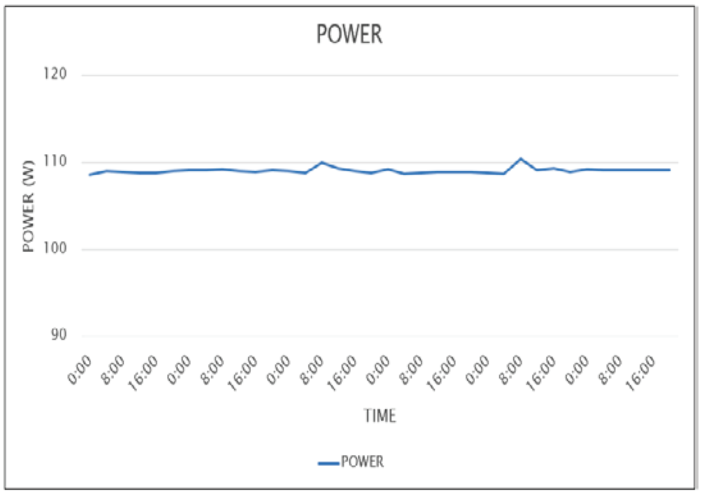

Figure 12: Power (W) vs Time (Hours)

Figure 11 shows Inlet/Outlet temperatures of the server with respect to time. The pre-installed Agilent software did data logging at every 4 hours of interval. The difference between inlet and outlet temperature was around 3°C. Figure 9 shows the temperature difference of 1°C for all the environment (ambient) temperature of the server. The increase in the temperature difference can be due to

Figure 12 shows server power with respect to time. It is evident that the average power consumption of the server at 45°C is around 109W, which is same as shown in Figure 7. The power consumption of the server was almost constant for the whole cycle (144 hours).

CONCLUSION

From the experiment results, it can be inferred that the fully submerged server can be used in extreme weather conditions. As there is no direct contact with the surrounding environment the reliability of the server increased. At elevated temperatures, the server was performing efficiently without compromising its reliability. From above results, hereby we can conclude that the server threshold temperature is 55°C as the core junction temperature reached its maximum temperature limit, which is 92°C. There was no leakage through any connectors and no abnormal noise from the server. The server is robust and can withstand the harsh environment as well. From 144 hours of experiment, it is evident that the performance of passive heat exchanger was very efficient. This server can be adapted in military and industrial applications as its performance was very efficient and showed very promising results in high temperatures. The waste heat from the server can be reclaimed thus the thermal efficiency can be increased further. Since the server is compact the size of racks can be reduce which will further reduce the initial capital cost.

ACKNOWLEDGEMENT

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