Castrol Coolant Safety Study with Intel's Open IP Immersion Cooling Solutions for Data Center Deployment

Technical Paper

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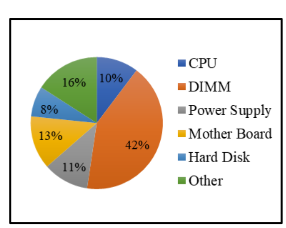
Executive Summary

With the booming development of artificial intelligence applications, a large amount of data is generated. To handle these massive amounts of data, thousands of data centers have emerged. The TDP of CPU and GPU has also increased exponentially to obtain better performance, causing traditional air cooling to reach a bottleneck. In addition, the energy required for the cooling of a data center makes up close to 40% of the total energy consumed[1]. Immersion cooling (completely immersing the hardware in a dielectric fluid to remove heat from the device) not only addresses the heat generated by high TDP CPUs and GPUs, but also reduces the Power Usage Effectiveness (PUE) of the data center. However, as immersion cooling is gradually used in different scenarios such as high-performance computing and edge computing, end customers urgently need to understand the safety of the dielectric fluid for immersion cooling. The following paper showcases the results of this consortium to the data center industry and demonstrates safe testing methods for immersion in coolant.

In immersion cooling design, many kinds of fluids have been adopted by customers; fluorinated-based fluids and hydrocarbon-based fluids are used as typical liquids to immerse electronic components. Among them, fluorinated-based fluids have inflammable behavior and have been used in edge computing and enterprise customers for a while, but because of high Global Warming Potential (GWP) and hazard risk, they are fading out in Europe and the US step by step. Hydrocarbon-based fluids are another kind of immersion cooling solution in data center since they have good thermal properties, but the IT industry is concerned about flame-related flash point of fluids. Customers are eager to understand hydrocarbon-based fluid immersion cooling safety test. To fill this gap of industry, the alliance provides several methods to measure the liquid immersion cooling safety. The focus of this paper is on hydrocarbon-based fluid.

This paper also exploits the power supply unit of the server to ignite unsafety conditions for immersion cooling fluid. When a power supply unit is damaged, a large amount of heat will be generated, and arcs or sparks may easily occur due to electrode rods, fuse, and so on. In Figure 1, according to Baidu Cloud historical data, power supply unit crashes account for 11% of server hardware failures. Therefore, the failure of the power supply unit is also a risk issue in the data center. [2]

Figure 1. Breakdown of Hardware Failures



This technical paper introduces the collaborative research results of Intel and Castrol* on the safety of immersed cooling hydrocarbons-based fluid and collaborates with OPEN IP community members Foxconn Industrial Internet* (Fii*) and Gospower* to verify hydrocarbons-based fluid safety in real immersion cooling environment.

Introduction to Castrol ON Single-Phase Immersion Cooling [3]

Castrol ON's comprehensive range of single-phase immersion cooling fluids has been developed to meet the needs of data centers, edge computing, blockchain, and other IT applications.

Immersion cooling can help to increase the overall efficiency and sustainability of IT operations while ensuring hardware integrity due to material compatibility properties as well as ensuring safe operations.

Test Methods for Single-Phase Immersion Cooling

In this technical paper, Intel's 2U Open IP Immersion Cooling system in Figure 2[4] is being used.

Figure 2. 2U 3kW AAIC Intel's Open IP Immersion Cooling Tank

This 2U system is a stand-alone system and easy to deploy in any kind of environment, especially in harsh environments. This 2U with a 3kW cooling capacity shares the same uniform flow field design and modular scalable features. This immersion cooling system is tested as an immersion cooling environment, the figure shows and engineering prototype. This immersion cooling reference solution can be used for 12U, 24U, 36U, 48U, or larger form factor tank designs, along with multiple CDUs for both edge and hyperscale data centers. The 2U4N modular server immersed in the immersion cooling environment is designed by the Fii with Gospower's PSU. The hydrocarbon-based fluid is Castrol ON DC 15 fluid (Kinematic Viscosity around 7.79 cSt at 40°C, the flash point is 168°C with open cup method).

For the flash point measurement of fluids, the fluids are testing in a standard cup (open cup or closed cup), in the device, the sample is contained and heated. When it is heated to specific temperature, its flash point could be measured by a flame above the liquid surface. In real data center environments, the liquid would not be completely heated over operating temperature, for example at 50°C. It would be incomprehensible if only the flash point is used to be strongly related to evaluating the safety of immersion cooling. Therefore, an innovative test methodology was used to evaluate the liquid safety or the safety of surface liquid, which is a liquid-vapor mixed with air. Liquid safety was measured by igniting flame, heat, arc, and spark when the AI high-power 3500W power supply unit (3500W CRPS power from Gospower) failed. The safety of the liquid surface, which mixed the liquid-vapor and air, was evaluated to achieve sufficient natural or mechanical ventilation, avoiding flame on the surface.

In addition, the immersion cooling environment requires measuring the heat dissipation capabilities of the server and power supply at 30°C, 40°C, 50°C, and an ambient temperature of 30°C. According to the modeling results, the fluid flow rates used in this test were 1.2 LPM and 0 LPM. In addition, the air-cooling inlet 32000 rpm and 35 CFM are used as a benchmark.

In this collaborative testing, a comprehensive setup allowed us to research liquid or its surface in multiple conditions and investigate the efficiency of immersion cooling in marinating thermal stress for the IT hardware while maximizing performance and reliability.

a) Liquid Safety Test

In this collaborative testing, the flame propagation in immersion cooling liquid was evaluated using failure factors by high-power power supply unit. The main causes of server power failure include electrical failure, overheating, equipment failure, unsuitable environmental conditions, and human errors, among others. In this test, electrical faults, such as short circuits, overloads, over-voltage, slow change, and overheating were used to investigate if immersion cooling safety was sufficient. Table 1 defines the different causes of power supply unit failure, proving that immersion cooling can even prevent IT components from being badly damaged.

Table 1. High Power Supply Unit to Simulate Failure Conditions

Power supply condition	Failure Causes
Over voltage	Heat, Power
Over temperature	Heat
Overloading	Heat, Power
Slow charge	Spark
Short-circuit	Power, Heat, Spark
Circuit breaker trip	Fuse, Heat

b) Surface of Liquid Safety Investigation

After operating the immersion cooling tank for a while, the vapor of liquid would be produced. When it is mixed with air or oxygen, it will propagate a flame if it is ignited by spark, flame, and arc. Fundamentally there are three factors necessary to sustain a flame - heat, combustible vapor, and oxygen. When one of the factors is eliminated or limited, the risk of flame would be inhibited even if the other two are in abundance. Therefore, the control of the surface of liquid safety could be achieved by sufficient natural or mechanical ventilation to control the concentration of vapor to a maximum to prevent the unsafety conditions studied in this cooperation.

c) Immersion Cooling Efficiency Discussion

Immersion cooling could also lead to improved thermal management efficiency, it can be proved by comparing thermal stress with air cooling. Besides the high TDP CPU or GPU, the PSU is the main heat source in the immersion cooling environment. Improved PSU efficiency will benefit to the whole system, and the fluid can keep safe performance when the PSU is under high loads and high temperatures which are fully verified in this cooperation.

Immersion Cooling Power Safety Test Classifications

Liquid Safety Test

(1) Over Voltage to Test Liquid Safety

The power supply unit's under-over voltage would reach high power, generate heat, and cause the risk to a flame in air cooling. If the test is in immersion cooling fluids, the heat caused by over voltage would be risk for hydrocarbon fluids. In this test, repeatedly cycles using the maximum overvoltage to 285 VAC, the power supply unit performed from 266 VAC for 10 seconds to 285 VAC for 10 seconds as a cycle for 100 times. The fluid had no abnormal performance, and no flame occurred.

(2) Over Temperature Protection Test

The power supply was heated in immersion cooling fluids by from 50°C, gradually increasing the temperature of the power adapter using an external heater, the power adapter reacts during the heating process should be recorded as well, the heating rate was 1°C/five minutes. The power failure protection to avoid overload and ensure the safety of the test environment. Test methods include measuring the initial temperature of the power adapter with a thermometer, If the over-temperature protection function is working properly, the power adapter will automatically reduce or cut off the output power when the temperature reaches the specifications. During the test, the flow rates of power supply unit part is 1.2 L/minutes, and static condition.
When temperature of liquid reach to over temperature protection of power supply unit, which temperature was 65°C, the fluid showed no abnormal performance, and no flame occurred.

(3) Main and Secondary Side Overloading Test Removal Protection

Server power supply unit over-loading would be easy to exceed the power limit, generate lots of heat, and cause risk of safety and stability in air cooling, especially when the protection is removed, the fire or spark would be caused by the overloading situation. The requirement of main side and secondary side overloading test in an unprotection situation, the fire or spark caused by power supply should be inside of the power supply but was self-extinguish when the flow rate was 1.2 L/min, and static condition, compared in air condition, the power supply unit would cause damaged flame when main side reached to overloading conditions shown in Table 2.

Table 2. Circuit Overloading Limit

Circuit	Overloading
Main side	>150%
Secondary side	>200%

In this test, when the main side reached 180% load, the output of the main circuit fell after 3 seconds. The standby circuit ran normally with load, the state light was still green, the input still had power, and it continued to run for another 30 min without abnormal performance for the power supply unit and immersion cooling fluid. When the standby circuit reached 230% load, the main circuit and standby circuit hiccupped, the protection was triggered, the state light went out, and the input power was still operated. It continues to run for another 30 min without abnormal performance for the power supply unit and immersion cooling fluid.

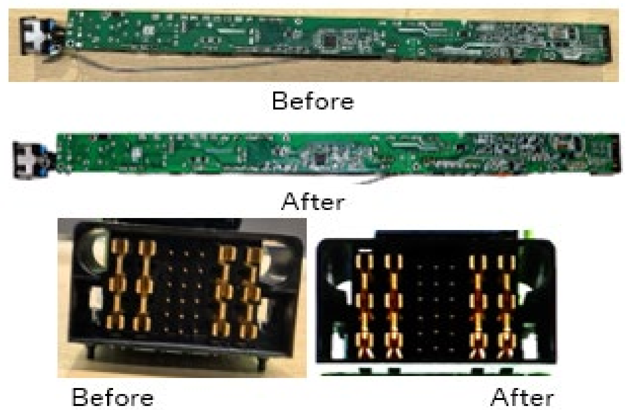
(4) Slow-charge Test

Power drops would increase the risk to fluids because the circuits are instability caused by the power supply when it is plugged in, such as power oscillation, system reboot, or connector ignition. The slow change test of the power supply unit was used to evaluate this risk because it would cause a spark in air cooling, especially when removing the protection. The voltage rate was 0.03 V/S to ensure the spark was ignited by the power supply unit, but in an unprotection situation, it did not cause any flame in the fluids.

(5) Short-circuit Test

By an overload or short circuit situation, the IT component would cause hardware damage. If the protection was removed, the fire or spark would be caused in air cooling. During this test, the fluid was tested when the power supply unit was in an unprotection situation, the fire or spark caused by the power supply unit. It did not cause any flame after the short circuit when the flow rate was 1.2 L/min and static condition. Additionally, the appearance of the power supply unit hardware should be observed and recorded because the obvious corrosion on the surface of the power supply, including cracks and rust spots, would be caused by a spark or flame when a short circuit happens. The color of PCB inside the power supply was not changed, the device and core hardware were not damaged.

Figure 3. The Power Supply Unit Appearance



(6) Circuit Breaker Trip Test

When the input trips, the fuse should be blown to provide power supply self-protected and ensure that the input power supply should be stable, but it would generate a lot of heat and ignite flame. The tinned copper wire in this test, and the length of wire was 38 ±2mm. During this test, the power supply input voltage is from mains power to the circuit breaker trip and to forces the fuse to be blown. The protection is removed to measure if the server power supply unit reacts in an immersion cooling environment. It did not cause any flame after the fuses were blown when the flow rate was 1.2 L/minute and static condition.

Six circuit breakers from different suppliers were tested. The circuit breakers were fused, and they did not cause any flame after a short circuit.

(7) Fluids Analysis

The fluids test properties which shall be monitored for dielectric liquid when operating immersion cooling tank and failure of electronics. The specifications and requirements may be different because of varying conditions, and the fluid analysis is critical for keeping immersion equipment running safely. The fluid's health could be monitored online or offline; the test methods of common contaminants in immersion cooling solution are listed in Table 3.

Table 3. Test Methods of Common Contaminants in Immersion Cooling Solutions

Contaminants	Test Method
Solid particle	Particle counter
Water	Water content
Organic pollutants	The dielectric constant, Fourier Transform Infrared Spectroscopy (FT-IR) or Proton Nuclear Magnetic Resonance (H-NMR) detection
Unexpected mixture of liquid substances	Conductivity, dielectric constant, viscosity, FT-IR, Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES), gas chromatography-mass spectrometry.
Unexpected chemical products formed due to reactions	Conductivity, acid value, viscosity, dielectric constant, FT-IR, ICP-AES, gas chromatography-mass spectrometry
Other inert organic pollutants	Non-volatile residue testing, FT-IR or H-NMR detection

In normal operation testing, one smart online monitoring technique was introduced to provide real-time property feedback and fluid analysis. Compared to conventional fluid test and analysis procedures, which would be time-consuming due to fluid sampling, test, and report generation, online monitoring techniques can significantly decrease turn-around time while being available to observe continuous fluid parameter change. Insights of both long-term durability and instantaneous variation tendency can be developed by online monitoring, which would be helpful for operation and maintenance. A power supply unit hardware failure may cause contaminants to enter the system, and the performance of fluids should be investigated to avoid cascading damage caused by contaminants. The fluid was not changed or topped up during the test. After failure tests, the sample was taken for analysis. The results showed no significant changes compared with the reference.

Table 4. Fluid Analysis

Property	Test method	Unit	Reference	Fluid Analysis
Appearance	visual	NA	Clear and Bright	Clear and Bright
TAN	ASTM D664	mg KOH/g	<0.1	<0.1
Kinematic Viscosity at 40°C	ASTM D445	mm^2/s	7.8	7.8
Kinematic Viscosity at 100°C	ASTM D445	mm^2/s	2.2	2.3
Water content	ASTM D6304	ppm	<100	<100
Dielectric strength, measured at 1 mm	DIN 60156	kV/mm	>6[+]	10.8
Copper (Cu)	ASTM D5185	ppm	<1	<1
Iron (Fe)	ASTM D5185	ppm	<1	<1

[+]OCP base specification for immersion fluids

Surface of Liquid Safety Test

The reactions by ignitions in a liquid or its surface should be measured to evaluate the safety of the immersion cooling data center. The fluids in unsafe conditions would produce a flash of fire by igniting several sources, for example, arc, flame, and heat. The control of the surface of liquid safety could be achieved by sufficient natural or mechanical ventilation to control the concentration of vapor to a maximum to prevent unsafety conditions studied in this cooperation. Control of the explosion hazard is usually achieved by sufficient natural or mechanical ventilation, to limit the concentration of flammable vapors to a maximum level:

$$\frac{\mathrm{L_v}}{\mathrm{V-L}} \leq \mathrm{P_o}/101.3\ \mathrm{k\ Pa}$$

where:

L_v = Liquid Vapor Volume
V = Container Vessel Volume
L = Liquid Volume
P_o = Saturated Pressure

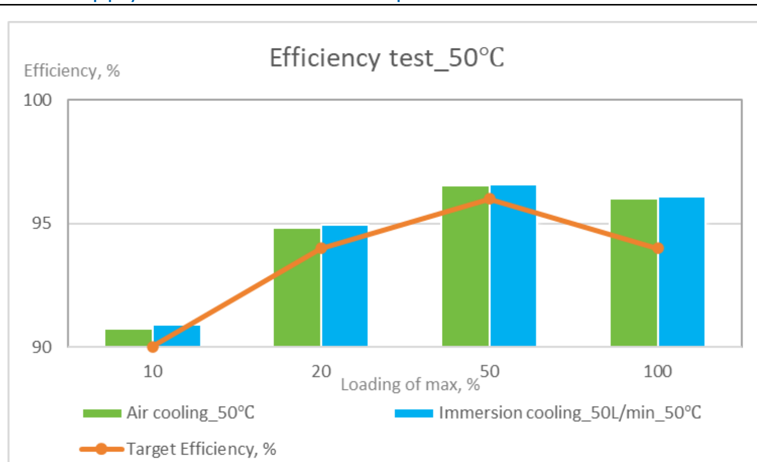
Temperature would influence limits. For example, the saturated pressure would be mainly impacted by temperature; the criteria should be measured at a reasonable temperature target in the equation. Moreover, higher pressure, as well as higher concentrations of the oxidizer (primarily oxygen in the air), contaminate vapor, or dust, would result in the adjustment of ventilation procedures. At the same time, it is also necessary to effectively manage the safety of liquid vapor with the firefight design of the data center and to follow the local regulatory requirements.

Reliability and Efficiency Improvement Test

(1) Efficiency test of power supply

In immersion research, improving the efficiency of IT components while ensuring the safe operation of equipment is also attracting attention. The fluid was test with power supply for improving the efficiency to meet efficiency demands from customers. At various inlet temperature, 30°C, 40°C, 50°C, efficiency performance increasement was observed and to compare efficiency performance between air cooling and immersion cooling. Be benefit from immersion cooling, efficiency could be improved.

Figure 4. Efficiency Result of Power Supply Unit for Tank Inlet temperature at 50°C



During testing, this power supply unit met the specification requirements; no smoke, no spark, and no fire was observed in the immersion cooling tank.

(2) Thermal Stress Test

The fluid was tested under thermal stress. The inlet temperatures for immersion cooling and air cooling are 30°C, 40°C, 50°C, respectively. In Table 5, when the inlet temperature is at 30°C, the average temperature in immersion cooling is 8.04°C lower than that in air cooling. When it is 40°C, the average temperature in immersion cooling is 11.00°C lower than that in air cooling. When it is 50°C, the average temperature in immersion cooling is 14.01°C lower than that in air cooling.

Table 5. The Average Temperature

Inlet Temperature, °C	30	40	50
Average Temperature in Immersion Cooling, °C	50.78	59.34	67.69
Average Temperature in Air Cooling, °C	58.82	70.33	81.70
Delta Average Temperature, °C	8.04	11.00	14.01

During testing, this power supply unit met the specification requirements; no smoke, no spark, and no fire was observed in the immersion cooling tank.

Conclusion

This article proves and promotes the safety test method of liquid immersion cooling through project-related work. The industry's technological development brings better application benefits to users by introducing this innovative and key technical method. The fluids used are safe in this specific immersion cooling environment. Moreover, not only fluid but also the key IT component failure performance was considered in immersion cooling. By testing and analyzing power supply failures in various situations, an electronic safety test method has been created and deployed in a real immersion cooling environment. The method will cover multiple test classifications to prove the safety of immersion cooling in a data center. Immersion cooling could also improve the efficiency and safety performance of the power supply unit in data centers. The IT hardware in unsafe conditions would produce a flame because of several sources, for example, arc, flame, and heat. Many safety professionals to be happened on exposure to this specific condition. Under proper operation, ignition causes, including electrode rods, spark, fuse, and power could be prevented by immersion cooling. The fluid used in this paper could prove to be safe if ignited by several unsafe conditions. The safety of immersion applications is not determined by a single element of the liquid but also requires the right environment, proper operation, fire protection, and a range of online or offline procedures to monitor the health status of the liquid. At the same time, it is also necessary to combine the corresponding safety management methods and fire safety measures with immersion cooling applications to provide a comprehensive and reasonable environment for the data center. In immersion cooling applications, fluid management or storage should follow local regulations, and the firefighting systems should be deployed in the larger data center accordingly.

Further Information

[1]. Energy Logic: Reducing Data Center Energy Consumption by Creating Savings that Cascade Across Systems

Energy-Logic-Reducing-Data-Center-Energy-Consumption-by-Creating-Savings-that-Cascade-Across-Systems-White-Paper.pdf (techplaninc.com)

[2]. X. Liu et al., "Smart Server Crash Prediction in Cloud Service Data Center," 2020 19th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems (ITherm), Orlando, FL, USA, 2020, pp. 1350-1355

[3]. ASTROL ON IMMERSION COOLING FLUIDS FOR DATA CENTRE AND EDGE APPLICATIONS

DATA CENTER AND IT COOLING | HOME (castrol.com)

[4]. Intel's Open IP Immersion Cooling Reference Solutions – Single Phase – 2U and 4U AAIC

https://www.intel.com/content/www/us/en/content-details/816305/intel-s-open-ip-immersion-cooling-reference-solutions-single-phase-2u-and-4u-aaic.html