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Compute Project

Guidelines for Using Dielectric Heat Transfer Fluids in Two-Phase Cold Plate-Based Liquid-Cooled Racks

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Executive Summary

This whitepaper provides a comprehensive framework for implementing dielectric heat transfer fluids within two-phase cold plate-based liquid-cooled racks. As computing power densities continue to rise, these fluids offer an efficient and scalable means of managing heat in high-power, densely packed environments.

The guidelines address fluid selection, material compatibility, system design, installation, operation, monitoring, and end-of-life handling. Emphasis is placed on interoperability, reuse of cooling infrastructure across IT refresh cycles, and alignment with recognized industry practices such as those promoted by ASHRAE and the Open Compute Project. By following these guidelines, data center operators, designers, and equipment vendors can reduce deployment risk, improve operational consistency, and accelerate the adoption of advanced liquid cooling technologies.

Ultimately, the framework supports multi-vendor ecosystems in which liquid cooling infrastructure can be reused across multiple generations of IT hardware.

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1. General Overview

This white paper outlines essential guidelines for the operation and implementation of dielectric heat transfer fluids in two-phase cold plate-based liquid-cooled racks. As high-performance computing systems demand more efficient cooling solutions, dielectric liquids have become an ideal medium for managing heat dissipation in densely packed, high-power systems. The guidelines aim to provide best practices for the selection, handling, and maintenance of dielectric fluids in two-phase cooling setups, ensuring optimal thermal performance, system longevity, and safety. Additionally, the document addresses operational considerations, fluid properties, and system design principles to support the effective integration of dielectric fluids into liquid-cooled racks, promoting both performance and reliability in modern data centers and high-performance computing environments.

1.1 Objectives

The objective of this whitepaper is to propose and promote guidelines for the operation of liquid- cooled computer racks using a dielectric liquid-based heat transfer fluid.

There are various options available for liquid cooling of IT racks, including different types of heat transfer fluids. The project owner and design team will need to evaluate the specific requirements of the project to determine the applicability of this whitepaper and make necessary modifications. Additionally, the construction contractor, IT system supplier, and heat transfer fluid supplier should collaborate to ensure the compatibility of all wetted materials and may suggest alternatives (see Section 5.1 for more details).

Compatibility is driven by the wetted materials, the heat transfer fluid, connectors, and operating conditions (e.g., temperatures and pressure). In the case of the heat transfer fluid, compatibility is particularly important with the wetted materials list.

The heat transfer fluid would be used in the secondary or closed loop between the heat exchanger (e.g., Coolant Distribution Unit (CDU)) and the cold plates or other heat exchangers within the rack/servers. This loop is designated the Technology Cooling System (TCS) by the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE). The overall goal is to encourage multi-vendor solutions for liquid-cooled computer racks where the liquid cooling infrastructure can be reused through multiple refreshes of liquid-cooled computer hardware.

The primary audiences for this whitepaper are design and facility engineers and managers who will be responsible for the design, procurement, setup and operation of the TCS loop. A secondary audience is the liquid cooling equipment suppliers and vendors whose products could be utilized.

1.2 Description of work

This guidelines document provides suggestions for the effective use of dielectric heat transfer fluids in two-phase cold plate-based liquid-cooled racks. The document aims to improve performance, safety, and reliability in the cooling systems of mission-critical facilities such as data centers.

Key components of the suggestions include:

- **Selection of Dielectric Fluids**: Recommendations for choosing suitable dielectric heat transfer fluids, including performance characteristics, compatibility with materials, and environmental considerations.
- **Operational Best Practices**: Suggestions for monitoring and maintaining fluid quality, system pressures, and temperatures to ensure optimal operational conditions.
- **Safety and Compliance**: Safety measures and regulatory compliance related to handling dielectric fluids.
- **Documentation and Reporting**: Suggestions for maintaining records of fluid usage, system modifications, and maintenance activities, supporting accountability and future system enhancements.

By following these suggestions, stakeholders can improve the effective and safe implementation of dielectric heat transfer fluids in liquid-cooled racks, ultimately enhancing the performance of IT infrastructure.

2. Compliance with Open Compute Project Tenets

2.1 Openness

The document promotes multi-vendor ecosystems by encouraging standardized interfaces, defined material compatibility validation, and reusable liquid cooling infrastructure. By establishing clear expectations for system integration and component interaction, these guidelines reduce vendor lock-in, enable interoperability across suppliers, and support broader industry collaboration.

2.2 Efficiency

The recommendations are designed to maximize thermal performance while minimizing energy consumption, pressure losses, and operational complexity. Dielectric two-phase cooling enables highly efficient heat transfer, allowing higher rack power densities to be supported without a proportional increase in pumping power or overhead infrastructure.

2.3 Impact

By providing a common reference for design, operation, and validation, the guidelines reduce deployment risk and accelerate adoption of liquid cooling technologies. This shared framework supports consistent implementations, improved reliability, and faster innovation across the industry.

2.4 Scale

The guidelines support modular designs and reuse of liquid cooling infrastructure across multiple generations of IT hardware. This approach allows data center operators to scale deployments incrementally while reducing capital costs, shortening deployment timelines, and minimizing operational disruption.

2.5 Sustainability

The use of low GWP, zero ODP dielectric fluids and long service life expectations aligns with OCP goals to reduce environmental impact and improve overall data center sustainability.

3. Heat Transfer Fluid Typical Properties

3.1 Approved Dielectric Liquid-Based Heat Transfer Fluid

The dielectric heat transfer fluid must meet the minimum criteria outlined in Table 1. Specifically, the fluid should exhibit low toxicity, be non-flammable, and have a boiling point within the range of -26.3°C to 60°C. Additionally, the fluid should possess a low global warming potential (GWP) and a zero ozone depletion potential (ODP), ensuring it is environmentally responsible while maintaining the necessary thermal performance.

3.2 Typical Properties of Dielectric Liquid-Based Heat Transfer Fluid

Following in Table 1 is a list of some of the typical properties of dielectric liquid-based heat transfer fluids.

Table 1. Typical properties of dielectric liquid-based heat transfer fluids

Parameter	Performance	Notes
Ozone Depletion Potential (ODP)	~0	
Global Warming Potential (GWP)	<700	
ASHRAE Std. 34 Safety Classification	A1	
Boiling point at 101.3 kPa	Between 26.3℃ and 60℃	
Freezing point at 101.3 kPa	<-100 ℃	
Vapor thermal conductivity at 25℃	< 20 mW/mK	
Liquid thermal conductivity at 25℃	<80 mW/mK	

4. Safety

Before commencing any work involving heat transfer fluids or chemicals, it is essential to review the Safety Data Sheet (SDS) for the specific fluid. The SDS provides critical information on potential hazards, handling precautions, and first-aid measures. When handling the fluid, always wear appropriate personal protective equipment (PPE), including safety glasses or goggles, nitrile or other impervious gloves, and suitable protective clothing to minimize exposure to the fluid. It is also important to adhere to the handling and storage guidelines outlined in the SDS to ensure safe management of the fluid throughout its lifecycle, including during storage, transportation, and disposal. Following these safety procedures will help mitigate risks and protect personnel from potential hazards.

5. System Design Consideration

5.1 Compatibility

Wetted Materials: The materials that touch the fluid are collectively referred to as the wetted materials. The data center operator shall certify compatibility of the heat transfer fluid with liquid cooled rack system including all wetted components (including but not limited to pump seals, heat exchangers and quick connect seals) and the wetted material list at maximum operating temperatures as specified in section 5.2.

The heat transfer fluid specification is tied closely to the wetted material list. Any additions to the wetted material list will require (re)evaluation of the heat transfer fluid.

Each material will need to be tested for the specific dielectric liquid. There is a need to verify that the sealing weight, stiffness and volume of the components did not change by more than 5%, during a period simulating the system lifetime.

Following in **Tables 2 and 3**, are examples of acceptable materials for a specific dielectric liquid, where it can be seen that there is no change of more than 5% in the said parameters.

Table 2: Example of test results of Metals and Metal Alloys for a specific dielectric liquid:

Material	Weight Loss	Surface appearance	Solvent appearance	Fluoride IC	Comments
Aluminum	None	No Change	Clear, Colorless	<0.5 ppm	Acceptable
Copper	None	No Change	Clear, Colorless	<0.5 ppm	Acceptable
Brass	None	No Change	Clear, Colorless	<0.5 ppm	Acceptable
Stainless steel	None	No Change	Clear, Colorless	<0.5 ppm	Acceptable
Carbon Steel	None	No Change	Clear, Colorless	<0.5 ppm	Acceptable

Table 3: Example of test results of Elastomers, Plastics and Other Materials for a specific dielectric liquid:

Symbol	Material	% Weight Change	% Volume Change	% Hardness Change	comments
NR	Natural Rubber	4.4	1.9	0.0	Acceptable
CR	Polychloroprene	0.8	0.1	0.0	Acceptable
NBR	Acrylonitrile Butadiene	15.3	2.6	-13.6	Not Acceptable
FKM	Fluoro- elastomer	7.9	-3.4	-2.9	Acceptable
T	Thiokol	0.3	6.7	-6.1	Not Acceptable

ABS	Acrylonitrile-Butadiene-Styrene	-0.1	-0.6	0.0	Acceptable
HIPS	High Impact Polystyrene	0.3	-0.4	-2.9	Acceptable
PET	Poly (Ethylene Terephthalate)	0.0	0.7	-1.2	Acceptable

While widely recognized standards, such as those from ASTM, are available, they do not address all components of the system. Therefore, additional testing is required to verify the compatibility of materials used with the dielectric fluid. It is recommended to conduct both component functionality tests and long-term system performance tests. These tests are critical to ensure that the fluid does not interact negatively with system materials, cause degradation of components, or impact the overall operation and reliability of the system.

The Soxhlet extraction compatibility test is intended to quantify compatibility by measuring the ability of the fluorinated fluid to extract relatively non-volatile materials such as oils from the sample and the ability of the sample to absorb the fluorinated fluid under atmospheric reflux conditions in a Soxhlet extractor. Its ability to separate extraction ($me\%$) and absorption ($ma\%$) makes the Soxhlet test more useful for assessing compatibility than conventional soak tests which provide only an overall mass change. 72-hour Soxhlet extraction test gives "worst case" results at fluid boiling point.

To test the materials compatibility for a specific cooling system it is recommended to place the tested material in a Soxhlet extractor for 72 hours to verify that the sealing weight, stiffness and volume did not change by more than 5%, the Soxhlet positive results should be followed by a verification process of a 2-month monitored functional testing in a working system.

The following procedures are recommended for material compatibility testing:

- Components tests
    - Pumps performance
    - Cold plate thermal performance
    - System performance
- Functionality tests
    - Components functionality
        - PRV long term performance
        - Solenoid
    - Full system tests
- Compatibility

- Identify critical components
- 72h Soxhlet tests
- Full system test

The standard procedure for testing the compatibility of metals and metal alloys involves exposing them to the dielectric fluid at 100°C (212°F) for a duration of 2 weeks.

For plastics and elastomers, the compatibility test typically involves exposure to the fluid at room temperature for 2 weeks. These tests help assess the material's ability to withstand prolonged contact with the fluid without degradation or adverse reactions.

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5.2 Operating Temperature

The typical operating temperature range for closed-loop cooling systems is below 5°C (41°F), with an upper limit not exceeding 45°C (113°F). Operating temperatures above 45°C (113°F) will necessitate a thorough review of the wetted materials list to ensure material compatibility and integrity at the elevated temperature.

5.3 System Leak Checks

Given that the dielectric liquid used in the cooling system is non-conductive and poses no risk to the server or its components, there is no immediate requirement to shut down the server or power off the components in the event of a leak. However, upon detection of a liquid loss, it is essential to accurately locate the source of the leak. This can be accomplished using a standard refrigerant sniffer, which should be employed to pinpoint the specific area of leakage for further investigation and corrective action. This approach ensures both the safety and continuity of server operations while enabling efficient leak detection and resolution.

5.4 Mechanical Design Considerations

The design of system and component redundancy should align with the specific redundancy requirements of the local system to ensure reliable operation and minimize the risk of failure. In particular, the total pressure loss between the evaporator and condenser should be maintained at less than 0.2 bar to optimize system efficiency and performance. It is important to note that in dielectric liquid-based cooling systems, the liquid side and vapor side of the system exhibit distinct differences in tubing size, pressure, and flow rate. These differences must be carefully considered during the design and integration phases to ensure proper system balance, effective heat transfer, and overall operational stability.

A. Liquid Addition and Drainage:

Install ports to fill and drain heat transfer fluid. All components used for fluid addition and draining should comply with the wetted materials list.

B. Filtration:

Given that the dielectric fluid is not expected to promote biological growth, corrosion, or the formation of residues, the system only requires minimal filtration, typically at 100 µm, to maintain optimal performance. However, it is also recommended to implement additional filtration during the process of loading the fluid into the system or when performing system cleaning. This extra filtration ensures that any particulate matter or contaminants introduced during these operations are effectively removed, helping to maintain fluid integrity and prevent potential blockages or damage to system components.

6. Fluid Installation and System Operation

6.1 Overview

This section outlines the procedures for fluid installation and system operation, encompassing the critical steps of system start-up, liquid filling, and ongoing operation. Proper installation and commissioning are essential for ensuring optimal performance and longevity of the cooling system. During start-up, careful attention must be paid to verifying all components and ensuring the system is properly primed before initiating fluid flow. The liquid filling process should be performed systematically to avoid air entrapment and ensure uniform distribution throughout the system. Once the system is filled and operational, it is crucial to monitor key parameters such as pressure, flow rate, and temperature to confirm that the system is functioning within the specified design parameters. Regular checks and maintenance are also emphasized to maintain fluid integrity and system performance throughout the operational lifecycle.

6.2 Start-Up

Certificate of Analysis (COA): Vendors are required to provide a Certificate of Analysis (COA) for all manufactured products to verify product quality. A copy of the COA should be retained for record-keeping purposes.

Safety and Operational Checks: It is essential to thoroughly review and comprehend all relevant safety requirements, rules, regulations, and recommendations prior to system operation. Ensure that the refrigerant buffer is fully charged; if additional refrigerant is needed, follow the prescribed servicing instructions.

Environmental Conditions: Verify that the ambient temperature remains within the specified range of 5°C - 35°C (41°F - 95°F) to ensure proper system function.

Hardware Inspection: Conduct a comprehensive visual inspection of all hardware, checking for any mechanical defects, including bent tubes, cracks, or broken connectors. Any issues identified should be addressed promptly to maintain system integrity.

Cleanliness and Handling: In coordination with the installer or fabricator, ensure that all components, including dielectric liquid-cooled servers and data communications equipment, are handled appropriately to prevent contamination. Specifically, confirm the following:

- All products in the thermal cooling system (TCS) loop comply with the Wetted Materials List.
- All components remain clean and are factory sealed until installation.
- Immediately notify the owner if there is any evidence of mishandling or cleanliness issues, and develop a remediation plan to rectify such conditions.

These measures are essential to ensure system performance, safety, and longevity.

Compatibility: Assure effectiveness and compatibility with wetted materials.

6.3 Liquid Filling

As servers are periodically replaced or added to the rack, each new server may introduce a small volume of air into the cooling system. Over time, as the accumulation of non-condensable gases (air) increases, it can reach a threshold that may affect system performance. Once this threshold is exceeded, the system should trigger a non-critical alarm indicating that purging is required to remove the excess air. The purging process can be carried out using a dedicated purge system connected to the purge port located on the buffer. Importantly, the system does not need to be shut down during the purging operation, allowing for continuous operation while the non-condensable gases are removed. Regular purging ensures the system maintains optimal performance and prevents any negative impact on heat transfer efficiency.

6.4 Operation

The system must be operated and maintained in full compliance with the established Treatment Plan and the Owner's Manual to ensure its continued efficiency, reliability, and safety. Adherence to these documents is essential for proper operation, covering aspects such as system configuration, component specifications, and recommended operating conditions. In addition, the system should be continuously monitored as per the guidelines outlined in the Monitoring and Maintenance section (Section 7). This includes regularly assessing critical parameters such as temperature, pressure, flow rates, and fluid levels. By following these monitoring protocols, potential issues can be identified early, enabling proactive maintenance and minimizing the risk of system failure.

7. Monitoring and Maintenance

7.1 Routine Monitoring

To ensure the optimal performance and reliability of the system, it is strongly recommended to routinely monitor the following key parameters:

- Vapor pressure
- Vapor temperature
- Liquid pressure
- Liquid temperature
- Liquid level in the buffer

If a significant deviation is observed between the actual vapor pressure and the theoretically calculated vapor pressure for a specific boiling temperature, a purge of the system will be required. A significant difference is defined as a discrepancy greater than 25% between the measured vapor pressure and the calculated theoretical pressure. Such a condition indicates the presence of excess non-condensable gases or other anomalies, necessitating purging to restore the system to its designed operating state. Regular monitoring of these parameters will help maintain efficient operation and prevent potential performance degradation.

8. Fluid Lifetime and Disposal

8.1 Useful Life

Usually, the liquid has no expiration date, hence no fluid replacement is expected to occur.

8.2 Regulatory Considerations

Refer to supplier's Safety Data Sheets (SDS) and product labels to review regulatory information.

8.3 Fluid Disposal

Upon decommissioning a rack, the dielectric fluid should be drained back into an appropriate liquid container through the designated liquid port, following the specified draining instructions. As the fluid does not have an expiration date, it can either be reused in a new system or returned to the manufacturer for refurbishment.

It is essential that all fluid disposal practices adhere to applicable Federal, State/Provincial, and local regulations, as these requirements may vary depending on the location. Compliance with these regulations is critical to ensuring safe and responsible handling of the fluid throughout the disposal or recycling process.

9. Submittals

Maintain a comprehensive file for each system that includes the identification and source of the heat transfer fluid, documentation of all fluid analyses, and a record of any cooling system components that have been replaced. Additionally, ensure that a detailed record is kept of the materials of construction for each system, including metals, elastomers, and other relevant materials. This documentation is essential for ongoing maintenance, troubleshooting, and ensuring material compatibility throughout the system's lifecycle.

10. Conclusion

This document provides a comprehensive set of guidelines for the deployment and use of dielectric liquid-based heat transfer fluids in two-phase cold plate-based liquid-cooled racks. Key focus areas include the selection of appropriate wetted materials compatible with the fluids, as well as a detailed analysis of the essential fluid properties required for optimal system performance. In developing these guidelines, the authors have collaborated with industry experts and leveraged insights from other reputable forums, such as ASHRAE, which are engaged in similar standardization efforts. This collaboration ensures a consistent and unified approach across the industry, promoting best practices and advancing the integration of dielectric fluid-based cooling solutions within the broader ecosystem of thermal management technologies.

Appendix: Glossary

This glossary provides definitions within the context of using dielectric liquid based heat transfer fluids within data centers.

CDU (Coolant Distribution Unit)	A piece of equipment used in liquid cooling systems that is responsible for pumping and conditioning the coolant before it is distributed to the components being cooled.
TCS (Technology Cooling System)	A closed liquid circuit which allows the transfer of heat from an immersion system to the FWS.
ODP (Ozone Depletion Potential)	A measure of a substance's potential to cause depletion of the ozone layer. The lower the ODP, the less harmful it is to the ozone layer.
GWP (Global Warming Potential)	A measure used to compare the ability of different greenhouse gases to trap heat in the Earth's atmosphere.
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers, a US Non-Profit professional organization that develops standards and guidelines for HVAC systems.
Boiling Point	The temperature at which a liquid's vapor pressure equals the atmospheric pressure, causing the liquid to boil and transition into a gas.
Freezing Point	The temperature at which a liquid solidifies into a solid under standard atmospheric pressure.
Thermal Conductivity	A measure of how well a vapor conducts heat. It is usually given in mW/mK (milliwatts per meter per kelvin).
SDS (Safety Data Sheet)	A document that provides detailed information about a specific substance or mixture used in workplaces.
PPE (Personal Protective Equipment)	Protective clothing, helmets, goggles, or other garments or equipment designed to protect the wearer's body from injury or infection.
Wetted Surface Area	The surface area of a component that is in direct contact with a coolant.
Wetted Materials	Materials that come into direct contact with a liquid in a system, such as seals, pumps, and heat exchangers
Soxhlet Extraction Test	A laboratory procedure used to assess the compatibility of materials by measuring how much material (e.g., oils) is extracted by a fluid under specific conditions.
Fluorinated Fluid	A liquid that contains fluorine atoms, is often used for cooling or insulation purposes, such as dielectric fluids in heat transfer systems.
Certificate of Analysis (COA)	A document from the manufacturer that certifies the quality and composition of the heat transfer fluid.

Appendix: References

- OCP Immersion Workgroup: on-going projects information (see wiki for details) https://www.opencompute.org/wiki/Cooling_Environments/Immersion

About Open Compute Project

The Open Compute Project Foundation is a 501(c)(6) organization which was founded in 2011 by Facebook, Intel, and Rackspace. Our mission is to apply the benefits of open source to hardware and rapidly increase the pace of innovation in, near and around the data center and beyond. The Open Compute Project (OCP) is a collaborative community focused on redesigning hardware technology to efficiently support the growing demands on compute infrastructure. For more information about OCP, please visit us at http://www.opencompute.org