

OPEN Compute Project

Cooling Environment – Cold Plate sub-project Workstream

Base Specification for Two-Phase Dielectric Fluid-Based Heat Transfer Fluid

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Base Specification
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1.2. Acknowledgements

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2. Compliance with OCP Tenets

2.1. Openness

This specification supports the OCP Openness Tenet by defining a vendor-neutral, openly shared specification that enables interoperability and broad adoption. By providing open guidelines and reference architectures, the document enables manufacturers, integrators, and operators to implement and adapt the solution to their specific needs, in line with OCP's principle of openness. It avoids proprietary approaches, allowing multiple vendors to develop compatible solutions and foster collaboration across the ecosystem.

2.2. Efficiency

The specification advances efficiency by enabling more effective thermal management for high-density IT equipment, reducing the energy required for cooling compared to traditional air-based systems. By standardizing dielectric fluid requirements and integration practices, the solution minimizes operational overhead, supports optimized heat transfer, and enables data centers to achieve higher compute densities with lower power consumption.

2.3. Impact

This contribution has a meaningful positive impact on the OCP ecosystem by introducing a standardized, interoperable approach to liquid cooling. It leverages new technologies, such as advanced dielectric fluids, to improve reliability and safety, while also enabling scale-out computing by supporting modular, high-density deployments. The specification fosters a more robust supply chain by providing clear guidelines for fluid selection and system integration, benefiting both manufacturers and operators.

2.4. Scale

Scalability is addressed by ensuring the solution supports deployment across a wide range of data center sizes and configurations. The architecture is modular, allowing for easy expansion and integration into existing facilities.

2.5. Sustainability

The specification promotes sustainability by encouraging the use of fluids and system designs that reduce environmental impact, such as minimizing water and energy consumption and supporting heat reuse. It emphasizes responsible material selection and

the long-term reliability of components, aligning with OCP's focus on maximizing transparency of environmental impacts and driving continuous improvement in resource efficiency.

3. Scope

This specification focuses exclusively on the **dielectric fluids** used for thermal management in cold plate-based liquid cooling systems within the Open Compute Project (OCP) ecosystem. It defines the properties, selection criteria, handling requirements, and integration considerations for dielectric fluids used in both closed-loop and facility-integrated liquid cooling systems. The scope includes fluid compatibility with materials, safety and environmental considerations, and operational performance parameters.
The goal is to ensure safe, reliable, and standardized use of dielectric fluids across vendors and platforms in support of scalable and energy-efficient cooling solutions.
Any use of dielectric fluids in this base specification means two phase dielectric fluid.

4. Overview

Two-Phase Cold Plate Cooling with Dielectric Fluids:
Two-phase cooling systems leverage the phase change of the dielectric fluid from liquid to vapor to efficiently remove heat from electronic components. As heat is generated, the liquid boils, absorbing significant latent heat, and turns into vapor. This vapor then travels to a condenser, where it cools and condenses back into liquid form, completing the cycle. This method offers superior heat absorption and transfer compared to single-phase liquid cooling, making it ideal for high-performance computing and systems with high heat dissipation needs.

Standardizing cold plate dielectric fluids
This specification contributes to the OCP community by defining an open, vendor-agnostic framework for integrating dielectric fluids in cold plate-based cooling systems, enabling safe and efficient thermal management in high-density server environments. This specification fills the critical data center cooling solutions high performance gap:

- A standardized approach to dielectric-based cold plate cooling that supports a range of hardware form factors and power envelopes.
- Interoperability guidance for components such as fluid connectors, sensors, and monitoring systems.
- Materials compatibility and fluid selection matrix, allowing vendors to independently verify compliance.

Problems Addressed:

- Thermal Management Limits: Air cooling and single phase direct (water-based non-dielectric fluids) to chip are increasingly insufficient for high-density, high-TDP IT equipment. This specification addresses the need for efficient, scalable liquid cooling that handles modern workloads.

- Safety and Reliability: Dielectric fluids minimize the risk of electrical shorts, allowing direct contact with electronics and reducing the consequences of leaks compared to water-based systems.
- Material Compatibility and Maintenance: The specification provides clear requirements for material compatibility and fluid integrity, reducing the risk of corrosion, contamination, and system failure.
- Interoperability and Vendor Lock-In: By defining open standards for fluids and interfaces, this specification enables multi-vendor ecosystems, reducing barriers to adoption and innovation.
- Sustainability and Efficiency: The modular approach supports efficient operation, reduced energy and water use, and easier implementation of heat reuse strategies, contributing to data center sustainability goals.

Key benefits derived from the chosen fluid's properties are:
- Enables high heat flux removal.
- Reduces water consumption in data centers.
- Allows for higher server densification.
- Ensures continuous operation in case of leaks due to non-conductive nature.
- Potential for heat reuse

Ultimately, this specification promotes interoperable, open, and scalable thermal management for next-generation computing, while empowering a more diverse set of contributors to participate in and extend the OCP platform.

Base Specifications

4.1. Description

This OCP base specification document outlines the requirements for dielectric fluids used in cold plate liquid cooling systems, primarily for data center and high-performance computing environments. The solution focuses on enabling efficient, reliable, and safe thermal management for IT equipment by leveraging dielectric fluids that are electrically non-conductive, ensuring compatibility with sensitive electronics.
Intended users are data center operators, IT equipment manufacturers, system integrators, and fluid suppliers seeking OCP compliance for liquid-cooled solutions. This specification assumes a modular approach to cooling infrastructure, compatibility with OCP hardware, and adherence to sustainability goals such as reduced water usage and energy efficiency.

4.2. Goals and Vision

The core goals of this specification are:

- To standardize the use of dielectric fluids in cold plate-based thermal management solutions across the OCP ecosystem.
- To ensure cross-vendor interoperability and component compatibility for easier system integration.
- To enable safe, low-maintenance cooling solutions for high-performance servers in dense compute environments.
- To reduce total cost of ownership (TCO) by extending component life and improving energy efficiency.

The vision is to create a robust, open, and sustainable ecosystem for liquid-cooled IT infrastructure, where standardized dielectric fluids and cold plate designs enable scalable, efficient, and reliable data center operations, paving the way for next-generation computing workloads.

4.3. User Requirements/User Stories

User requirements:

- The system shall maintain IT component temperatures within manufacturer-specified limits under all operating conditions.
- Dielectric fluids shall be compatible with all wetted materials in the cold plate loop, including copper, aluminum, stainless steel, and relevant polymers.

- Routine serviceability and fluid maintenance shall be achievable without significant downtime or specialized expertise.

User stories:

- As a data center operator, I want a dielectric cooling solution that enables safe and reliable deployment of high-density compute racks, so that I can maximize compute density while minimizing operational risk.
- As a fluid engineer, I want a working fluid that provides predictable and stable thermal performance, so that the cooling system can operate consistently across its intended operating range.
- As a reliability engineer, I want a working fluid that maintains its properties throughout the system lifetime, so that long-term reliability and maintainability are ensured.
- As a platform integrator, I want a cooling solution that is straightforward to integrate into data center infrastructure, so that deployment complexity, cost, and operational risk are minimized.
- As a sustainability officer, I want a cooling fluid with a strong environmental and safety profile, so that the solution supports organizational sustainability and regulatory objectives.

4.4. Key Properties and Types of Dielectric Fluids for cold plates

The selection of a dielectric fluid for cold plates is critical and depends on several factors, including thermal performance, electrical insulating properties, material compatibility, safety, and environmental impact.

4.4.1. Essential Fluid Properties

- **Heat Transfer Effectiveness:** High thermal conductivity and specific heat capacity are crucial for efficient heat absorption and transfer.
- **Electrical Insulating Properties:** Dielectric fluids are non-conductive, preventing electrical discharges and ensuring the safety and reliability of electronic components. High dielectric strength and low dielectric loss are desirable.
- **Boiling Point:** Fluids with boiling points of -50°C to 60°C are preferred to facilitate phase change cooling.
- **Viscosity:** Low viscosity is important for efficient fluid circulation and reduced pumping requirements.
- **Oxidation Stability:** The fluid shall be stable at elevated temperatures and over the lifetime of the system.
- **Material Compatibility:** The fluid shall not degrade or corrode the materials within the cooling system, including metals (e.g., copper, aluminum, stainless steel), polymers, and elastomer seals.

- **Flammability:** Non-flammable fluids are highly desirable for safety (1 according to ASHRAE standard 34) , however, lower flammability fluids may be acceptable in certain use cases (2L according to ASHRAE standard 34).
- **Toxicity:** Low toxicity is important for worker health and safety.
- **Environmental Impact:** Considerations include Global Warming Potential (GWP), biodegradability, and ozone depletion potential. Low GWP fluids are preferred for long-term sustainability. The refrigerant fluid shall comply with applicable global regulations for use in the application and take into account potential future requirements, such as those related to Per- and polyfluoroalkyl substances (PFAS) or GWP.

4.4.2. Types of Dielectric Fluids

While various dielectric fluids exist, fluorinated fluids are commonly used in two-phase immersion and cold plate cooling due to their suitable boiling points, low viscosity, non-flammability, and high chemical/thermal stability.

Perfluorocarbons (PFCs): Historically used, offering excellent dielectric properties, but have very high GWP.

Hydrofluoroethers (HFEs): Good thermal properties and lower GWP than PFCs, though with slightly less effective dielectric properties.

Hydrofluorocarbons (HFCs): Good thermal properties and widely available in the market, however, HFCs tend to have higher Global Warming Potential.

Hydrofluoroolefins (HFOs): Newer generation fluids with ultra-low GWP, good chemical stability, excellent material compatibility, and dielectric properties.

4.5. Requirements

4.5.1. Thermal Performance Requirements

Attribute	**Requirement / Specification**
Boiling Point Range	-50°C to 60°C at atmospheric pressure (application-dependent)
Latent Heat of Vaporization	≥ 100 kJ/kg
Heat Transfer Mode	Nucleate boiling or evaporation
Evaporation Stability	Thermal performance remains stable after lab testing simulating five years of operation

4.5.2. Density

To provide adequate momentum for flow and stability in cold plate systems, fluid density shall be more than 800 kg/m³ @ 25°C.

4.5.3. Boiling point

Range: -50°C to 60°C @ 1 atm, Application-dependent selection ensures optimal balance between heat absorption and system pressure.

4.6. Safety, Environmental and Chemistry requirements

Chemical Stability: No degradation or polymerization in the presence of copper, aluminum, or stainless steel.

Toxicity: Non-toxic, non-carcinogenic; safe for incidental contact during servicing. Typically, `this means using an “A” rated fluid (for example, A1).

Flammability: No flammability (class 1 ASHRAE standard 34-2022) - refrigerants that do not propagate a flame when tested according to the standard or lower flammability (class 2L ASHRAE standard 34-2022) - refrigerants that do not propagate a flame when tested according to the standard (ASHRAE Standard 34-2022).

GWP and ODP: Fluids shall have a low Global Warming Potential (GWP). As a reference, the United States Environmental Protection Agency (EPA), under the AIM Act, requires that all new data center cooling equipment use refrigerants with a GWP below 700. In Europe, the refrigerant used in chillers will be subject to new regulations starting in 2027. Additionally, refrigerants with zero or near-zero Ozone Depletion Potential (ODP) are preferred.

Environmental Compliance: Shall meet local and global standards and approval for use in the application

Fluid Maintenance: fluid shall be monitored for purity annually. Fluid replenishment shall be performed as needed to compensate for minor evaporative losses and to maintain system integrity in the event of leakage.

System Integration: Note that the fluid choice influences other system components like pumps, heat exchangers, and reservoirs.

4.7. Constraints

To ensure robust performance under typical datacenter and edge conditions the fluid operating temperature shall range between 4°C to 75°C.

- To prevent decomposition or volatility shifts during shipping and long-term storage, the storage temperature shall range between –20°C to 60°C.

4.8. Test and Validation Requirements

A comprehensive validation plan shall include:

- Material Compatibility Testing: Prolonged exposure tests on metals and polymers per ASTM D471.
- Fluid Life Expectancy: Simulated aging (1,000 hours at 60°C) followed by chemical analysis (GC-MS). Alternatively the simulation are allowed to be done under 100°C or higher temperature for a period of 7 or 14 days.
- Environmental Simulations: oxidation potential, and flammability validation.
- Fluid Purity test: AHRI standard 700-2024 (SI) purity specifications to verify composition, and to specify the associated methods of testing for acceptability specifications for refrigerants.

4.9. Compliance

Attribute	**Requirement / Specification**
Thermal Properties	
Boiling Point Range	-50°C to 60°C at 1 atmospheric pressure (application-dependent)
Latent Heat of Vaporization	≥ 100 kJ/kg
Fluid density	>800 kg/m³ @ 25°C
Heat Transfer Mode	Nucleate boiling during vapor phase; condensation elsewhere
Thermal Stability	Thermal performance remains stable after lab testing simulating five years of operation.
Electrical Properties	
Chemical Stability	No degradation or polymerization shall occur in the presence of copper, aluminum, or stainless steel under laboratory testing conditions simulating five years of operation.
Safety and Environmental	
Toxicity	Class A according to ASHRAE Standard 34-2022
Flammability	Class 1 or 2L according to ASHRAE Standard 34-2022
GWP (Global Warming Potential)	Low-GWP (< 700)
ODP (Ozone Depletion Potential)	<1.01 ozone-depleting
Environmental Compliance	Shall meet applicable local and global regulations
Material Compatibility	Compatible with all wetted materials in the cold plate loop tested by the supplier
Fluid Purity	According to AHRI Standard 700

5. References

[1] ASHRAE standard 34-2022 https://www.ashrae.org/technical-resources/standards-and-guidelines/ashrae-refrigerant-designations

[2] AHRI standard 700-2024 https://www.ahrinet.org/system/files/2026-05/AHRI%20Standard%20700-2024%20%28SI%29_0.pdf

[3] Guidelines for Using Dielectric Heat Transfer Fluids in Two Phase Cold Plate-Based Liquid-Cooled Racks https://www.opencompute.org/documents/guidelines-for-using-dielectric-heat-transfer-fluids-in-two-phase-cold-plate-based-liquid-cooled-racks-final-pdf

Appendix: Glossary

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

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.
Thermal Conductivity	A measure of how well a vapor conducts heat. It is usually given in mW/mK (milliwatts per meter per kelvin).
Wetted Materials	Materials that come into direct contact with a liquid in a system, such as seals, pumps, and heat exchangers
Fluorinated Fluid	A liquid that contains fluorine atoms, is often used for cooling or insulation purposes, such as dielectric fluids in heat transfer systems.