

**OPEN**
Compute Project

GUIDELINES FOR USING PROPYLENE GLYCOL-BASED HEAT TRANSFER FLUIDS IN LIQUID COOLED RACKS

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Executive Summary

The objective of this project is to propose and promote open specifications for the construction and operation of liquid-cooled computer racks. This document provides guidelines and recommendations for the use of propylene glycol-based heat transfer fluids, specifically PG25 inhibited formulations, within liquid cooling systems. PG25 inhibited fluid is selected for its excellent thermal stability, corrosion protection, biostatic nature and compatibility with common materials used in IT cooling loops.

In direct-to-chip liquid-cooled data centers, this fluid is utilized in the secondary (closed) loop, which connects the Coolant Distribution Unit (CDU) to the cold plates mounted on CPUs, GPUs and other high-power components inside IT server racks. This loop, referred to as the

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Technology Cooling System (TCS), plays a critical role in transferring heat away from compute components to the facility water loop via a heat exchanger. The adoption of PG25 inhibited fluid in the TCS ensures corrosion protection for mixed-metal environments (e.g., copper cold plates, stainless steel piping) and operational reliability through reduced fouling and extended fluid life.

The Open Compute Project (OCP) is developing complementary whitepapers for other liquid cooling technologies, such as immersion cooling and rear-door heat exchangers. OCP's collaborative framework enables organizations to share intellectual property and accelerate innovation in IT infrastructure, ensuring that liquid cooling solutions evolve to meet the growing demands of high-density computing environments.

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1 Introduction

The primary audience for this guideline includes design engineers, facility operators and data center personnel responsible for the specification, installation, commissioning and operation of Technology Cooling Systems (TCS). A secondary audience includes liquid cooling equipment manufacturers, material suppliers and heat transfer fluid providers whose products and components are implemented within these systems.

This document focuses on the closed-loop Technology Cooling System (TCS), specifically the secondary loop between the Coolant Distribution Unit (CDU) and IT equipment utilizing cold plate–based direct-to-chip liquid cooling. The Facility Water System (FWS) is outside the scope of this document. By design, closed-loop systems limit exposure to atmospheric contaminants and reduce oxygen ingress, supporting improved fluid stability and reduced maintenance complexity.

The guidance presented in this document addresses key considerations across the lifecycle of the cooling system, including:

- Typical properties and behavior of propylene glycol–based heat transfer fluids
- Wetted material selection and compatibility, including both commonly used materials and approaches for validation of new or unlisted materials
- Cleaning, flushing and commissioning practices to establish appropriate baseline system cleanliness
- Filtration and contamination control strategies
- Fluid monitoring, analysis and ongoing maintenance practices to support system reliability

Rather than prescribing rigid requirements, this document provides a baseline framework of recommended practices intended to support consistent implementation across a wide range of

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system designs and operating environments. Variability in materials of construction, fluid formulations, system configurations and operating conditions should be expected and users are encouraged to evaluate and adapt this guidance based on project-specific requirements.

Multiple approaches to liquid cooling exist, including alternative heat transfer fluids such as treated water and dielectric fluids, which are addressed in separate OCP workstreams. Users should assess the applicability of this guidance in the context of their specific application. Final responsibility for material compatibility and system suitability rests with the relevant stakeholders, including equipment manufacturers, fluid suppliers, contractors and system operators, who should work collaboratively to validate selections and identify appropriate alternatives where needed.

2 Compliance with Open Compute Project Tenets

The Open Compute Project (OCP) is a collaborative initiative aimed at redesigning hardware technology to support the growing demands of compute infrastructure efficiently. At its core, OCP is guided by five foundational tenets that shape its contributions and community standards, including:

1. Openness
2. Efficiency
3. Impact
4. Scale
5. Sustainability

This section outlines how the Guideline complies with each tenet.

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2.1 Openness

The development of this Guideline reflects the Open Compute Project's core tenet of Openness through its collaborative and transparent approach. Created in partnership with fluid suppliers and industry experts, both within and outside the OCP community, the specification embodies the spirit of shared innovation.

Prior to formal submission, the document will be made publicly available for review, inviting feedback from the broader OCP community as well as external stakeholders. This inclusive process ensures that diverse perspectives are considered and that the specification evolves to meet the needs of a wide range of users and applications. Furthermore, the workgroup responsible for this specification is committed to ongoing dialogue and responsiveness. Should future changes be necessary, the group will actively revise and resubmit the specification, maintaining its relevance and utility over time.

By fostering open collaboration, public review and iterative improvement, this Guideline exemplifies the OCP tenet of Openness, ensuring that innovation is accessible, inclusive and community driven.

2.2 Efficiency

This Guideline supports the tenet of Efficiency by enabling the adoption of advanced cooling solutions—specifically, the use of PG25-based liquid cooling in place of traditional air-cooling methods. This shift results in significantly improved thermal management, reduced energy consumption and enhanced system performance. By lowering Power Usage Effectiveness (PUE) compared to air cooling, the specification contributes to more sustainable and cost-effective data center operations. Additionally, the standardized guidance ensures consistent

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implementation across suppliers, further streamlining deployment and maintenance while maximizing operational efficiency.

Through these improvements, this Guidelines exemplifies OCP's commitment to driving innovation that reduces waste, optimizes resources and enhances overall infrastructure performance.

2.3 Impact

This Guideline represents advancement in data center cooling technology. As the first propylene glycol (PG)-based fluid specification tailored for both current and future IT equipment, it sets a new industry benchmark for liquid cooling solutions. This document not only provides foundational guidance for propylene glycol-based fluids used in cold plate cooling applications but also establishes a framework for future enhancements and discussions. By enabling the use of alternative PG-based fluids, the document supports a more resilient and diversified supply chain, reducing dependency on single-source formulations and enhancing global availability.

Through its pioneering approach and forward-looking adaptability, the Guideline exemplifies the OCP tenet of Impact by driving innovation, shaping industry standards and enabling scalable, sustainable infrastructure for the future.

2.4 Scale

This Guideline is designed to support global scalability by providing clear, standardized guidance for suppliers on the minimum production requirements. By defining a consistent offering of supplemental chemicals and operational protocols, the specification ensures that suppliers across regions can reliably produce and maintain systems that meet OCP standards.

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This consistency enables seamless deployment and maintenance of infrastructure at scale, reducing variability, simplifying training and enhancing operability across geographies. The specification also supports scalable operations by addressing long-term maintenance needs, ensuring that systems remain efficient and serviceable throughout their lifecycle.

In doing so, the Guideline directly supports the OCP tenet of Scale, enabling widespread adoption and streamlined operations in diverse environments.

2.5 Sustainability

This Guideline promotes a more sustainable approach to liquid cooling in data center environments. By enabling the use of propylene glycol (PG)-based fluids, the specification supports environmentally conscious alternatives to traditional cooling methods.

This guidance empowers fluid vendors to align their products with their own company-specific sustainability goals, fostering innovation in formulations and manufacturing practices. The specification also encourages broader adoption of liquid cooling technologies that reduce energy consumption and improve thermal efficiency which are key factors in lowering the environmental footprint of IT infrastructure.

Through its emphasis on energy-efficient cooling and support for vendor-driven environmental initiatives, the Guideline exemplifies the OCP tenet of Sustainability and helps to advance responsible and resilient data center operations.

3 Heat Transfer Fluid Typical Properties

3.1 Glycol-Based Heat Transfer Fluids

For glycol-based heat transfer fluids, propylene glycol is added for its biostatic properties and enhanced freeze protection, versus water, in shipping, storage and use scenarios. A corrosion

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inhibitor package is also added to prevent corrosion of the metals present in the TCS loop. The selected heat transfer fluid must be appropriate for the type of metallurgy utilized for the cold plate and all other system components that are in direct contact with the fluid (wetted surfaces).

Table 1 lists typical properties of fresh inhibited propylene glycol-based heat transfer fluids at either a 25% (PG25) or 55% (PG55) propylene glycol concentration. Fluids, when used at these concentrations, should exhibit the properties below. However, users may choose to use a fluid with an alternative propylene glycol concentration.

Table 1: *Typical Properties of New PG25 and PG55 Heat Transfer Fluids

Characteristic	Typical Property	Test Method
Appearance	Clear and particulate free <i>(visual inspection, free of cloudiness)</i>	Visual
Propylene Glycol, volume %	PG25: 24.5 - 27.5% <i>Inhibitors + water should make up approximately 75% of formulation</i> PG55: 53.0 - 57.5% <i>Inhibitors + water should make up approximately 45% of formulation</i>	ASTM E202 or ASTM D3321 <i>The refractive index value obtained using ASTM D3321 should always be compared against the manufacturer's published data for the specific heat transfer fluid being used. Inhibited formulations, such as those containing corrosion inhibitors and additives, can alter the refractive index, meaning the correlation between refractive index and freeze point may vary from one manufacturer to another.</i>

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Freeze Point	PG25: 9 to 14°F (-13 to -10 °C) PG55: -51 to -37°F (-46 to -38°C)	Based on results for ASTM D3321 <i>Note: Fluid suppliers may follow ASTM D1177 to determine freeze point of the fluid, which can then be used to generate a scale correlating refractive index versus freeze point.</i>
Fluid pH	8.0 - 10.5 (non-OAT-based coolants) 7.0 - 10.5 (OAT-based coolants) <i>Fluid pH is dependent on corrosion inhibitor formulation</i>	ASTM D1287
Reserve Alkalinity <i>Measure of the buffering capacity of the fluid. Test should be performed on pre-diluted fluid.</i>	> 6 mL, for conventional technologies For OAT-based technologies, reserve alkalinity is 'to report' <i>Reserve alkalinity is dependent on corrosion inhibitor formulation</i>	ASTM D1121 <i>Based on a 10 mL sample of pre-diluted (ready-to-use) fluid</i>
Total Hardness <i>(as CaCO₃)</i>	<25 ppm <i>High hardness values may indicate use of poor-quality water</i>	ASTM D6130
Sulfate <i>(SO₄)</i>	< 10 ppm <i>High sulfate values may indicate use of poor-quality water</i>	ASTM D5827

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Chloride (Cl)	< 5 ppm <i>High chloride values may indicate use of poor-quality water</i>	ASTM D5827
Corrosion Rates	Approved fluids should meet the corrosion rate criteria as outlined in Table 10	ASTM D8040

**The data presented are representative values and should not be interpreted as specifications.*

3.2 Inhibitors and Additives

Heat transfer fluids used in liquid-cooled computer racks are formulated with corrosion inhibitors and typically include antifoam agents and dyes to ensure reliable performance in this specialized application. Corrosion inhibitors interact with metal surfaces to form a protective layer which consumes the inhibitor gradually.

Over time, inhibitor concentrations may decline due to utilization, system aging or fluid degradation. Periodic monitoring and analysis, as recommended by the fluid supplier, is essential to maintain proper protection. When analysis indicates depletion, only use additives approved by the original fluid supplier to restore inhibitor levels and maintain chemical compatibility. Introducing unapproved additives or overdosing can lead to adverse effects such as:

- Precipitation of inhibitor compounds, causing fouling or blockages.
- Reduced heat transfer efficiency due to changes in fluid properties.
- Accelerated corrosion from chemical imbalance.

All additions, adjustments or system changes must be fully documented in accordance with Section 5.1 to ensure traceability and compliance with maintenance protocols.

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4 Safety

4.1 Safety Considerations

When handling propylene glycol-based heat transfer fluids, it is important to follow established safety and handling practices. Before beginning any work, always review the applicable Safety Data Sheet (SDS) to understand hazards and recommended precautions. Ensure the use of appropriate personal protective equipment (PPE), including safety glasses or goggles, impervious gloves such as nitrile and suitable protective clothing.

In the event of a spill, minor releases should be contained and absorbed using standard absorbent materials, while larger spills should be managed using appropriate safety equipment to pump the fluid into suitable containers for recovery or disposal. Any residual material should be thoroughly cleaned with water. If accidental exposure occurs, immediately flush affected eyes or skin with water. Additionally, care should be taken to avoid inhalation of glycol mists by maintaining adequate ventilation during handling and use.

5 Record Management & Traceability

5.1 Records

To ensure proper system management and traceability, it is essential to maintain comprehensive records for each liquid cooling system as follows:

Table 2: Record Keeping Requirements

Record	Details
System Identification and Fluid Source	Document the fluid type and supplier of the heat transfer fluid used in each system

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	• Include batch numbers, delivery dates and Certificates of Analysis (COA) for quality verification
Fluid Analysis and Maintenance History	• Keep copies of all fluid analysis reports, including inhibitor concentration, pH and contamination checks • Record a chronological history of component replacements (e.g., pumps, valves, cold plates) to track potential material compatibility issues
System Volume and Capacity	• Maintain accurate records of the total fluid volume for each system -- this information is critical for calculating inhibitor additions and ensuring proper chemical balance
Adjustment and Treatment Log	• Document all adjustments or corrective actions, including: • Date of service • Type and amount of inhibitor or additive introduced • Reason for adjustment (e.g., low inhibitor level, pH correction)
Materials of Construction and Compatibility	• Record the metals, elastomers and non-metallic materials used in each system • Include confirmation of compatibility with the heat transfer fluid and inhibitors, referencing any material testing performed

6 Wetted Material Considerations

6.1 Overview

All components that come into direct contact with the heat transfer fluid are collectively referred to as wetted materials. It is essential for the data center design engineer, general contractor and

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subsequently the operator to verify the compatibility of the selected heat transfer fluid with all wetted materials in the liquid-cooled rack system. This includes, but is not limited to:

- Cold plates
- Coolant Distribution Units (CDUs)
- Hoses and piping
- Pump seals
- Heat exchangers
- Quick-disconnect seals

6.2 Verification of Wetted Material Compatibility

Compatibility should be confirmed at the maximum operating temperature of the system. Any future changes to wetted materials, whether due to component replacement or design modifications, must also undergo compatibility verification (refer to Section 8 for detailed testing procedures).

Compatibility testing or verification can be performed by:

- The material supplier
- The component manufacturer
- The heat transfer fluid supplier
- The data center operator
- Outsourced to a qualified testing laboratory

Tables 3, 4 and 5 provide guidance on commonly utilized materials which are generally considered compatible with inhibited propylene glycol-based heat transfer fluids. Materials listed in Table 4 represent common formulations, however, elastomers and plastics can vary significantly based on:

- Catalysts

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- Curing agents
- Copolymers
- Plasticizers
- Molecular weight distribution
- Other additives

Because of these variations, it is strongly recommended to work directly with material suppliers to confirm suitability for your specific application. Table 4 should be treated as a starting point, not an exhaustive list. Additional materials may also be acceptable for service even if not currently included.

6.3 Commonly Utilized Wetted Materials – Metals and Metal Alloys

Table 3 provides a representative, not comprehensive, list of metals and metal alloys that are expected to be compatible with PG25 heat transfer fluids. This table is not an exhaustive list. Additional materials may also be acceptable for use.

Table 3: Commonly Utilized Metal and Metal Alloys

Material	Details	Comments
Copper	CDA110, CDA1020, CDA1220, CDA1100	
Brass		Brass with <15% zinc is preferred as concentrations >15% zinc is more prone to dezincification of the alloy. If using an alloy with >15% zinc it should be verified that the material is dezincification resistant by performing ISO 6509, as a first pass and consulting

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		the material manufacturer to confirm acceptability for use.
Stainless Steel	304L, 316L or higher grades preferred	Most SS alloys should be acceptable, including 303 and 410.
Nickel, high nickel alloys	Avoid Hastelloy B and other alloys designed for reducing environments	**See note below
Chromium	Plated corrosion resistant materials	**See note below
Titanium	Grade 2 (UNS R50400)	
B-Ni-6	88.9% Ni + 11% P	Brazing material in copper cold plate
BCuP-1	95% Cu + 5% P	
BCuP-2	93% Cu + 7% P	
BCuP-3	Cu 89%, Ag 5%, P 6%, others 0.15%	
BCuP-4	Cu 87%, Ag 6%, P 7%	Brazing material in copper cold plate
BCuP-5	Cu 80%, Ag 15%, P 5%	Brazing material in copper cold plate

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TF-H600F	Cu 74.9%, Sn 15.6%, P 5.3%, Ni 4.2%	Brazing material in copper cold plate
-----------------	-------------------------------------	---------------------------------------

***Quick connects made of stainless steel should be used. It is recommended to avoid nickel plated and chromium plated quick connects until these are proven satisfactory. This is because after many uses, the plating can be worn away and the underlying metal exposed to the heat transfer fluid. Although corrosion inhibitors may protect underlying metal, the galvanic couple created by the exposed metal with the plating material may increase the corrosion tendency. For example, brass corrosion will introduce zinc and potentially copper, into the heat transfer fluid. The consequences of dissolved zinc on the long-term performance of the copper cold plates have not been determined at this time and identification of acceptable thickness of plating metals is outside the scope of this document. Plated quick connects should be inspected regularly or as needed based on fluid analysis.*

6.4 Commonly Utilized Wetted Materials – Plastics, Elastomers and Other Materials

Table 4 provides a representative, not comprehensive, list of elastomers, plastics and other materials that are expected to be compatible with PG25 heat transfer fluids. This table is not an exhaustive list. Additional materials may also be acceptable for use.

Table 4: Commonly Utilized Elastomers, Plastics and Other Materials

Material	Details	Comments
EPDM	Ethylene propylene diene monomer	Peroxide cured EPDM is recommended. Sulfur-cured EPDM can introduce sulfate into the heat transfer fluid over time, leading to issues with corrosion and should be used with caution.

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Material	Details	Comments
FKM	Fluorocarbon elastomer	Viton A, GF, ETP
FEP	Fluorinated ethylene propylene polymer	
PTFE	Polytetrafluoroethylene polymer	
PP	Polypropylene	
HDPE	High density polyethylene	
PEEK	Poly ether ether ketone	

Note: Thread sealants are not addressed in this table. Consult sealant manufacturer for guidance on compatibility.

Note: Materials currently under evaluation and/or consideration include: polyamide 11 and 12 (unplasticized) and various grades of thermoplastic elastomers, including TPV. Other materials of interest include: LG PPS+GF40, PA66+GF30, mPPO+GF30 with PG25 coolant. Evaluation of these materials will take place in the OCP Cold Plate - Wetted Materials workstream.

6.5 Commonly Utilized Wetted Materials – Filter Media

Table 5 provides a representative, not comprehensive, list of filter materials that are expected to be compatible with PG25 heat transfer fluids. This table is not an exhaustive list. Additional materials may also be acceptable for use.

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Table 5: Commonly Utilized Disposable Absolute Filter Media

Filter Media	Notes
Polypropylene	Common choice for glycol systems; cost-effective and chemically stable.
Polyester	Can degrade due to long-term glycol exposure
Glass Microfiber	Can undergo hydrolysis at elevated temperatures or pH; use stabilized grades.

Note: Gaskets used in filter housings and/or cartridges are a potential point of failure so compatibility of these materials with propylene glycol should be considered. EPDM, silicone, Buna Nitrile and PTFE are all common gaskets and good for duty.

Note: Polypropylene filters can introduce challenges when used in systems containing siloxane-based antifoams, as the filter media may unintentionally adsorb or strip out the active siloxane components. This unintended removal can diminish the antifoam's performance by reducing its effectiveness.

Please note, further work is actively underway to expand and refine the list of acceptable wetted materials for use with PG-based heat transfer fluids. A dedicated workstream (OCP Cold Plate – Wetted Materials Workstream) has been formed to support the validation and testing of additional candidate materials, with the objective of enabling new materials while improving the technical basis for acceptance criteria, test procedures and performance limits. As this workstream advances and additional validation data become available, materials not currently listed may be considered acceptable for use with PG-based fluids. Accordingly, the wetted materials guidance in this section should be viewed as representative of the current state of knowledge and will be updated over time to reflect newly qualified materials and refined best-practice recommendations.

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6.6 Operating Temperature

The typical operating temperature of closed loop cooling systems is expected to be between 17 to 66°C (63 -151°F). Operating above this range will require review of the wetted materials list, particularly elastomers and plastics, to ensure compatibility at the new temperature.

7 Filtration Considerations

7.1 Overview

This section serves as a general overview of filtration considerations to reduce particulate contamination and is not intended to prescribe requirements for type of filtration utilized, sizing or efficiency ratings. These items should be addressed in the design phase, in coordination with pump sizing. Separate documents may detail filtration requirements.

It is important to note that maintaining fluid cleanliness begins at the point of manufacture. PG25 heat transfer fluid should be filtered by the fluid manufacturer prior to being introduced into any transportation vessel (e.g., tanker trucks or ISO containers) or package (e.g., drums, totes, or pails). Filtration should be conducted using filters rated at 50 microns or finer, with filters rated at 25 microns or finer preferred. The selected filtration system and filter media shall be suitable for and compatible with propylene glycol service.

7.2 Sidestream Filtration vs. Full Flow (Inline) Filtration

Effective filtration is crucial for maintaining the condition of the TCS loop and for protection of cold plates, particularly those with narrow microchannel widths. It helps capture residual suspended solids in the recirculating fluid, ensuring system efficiency and longevity. Two primary filtration methods can be implemented:

- Sidestream Filtration

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- Full Flow Inline Filtration

The more common filtration method is likely to be sidestream filtration as clogging of the filter does not cause back-pressure problems on the TCS loop when this method is employed. Filter replacement is often easier as well. Sidestream filtration involves diverting a small proportion (typically 5–15% of the total volume, depending on system size) of the circulating flow through a filter continuously. This ensures the entire water system volume is filtered at least once over a 24-hour period.

Sidestream filtration is strongly recommended for systems greater than 250 gallons of heat transfer fluid, but systems below this volume can benefit as well. Not only is this type of filtration cost effective, but it also does not create back-pressure issues for the main system if clogging of the filter were to occur. The efficiency rating of the filter should be considered as high efficiency filters will remove particles smaller than the micron rating; however, at a lower efficiency. This is important as overly fine filtration may inadvertently remove some antifoam additives included in the fluid. Consult the filter and fluid manufacturers for guidance.

Full flow or inline filtration processes 100% of the system flow, making it suitable for applications where comprehensive filtration is required. In this scenario, duplex filters are recommended as this setup enables filter cleaning or replacement without a system shutdown, leading to quick and precise cleaning. Most CDUs may also contain less fine (e.g., 25 or 50 μm) inline filters which can work in tandem with sidestream filters to protect heat exchangers and QDs.

7.3 Filter Media

Choosing the right filter media is key to maintaining the integrity of the heat transfer fluid and protection of system components. Incompatible media can break down, leach contaminants or even clog system components (e.g., cold plates), leading to decreased thermal efficiency and

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increased maintenance costs. If the media is not rated to withstand operating temperatures, it may deform or lose structural integrity which can lead to system failure or contamination. Proper filter media will remove particulates that can cause fouling or blockages in cold plates, heat exchangers and piping, helping to maintain fluid cleanliness and system longevity.

All filter media should be compatible with the heat transfer fluid at the expected operating temperature(s) as well as with any dosing chemicals that will be introduced into the fluid stream. This is particularly important if the filter housing will be used as the point of introduction. In this case, it is recommended to remove the filter from the housing prior to introduction of chemicals for which compatibility with the filter is unknown.

Table 5 includes commonly utilized filter media which are considered to be acceptable for use with propylene glycol-based fluids in this application.

7.4 Filter Size and Efficiency

Filters are available in various micron sizes and can have varying efficiencies, for example, absolute and nominal. The difference between absolute and nominal filtration is related to how efficiently the filter removes particles of a specified size. Absolute filters maintain consistently high efficiency ($\geq 99.9\%$) across all micron sizes, whereas nominal filters show increasing efficiency with larger micron sizes but never reach the precision of absolute filters. Nominal filtration captures approximately 85-95% of particles at the referenced micron size and is typically used where some particle pass-through is acceptable, above the referenced micron size. Absolute filtration can capture $>99.9\%$ of particles at the referenced micron size and is commonly used where virtually no particle pass-through is acceptable, above the referenced micron size.

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Absolute ratings are often verified using standardized tests such as Beta ratio (b) testing (e.g., multi-pass or single-pass test). The Beta ratio is calculated by dividing the number of particles of a certain size upstream of the filter by the number of particles of that size downstream from the filter. The value indicates how efficiently the filter removes particles from the fluid. For example, if a filter removes 50 out of every 100 particles ($>X \mu\text{m}$), the efficiency would be 50% and the Beta ratio would be 2.

Table 6: Beta Ratios for Absolute Filters

Beta Ratio	Efficiency
2	50%
10	90%
100	99%
1000	99.9%
5000	99.98%

Filtration type, sizing and efficiency should be selected with consideration of cold plate channel dimensions and other internal flow specifications to minimize the risk of particle-induced blockage. Filter sizing and efficiency should be appropriate for the smallest flow passages in the system and implemented in a manner that protects sensitive components such as heat exchangers and quick disconnects. Regardless of filtration approach, the selected micron rating should balance cleanliness objectives with acceptable pressure drop and service life, taking into account expected contamination loading and operating conditions.

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7.5 Filter Storage and Disposal

To maintain the integrity and performance of filter elements, especially those made from polymeric or sensitive materials, it is essential to follow proper storage guidelines. Improper storage can lead to degradation, reduced efficiency or even failure during operation. The following best practices should be observed:

- **Follow Manufacturer's Instructions:** Always refer to and comply with the storage recommendations provided by the filter manufacturer. These guidelines are tailored to the specific materials and construction of the filter.
- **Avoid Exposure to Direct Sunlight:** Polymeric filter elements can degrade when exposed to ultraviolet (UV) radiation. Store filters in a shaded or enclosed area to prevent UV damage.
- **Control Temperature and Humidity:** Elevated temperatures and high humidity can accelerate material degradation. Store filters in a cool, dry environment, ideally between 10°C and 40°C (50°F to 104°F), unless otherwise specified.
- **Keep Filters in Original Packaging:** The original packaging is designed to protect filters from dust, moisture and mechanical damage. Do not remove filters from their packaging until the filters are ready for use.
- **Rotate Stock (FIFO Method):** Use the “First In, First Out” method to ensure older filters are used before newer ones, minimizing the risk of expired or aged inventory.
- **Label and Date Inventory:** Clearly label storage areas and date all incoming filter stock to facilitate proper inventory management.

After use, filters may require incineration due to contamination with glycol, corrosion products and metal particles. Landfilling may not be acceptable depending on local environmental regulations.

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8 Validation of Wetted Materials – Elastomers and Plastics

8.1 Overview

Elastomers are polymers that exhibit high viscosity and elasticity, allowing them to return easily to their original shape once mechanical stress is removed. Elastomers are often used for hoses, seals and gaskets and may make up a significant portion of a server rack cooling loop.

Plastics consist of a wide range of synthetic or semi-synthetic materials that use polymers as a main ingredient. Plastics play a crucial role in data center liquid cooling loops due to their durability, flexibility and resistance to corrosion. Plastics may be used in piping systems, tanks and reservoirs or sealing components and can also make up a significant portion of a server rack cooling loop.

Ensuring that all wetted materials are compatible with the selected heat transfer fluid is essential for maintaining the integrity and performance of the entire TCS loop, including the fluid itself. For any materials which are not known to be compatible with the chosen heat transfer fluid, it is strongly recommended to conduct the compatibility tests outlined in this section, which address elastomers and plastics.

To verify compatibility for use, elastomeric and plastic coupons should be tested before and after exposure to the selected heat transfer fluid, according to ASTM methods in Table 7 (or other similar methods, e.g., ISO). These standardized tests simulate real-world conditions to evaluate how materials will perform when exposed to specific fluids. This is particularly important when test data is not available from either the fluid manufacturer or the elastomer supplier. Exposure temperature and duration should follow guidance from the material manufacturer as the recommendations in this section are intended as a starting point for testing.

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It is advisable to assess changes in weight, volume, tensile strength and hardness of the coupons before and after exposure. Additionally, fluid purity testing may be conducted concurrently to ensure comprehensive evaluation.

Please note, a dedicated workstream has been established to further address wetted materials validation and testing for liquid cooling applications. The objectives of this workstream include enabling the evaluation and potential adoption of new materials for use in these systems, as well as refining test methodologies, procedures and acceptance criteria based on expanding data sets and industry experience. This effort is intended to be a collaborative initiative involving both material suppliers and heat transfer fluid providers to ensure alignment across materials, fluid and system operating conditions. As this work progresses, refinements to test procedures, performance limits and best-practice guidance may result in updates to portions of this document. Accordingly, the guidance presented in this document should be viewed as a baseline based on current knowledge and available data and will be revised as more comprehensive validation data become available.

8.2 ASTM Methods

Table 7: Referenced ASTM Methods

Method	Overview
ASTM D471 - Standard Test Method for Rubber Property—Effect of Liquids	<i>Procedure for evaluating the effect of rubber exposure to a heat transfer fluid</i>
ASTM D412 - Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension	<i>Procedure for determining the tensile properties of elastomers</i>

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ASTM D3182 - Standard Practice for Rubber—Materials, Equipment and Procedures for Mixing Standard Compounds and Preparing Standard Vulcanized Sheets	<i>Procedure for preparing rubber compounds and vulcanized sheets that are used in testing and evaluation</i>
ASTM D3183 - Standard Practice for Rubber—Preparation of Pieces for Test Purposes from Products	<i>Procedure for cutting or extracting test specimens from finished rubber products (rather than from molded or prepared sheets)</i>
ASTM D2240 - Standard Test Method for Rubber Property—Durometer Hardness	<i>Procedure for measuring hardness of elastomers with a Type A durometer</i>
ASTM D543 - Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents	<i>Procedure for assessing how plastic materials respond when exposed to various chemical environments.</i>
ASTM D638 - Standard Test Method for Tensile Properties of Plastics	<i>Procedure for determining mechanical properties of plastic materials when subjected to tensile forces</i>
ASTM D4703 - Standard Practice for Compression Molding Thermoplastic Materials into Test Specimens, Plaques or Sheets	<i>Procedure for molding thermoplastic materials into uniform sheets or plaques</i>
ASTM D1414 - Standard Test Methods for Rubber O-Rings	<i>Procedure for evaluating the performance of elastomeric O-ring</i>
ASTM D395 - Compression Set of Rubber	<i>Test method for assessing the permanent deformation (compression set) of rubber</i>

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	<i>after prolonged compressive stress in air or liquid environments</i>
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Note: Material manufacturer may also perform ASTM D865 – Standard Test Method for Rubber – Deterioration by Heating in Air (Test Tube Enclosure), which is a procedure for evaluating the thermal and oxidative aging resistance of rubber materials

Note: If O-rings are being tested, refer to ASTM D1414 - Standard Test Methods for Rubber O-Rings, which is the Procedure for evaluating the performance of elastomeric O-ring

8.3 Test Coupons

Obtain elastomeric or plastic coupons (specimens) based on desired testing and according to referenced ASTM methods (e.g., ASTM 3182, 3183, 4703).

Elastomers

- Elastomer coupons being tested according to ASTM D471 shall be prepared in accordance with ASTM D3182 or D3183 using rectangular coupons with typical dimensions of approximately 50 mm × 25 mm and thickness controlled by the molded sheet (commonly 2 mm).
- For tensile testing of elastomers, dumbbell coupons shall be cut from injection molded sheets or plaques with a thickness of 3.0 +/- 0.3 mm, using Die C, in accordance with ASTM D412. If material thickness or test requirements necessitate an alternative coupon geometry, refer to the method for guidance.

Plastics

- Plastic coupons being tested according to ASTM D543 shall be prepared in accordance with the method, depending on the form of the materials.

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- For tensile testing of plastics, Type I coupons shall be prepared in accordance with ASTM D638 unless material thickness or geometry necessitates the use of an alternative coupon type as defined within the standard.

A minimum of 3 coupons is needed for every variable (duration, material, fluid and temperature combination). For tensile testing, an additional 5 coupons would be required to serve as reference or control coupons which are needed to measure properties on unexposed coupons. A small hole measuring approximately 2 mm should be punched in each coupon to allow for suspension in the testing medium.

8.4 Pre-Cleaning of Test Coupons

Generally, if there is no visible contamination on the coupons, it is not necessary to clean samples in advance for these tests. However, if fluid purity testing will be done, cleaning of coupons is necessary. In this case, all coupons should be cleaned of manufacturing debris or oils with the minimum aggressive method necessary to clean (e.g., nothing, dry cloth, water, soapy water, solvent, etc.). If solvents must be used, select one appropriate for the material. Coupons should be allowed to fully dry before any measurements are performed.

8.5 Pre-Exposure Measurements for Rectangular Coupons

Weight Measurements

Once coupons have been cleaned and allowed to thoroughly dry, measure and record the starting weight (grams) for each coupon using a 4-place balance. All measurements should be collected in triplicate. Make sure it is easy to distinguish between coupons as it will be necessary to correlate the post-exposure measurements for each coupon with the pre-exposure measurements. Note: Storage conditions of materials, prior to the start of testing, should be indicated with test results.

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Volume Measurements

Once coupons have been cleaned and allowed to dry, measure the starting volume for each coupon, in triplicate. The preferred method for measuring density is via a density balance. Coupons must be allowed to fully dry before attempting to take duplicate and triplicate measurements.

If using a micrometer to determine volume, although not the most reliable method, measure and record the length, width and thickness of each coupon. Refer to ASTM D471 or ASTM D543 for guidance on how to perform these measurements.

Hardness Testing

For pre-exposure hardness measurements of elastomers using a Type A or Type D durometer, refer to ASTM D2240 for guidance.

Table 8: Hardness Test Methods

Material	Method/Durometer	Notes
Elastomers	Shore A	<i>Some elastomers may require Shore D testing</i>
Thermoplastics	Shore D	<i>Some plastics may require Shore A testing</i>

Note: The test method must be reported with test results

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8.6 Pre-Exposure Measurements for Dumbbell Coupons

The original thickness of each dumbbell should be measured with a micrometer and recorded. These values will be used as the sample thickness during post-exposure calculations, per ASTM D412 and ASTM D638. Tensile testing of control (unexposed) coupons can be done at the same time as the post-exposure coupons are tested. At the start of testing, ensure that 5 control dumbbell coupons are maintained. It is best practice to store the control coupons in a desiccator at room temperature to avoid moisture absorbance from the environment. These will not be exposed to the heat transfer fluid but will be tested while exposed coupons are tested.

Note: For hygroscopic materials, it is recommended to condition the control samples in deionized water for 3-5 days to establish original control sample physical properties.

8.7 Exposure Testing

Once initial measurements are taken, obtain clean borosilicate analytical grade glassware or an appropriately temperature rated plastic jar. Suspend coupons from a stainless-steel wire with Teflon spacers or glass beads to separate each coupon. Use a stainless-steel holder or other suitable method to hold the wire in place during testing. Make sure it is easy to distinguish between coupons as it will be necessary to correlate the post-exposure measurements for each coupon with the pre-exposure measurements. Rectangular and dumbbell-shaped coupons may be placed in the same jar. Fill the jar with heat transfer fluid at the desired concentration (e.g., PG25) until the coupons are covered with some excess.

Note: Test tubes with open condensers are specified by ASTM D471 (section 8) or ASTM D543 to limit evaporation at typical time and temperature profiles. However, jars are acceptable in this case because pressure build-up is not a concern as the fluid is not being tested near the boiling point.

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Once coupons are in place, tightly cap each jar, making sure to properly label with the start date, testing medium, exposure temperature and test duration or end date. Heat each jar at the desired temperature for the length of testing.

Typical Exposure Length: 6 weeks

Typical Exposure Temperature: 65 °C to 85 °C

If fluid purity after exposure to elastomers is of concern, it is important to include two control samples. In this case, two glass jars should be filled with the same volume of fluid as all other test variables, but without any elastomers included. One jar is left at room temperature and the other jar is heated to the same temperature as all other variables for the duration of testing. The room temperature control sample is for a baseline, while the heated control sample is for capturing any effects that the heat might have on the fluid regardless of elastomer.

8.8 Ending Test

At the end of the test period, remove jar(s) from heat (if applicable) and allow to cool to room temperature. Samples should immediately be quenched for 30-60 minutes in fresh room temperature test fluid before any testing is completed. Post-exposure measurements should be done as soon as possible, preferably within 2 hours after the test has ended. Remove coupons from the test solution (one variable at a time) and rinse with high purity water and blot dry. If dumbbell coupons are in the same jar as the rectangular coupons, do not remove them until you are ready for tensile testing.

8.9 Post-Exposure Measurements for Rectangular Coupons

At the end of testing, measurements should be taken according to applicable ASTM methods. This includes the following:

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- Coupon Weight
- Coupon Volume
- Hardness

8.10 Post-Exposure Measurements for Dumbbell Coupons

Tensile Testing: Refer to ASTM D471 or ASTM D543, for guidance on pre- and post-exposure tensile testing.

Elongation Testing: Refer to ASTM D471 or ASTM D543, for guidance on pre- and post-exposure elongation testing.

8.11 Post-Exposure Fluid Purity Testing

If fluid condition after exposure to wetted materials is of concern, the fluid may be analyzed at the end of the exposure period to evaluate overall fluid condition and assess whether any contaminants or degradation products were introduced from the elastomer. The aged fluid(s) should be compared against an unaged (room temperature), unexposed control sample of the heat transfer fluid from the same batch.

Routine fluid analysis is recommended to identify any measurable changes in key properties, which may include the following, as an example:

- pH
- Inhibitor concentration or reserve alkalinity
- Glycol concentration
- Presence of dissolved or suspended metals
- Evidence of precipitation or a change in turbidity
- Introduction of particulate or other contaminants

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Where additional insight is needed, more targeted analytical techniques may be considered to identify or quantify specific compounds associated with the elastomer formulation (e.g., extractables, additives, plasticizers or degradation byproducts).

The selection of analytical methods and acceptance criteria should be aligned with the objectives of the evaluation and the expected fluid/material interactions.

8.12 Interpreting Results

Although the heat transfer fluid supplier may be able to provide input on acceptable values for changes in weight, volume, hardness and tensile strength, it is recommended to consult the component manufacturer for guidance on acceptable maximum values as these may differ by material, exposure temperature, test duration and the application (dynamic versus static).

In general, values within the ranges listed below would be generally considered acceptable, however, results should be interpreted based on the specific application and material. It is always best practice to consult the material supplier for guidance on interpreting results. For values outside of these ranges, consult the component manufacturer for additional guidance.

- **Volume Change, %:** -10% to +10%
- **Hardness Change, %:** -10 to +10 durometer change
- **Tensile Strength Change, %:** -30% to +30%, provided no excessive hardening, embrittlement or loss of functional performance is observed
- **Elongation Change, %:** -30 to +30%, provided no excessive hardening, embrittlement or loss of functional performance is observed

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9 Validation of Wetted Materials – Metals and Metal Alloys

9.1 Overview

A TCS loop will likely contain various copper, stainless steel and brass components that are used to construct cold plates, piping, quick connects, fittings and valves. It is critical to ensure that all wetted materials, especially metals, are chemically compatible with the chosen heat transfer fluid as incompatible combinations can lead to accelerated corrosion, erosion or chemical degradation. This may compromise system integrity, reduce thermal efficiency and lead to costly maintenance or catastrophic failure.

To mitigate these risks, ASTM corrosion testing methods are essential. These standardized tests simulate real-world conditions to evaluate how materials will perform when exposed to specific fluids and provide quantitative data on corrosion rates to help identify potential issues before deployment. This allows users to select appropriate materials for long-term reliability. Ensuring that all wetted materials are compatible with the selected heat transfer fluid is essential for maintaining the integrity and performance of the entire TCS loop, including the fluid itself. For any materials not known to be compatible with the chosen heat transfer fluid, it is recommended to perform ASTM D8040-18(2023) corrosion testing of those alloys, with modifications as documented in this section.

Note: This section does not address risks associated with galvanic coupling.

9.2 ASTM Methods

Following is a summary of ASTM methods used to evaluate corrosion resistance of metals and metal alloys.

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Table 9: Referenced ASTM Methods

Method	Overview
ASTM D8040-18 (Reapproved 2023) - Standard Test Method for Corrosion Test for Heat Transfer Fluids in Glassware <i>Note: Testing should be performed with modifications as outlined in this section</i>	<i>Provides a beaker-type procedure to evaluate the corrosive effects of heat transfer fluids (HTFs) on common metals under controlled laboratory conditions.</i>
ASTM G1-25 - Standard Practice for Preparing, Cleaning and Evaluating Corrosion Test Specimens	<i>Outlines procedures for preparing metal specimens before corrosion testing.</i>

9.3 ASTM D8040 with Modifications

The ASTM D8040 method primarily serves as a screening tool to distinguish fluids that are clearly corrosive from those suitable for further evaluation. Results do not guarantee long-term service performance as this would require additional field or extended testing.

The method indicates that a concentrated heat transfer fluid should be diluted down to 30% by volume using water with corrosive salts added. However, given that PG-based fluids intended for direct-to-chip applications are commonly pre-diluted (ready-to-use), the method must then be performed with modifications.

Pre-diluted fluids (for example, PG25 and PG55) should be tested without further dilution. Corrosive salts should be added as instructed in D8040-18(2023), section 8.1.1. Perform testing in three separate beakers. Additional coupons of each alloy can also be included in each beaker.

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Concentrated fluids or fluids designed to be diluted prior to use should be diluted to the intended usage concentration and the corrosive salts (sodium sulfate, sodium chloride, sodium bicarbonate) added according to D8040-18(2023) section 8.1.2.

- Sodium chloride: 110 mg per liter of test solution
- Sodium sulfate: 99 mg per liter of test solution
- Sodium bicarbonate: 92 mg per liter of test solution

Testing should be completed with materials of concern (e.g., copper, brass, stainless steel) unless the component manufacturer or heat transfer fluid manufacturer or component has provided corrosion data for these or similar materials. Use insulating spacers of polytetrafluoroethylene (PTFE, Teflon™) in between all coupons and between the coupons and the coupon bundle legs so that the coupons will be non-galvanically coupled.

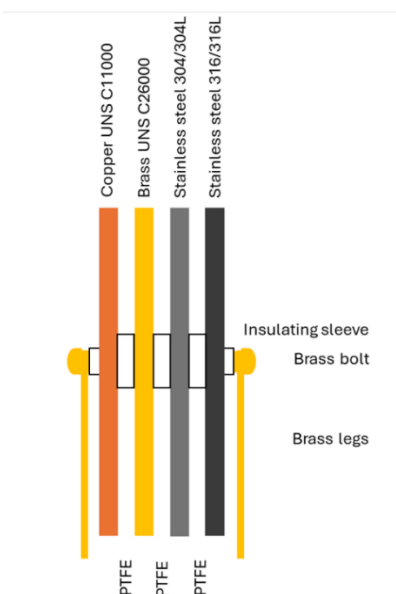


Figure 1: Metal coupon bundle arrangement according to modified ASTM D8040 test, example

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All other steps should be followed according to ASTM D8040-18. Testing should be done at 88°C for 2 weeks (336 hours) with continuous aeration.

Refer to ASTM G1-25, Section 8, for guidance on calculating corrosion rates for each coupon. If desired, pre- and post-testing of the heat transfer fluid can be completed to determine metal ion concentration(s). Maximum allowable corrosion rates are as follows:

Table 10: Maximum Acceptable Corrosion Rates

Metal	*Corrosion Rate, <i>max</i>	*Weight Loss, <i>max</i>
Copper (UNS C11000)	0.2 mpy	5 mg
**Brass (UNS C26000)	0.2 mpy	5 mg
SS 304L	0.1 mpy	2 mg
SS 316L	0.1 mpy	2 mg

*** Note:** While even lower corrosion rates than 0.2 mpy for copper are desirable, the limitations of the D8040 coupon corrosion test should be considered. There can be variations in coupon mass loss results both within a given lab and in comparing results from different labs. The authors consider the 0.2 mpy (5 mg/coupon mass loss) values to be the limits of the test's ability to discriminate results. That is, it cannot differentiate adequately between 0.1 mpy and 0.2 mpy. These concerns do not apply to stainless steel alloys.

**** Note:** Use caution if a change in color is noted in the coupon, such as a copper appearance that indicates dezincification corrosion. Also, use caution if pitting corrosion is evident as this could indicate dezincification corrosion.

Note: For non-standard alloys (e.g., bronze), a custom coupon bundle can be created to include the alloys and their anticipated galvanic couples. Corrosion rates should be 0.2 mpy or less for non-standard alloys.

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9.4 Long-Term Performance

The guidance provided in Sections 8 and 9 focuses on short-term materials testing for metals and non-metals exposed to PG-based heat transfer fluids. While these methods are useful for screening material compatibility and may provide some indication of relative performance, these methods do not ensure long-term reliability in operating systems.

Actual system performance is influenced by a wide range of variables not captured in these tests, including but not limited to changes in fluid condition over time, system operating conditions, interactions among multiple materials and the presence of contaminants or byproducts. In addition, materials used in deployed systems may differ from those evaluated during testing. As such, short-term wetted materials testing should not be considered predictive of long-term behavior with respect to material degradation, corrosion or fluid stability.

To better assess in-service performance, it is recommended that operators consider a combination of approaches, such as routine fluid analysis, monitoring of system performance indicators and evaluation of components during maintenance or replacement events. When components are removed from service, the components may be examined for signs of corrosion, fouling or material degradation to help inform future material selection and maintenance practices.

More extensive and application-relevant testing (e.g., longer-duration exposure, system-level testing or dynamic testing under representative conditions) may be necessary where long-term performance is critical.

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10 System Cleaning, Flushing & Start-Up

10.1 Overview

This section provides general guidance on flushing considerations for systems that will be filled with PG25 heat transfer fluid. It is not intended to prescribe detailed flushing procedures or commissioning practices. Instead, it outlines best practices for selecting an appropriate flush fluid based on system requirements, minimizing the introduction of contaminants during flushing operations and reducing the risk of particulate or chemical carryover into the PG25 fluid during final system fill and operation.

To ensure proper installation and long-term performance of PG25 heat transfer fluid, adhere to the following recommendations:

- **Supply and Planning:** Ensure the selected flush fluid, PG25 heat transfer fluid and all required chemicals, equipment and filtration devices are available on-site before flushing or commissioning activities begin. All work should follow supplier guidelines and warranty conditions.
- **Contamination Control:** Implement practices that minimize the introduction of particulate matter, debris and other contaminants during flushing, installation and commissioning activities. Equipment, hoses, temporary connections, storage vessels and transfer containers should be clean and suitable for the intended service.
- **Fluid Integrity:** Use heat transfer fluid only from unopened containers or properly resealed containers that have been stored according to the supplier's shelf-life recommendations. Proper storage and handling help prevent contamination prior to system fill.
- **Material Compatibility:** Coordinate with parties supplying wetted materials, flushing chemicals and related equipment to confirm compatibility with all fluids used.

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- **Installation and Start-Up:** Follow the recommended procedures for system flushing, fluid installation, and start-up (refer to System Fill). Collect a sample from each system after commissioning and retain it until the fluid in the system is replaced.

10.2 Start-Up Considerations

Documentation

Retain documentation for all fluids and chemicals introduced into the system throughout its lifecycle, including cleaning agents used during pre-commissioning, PG25 used during operation and any remediation chemicals applied over time. Maintaining this information provides traceability and supports effective troubleshooting, maintenance and root cause analysis should issues arise. Where available, vendor documentation such as Certificates of Analysis (COAs) may be retained to support product identification and quality verification. Collectively, these records help establish a complete history of the system and materials introduced.

System Cleaning Procedures

Document the steps taken, including the chemicals and methods used for flushing or cleaning prior to installation. Record the date, passivation method used, chemical concentrations, exposure time and test results. Maintain records for quality control and compliance purposes.

- **System Volume:** Record the total fluid volume to assist with accurate remediation or replacement if needed.
- **Additional Installation Notes:** Include any relevant procedures, compatibility checks and safety measures followed during installation.

Comprehensive documentation helps ensure traceability, supports troubleshooting and simplifies corrective actions if contamination or performance issues arise.

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Refer to [Guidelines for Pre-Commission Preparation of Technology Cooling System \(TCS\) Row Manifolds in Liquid Cooled Data Centers](#) for additional guidance on system cleaning with water.

Compatibility

Before installation of PG25, it is essential to confirm that all wetted materials in direct contact with the selected PG25 heat transfer fluid are fully compatible with both the fluid and the anticipated operating conditions. Users should verify compatibility by consulting the material manufacturer's chemical resistance data, reviewing the PG25 fluid's technical datasheet and considering factors such as temperature and exposure duration. If uncertainty remains, performing a controlled compatibility test or contacting the fluid supplier for recommendations is strongly advised.

Cleanliness

In collaboration with the installer(s) or fabricator(s), verify proper handling and cleanliness of all products with fluid passages, including propylene glycol-cooled servers and datacom equipment. It is important to understand what fluids or chemicals were used for cleaning or passivation and what, if any, residuals may remain. This information will guide appropriate on-site flushing practices. Immediately notify the owner of any signs of mishandling or contamination and develop a remediation plan.

10.3 Cleanliness Assessment

When preparing new TCS components and infrastructure for service, it is important to ensure that all surfaces and internal passages are clean and free of contaminants that could compromise system performance or fluid integrity. The approach to cleaning may vary depending on whether components were fabricated on-site or off-site, as job-site fabrication often introduces additional contaminants such as dust, debris or flux residues that require more

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rigorous on-site cleaning. Conversely, off-site fabricated components may have undergone pre-cleaning or passivation and will not require extensive cleaning. Because system designs and conditions differ, there is no single cleaning procedure suitable for all scenarios. The flushing guidance outlined in this document provides general considerations for cleaning and commissioning rather than prescriptive steps.

Before initiating any on-site cleaning, confirm with component suppliers (e.g., ODMs and OEMs) or fabricators as to what cleaning and passivation processes have already been completed off-site. This information is critical for determining the scope of additional cleaning required. Understanding these differences will help tailor on-site flushing and commissioning practices.

Whenever possible, review available documentation to verify manufacturer or installer records detailing any cleaning procedures, passivation steps and chemicals used prior to shipment. A visual inspection should also be performed to check components for signs of debris, residue or corrosion that may warrant further cleaning. Based on these findings, the scope of on-site cleaning and flushing should be adjusted as needed, taking into account the fabrication method and any residual chemicals, to achieve the desired level of system cleanliness.

10.4 Selecting a Flush Fluid

When selecting a flushing fluid, consider the level of cleaning required based on the starting cleanliness of parts or components. As discussed in Appendix G of the [OCP Modular TCS Paper](#), components that have been thoroughly cleaned and passivated off-site may already meet cleanliness standards and only require minimal flushing or verification steps, while others may need more extensive on-site cleaning. Light debris may be removed with water, while oils, greases or manufacturing residues may require specialized cleaning agents. Typically, a water-based cleaning solution or a propylene glycol-based heat transfer fluid would be used. However,

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in some scenarios, uninhibited water may be sufficient. Following are general options and considerations.

Table 11: Flush Fluid Selection Guide

Flush Fluid Options	
Cleaning Solution	
Pros	• Effective at removing oils, greases, machining residues, biofilm and installation debris - when properly formulated • Can target specific contaminants (e.g., silicates, corrosion products) • Improves baseline cleanliness prior to fill
Cons	• Requires complete removal and multiple rinses to avoid residue carryover • Risk of chemical incompatibility with elastomers, seals, coatings • Residual surfactants can cause foaming or film formation in service fluid • Adds process complexity and time
Comments	• Best when used if the system is heavily contaminated or after construction/retrofit • Incomplete removal is a common root cause of early-life fluid issues (foaming, filter loading, film).
Heat Transfer Fluid	
Pros	• Fully compatible with system materials and final operating fluid • No risk of cross-contamination from foreign chemistry • Simplifies transition to commissioning (can often be retained)

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	Provides early corrosion protection (inhibited system)
Cons	- Less effective cleaning power vs. dedicated cleaners (poor removal of oils/films) - Can become contaminated during flushing (may not be suitable for re-use) - Higher cost if used as disposable flush fluid
Comments	Preferred for final-stage flushing after bulk debris removal. Often used with filtration loops (side-stream) to reach cleanliness targets. Aligns with best practice to avoid introducing foreign chemistries late in commissioning.
Uninhibited Water	
Pros	- Low cost, readily available - Good for removing loose particulates and soluble salts - No organic residues if properly removed
Cons	- Higher corrosion risk - Can promote microbial growth if stagnant - Difficult to fully dry → residual water dilutes glycol and affects inhibitor balance - No cleaning capability for oils/films
Comments	Should be limited to early flushing only, if used at all. Requires rapid drain + dry-out and immediate follow with inhibited fluid. Residual water carryover is a major issue in PG systems (dilution + biological risk). Avoid prolonged residence time.

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10.5 Flushing with a Cleaning Solution

A cleaning solution may be used when components have oils, greases or residues present. In this case, it is important to use high purity water (meeting the requirements in Table 12) mixed with suitable additives as recommended by a qualified cleaning company. Typical additives include corrosion inhibitors to protect system metallurgy during cleaning, surfactants to aid in removing oily contaminants and biocides to control microbial growth during cleaning. **The additives listed below are examples of what may be used for flush water chemistry, however, other additives may also be acceptable for use. Consult the cleaning company for guidance.** Some considerations include, but are not limited to:

Corrosion Inhibitors

Corrosion inhibitors are added to cleaning solutions to protect metal surfaces during the cleaning process. Inhibitors form a protective layer on the metal surface reducing the risk of damage before the heat transfer fluid is introduced. There are various types of corrosion inhibitors and the correct selection and dosage depends on system metallurgy and water chemistry. Tolyltriazole or benzotriazole is often used for protection of copper-based alloys. Phosphate or other suitable additives such as carboxylates, are often used as a corrosion inhibitor and pH buffer. The typical usage level should be determined by the qualified company performing cleaning. Some wastewater treatment streams may not allow disposal of phosphate-based additives, when used above certain levels.

The appropriate type and concentration should always be determined by a qualified cleaning company or chemical supplier to ensure compatibility and effectiveness.

Surfactants

Surfactants are commonly included in cleaning solutions for piping systems prior to the installation of a heat transfer fluid because surfactants help break down and remove oils,

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greases and other hydrophobic residues that water alone cannot effectively eliminate. By reducing surface tension, surfactants allow the cleaning solution to penetrate and lift contaminants from internal surfaces, ensuring a cleaner system and reducing the risk of fouling or corrosion once the heat transfer fluid is introduced.

There are many surfactant options available and the appropriate type and dosage to use will depend on system design, materials and contamination level. The type and addition rate should always be determined by a qualified cleaning company or chemical supplier to ensure compatibility and effectiveness. It is important to note that surfactants should not be included in the final flush as residual surfactants may lead to foaming after installation of PG25 or PG55.

Biocides

Biocides are used in cleaning solutions to control microbial growth during the cleaning process. Standing water or cleaning solutions can create an environment conducive to bacteria and biofilm formation, which can lead to fouling, corrosion and reduced heat transfer efficiency. Biocide helps eliminate these risks before the system is filled with heat transfer fluid. Many biocide options exist, including non-oxidizing types that minimize interference with metal passivation layers. The selection and dosage should always be determined by a qualified cleaning company or chemical supplier to ensure proper application and environmental compliance. It is important to note that biocides should not be included in the final flush prior to installation of PG25 or PG55.

Additives to Avoid

Silicate-based additives should be avoided as these additives can form insoluble deposits on metal surfaces which are difficult to remove. These deposits can interfere with the corrosion inhibitor package in PG25, reducing its effectiveness and potentially causing instability in fluid chemistry.

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Cautionary Additives

Certain inhibitors and additives, such as chromates, nitrites, nitrates and molybdates, may present environmental, regulatory or disposal considerations depending on local requirements and site-specific waste handling practices. As a result, their use should be evaluated in the context of applicable regulations and facility capabilities. Amines may also warrant consideration, as some can react with nitrites to form nitrosamines under certain conditions. In systems where nitrites are not present, the use of amines may be acceptable; however, overall suitability should be assessed on a case-by-case basis.

10.6 Flushing with a Heat Transfer Fluid

Using PG25 fluid as the flushing medium offers some benefits compared to high-purity water or a chemical cleaning solution. If residual fluid remains in the system after flushing, using PG25 prevents over-dilution of the operational heat transfer fluid which could increase the risk of bio-growth. In contrast, leftover water from cleaning solutions of uninhibited water can significantly reduce glycol concentration, requiring corrective adjustments. Additionally, cleaning solutions often contain inhibitors, surfactants or biocides that must be completely removed before system fill. Using PG25 eliminates the risk of these chemicals interfering with the corrosion protection package in the final fluid.

Although the use of PG25 can simplify commissioning by reducing the number of flushing steps, it has limited cleaning power for oils and greases. If these contaminants are present, a dedicated cleaning solution with surfactants may still be necessary. Another downside is that disposal may be more complicated, unless the PG25 will be used for other flushing projects. Flushing with PG25 should be considered when the system is relatively clean (e.g., minimal fabrication residues) and the goal is to streamline commissioning while avoiding chemical

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carryover. For heavily contaminated systems, it is recommended to perform an initial cleaning with water and appropriate additives.

After flushing, all heat transfer fluid should be fully removed from the system. If the heat transfer fluid is intended to be reused for additional flushing or testing, the fluid supplier should be consulted in advance, as the supplier can provide best-practice guidance on filtration, handling and testing to help maintain fluid integrity. Where reuse is deemed appropriate, the removed fluid must be filtered with high efficiency filtration prior to reuse. Flushing fluid should be evaluated against key quality parameters, such as pH, reserve alkalinity, glycol concentration and overall appearance, to confirm suitability before reuse. Testing scope and frequency should be determined in coordination with the heat transfer fluid supplier and may be adjusted based on usage conditions.

10.7 Flushing with Uninhibited Water

Flushing with uninhibited water is not preferred due to an increased risk of corrosion for certain metallurgy. Water alone will not remove oils, greases or other manufacturing residues. Additionally, prolonged exposure to uninhibited water will increase corrosion risks. For systems with a minimal risk of contaminants, it may be acceptable to use uninhibited water, however, it is best practice to maintain constant flow during use and ensure the water does not remain in the system longer than 24 hours before removal. If this method is utilized, consult a reputable cleaning company to determine if there will be any unintended consequences to using uninhibited water.

Any water used for flushing or cleaning must meet or exceed the limits outlined in Table 12. This is critical as residual flush water left in the system can lead to significant operational and reliability issues, such as:

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- **Scaling:** Calcium and magnesium can precipitate and form scale deposits on heat exchangers and cold plate surfaces, reducing thermal performance.
- **Corrosion:** Chloride and sulfate ions accelerate corrosion, which can compromise system integrity, cause leaks and shorten component life.
- **Microbial Growth:** If water is not fully removed, stagnant conditions can promote microbial contamination, leading to biofilm formation and fouling.

Although carbon steel is not recommended for use in this application, if it is present, uninhibited water should not be used for cleaning.

Table 12: Flush Water Recommendations

Parameter	Acceptable Level
*pH	5 - 8
Chloride (Cl)	<25 ppm
Sulfate (SO ₄)	<25 ppm
Total Hardness (as CaCO ₃)	<25 ppm
Electrical Conductivity	<25 µS/cm
Bacteria	<100 CFU/mL
Turbidity	<1 NTU
Iron	<2 ppm

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*Due to the low ionic strength of high-purity water, pH measurements may be unstable and influenced by atmospheric CO₂. As such, pH should be interpreted alongside conductivity and ionic contamination metrics.

Note: Softened water will not likely meet these requirements. While softened water removes calcium and magnesium, it will not eliminate chloride and sulfate, which are critical for maintaining fluid integrity.

Note: Differences between the water quality parameters presented in this table and those contained in other OCP or industry documents are intentional and reflect differing application objectives. For example, the flush water quality parameters specified in Table 5 of [Guidelines for Pre-Commission Preparation of Technology Cooling System \(TCS\) Row Manifolds in Liquid Cooled Data Centers](#) emphasize parameters that can be practically verified in the field. The parameters in Table 12 focus on limiting the introduction of contaminants into the PG25 coolant and therefore may include more stringent acceptance criteria.

10.8 Flushing Considerations

Effective flushing relies on establishing sufficiently turbulent flow conditions to mobilize and transport particulate contamination out of the system. While turbulent flow is generally beneficial, turbulence alone may not be adequate to dislodge or carry larger particles (e.g., dust, dirt or construction debris), particularly in larger-diameter piping. As a result, flushing effectiveness should be evaluated holistically, with consideration given to flow velocity, pipe diameter, fluid viscosity, temperature and the size and nature of expected contaminants. In some cases, especially in larger pipes, higher flow velocities may be required to achieve adequate particle transport. It is therefore recommended to assess flushing performance based on the ability to remove debris, rather than relying on any single parameter or threshold as a proxy for effective cleaning.

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With filtration in place, system flushing may be performed using a staged filtration approach, starting with a coarser filter and progressively transitioning to finer filtration as particulate loading is reduced. The filtration strategy (e.g., inline versus side-stream) and operating conditions should be selected based on system configuration, flow rates and expected contaminant types. Rather than relying on fixed flushing durations or pass counts, flushing should continue until the desired level of cleanliness is achieved, as indicated by stable pressure drop across filters, reduced particulate generation and/or verification through visual inspection or analytical testing. Multiple flushing cycles may be required to meet cleanliness objectives, particularly in systems with higher initial contamination levels.

When a cleaning solution is used, the system should be flushed with high purity water (meeting the requirements in Table 12) until key water quality indicators, such as conductivity, fluid pH and turbidity, demonstrate consistency throughout the system, indicating that residual biocides and surfactants have been effectively removed. To confirm adequate system cleanliness, samples should be collected from multiple representative locations, when possible and compared against the system average. If measured values show excessive variation between sampling locations, additional flushing may be warranted. A shake test may also be performed as a qualitative check for the continued presence of surfactants following the cleaning process.

The final flush may be done with inhibited water as long as it contains additives which are compatible with the heat transfer fluid that will be used and does not contain biocides and surfactants. If surfactants remain in the system once the heat transfer fluid is added, this can lead to foaming issues. If biocides remain in the system, this can interfere with the corrosion inhibitors in the heat transfer fluid and diminish corrosion protection.

Once the desired level of cleaning has been achieved, drain all water out of the piping via valves located in all the low spots. Blow compressed air through the system to help remove any remaining water (ensure contaminants are removed from compressed air). As needed, replace

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all accessible filters with new filters which are the appropriate micron size for operation with the chosen heat transfer fluid.

If passivation of the stainless steel piping will be performed, refer to Passivation of TCS Piping below. Otherwise, install the heat transfer fluid as soon as possible following the final flush, preferably within 24 hours. This is important to avoid bacterial growth. If the system will not be filled for 24 hours or greater, purge with nitrogen and seal the system. For systems containing only stainless steel, elastomers and/or plastic components, exposure to air is acceptable for up to 72 hours. If the storage will last beyond 72 hours, use nitrogen gas to purge the system as described above.

If the system is not filled immediately with the heat transfer fluid, the flushing fluid (e.g., PG25 or inhibited water containing inhibitors, biocides and/or surfactants) may be left in the system until ready for final fill. During this interim period, circulation and handling practices should be reviewed with the water treatment or fluid supplier to ensure the flushing fluid remains effective and does not introduce unintended risks (e.g., stagnation, depletion of inhibitors or microbiological growth). Uninhibited water should not remain in the system for extended durations and is generally not recommended to be left in the system longer than 24 hours prior to filling with the heat transfer fluid.

Note: Any remaining flush water will inadvertently dilute the PG25 or PG55 heat transfer fluid. It is possible to dilute the glycol concentration below the lower limits set in place by the fluid manufacturer. In this case, it is important to have a way to increase the glycol concentration to within acceptable limits, such as via addition of PG55 heat transfer fluid or a more concentrated blend from the manufacturer.

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10.9 Passivation of TCS Piping

This document does not provide specific procedures or requirements for performing passivation of TCS piping. Detailed passivation processes are considered outside the scope of this document. Guidance related to passivation of TCS piping systems is addressed separately under the Modular TCS Workstream, specifically within the Commissioning Considerations documentation.

10.10 System Fill

After piping has been cleaned, passivated (if required) and all flush water has been completely removed, fill the system with the chosen ready-to-use (pre-diluted) heat transfer fluid.

During system fill, verify and maintain the cleanliness of the heat transfer fluid. Even new, pre-mixed fluids may introduce particulates into the system. Filtration of the heat transfer fluid using appropriately rated filters (e.g., 5–10 micron absolute), as it is being introduced into the system, is highly recommended to achieve appropriate cleanliness targets.

Once the heat transfer fluid is installed, verify the propylene glycol concentration of the final blend in the system. This step is important because residual water remaining from commissioning or flushing activities can lead to inadvertent over-dilution if not adequately accounted for. Where practical, samples should be collected from multiple representative locations within the system to confirm the system is well mixed and that residual water has been uniformly blended with the PG-based fluid. For on-site verification, a handheld refractometer may be used to confirm concentration. If measured concentrations are below the intended target after sufficient circulation and sampling, adjustments should be made in accordance with the heat transfer fluid manufacturer's guidance.

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Please note: Cleaning & commissioning of TCS pipe systems is also addressed in Modular TCS Workstream - Commissioning Considerations

10.11 System Start-Up

During final system start-up, bleed air from the system if necessary and check for any system leaks while circulating fluid for a minimum of 30 minutes. Take a representative sample from each system within the first 1-3 days of operation and retain for the life of the fluid. It is also best practice to take a sample of the fresh heat transfer fluid (unexposed to any system components) and keep for the lifetime of the fluid. Be sure to properly label samples with identifying unit, fluid identity and date. See Monitoring & Maintenance for information on sample analysis. It is recommended to submit this initial sample for analysis to ensure there was no contamination and provide the time zero or baseline values. Monitor the fluid level during the first few hours of operation and add additional heat transfer fluid to achieve the desired fill volume.

11 Fluid Analysis & Maintenance

11.1 Overview

Maintaining optimal thermal performance and system reliability is crucial in a liquid cooled data center environment. An essential aspect of this is the regular testing of heat transfer fluids, whether through a qualified laboratory or on-site diagnostics. Over time, fluids can degrade or become contaminated, leading to corrosive conditions that may damage piping, heat exchangers and other critical components. Bio-growth may also occur if the propylene glycol concentration is not maintained at ~25% or above. Testing can help detect early signs of potential corrosion or chemical imbalance, allowing for corrective action before irreversible damage occurs. Additionally, some equipment manufacturers may require routine fluid analysis

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as part of warranty conditions or compliance protocols. Adhering to these requirements helps protect investments and ensure accountability.

Routine analysis provides insight into fluid properties such as pH, propylene glycol concentration, inhibitor levels, corrosion and contaminants. These indicators are essential for assessing the overall health of the cooling system and ensuring it operates within manufacturer-recommended limits. Whether conducted on-site or through a qualified lab, it provides critical data that supports informed decision-making and long-term operational success.

11.2 Sampling Frequency

The recommended sampling frequency may vary based on operating conditions, risk factors and user requirements. Table 13 outlines guidance on sampling frequency for Low, Medium and High-risk scenarios. These are general guidelines as the sampling frequency will ultimately depend on use case, expected service events and frequency of introduction of new equipment (nodes, racks, etc.).

At a minimum, each individual TCS loop should be tested annually by a qualified lab with analytical reports indicating the following, at a minimum:

- Propylene glycol concentration
- Fluid pH
- Reserve alkalinity
- Visual appearance (e.g., sediment, cloudiness, oiliness, etc.)
- Inhibitor concentration(s)
- Chloride
- Sulfate
- Total Hardness
- Degradation Acids

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- Dissolved metals

Note: Contact the heat transfer fluid supplier to discuss available testing options

Note: Sample should be collected from a location that reflects well-mixed, circulating fluid.

Avoid sample collection from expansion tanks, reservoirs, drain valves at low points or dead legs. It is best to flush some fluid through the sample port to eliminate stagnant fluid. This material should be discarded before collecting the final sample.

Guidelines for Introduction of New Equipment

In the event of a high number of service events or introduction of new equipment after initial commissioning has been completed, it is best practice to increase sampling frequency for a short interval of time (until confirmation of fluid stabilization) by submitting a sample to an external lab to confirm fluid health and glycol concentration, however, this is not a requirement.

It is recommended to use the same heat transfer fluid through design, manufacturing, testing and cleaning to avoid introduction of different fluids. If the equipment contains another fluid, other than the operating fluid, (e.g., water, alternative PG25 formulation), flush and fill with the operating fluid before introduction. Consult the fluid supplier for acceptable flushing protocol.

As best practice, it is advised to retain an as-received sample from every bulk delivery. Additionally, it is best practice to retain a sample from every lot/batch for package materials prior to use. This sample does not need to be analyzed but will serve as a baseline for fluid properties before introduction to the system. Samples should be stored in plastic (e.g., HDPE) bottles with a label that includes the delivery date and batch number and retained for a minimum of 6 months before disposal.

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Sampling Guidance for Small TCS Loops (<100 gallons)

For small TCS loops, it may not be feasible to test every rack at a regular frequency due to availability of resources for sampling, a high volume of racks on-site or lack of training or unfamiliarity with sampling and testing protocols. However, it is important to verify the refractive index/glycol concentration and pH of each and every rack before or during start-up (this may be verified by the rack manufacturer). After start-up, it is recommended to sample a statistically significant subset of the racks on-site and analyze at a qualified lab on a bi-annual basis, at a minimum. The racks selected for sampling may change every 6 months to achieve eventual sampling of all racks over time. In the event that anomalies are noted in the bi-annual analyses, such that the fluid is considered to be a warning zone where action or potential action is warranted, the sampling rate should increase (e.g., from 20% to 40%) to confirm if the problem is widespread.

Note: This guidance is for racks of a similar type and with the same materials of construction.

Table 13: Suggested Sampling Guidance for TCS Loops

Scenario	In-line monitoring deployed (<i>pH and refractive index, at a minimum</i>)	Wetted materials* are acceptable for use with chosen heat transfer fluid.	User is familiar with the heat transfer fluid.
Risk Level	LOW		
Analysis Type	Analysis at qualified lab		
Sampling Frequency	Test at commissioning (baseline measurement) and annual thereafter.		
Comments	Users may opt for analysis at 6 months as an additional data set during the first year of operation. Test after **anomalies noted with inline sensors that cannot be disproven by on-site testing and/or sensor calibration or replacement.		
Analysis Type	On-Site Testing (e.g., pH, refractive index, visual, etc.)		
Sampling Frequency	Not required		

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Comments	Users may opt for bi-annual on-site testing or testing after **anomalies noted with inline sensors.
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Scenario	NO In-line monitoring deployed	Wetted materials* are acceptable for use with chosen heat transfer fluid.	User is NOT familiar with the heat transfer fluid.
Risk Level	MEDIUM		
Analysis Type	Analysis at qualified lab		
Sampling Frequency	Test at commissioning (baseline measurement) then bi-annually for the first 1.5 years		
Comments	After 1.5 years of operation, users may choose to scale back to annual analysis if fluid health is stable.		
Analysis Type	On-Site Testing (e.g., pH, refractive index, visual, etc.)		
Sampling Frequency	Bi-annual		
Comments	After 1.5 years of operation, users may choose to scale back to annual analysis if fluid health is stable.		

Scenario	NO In-line monitoring deployed	Wetted materials* are mostly acceptable for use with chosen heat transfer fluid.	User is NOT familiar with the heat transfer fluid.
Risk Level	HIGH		
Analysis Type	Analysis at qualified lab		
Sampling Frequency	Test at commissioning (baseline measurement) then quarterly for the first 1.5 years.		
Comments	After 1.5 years of operation, users may choose to scale back to bi-annual analysis if fluid health is stable.		
Analysis Type	On-Site Testing (e.g., pH, refractive index, visual, etc.)		
Sampling Frequency	Not required		
Comments	n/a		

**Based on Tables 3 and 4 and/or guidance from the fluid supplier and component supplier*

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****Refer to Establishing Operational Limits and Actions**

Note: Refer to APPENDIX 2 for a visual representation of this table.

11.3 External Laboratory Requirements

The qualified lab should be managed or recommended by the heat transfer fluid supplier and be capable of performing a comprehensive heat transfer fluid analysis. The laboratory should have a service department and qualified technical service representatives on staff that are capable of performing analyses. Recommendations on fluid remediation should be given by the heat transfer fluid supplier.

11.4 Acquiring Fluid Samples

Appropriate PPE should be worn when collecting a representative fluid sample (refer to manufacturer's SDS for specific guidance). Typical safety equipment may include safety glasses, impermeable gloves (e.g., nitrile) and long sleeves, as an example. Fluid should be collected in a clean, dry, unused sample bottle (e.g., HDPE) with 4-6 oz. of sample being necessary for a standard analysis.

Care should be taken to use consistent naming conventions for systems, loops and samples each time the samples are submitted for analysis. Maintaining consistency across submissions enables historical data to be trended over time, allowing the laboratory and fluid supplier to evaluate current results in the context of prior analyses and provide more informed, data-driven recommendations related to fluid condition, remediation or maintenance practices.

As a best practice, sample information should be clearly documented on both the submission paperwork and the sample container itself. Printed labels that are securely affixed to each sample bottle and resistant to smudging or fading during handling and shipment are strongly

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recommended. Clear and durable labeling reduces the risk of transcription errors, improves chain-of-custody clarity and helps ensure that laboratory reports accurately reflect the system and conditions from which each sample was obtained.

Label each sample bottle and/or submittal paperwork with identifying information, for example:

- Date sample(s) collected
- Data Center owner and tenant (if applicable)
- Location (include location code, if applicable)
- System Identifier (e.g., name, asset number, equipment number, loop number)
- Work order number (if applicable)
- Any other numbers or codes specific to the data center/tenant/job/location, etc.

Once samples are appropriately labeled and required paperwork has been completed in accordance with laboratory requirements (e.g., the laboratory may have its own submittal forms), ship the samples via the preferred carrier and retain shipping and tracking information. Maintaining tracking records is important in the event that a shipment is delayed, lost in transit or if sample receipt is not confirmed by the laboratory, as it provides a means to locate the package and resolve discrepancies. Retain copies of all analytical report(s) for quality assurance, traceability and future reference.

11.5 Fluid Specific Parameters

Heat transfer fluid quality should be monitored against the parameters outlined in Table 14, as a starting point. These parameters represent commonly monitored indicators of fluid condition, however, **these parameters are not intended to be an exhaustive list of all characteristics that may be relevant for a given system or formulation.** Additional testing may be appropriate based on formulation-specific inhibitors, materials of construction and potential

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contaminants introduced during operation (e.g., metals, degradation byproducts or environmental ingress).

Deviation outside the ranges shown, to some degree, does not necessarily warrant fluid replacement and consultation with the heat transfer fluid supplier is recommended for formulation- and site-specific guidance. Individual fluid suppliers may provide their own monitoring recommendations, which may vary slightly from what is shown below.

Table 14: In-Use Heat Transfer Fluid Quality Characteristics

Characteristics and Methods	Performance	*Remediation Following Lab Analysis
Appearance	Clear and particulate free	Consult the fluid supplier. Additional filtration may be implemented.
Visual		
Propylene Glycol, vol %	PG25: 24 - 29% <i>*inhibitors + water should make-up ~75% of formulation</i> Note: A fluid with 24-29% PG will have a freeze point between 9 to 15 °F (-13 to -9 °C). PG55: 53 - 58% <i>*inhibitors + water should make-up ~45% of formulation</i>	If propylene glycol concentration is <24%, add a more concentrated fluid (approved by the heat transfer fluid supplier) to increase concentration If concentration >29%, add high purity meeting the requirements in Appendix 1 water to decrease concentration. All adjustments should be made
ASTM E202 or D3321		

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	Note: A fluid with 24-29% PG will have a freeze point between -37 to -51 °F (-38 to -46 °C) **If using other glycol concentrations (e.g., PG50), glycol concentration should be maintained within +/-3% PG, by volume. <i>The refractive index value obtained using ASTM D3321 should always be compared against the manufacturer's published data for the specific heat transfer fluid being used. Inhibited formulations, such as those containing corrosion inhibitors and additives, can alter the refractive index, meaning the correlation between refractive index and freeze point may vary from one manufacturer to another.</i>	under guidance from the fluid vendor. **Refer to fluid vendor to determine if a sample should be submitted for analysis to confirm glycol concentration and for guidance on calculations (system volume must be known).
pH	8.0 - 10.5, for IAT-based technologies (conventional)	If fluid pH is outside of recommended limits (based on fluid-specific parameters), consult the fluid supplier to discuss the path forward.
ASTM D1287 ASTM D5464 (for low conductivity fluid, <500 µs/cm)	6.5 - 9.5, for OAT-based or other technologies (hybrid)	

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	Note: <i>These ranges may vary slightly based on guidance from the fluid supplier.</i>	Additives may be available to increase fluid pH but should only be added under guidance from the fluid supplier.
Reserve Alkalinity ASTM D1121 <i>Based on a 10 mL sample of ready-to-use fluid</i>	> 4 mL, for conventional technologies For OAT-based technologies, reserve alkalinity is 'to report' <i>Reserve alkalinity is dependent on corrosion inhibitor formulation</i>	If reserve alkalinity is outside of recommended limits, consult the fluid supplier to discuss the path forward. Additives may be available to increase reserve alkalinity but should only be added under guidance from the fluid supplier.
Copper ASTM D6130	<3 ppm	If copper >5 ppm, monitor level more frequently to determine if levels are rising. Consult the fluid vendor for guidance.
Iron ASTM D6130	<3 ppm	If iron >5 ppm, monitor level more frequently to determine if levels are rising. Consult the fluid vendor for guidance.
Total Hardness (as CaCO₃) ASTM D6130	<50 ppm <i>*High hardness indicates the use of poor-quality water</i>	If total hardness is >50 ppm, consult fluid supplier for guidance – source of hardness should be considered.

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Chloride	<25 ppm <i>*High chloride values indicate the use of poor-quality water</i>	If chloride is >25 ppm but <50 ppm, continue to monitor level as well and look for evidence of corrosion (e.g., ICP analysis for metals). If >50 ppm, consult the fluid supplier for guidance.
ASTM D5827		
Sulfate	<25 ppm <i>*High sulfate values indicate the use of poor-quality water or use of sulfur-cured polymers.</i>	If sulfate is >25 ppm but <100 ppm, continue to monitor level and look for evidence of corrosion (e.g., ICP analysis for metals). If >100 ppm, consult fluid supplier for guidance.
ASTM D5827		

*Example only – refer to heat transfer fluid manufacturer for guidance

**Formulated heat transfer fluids should only be diluted if the concentration falls above the acceptable range indicated by the fluid manufacturer. This can occur due to loss of water from the formulation over time or can be caused by improper dosing of a more concentrated fluid which is typically used to increase glycol concentration. In this case, the water used to decrease glycol concentration to an acceptable level must meet or exceed the criteria outlined in Appendix 1.

Note: The acceptance criteria for new PG25 and in-use PG25 differ because the operating environment introduces changes that are not present in newly manufactured fluid. Over time, interactions with system materials, commissioning residuals, maintenance activities and normal fluid aging can result in changes to analytical parameters. Therefore, in-use limits are established to reflect realistic operating conditions while continuing to support fluid reliability, materials protection and long-term system performance. These values are intended to serve as

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guidance for assessing fluid health and identifying abnormal conditions rather than requiring a return to the original properties of new fluid.

11.6 On-Site Testing

Aside from testing at a qualified lab, some routine testing can also be completed on-site to confirm that the heat transfer fluid remains within the supplier's recommended specifications. This is useful after introduction of new equipment or to use as a check point outside of the lab analysis schedule that is in place. This testing is straightforward, inexpensive and does not require extensive training on methodology.

Not only does on-site testing provide instant results to confirm the heat transfer fluid is within recommended operating limits but it also provides valuable supplementary data to validate the accuracy of inline monitoring systems. By offering a direct, independent measurement, it adds an additional layer of certainty and confidence in process control, helping to quickly identify discrepancies and ensure consistent product quality.

Below are some available options for inline monitoring, however, testing protocol (type of testing and frequency) should be determined by the owner or operator. If resources are not available to handle on-site testing, inline monitoring can be deployed (refer to Section 12), if desired.

Table 15: Optional Tests to Perform On-Site

Parameter	Details
pH	Fluid vendors will define acceptable operating ranges for pH to ensure adequate buffering and corrosion protection. This measurement can be done on-site with a handheld or benchtop pH meter. It is important to routinely calibrate the meter with pH 4.0, 7.0 and 10.0 standards to ensure

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	the accuracy of the readings. If a pH meter is unavailable, pH papers/strips can be used although this method is not as reliable. Refer to guidance from the fluid supplier to determine acceptable pH levels.	
	Pros	Cons/Limitations
	• Simple, widely understood indicator of fluid condition • Provides early indication of degradation, contamination or inhibitor depletion • Can be measured on-site with relatively low effort	• Routine calibration necessary when certified calibration standards • Paper/strip methods provide limited precision
Refractive Index	Glycol-based fluids contain corrosion inhibitors that are formulated to work within a specific concentration range. Operating below acceptable levels can compromise the effectiveness of these inhibitors and increase the risk of microbial contamination. A handheld digital refractometer with temperature compensation and high accuracy can be used to monitor propylene glycol concentration to ensure fluid is with acceptable limits. The refractive index values should be compared against a fluid-specific table from the fluid supplier to determine actual glycol concentration (by weight or by volume).	
	Pros	Cons/Limitations
	• Quick and practical method to estimate glycol concentration • Useful for detecting dilution from make-up water or leaks, allowing for fast remediation	• Cannot accurately determine concentration if significant contamination is present • Assumes base fluid composition is unchanged • Not a direct measure of inhibitor health

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	• Well suited for routine field checks	
Appearance	Fluid appearance can indicate glycol breakdown or aging, contamination, incompatible materials or microbial growth. A visual check of the fluid should indicate the fluid is free of contamination, sediment and cloudiness.	
	Pros	Cons/Limitations
	• Rapid, no-instrument screening tool • Can identify some significant contamination or incompatibility issues	• Subjective and non-quantitative • Cannot detect subtle degradation or early-stage issues • Should be supplemented with analytical testing
Turbidity <i>(optional)</i>	Turbidity is useful for monitoring system health as it may indicate presence of suspended solids such as corrosion products, degradation byproducts, bio-growth, entrained air or other contaminants. Typically, it is recommended to use an optical turbidity sensor with an infrared or LED light source and ATC. Avoid meters that rely solely on colorimetric detection, as dye can affect color-based readings. Refer to fluid supplier for guidance.	
	Pros	Cons/Limitations
	• Measures cloudiness or haziness of the fluid • Sensitive to particulate contamination and suspended solids • Useful for trending system cleanliness over time	• Does not identify particle composition or source • Readings may be influenced by air entrainment or color changes • Measurements can be influenced by light source, color/dye, air bubbles and level of additives in the fluid

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Electrical Conductivity <i>(optional)</i>	Conductivity probe, ATC	
	Electrical conductivity provides a general indication of ionic content in a fluid, however, it is not typically a primary monitoring parameter for inhibited glycol solutions due to their inherently higher electrical conductivity compared to conventional treated water. As a result, conductivity measurements in inhibited glycol systems are generally more useful for trending purposes and for identifying significant changes, such as major contamination events, fluid mixing errors or severe over-dilution, rather than for detecting small incremental changes over time. For on-site testing, a handheld conductivity meter with automatic temperature compensation (ATC) is recommended to account for the strong temperature dependence of conductivity in glycol-water solutions, provided the meter's operating range is appropriate for the expected conductivity levels. Conductivity results should be interpreted in conjunction with other fluid condition indicators and in consultation with the heat transfer fluid supplier, who can advise on appropriate use and data interpretation for the specific formulation.	
	Pros	Cons/Limitations
	• Useful as a trending parameter when baseline is established	• Does not identify specific contaminants • Strongly temperature dependent • Limited diagnostic value without supporting data – results may be difficult to interpret into actionable feedback

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		• Based on additive package, electrical conductivity value may be outside the range of some instruments
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11.7 Fluid Remediation

Following on-site testing which indicates the fluid may be outside of recommended limits, it is best to consult the fluid provider for guidance or to validate the results. A sample should be sent to a qualified lab within one week once a test indicates an out of spec result. General guidance is listed in the table below.

Table 16: Fluid Remediation Guidance

Parameter Outside of Recommended Limits	Remediation
Fluid pH	• If fluid pH is below recommended limits and has been following a similar trend over time, adjust pH via additives recommended by the fluid supplier. • If a sudden and/or atypical drop in pH is detected, ensure proper calibration of the pH probe followed by consulting with the fluid supplier for guidance. Fluid replacement may be necessary if fluid pH is too low. Consult fluid supplier for guidance on remediation timeline. • If fluid pH is above recommended limits, discuss the path forward with the fluid supplier.
Glycol Concentration	• If concentration <24%, consult the fluid supplier for guidance or submit a sample to a supplier approved lab to confirm the

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	glycol concentration. A concentrated fluid (approved by the heat transfer fluid supplier) may be added to increase concentration, following guidance from the supplier. Consult fluid supplier for guidance on remediation timeline. • If concentration is too low, fluid replacement may be necessary, however, the project stage (e.g., commissioning, long-term operation, etc.) and overall fluid health should also be considered. • If concentration >29%, add high purity water to decrease concentration. Refer to Appendix 1 for dilution water requirements. • Refer to the fluid vendor for guidance on calculations (system volume must be known). • Note: During the commissioning phase, it is best practice to have a more concentrated fluid on hand (e.g., PG55) in the event that over dilution occurs.
Appearance	• If particulates or cloudiness are noted, submit a fluid sample for analysis at a qualified lab. • Depending on the source of contamination, sidestream filters may be utilized to remove contaminants. • If severe contamination has occurred, fluid replacement may be necessary.
Other	• Consult fluid supplier for guidance

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12 In-Line (Real-Time) Monitoring & Sensors

12.1 Overview

In-line monitoring provides real-time visibility into the condition of the heat transfer fluid and the overall health and performance of the TCS loop. In mission-critical data center environments, where uptime and thermal stability are crucial, in-line monitoring offers several key benefits:

- **Proactive Maintenance:** Allows user to detect early signs of fluid degradation, contamination or system imbalance and enables timely interventions before issues escalate into failures or downtime
- **Reduces Sampling Requirements:** Minimizes the need for frequent manual fluid sampling and lab analysis and supports risk-based sampling strategies
- **Improves System Reliability:** Helps maintain optimal fluid chemistry, protecting sensitive components like cold plates and pumps to support consistent thermal performance and energy efficiency
- **Data-Driven Decision Making:** Provides continuous data trends for key parameters, enabling better diagnostics and long-term planning. Facilitates integration with BMS for automated alerts and control. The collected data may be shared with the fluid provider to compare against lab analytical data.

12.2 Sensor Selection

Multiple sensor types are available to track fluid health over time. The document outlines a handful of available probes that may be suitable for use in TCS loops; however, the choice to use each probe is up to the user depending on operational goals and comfort in using PG25.

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Once the sensor(s) has reached the end of its useful lifetime it will need to be replaced. Refer to the sensor manufacturer for expected lifetime and calibration or maintenance frequency when in contact with propylene glycol and water mixtures.

Table 17: Optional In-line Probes and Sensors

Parameter	pH	
Recommended Sensor Type	pH probe, ATC <i>Gel-filled or solid-state</i>	
	Probe should be rated for use with propylene glycol and water mixtures	
Details	Pros	Indicates fluid acidity/alkalinity, providing an early warning for degradation or contamination
	Cons	pH probes, especially in continuous inline use, are prone to drift, fouling and degradation over time. Glycol and additives can coat the probe, requiring frequent calibration and maintenance.
		Probes have shorter lifespan due to membrane degradation and fouling in glycol environments.

Parameter	Refractive Index	
Recommended Sensor Type	Digital refractometer, ATC	
Details	Pros	Estimates glycol concentration and fluid dilution factor to ensure fluid is operated >25% propylene glycol to reduce the risk of microbial contamination
	Cons	Concentration cannot accurately be determined in the event of severe contamination (e.g. fluids other than PG25 or water are added).

Parameter	Turbidity	
Recommended Sensor Type	Optical turbidity sensor with infrared (IR) or LED light source, ATC <i>Avoid meters that rely solely on colorimetric detection, as dye can affect color-based readings.</i>	

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Details	Pros	Measures cloudiness or haziness of the fluid – which can come from multiple sources (e.g., particles, corrosion by-products, microbial growth, scale, etc.). Measurement is primarily used in treated water applications but may be used for PG-based fluids in the event of severe contamination.
	Cons	Turbidity testing is best used as a supporting indicator in a broader monitoring strategy. Not likely to detect minor fouling. Measurement can be influenced by light source, color/dye in the fluid, air bubbles and the level of additives in the fluid. Note: Turbidity does not indicate particle size/count.

Parameter	Electrical Conductivity	
Recommended Sensor Type	Conductivity probe, ATC <i>Conductivity range of the chosen sensor should cover values across the entire anticipated operating range as electrical conductivity increases with temperature.</i>	
Details	Pros	Tracks ionic content – primarily used in treated water applications but may be used for PG-based fluids in the event of severe contamination or over-dilution. May be best suited for monitoring of low electrical conductivity fluids.
	Cons	Does not identify specific contaminants or chemical changes but may be used as a proxy measurement. Significant changes in additive levels or metal ion concentrations may not cause noticeable shifts in conductivity. Based on the additive package, electrical conductivity value may be outside the range of most instruments. Value may be difficult to interpret into actionable feedback.

Parameter	Corrosion	
Recommended Sensor Type	Corrosion monitors/probes	
Details	Pros	Monitors real-time corrosion activity in the system.

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		Electrical Resistance (ER) - measures metal loss over time, suitable for long-term monitoring
		Inductive Resistance (IR) - operates similarly to ER by monitoring metal loss over time but uses induction instead of resistance. This is less sensitive to temperature changes and generally provides a more stable signal.
		Electrochemical Noise (EN) - detects localized corrosion, providing early warning of corrosion.
		Linear Polarization Resistance (LPR) - fast response to changes in corrosion rates, capable of measuring very low rates and is highly sensitive to changes in fluid chemistry
		Spectrophotometer - Monitors real-time corrosion activity in the system. May be able to detect ppb levels.
	Cons	Electrical Resistance (ER) - slow response time, not ideal for detecting rapid changes, sensitive to temperature fluctuations, does not distinguish between localized vs. uniform corrosion
		Inductive Resistance (IR) - utilizes large probes which may not work well in this application and a limited number of metal alloys
		Electrochemical Noise (EN) - sensitive to electrical interference, requires stable fluid conditions for reliable data, complex data interpretation
		Linear Polarization Resistance (LPR) - not ideal for long-term monitoring, can be affected by fluid degradation or contamination
		Spectrophotometer - Does not identify specific contaminants but may be used as a proxy measurement. Sensor technology is still under development.

Sensors should be compatible and rated for use with propylene glycol and should be selected based on anticipated operational temperature(s) of the heat transfer fluids. For example, electrical conductivity typically increases with temperature so it is important to understand the maximum operational temperature and take into consideration the electrical conductivity at that temperature. The selected probe should be accurate within this range with a buffer in the event that electrical conductivity increases over time.

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Sensors should be placed in the flow of coolant after filtration. If the sensor is placed where the coolant fluid is not as well mixed (e.g., in the bottom corner of the fluid reservoir) the measurements may not be representative of the fluid flowing across the cold plates. Additionally, sensors such as refractive index and optical clarity (spectrophotometry) provide the most accurate measurements where there are no bubbles due to cavitation or aeration.

12.3 Establishing Operational Limits and Actions

Establishing limits for inline sensors is essential for ensuring reliable monitoring, early detection of issues and effective maintenance planning. It is recommended to record initial sensor readings (pH, conductivity, turbidity, etc.) when the system is first filled with fresh, properly mixed fluid, as these values will serve as a baseline reference for future comparisons. Based on input from the heat transfer fluid manufacturer or published literature, set upper and lower control limits for each parameter based on:

- Fluid chemistry
- Operating temperature
- System criticality

For example:

Table 18: Actions for Fluids Outside of Typical Operational Limits

Parameter	*Typical Operational Limits	Suggested Action when Values Outside of Operational Limits
pH	8.0 - 10.5, for conventional technologies, IAT	When above or below limits set by the fluid manufacturer, confirm pH value with on-site testing (e.g., with calibrated standalone or handheld pH

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	6.5 - 9.5 , for OAT-based or other technologies (hybrid) Note: Range will depend on specific formulation	meter or pH strips). If the value is confirmed, submit a sample to a qualified lab for further analysis.
Refractive Index, 20°C	1.362 - 1.368 (24 - 29% propylene glycol by volume) **Note: Range will depend on specific formulation	When above or below limits set by the fluid manufacturer, confirm the value with a handheld refractometer with ATC. If value is confirmed, adjust glycol concentration according to manufacturer's recommendation or submit a sample to a qualified lab for further analysis.
Electrical Conductivity	1,000 – 10,000 μS/cm **Note: Range will depend on specific formulation and temperature	If values fluctuate $\pm 20\%$ from baseline or if a significant difference is noted in a short period of time, validate the result with a suitable handheld or benchtop conductivity meter or submit a sample to a qualified lab for full analysis. If changes are made to the fluid following analysis, re-tare or zero sensor readings to establish new baselines.
Turbidity	<10 NTU **Note: Range will depend on specific formulation and temperature	If values fluctuate >5 NTU from baseline measurement, validate the result with a suitable handheld or benchtop turbidity meter or submit a sample to a qualified lab for full analysis.

*Example only, contact fluid supplier to establish specific operational conditions and limits.

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12.4 Calibration of Sensors

Before commissioning of a system, all sensors should be calibrated. Refer to sensor manufacturer's guidance on calibration procedure and frequency. Establish a calibration schedule for each type of sensor (e.g., routine and event-based calibration) as well as a maintenance plan (e.g., cleaning, replacement, etc.). Use only certified calibration solutions and ensure the solutions are stored properly with expiration dates clearly noted. Follow manufacturer recommendations for sensor lifespan (typically 1–5 years). Ensure staff are trained on proper calibration techniques and recognizing drift in values and sensor failure. Replace sensors showing signs of inconsistent readings, slow response time or physical damage and fouling, particularly if calibration and/or cleaning has proven ineffective. It is good practice to compare values of in-line sensors with lab sample analysis reports at a given frequency (e.g., annually, bi-annually).

12.5 Data Ownership and Interpretation

It is the responsibility of the sensor owner to ensure understanding of how each sensor responds to the heat transfer fluid at the usage temperature and to validate the accuracy of the readings. Once operational limits are defined, the limits should be reviewed annually or after major system changes (e.g., fluid replacement, hardware upgrades, etc.) and adjusted if any discrepancies are found. Due to differences in sensor capabilities, some readings may serve as proxy measurements for which the user should define acceptable operating parameters and actions when values fall outside of these ranges. It may be useful to look for the rate of change over time and not just absolute values. Sensor readings should be integrated with BMS for automated alerts and control.

Sampling Strategy and Risk Management

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If inline monitoring is deployed, the user may be able to reduce sampling frequency over time. Regardless of capabilities, it is still recommended to test fluid on an annual basis to confirm findings from inline monitoring.

Documentation

Maintain a sensor logbook which includes calibration dates and results, cleaning and maintenance records, corrective actions and sensor replacements and firmware updates.

13 Fluid Lifecycle and End-of-Life Management

13.1 Overview

The service life of the heat transfer fluid can vary significantly depending on the specific application. Key factors influencing fluid longevity include operating temperature, system materials and the type of fluid used. To maximize fluid lifespan, it is essential to operate the system within the parameters outlined in this document and to avoid using materials that are incompatible with the fluid. The fluid manufacturer can provide specific recommendations regarding replacement intervals and any necessary system modifications.

13.2 Replacement Guidelines

The heat transfer fluid should be replaced with fresh fluid either at the end of its useful life, as determined by the supplier's recommendations, or when it no longer meets the performance specifications as outlined by the fluid supplier. It is important to note that fluid suppliers typically do not guarantee the performance or lifespan of the fluid.

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13.3 Regulatory Considerations

Refer to supplier's SDS to review regulatory information and ensure safety and compliance guidance is followed.

13.4 Storage Guidelines

Unopened containers (e.g., pails, drums, or totes) should be stored in accordance with the fluid supplier's recommendations, in a dry location protected from direct sunlight and environmental contamination. Storage duration and shelf life should be confirmed with the fluid supplier. For bulk storage, tanks should be constructed of compatible materials, maintained in a closed condition when practical, and protected from the ingress of water, dirt, and other contaminants. Storage in galvanized steel containers or tanks is not recommended due to potential incompatibility with glycol-based fluids.

13.5 Fluid Disposal

Do not dump new or used fluid into any sewers, on the ground or into any body of water. All disposal practices must be in compliance with all Federal, State/Provincial and local laws and regulations. Regulations may vary in different jurisdictions worldwide. Waste characterizations and compliance with applicable laws are the responsibility solely of the waste generator. Contact fluid recycler if recycling is preferred over disposal. Most used propylene glycol-based heat transfer fluids can be supplied as feedstock to commercial glycol recycling companies.

14 Conclusion

This whitepaper provides best-practice guidance for the selection, installation, operation, monitoring and lifecycle management of inhibited propylene glycol-based heat transfer fluids, specifically PG25 formulations, used in liquid-cooled systems. Developed through broad

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industry collaboration under the Open Compute Project (OCP), the intent of this document is to support reliable, long-term operation of Technology Cooling Systems (TCS) while accommodating the wide range of system architectures, materials of construction, operational conditions and organizational practices present across data center deployments.

Rather than prescribing rigid requirements or system design mandates, this guidance emphasizes a flexible, risk-based approach grounded in fundamental principles of fluid chemistry, materials compatibility, cleanliness control and condition monitoring. Topics such as wetted material selection and validation, filtration strategy, cleaning and commissioning practices, fluid quality monitoring and remediation are presented as starting points that should be adapted based on site-specific conditions and in coordination with component manufacturers, fluid suppliers and service providers.

A recurring theme throughout this document is the importance of traceability, documentation and trend-based evaluation. Effective recordkeeping, representative sampling and baseline establishment enable operators to better understand system behavior over time, distinguish normal aging from abnormal conditions and respond appropriately when deviations occur. Similarly, on-site testing and in-line monitoring are presented as complementary tools, most effective when used for trending and early detection rather than as standalone diagnostics.

As liquid cooling technologies continue to evolve alongside higher power densities and new system architectures, the authors recognize that materials, fluids and operating practices will likewise continue to advance. This document should therefore be viewed as a living framework that reflects current industry knowledge and experience and which may be refined as additional data, validation testing and operational feedback become available through OCP and related industry efforts.

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Ultimately, successful deployment of PG25-based heat transfer fluids in direct-to-chip applications depends on informed decision-making, cross-discipline coordination and ongoing engagement with the broader ecosystem. By applying the guidance outlined in this document and by working closely with fluid suppliers, equipment manufacturers and standards organizations, operators can help promote consistent performance, protect critical hardware and support the long-term reliability of liquid-cooled data center infrastructure.

15 Glossary

Table 19: Terminology

Terminology	Definition
Absolute Filtration	Filtration having a defined and verified particle-removal efficiency at a specified particle size, commonly expressed using a beta ratio under stated test conditions.
Automatic Temperature Compensation (ATC)	A feature in measurement instruments that corrects readings for temperature-dependent changes in fluid properties.
Beta Ratio (β)	A quantitative measure of filter performance defined as the ratio of upstream to downstream particle counts at a given particle size.
Biostatic	A property of a fluid that inhibits microbial growth without actively killing microorganisms, typically achieved through adequate glycol concentration and proper system control.
Closed-Loop System	A cooling loop designed to minimize fluid loss and external contamination by limiting exposure to the atmosphere under normal operation.
Commissioning	The process of cleaning, flushing, testing, filling and verifying system readiness prior to placing a cooling system into service.

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Coolant Distribution Unit (CDU)	System module that circulates coolant through IT racks and interfaces between the facility loop and the technology cooling system.
Corrosion Inhibitor	A chemical component added to a heat transfer fluid to reduce corrosion of compatible system metals by protecting system materials and supporting fluid stability.
Corrosion Rate	The rate at which a material is lost through corrosion, commonly reported in mils per year.
Dezincification	A form of selective corrosion in brass alloys where zinc is preferentially removed, potentially weakening the alloy and introducing contaminants into the fluid.
Direct-to-Chip Liquid Cooling	A form of direct liquid cooling in which coolant circulates through cold plates attached to heat-generating IT components.
Electrical Conductivity	A measure of a fluid's ability to conduct electrical current, typically reported in $\mu\text{S}/\text{cm}$. In inhibited glycol fluids, conductivity is influenced by formulation, ionic additives, contamination, dilution and temperature and is generally most useful as a trending parameter.
Facility Water System (FWS)	The facility-side cooling-water loop that transfers heat between the Coolant Distribution Unit heat exchanger and the facility heat-rejection infrastructure. The FWS is outside the primary scope of this document.
Galvanic Coupling	Electrical contact between dissimilar conductive materials in the presence of an electrolyte, which can alter their relative corrosion behavior.
Heat Transfer Fluid (HTF)	A liquid used to absorb, transport and dissipate heat from system components; in this document, primarily inhibited propylene glycol–water mixtures used in TCS loops.
IAT (Inorganic Acid Technology)	A corrosion inhibition approach based primarily on inorganic compounds.
Inductively Coupled Plasma (ICP)	An elemental-analysis technique used to measure metals and other specified elements in a fluid.
Inhibited Glycol	A glycol-water solution containing a formulated package of corrosion inhibitors and additives designed to protect system materials and maintain fluid stability.
In-Line Monitoring	Continuous or frequent automated measurement of fluid or system parameters using sensors installed in or connected to the circulating fluid system.

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Ion Chromatography (IC)	An analytical technique used to separate and quantify ionic species, such as chloride and sulfate, in a fluid.
Nominal Filtration	Filtration characterized by an approximate particle-removal efficiency at a stated micron size. Unlike an absolute rating, a nominal rating does not establish a consistently verified high-efficiency capture threshold.
OAT (Organic Acid Technology)	A corrosion inhibition approach based primarily on organic acids.
Over-Dilution	A condition where residual or makeup water reduces glycol concentration below intended operating limits, potentially compromising corrosion protection and biostability.
Passivation	A chemical surface treatment applied to stainless steel piping to enhance corrosion resistance by removing free iron or iron-based contamination from the surface and promoting the formation of a stable, chromium-rich oxide layer.
PG25	A heat transfer fluid containing approximately 25% propylene glycol by volume, together with water and a formulated corrosion-inhibitor package. Unless otherwise stated, PG25 in this document refers to an inhibited, ready-to-use fluid.
PG55	An inhibited, ready-to-use heat transfer fluid consisting of approximately 55% propylene glycol by volume, water, and a corrosion-inhibitor package.
Propylene Glycol (PG)	A glycol used in aqueous heat transfer fluids to provide freeze protection and, at an adequate concentration, contribute to control of microbial growth.
Quick Disconnect (QD)	A fluid connection designed to allow rapid connection or separation of hoses or components while limiting coolant loss and air ingress.
Ready-to-Use Fluid	A heat transfer fluid supplied at its intended use concentration and generally not requiring dilution before installation. Also referred to as a pre-diluted or pre-mixed fluid.
Refractive Index	An optical property used to estimate glycol concentration when the measured value is compared with fluid-specific data supplied by the heat transfer fluid manufacturer.
Reserve Alkalinity (RA)	A measure of a fluid's acid-neutralizing or buffering capacity under the conditions of the applicable test method. Reserve alkalinity should be interpreted in relation to the specific inhibitor technology and fluid supplier guidance.

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Sidestream Filtration	A filtration approach where a portion of the circulating flow is continuously diverted through a filter, enabling system-wide cleanliness without full-flow pressure penalties.
Technology Cooling System (TCS)	The closed-loop cooling system circulating coolant between the Coolant Distribution Unit (CDU) and cold plates within IT server racks.
Turbidity	A measure of fluid cloudiness or light scattering caused by suspended material, precipitates, entrained air or other dispersed matter, commonly reported in nephelometric turbidity units (NTU).
Wetted Materials	All materials that come into direct contact with the heat transfer fluid, including metals, elastomers, plastics, seals, hoses and filter media.

16 References

The publications listed below form a part of this guideline, to the extent referenced.

1. Open Compute Project Foundation, Liquid Cooling Integration and Logistics White Paper, Revision 1.0.1. [Online]. Available:
<https://www.opencompute.org/documents/ocp-liquid-cooling-integration-and-logistics-white-paper-revision-1-0-1-pdf>
2. Open Compute Project Foundation, Guidelines for Pre-Commission Preparation of Technology Cooling System (TCS) Row Manifolds (Rev Q). [Online]. Available:
<https://www.opencompute.org/documents/ocp-document-submission-guidelines-for-pre-commission-preparation-of-technology-cooling-system-tcs-row-manifolds-revq-pdf-1>
3. “Standard Test Method for Corrosion Test for Heat Transfer Fluids in Glassware,” ASTM D8040-18(2023) (West Conshohocken, PA, ASTM). “Standard Practice for Preparing, Cleaning and Evaluating Corrosion Test Specimens,” ASTM G1-25 (West Conshohocken, PA, ASTM).
4. “Standard Test Method for Analysis of Engine Coolant for Chloride and Other Anions by Ion Chromatography,” ASTM D5827-22 (West Conshohocken, PA, ASTM).

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5. "Standard Test Method for Use of the Refractometer for Field Test Determination of the Freezing Point of Aqueous Engine Coolants," ASTM D3321-19(2023) (West Conshohocken, PA, ASTM).
6. "Standard Test Method for pH of Engine Coolants and Antirusts," ASTM D1287-25 (West Conshohocken, PA, ASTM).
7. "Standard Test Method for Reserve Alkalinity of Engine Coolants and Antirusts," ASTM D1121-25 (West Conshohocken, PA, ASTM).
8. "Standard Test Method for Determination of Silicon and Other Elements in Engine Coolant by Inductively Coupled Plasma-Atomic Emission Spectroscopy," ASTM D6130-24 (West Conshohocken, PA, ASTM).
9. "Standard Test Method for Rubber—Deterioration by Heating in Air (Test Tube Enclosure)," ASTM D865-22 (West Conshohocken, PA, ASTM).
10. "Standard Test Methods for Rubber O-Rings," ASTM D1414-22 (West Conshohocken, PA, ASTM).
11. "Standard Test Method for Rubber Property—Effect of Liquids," ASTM D471-23 (West Conshohocken, PA, ASTM).
12. "Standard Test Methods for Vulcanized Rubber and Thermoplastic Elastomers—Tension," ASTM D412-23 (West Conshohocken, PA, ASTM).
13. "Standard Practice for Rubber—Materials, Equipment and Procedures for Mixing Standard Compounds and Preparing Standard Vulcanized Sheets," ASTM D3182-24 (West Conshohocken, PA, ASTM).
14. "Standard Practice for Rubber—Preparation of Pieces for Test Purposes from Products," ASTM D3183-23 (West Conshohocken, PA, ASTM).
15. "Standard Test Method for Rubber Property—Durometer Hardness," ASTM D2240-23 (West Conshohocken, PA, ASTM).
16. "Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents," ASTM D543-23 (West Conshohocken, PA, ASTM).

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17. “Standard Test Method for Tensile Properties of Plastics,” ASTM D638-24 (West Conshohocken, PA, ASTM).
18. “Standard Practice for Compression Molding Thermoplastic Materials into Test Specimens, Plaques or Sheets,” ASTM D4703-23 (West Conshohocken, PA, ASTM).
19. “Standard Test Methods for Vulcanized Rubber—Compression Set,” ASTM D395-23 (West Conshohocken, PA, ASTM).

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A Appendix

Appendix 1: Dilution Water Requirements

Component	Acceptable Level	Method
Chloride (Cl)	<10 ppm	ASTM D5827
Sulfate SO ₄	<10 ppm	ASTM D5827
Calcium	<2 ppm	ASTM D6130
Magnesium	<2 ppm	ASTM D6130
Total Hardness (CaCO ₃)	<15 ppm	ASTM D6130
pH	5-8	ASTM D1287
Iron	<2 ppm	ASTM D6130
Bacteria	<100 CFU/mL	ASTM D5465
Electrical Conductivity, 20°C	<25 µS/cm	ASTM D1125

Note: While softened water effectively removes calcium and magnesium, it may not adequately eliminate chloride and sulfate, which are critical to control in order to maintain fluid integrity and prevent corrosion or scaling.

Note: It is recommended to filter any water that is introduced into a system using a 25 µm high efficiency filter, or better.

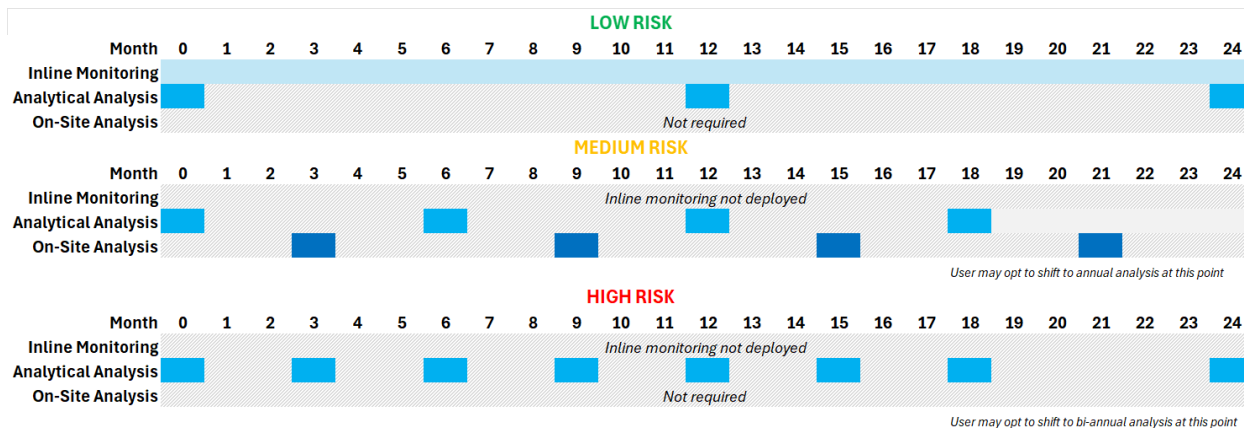
Note: Refer to section 11.5 and 11.7 for additional information

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Appendix 2: Sampling Guidance for TCS Loops



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