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Practical Design Guide to Optimizing Data Center Direct-to-Chip Liquid Cooling with PG 25

Green Paper

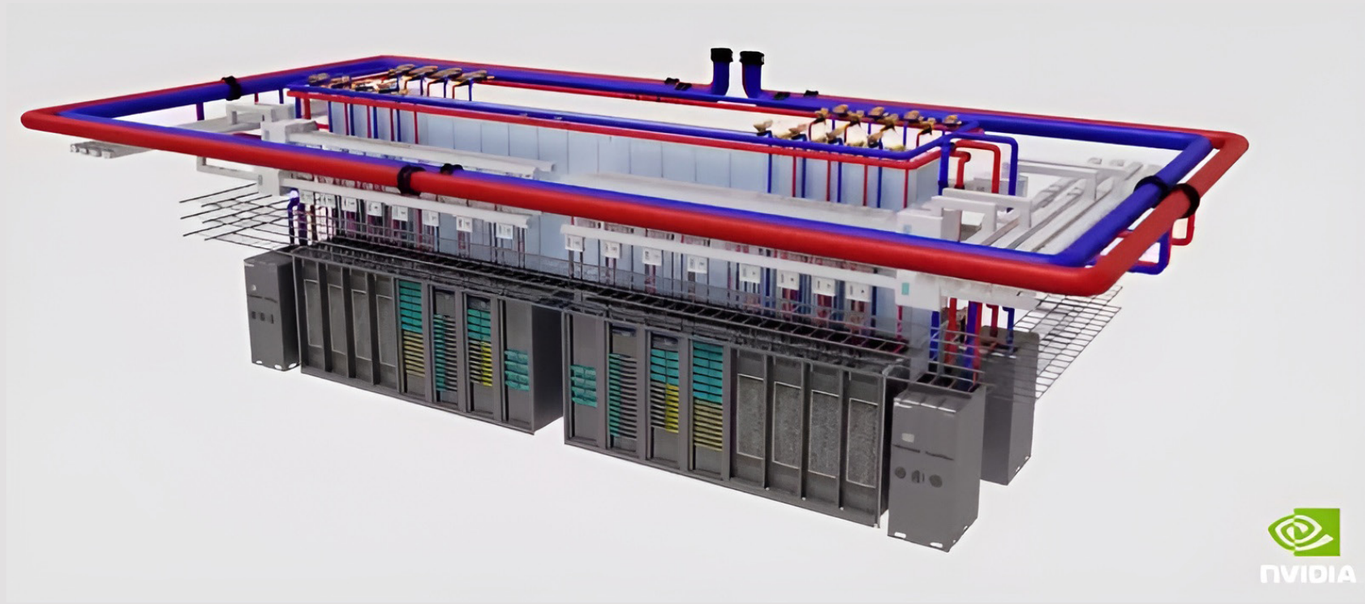
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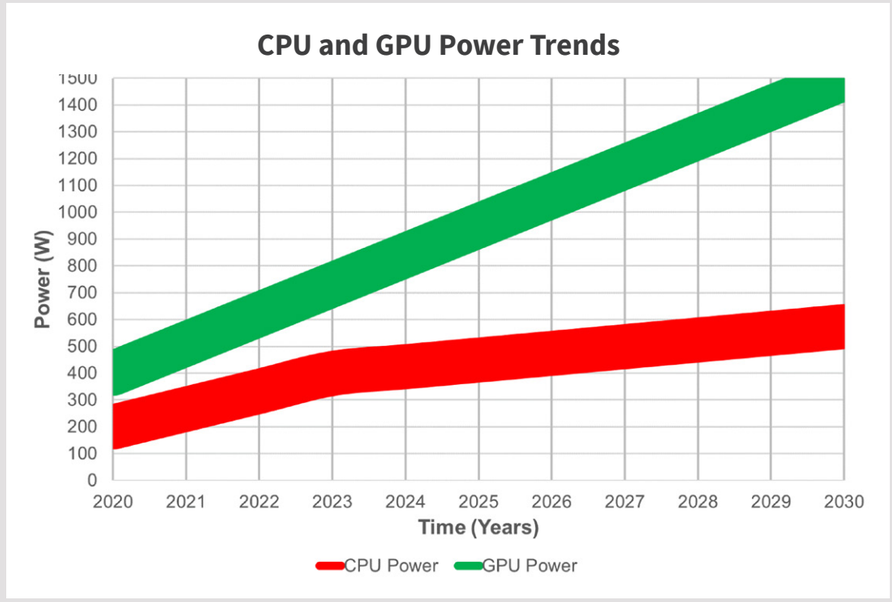
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Introduction
Data Center Cooling

With increasing power densities from AI and HPC workloads (100+ kW per rack), air cooling is no longer viable. The future of data center cooling is dominated by liquid cooling, specifically direct-to-chip, and immersion, with automation and AI-driven optimizations playing a crucial role in enhancing efficiency.



Over the past decade, the server cooling landscape has undergone a significant transformation, with liquid cooling emerging as a key consideration for data centers. Recent industry surveys indicate that 22% of data centers have already adopted direct liquid cooling (DLC), while an additional 61% are actively evaluating its implementation [1]. The rapid increase in processor power and the widespread adoption of AI are driving liquid cooling from its traditional niche in high-performance computing (HPC) to a mainstream solution for data centers. As CPU and GPU power consumption continues to rise sharply toward 2030, DLC will become essential to maximize performance, improve energy efficiency, and manage thermal loads in increasingly demanding workloads [6].



Courtesy of Dell Technologies [2,3]

Introduction

Direct liquid cooling, also known as direct-to-chip cooling, utilizes specialized heat transfer fluids, such as Castrol ON PG 25 [1], to regulate the temperatures of CPUs and GPUs. Cold plates are placed on top of heat-generating components, absorbing heat through the fluid. This heat is then dissipated via a heat exchanger located within a Coolant Distribution Unit (CDU), which can be positioned within the rack, the row, or at the room's periphery.

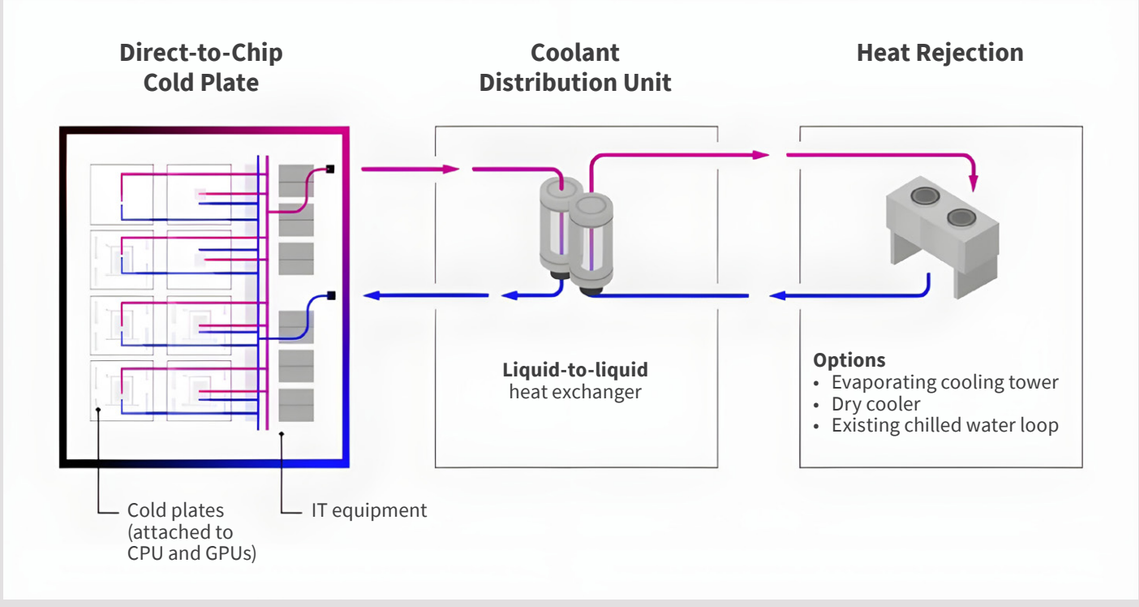
Data center cooling has undergone significant advancements over the past few decades, driven by increasing compute density, energy efficiency demands, and sustainability objectives. Below is an overview of this evolution and the industry's future trajectory.

Era	Cooling method	Key features	Efficiency
1970s–1990s	CRAC & raised floor systems	Basic airflow control, low efficiency	ACC
2000s	Hot/cold aisle containment	Airflow separation, economizers	DAC or WCCA
2010s	Direct-to-chip & rear door heat exchangers	Water-cooled cold plates, increased liquid use	HC/CT
POLAR	10.4 / 8.8	DAC	DAC

What is PG 25?

PG 25 is a ready-to-use cooling fluid designed for direct-to-chip applications in data centers. It is a water-based coolant comprising 25% propylene glycol and 75% water, along with additives such as metal corrosion inhibitors. It is used in liquid cooling systems, particularly for high-performance computing, data centers, and industrial applications. It is valued for its properties and high thermal efficiency, making it a preferred choice for direct-liquid cooling systems and direct-to-chip cooling fluid for data centers. Water is the ideal fluid thermal conductor due to its thermal properties, and its low viscosity enables efficient pump circulation and system performance. The propylene glycol component acts as an antifreeze agent, offering corrosion protection and inhibiting microbial growth. Unlike actual dielectric fluids, designed to be electrically insulating, PG 25 cannot safely come into contact with electronic components and must remain within a closed-loop system (e.g., direct-to-chip cold plate cooling systems).

While PG 25 offers high thermal stability, cost-effectiveness, and low viscosity, it has a potential risk of oxidation over time. A systematic approach involving material selection, fluid purity management, system design, and proactive maintenance is necessary to prevent and eliminate corrosion.



Courtesy of Vertiv

Using PG 25
Best Practices for Achieving a Corrosion-Free Liquid Cooling System

1. Choose the Right Product
A formulated PG 25 coolant, such as Castrol ON PG 25 or other coolants from reputable manufacturers, designed for liquid cooling, ensures the fluid contains corrosion inhibitors that protect copper, aluminum, and steel components. Notably, PG 25 is best suited for racks with a capacity of up to 130 kW. As rack capacities exceed 130 kW, PG 25 performance may be affected due to its thermal performance limitations, including lower thermal conductivity, increased viscosity, and a negative impact on cooling efficiency at extremely high heat loads. Such high capacity racks might require additional cooling measures to use PG 25.

2. Select Only Corrosion-Resistant Materials
One of the primary causes of corrosion is the interaction between metals and the cooling fluid. Selecting the right materials is the first step in eliminating this risk.

A. Use Corrosion-Resistant Metals
To prevent metal degradation, it is crucial to use corrosion-resistant materials such as:

- Copper and Copper Alloys (Brass). Generally corrosion-resistant, but should be used with caution in systems containing dissimilar metals to avoid galvanic corrosion. Isolation methods or corrosion inhibitors may be necessary.
- Stainless Steel (316L, 304)
- Anodized Aluminum (for situations where aluminum is necessary)
- Titanium (highly corrosion-resistant but expensive)
- FEP

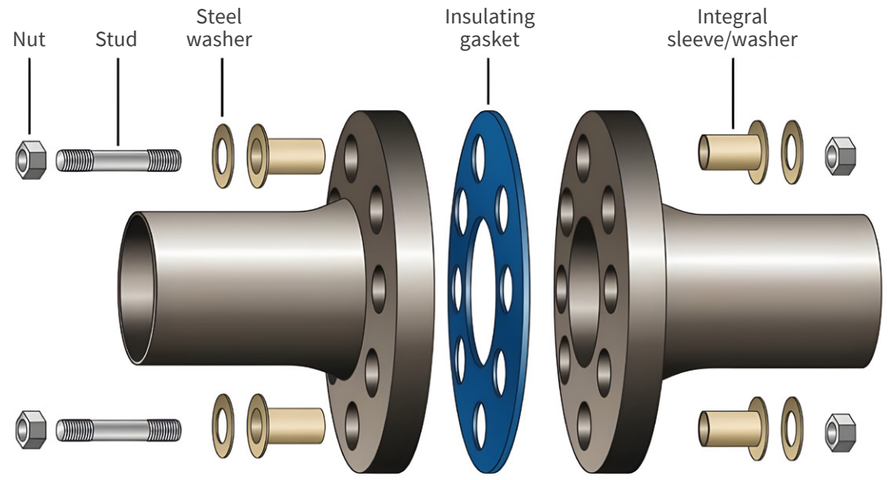
Metals to avoid:

- Unprotected carbon steel (High susceptibility to rust, highly reactive with water and oxygen, leading to rapid rust formation and structural integrity risks
- Zinc or magnesium-based alloys (Highly reactive in aqueous coolants, leading to galvanic corrosion, deposit formation, and system fouling.)
- Bare aluminum, unless properly coated, poses risks, including the formation of deposits and system fouling, galvanic corrosion, and the release of dissolved aluminum particles.
- Brass – While corrosion-resistant on its own, it can accelerate galvanic corrosion when used in contact with more anodic metals like aluminum. Use only with proper isolation and in systems designed to mitigate galvanic effects.
- PVC & natural rubber – degrade over time.

Tables 2 and 3 of the OCP [4] document titled *Guidelines for Using PG-Based Heat Transfer Fluids* provide a more comprehensive list.

B. Prevent Galvanic Corrosion
Galvanic corrosion occurs when dissimilar metals in contact create an electrochemical reaction. To prevent this:

- Use the same metal type for all submerged components.
- Apply dielectric barriers such as plastic spacers, insulated gaskets, or coatings between dissimilar metals.
- Utilize nickel plating on connectors to prevent unwanted reactions.



Courtesy of Corrosionpedia

Gasket material	Dielectric properties	Corrosion resistance	Temperature stability
PTFE (Teflon)	Excellent	Excellent	High
EPDM (Ethylene Propylene Diene Monomer)	Good	Good	High
Neoprene	Good	Moderate	Medium
Silicone	Good	Excellent	High
Glass-reinforced nylon	Excellent	Excellent	High

Using PG 25 – Best Practices for Achieving a Corrosion-Free Liquid Cooling System

C. Pipe Comparison

When designing a liquid cooling system, it is crucial to balance material compatibility, thermal performance, durability, operational considerations, and budget constraints to select the most suitable materials. The table below considers several factors when selecting the appropriate type of pipe material.

Factor	304SS	316L SS	Copper
Thermal conductivity (W/m·K)	16.2	13.0–16.0	401 (Excellent)
Cost ($) price difference from 304SS [8]	Baseline	Less than Ø2" ~35% higher Larger than Ø2" ~65% higher	Less than Ø2" ~10% higher Larger than Ø2" ~5-10% higher
Data center application suitability	Not recommended for direct-to-chip cooling due to poor thermal performance.	Not recommended; slightly better corrosion resistance than 304SS but still poor heat transfer.	Ideal for high-density AI & GPU cooling due to superior heat transfer efficiency.
Risk of downtime (due to poor heat transfer)	High – Poor heat transfer can lead to increased downtime, performance degradation, & overheating failures.	High – Slightly better than 304SS but still inadequate for high-power cooling.	Very low – Efficient cooling prevents thermal throttling & overheating.
Lifespan	Long – Highly durable but inefficient as a thermal conductor. 20-50 years.	Long – Excellent durability in corrosive environments but poor for cooling applications. 20-50 years.	Long–proven in liquid cooling systems with proper coolant management. 15-30 years (closed loop).
Maintenance cost over time	Higher – Less efficient heat transfer may require more aggressive cooling methods, increasing long-term costs.	Higher – Similar to 304SS, additional corrosion inhibitors may be required.	Low – Better heat transfer reduces wear on cooling infrastructure, lowering maintenance costs.
Corrosion resistance	Good – Resistant to oxidation but needs monitoring in aggressive environments.	Excellent – Superior corrosion resistance, especially in chloride-rich environments.	Good in closed-loop cooling with proper inhibitors.
Weight & handling	Small-dia. SS is heavier than copper (thicker walls and larger outer Ø). For large-dia., copper is heavier (higher density starts to outweigh the volume effect.)	Small-dia. SS is heavier than copper (thicker walls and larger outer Ø). For large-dia., copper is heavier (higher density starts to outweigh the volume effect.)	Small-dia. SS is heavier than copper (thicker walls and larger outer Ø). For large-dia., copper is heavier (higher density starts to outweigh the volume effect.)

Copper is ideal for high-performance data center applications due to its exceptional thermal conductivity. It significantly reduces the risk of downtime, enhances AI and GPU performance, and lowers long-term cooling infrastructure costs. Additionally, since copper is the primary material used for cold plates, which are in direct contact with the CPU and GPU, it can minimize thermal expansion mismatches between components, thereby reducing thermal stress and mechanical failure over time and enhancing thermal efficiency. While the initial investment is higher, it is justified by greater efficiency, reduced power consumption, and improved system reliability.

However, for budget-conscious applications where heat transfer efficiency is not a priority, 304SS and 316L SS may be suitable for general-purpose liquid transport but are inadequate for high-power chip cooling. Despite being lighter and highly durable, stainless steel's poor thermal conductivity can lead to overheating issues and increased maintenance costs. Ultimately, copper remains the best option for direct-to-chip cooling in AI and GPU-intensive data centers, where its superior heat dissipation capabilities far outweigh its higher upfront cost.

D. Using CFD to Mitigate Potential Corrosion

Data center cooling piping, heat exchanger hydraulic circuits, and cold plates are subject to variable thermal and mechanical stresses, which contribute to corrosion, biofouling, and system inefficiencies. These issues can lead to unexpected shutdowns, costly repairs, revenue loss, and a decline in customer confidence. The choice of coolant – such as PG 25 – introduces additional flow resistance, reduces specific heat capacity (which similarly impairs heat transfer), lowers thermal conductivity, and poses potential biofouling risks. Computational fluid dynamics (CFD) modeling plays a crucial role in identifying and mitigating these challenges by optimizing coolant flow dynamics, reducing stagnation zones, and enhancing thermal efficiency.

Using PG 25 – Best Practices for Achieving a Corrosion-Free Liquid Cooling System

i. Flow Stagnation and Corrosion Risks in PG-Based Coolants

Even in high-flow-rate hydraulic networks with AI-driven white space cooling optimizations, pockets of fluid stagnation and low-mixing regions can still develop [9]. This is particularly common in:

- Intricate coolant manifolds near chip cooling plates, which can be subject to localized stagnant flow and laminar flow transition, restricting mixing and heat dissipation, which promotes the accumulation of corrosive agents or ions on the surface of the metal.
- Pipe junctions and rack manifold transitions, where changes in flow direction can create recirculation zones that may result in localized thermal stress.

Due to PG 25's higher viscosity compared to water, it is more prone transitioning to laminar flow and to developing stagnation zones, where thermal fatigue, potential biofouling, and corrosion can occur. CFD simulations can identify stagnation zones by high local residence time, enabling engineers to optimize pipe design, pump configurations, and manifold layouts to maintain adequate flow velocity and promote sufficient turbulence.

ii. Corrosion and Biofouling Control

PG-based coolants require corrosion inhibitors because glycol-based solutions can support microbial growth under certain conditions. Microbially Influenced Corrosion (MIC) can be exacerbated in cooling systems where, among others, these conditions exist:

- Stagnant or low-flow regions provide an environment that may allow microbial colonies to develop.
- Poor heat dissipation increases the potential for biofilm formation, which can lead to localized corrosion on pipe and heat exchanger surfaces.

CFD analysis and material compatibility assessments can help predict areas at risk of biofouling and optimize flow conditions to minimize the potential for MIC. However, CFD analysis alone is not sufficient to mitigate microbial growth – a comprehensive approach is required involving:

- Corrosion inhibitors (e.g., phosphates, molybdates, organic acids) tailored for PG-based solutions.
- Ensuring a minimum 25% PG concentration to leverage its bacteriostatic properties.
- Filtration and system flushing to remove particulate contaminants.

iii. Thermal Conductivity and Cooling Performance

Since PG 25 has a lower thermal conductivity than water, it's essential to prevent localized heat accumulation in high-density computing environments. Water has excellent thermal conductivity, making it an ideal cooling fluid. However, its high freezing point and susceptibility to microbial growth present drawbacks.

Mixing water with propylene glycol helps overcome these issues while still preserving much of its thermal performance. This is particularly critical in:

- Direct-to-chip liquid cooling applications, where even minor inefficiencies in thermal dissipation can affect processor performance.
- High-compute racks, where sudden power surges can cause thermal loads to exceed steady-state conditions.

CFD-based thermal modeling enables data center designers to optimize rack-level cooling efficiency by dynamically:

- Optimizing coolant distribution to avoid hotspots
- Predicting thermal hot spots under peak workloads
- Enhancing coolant distribution to avoid hotspots

While AI-driven load-balancing systems help optimize overall cooling efficiency, they do not eliminate localized stagnation issues associated with fluid flow and coolant properties. Therefore, integrating CFD modeling into cooling infrastructure planning allows for more precise flow path optimization.

CFD analysis can integrate simulations of coolant flow through microchannels with conduction heat transfer in solid materials, providing a comprehensive understanding of heat distribution around the chip. This integration will facilitate the optimization of various cooling performance parameters.

iv. Hydraulic Resistance and Pumping Energy Optimization

The increased viscosity of PG 25 also affects hydraulic resistance, leading to higher pumping energy requirements [10,11]. This impact is most pronounced in:

- Long coolant loops, which increase frictional losses and raise operating costs.
- Pipe junctions and manifold transitions, where localized high-flow rates create cyclic shear stress, contributing to mechanical wear over time.

CFD modeling can help:

- Optimize pipe diameters and piping layouts to balance flow velocity and pressure drop.
- Determine ideal pump configurations to minimize energy consumption.
- Predict cyclic shear stress zones where mechanical degradation is likely to occur.

Additionally, material selection plays a critical role in mitigating mechanical and corrosion-related failures. Certain metals, such as aluminum and copper, can exhibit different corrosion behavior in PG-based coolants, making compatibility testing essential.

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v. Leveraging CFD for an Optimized Cooling Infrastructure
By integrating high-resolution CFD modeling with AI-driven cooling optimizations, data center designers can:

- Predict and mitigate areas of excessive shear stress
- Improve flow distribution and prevent thermal hot spots due to flow stagnation
- Enhance cooling performance while minimizing energy waste

Furthermore, a library of CFD simulations covering different workload scenarios coupled with AI software can serve as a proactive design tool for optimizing future data center cooling systems. CFD-driven insights, corrosion management strategies, hydraulic balancing, and material selection contribute to creating a resilient and efficient liquid cooling architecture that minimizes component wear, energy waste, and system failure risks.

3. Maintain PG 25 Fluid Purity

Contaminants can introduce corrosion risks over time. Therefore, it is crucial to keep the fluid clean and free of impurities.

A. Implement Filtration and Purification Systems
To maintain fluid purity, proper filtration is essential for removing contaminants, preventing clogging, and optimizing system efficiency.

i. Filtration Stages

- Initial Flushing & Coarse Filtration (Filter Size: 50–100 µm)
  a. Removes large debris, pipe scale, and construction residue before introducing PG 25 coolant.
  b. Prevents early clogging of finer filters in later filtration stages.
  c. Extends the lifespan of fine filtration media but does not capture microscopic particulates.
- Secondary Filtration for Fine Particles (Filter Size: 5–25 µm)
  a. Captures smaller particulates that could clog cold plates and heat exchangers.
  b. Reduces contamination risks, ensuring coolant remains within ISO 4406 cleanliness standards [9].
  c. Recommended before final system filling or as continuous filtration for operational cleanliness.
- Final Filtration for Long-Term System Operation (Filter Size: 1–5 µm)
  a. Inline particulate filters remove metal debris, oxidation byproducts, and microparticles that could accelerate corrosion.
  b. Ensures continuous coolant purity, but finer filters require more frequent replacement.
  c. Monitor filter differential pressure to detect clogging early and prevent excessive pressure drops in the system.

ii. Use a Combination of Filters for Optimal Efficiency
For best performance, a multi-stage filtration approach should be used:

- 50–100 µm Pre-Filter → Removes large debris and extends fine filter lifespan.
- 5–25 µm Fine Filter → Captures smaller particulates, improving coolant purity.
- 1–5 µm Inline Filter → Ensures long-term system operation by removing micro-sized contaminants.
- Best Practice: Position inline filters strategically at pump inlets, cold plate returns, and heat exchanger outlets to maximize efficiency and prevent system blockages.

iii. Regular Maintenance: Periodic replacement of filters ensures that PG 25 remains free from contamination and oxidation. Conduct periodic fluid analysis to check for:

- Moisture content
- Glycol concentration
- Turbidity
- Oxidation byproducts
- pH level stability (typically neutral to slightly basic, within the range of 7 to 8.5)
- Presence of dissolved metals.

Table 4 of the OCP [4] document, *Guidelines for Using PG-Based Heat Transfer Fluids*, provides a more comprehensive list.

The size of the filter in a PG 25 (25% propylene glycol, 75% water) cooling system plays a crucial role in maintaining fluid cleanliness, enhancing system efficiency, and prolonging the longevity of components. Choosing the proper filter size strikes a balance between contaminant removal and optimal flow rates and pressure stability.

B. Use a Fully Sealed System
A sealed system is crucial when using PG 25 to prevent oxidation, contamination (including dust and oxygen), water loss, air entrapment, and premature component wear. Properly sealed reservoirs, air eliminators, and pressure-controlled expansion tanks will maximize system efficiency, reliability, and longevity. Here are the key reasons for using a sealed cooling loop with PG 25.

i. Prevents Oxidation & Degradation of PG 25

- Exposure to oxygen triggers glycol oxidation, leading to the formation of acidic byproducts.
- Oxidized PG 25 can drop in pH, leading to corrosion of system components.

ii. Reduces Risk of Contamination (Particulates, Microbes & Dust)

- An open system allows airborne particles and microbial growth to enter the coolant.
- Contaminants clog pumps, filters, and heat exchangers.

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iii. Prevents Water Evaporation & Concentration Changes
- PG 25 contains 75% water, which evaporates if exposed to air.
- Water loss changes the glycol-to-water ratio, impacting cooling performance.

iv. Prevents Air Entrapment & Cavitation in Pumps
- Air pockets inside the cooling loop reduce heat transfer efficiency.
- Trapped air in pumps causes cavitation, leading to mechanical damage.

v. Extends the Lifespan of Cooling System Components
- A sealed system prevents premature corrosion, erosion, and scaling inside pipes and heat exchangers.
- Reduces maintenance costs and downtime associated with fluid degradation.

To enhance this:
- Completely enclose the cooling loop.
- Use desiccant breathers if external air exchange is necessary to remove humidity and prevent oxidation.

4. Control Temperature and Avoid Hot Spots
Extreme temperature fluctuations and stagnant fluid zones can accelerate the corrosion process. Proper thermal management is essential.

A. Maintain Optimal Temperature Ranges
Extreme temperature fluctuations and stagnant fluid zones can accelerate the corrosion process. Proper thermal management is essential.

- To prevent degradation, keep PG 25 within the recommended operating temperature range (typically between 30°C and 60°C, or 86°F and 140°F).
- Avoid temperature fluctuations that can cause the metal to expand and contract.

It is worth noting that even when global thermal controls are applied, unless set points within closed-loop control systems are located within each rack, thermal control can be highly improbable in pockets of low flow. In these areas, biofouling can occur when thermal conditions are ideal for bacterial growth. During the data center configuration phase, computational fluid dynamics (CFD) modelling can help determine where these pockets are likely to form, allowing rack assembly to be planned accordingly to minimize the potential for such pockets to develop.

B. Ensure Proper Fluid Flow

i. Design the cooling channels and pipes to maximize circulation.

ii. Avoid stagnant fluid zones, where contaminants can accumulate and corrosion may develop. This can be accomplished by:
- Optimize System Design: Use well-planned cooling loops and avoid dead-end sections where fluid can become trapped.
- Use Active Circulation: Utilize pumps or forced convection to maintain fluid flow through the system.
- Implement Proper Piping Layout: Ensure smooth transitions in bends and avoid unnecessary restrictions.
- Regular System Checks: Monitor flow rates and inspect for areas of low movement or temperature inconsistencies.

5. Use corrosion inhibitors
PG 25 is engineered to resist oxidation, prevent microbial growth, and inhibit corrosion. However, additional corrosion inhibitors can further enhance protection, extend the lifespan of metal components, and enhance system reliability by preventing surface deterioration.

A. Types of Corrosion Inhibitors

- Film-forming inhibitors: Create a protective barrier on metal surfaces.
- pH stabilizers Neutralize acids and prevent acidic corrosion. These stabilizers reduce the risk of fluid degradation while maintaining the coolant's fluid thermal and electrical properties.
- Organic Acid Technology (OAT) Metal passivators: When applied to metals, passivators chemically bond to specific corrosion-prone sites. These organic acids form a monolayer, a single-molecule-thick protective film, that is reversible, meaning it only reacts where corrosion occurs.

These inhibitors should be manufacturer-approved to avoid contamination of the PG 25 fluid.

6. Apply Protective Coatings to Metal Surfaces
Applying specialized coatings on metal components provides an added safeguard against corrosion.

A. Recommended Coatings

- Parylene Coating: Forms a dielectric protective layer to prevent corrosion. Note that coatings may deteriorate over time. Exercise caution and consult the manufacturer when using coatings to ensure long-term stability and reliability.
- Epoxy-based Coatings: Ideal for heat exchangers, pipes, and fittings that are exposed to prolonged fluid contact.
- Although it may be expensive, lined piping, valves, and components – such as those with PFA or PTFE linings – offer excellent corrosion protection. However, the selected lining must also be verified for compatibility with the selected fluid.

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7. Regular System Maintenance & Monitoring

No matter how well a system is designed, regular monitoring ensures that corrosion risks remain eliminated.

A. Routine Inspections

- Visually check all components for discoloration, evidence of microbial growth, oxidation, or wear.
- Ensure that connectors and heat exchangers remain corrosion-free.

B. Fluid Testing Schedule

- Initial fill: Comply with manufacturer's recommendations, including testing protocol and routine scheduled maintenance.
- Quarterly: Conduct a complete chemical analysis, including pH, contaminants, and oxidation levels.
- Annually: Flush and replace aging components if necessary.
- Consider installing an online refractometer to track glycol concentration

8. Choosing the Right Heat Exchanger

The type of heat exchanger (HX) used in a PG 25 cooling system significantly impacts its efficiency, longevity, and overall performance. The right heat exchanger ensures optimal heat dissipation, while the wrong type may lead to inefficiencies, corrosion, or thermal bottlenecks.

A. Heat Transfer Efficiency

Higher-efficiency exchangers remove heat more effectively, keeping PG 25 within its optimal temperature range. An inefficient exchanger may cause coolant overheating, reducing system effectiveness.

B. Compatibility with PG 25 Coolant Composition

Specific heat exchangers are better suited for glycol-based coolants, such as PG 25. Some heat exchanger materials, such as aluminum, can degrade more rapidly due to interactions with glycol. While copper is acceptable, the best choice is stainless steel, which has the highest resistance to PG 25 corrosion and long-term stability.

C. Flow Rate & Pressure Drop

Properly designed heat exchangers allow smooth flow of PG 25, maintaining optimal cooling performance. High-pressure drops can reduce coolant flow, leading to inefficient heat transfer.

Using plate heat exchangers for balanced efficiency and low-pressure drop is highly recommended.

D. Corrosion & Longevity Considerations

Certain heat exchanger materials are more suitable for use with PG 25 due to their built-in corrosion resistance. Incompatible materials, such as uncoated aluminum or bare copper, can corrode over time, contaminating the coolant. To ensure long-term durability in PG 25 systems, the optimal material for HX is 316L Stainless Steel or Nickel-Plated.

9. Regulatory and Sustainability Considerations

A. Environmental Impact of Cooling Strategies

- Water Consumption: Traditional water-based cooling systems can be highly water-intensive. Advanced liquid cooling solutions, including PG 25-based direct-to-chip cooling, help reduce overall water usage compared to evaporative cooling towers depending on location, seasonality, and approach temperature.
- Energy Efficiency: Liquid cooling is significantly more energy-efficient than air cooling, reducing data centers' overall Power Usage Effectiveness (PUE).
- Carbon Footprint Reduction: By improving heat transfer efficiency, PG 25-based systems contribute to lower cooling energy demands, reducing greenhouse gas emissions.
- Fluid Lifecycle and Disposal: PG 25 is biodegradable and has a lower environmental impact than synthetic dielectric fluids used in immersion cooling.

B. Regulatory Compliance

- ASHRAE Guidelines [5]: Ensuring compliance with ASHRAE thermal and humidity standards for liquid-cooled data centers.
- EU Energy Efficiency Directives: Meeting sustainability regulations, such as the European Commission's energy efficiency directives for data centers.
- U.S. EPA Regulations: Adhering to environmental guidelines for coolant disposal and hazardous waste reduction.
- Green Certifications: Implementing PG 25-based cooling in compliance with LEED (Leadership in Energy and Environmental Design) standards.

C. Future of Liquid Cooling with PG 25

- Growing role in AI-driven data centers & liquid-cooled HPC clusters.
- Greater integration with renewable energy & waste heat reuse strategies.
- Improvements in fluid longevity & next-gen corrosion-resistant additives.

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10. Pumping Energy

In PG 25 cooling systems, propylene glycol (PG) increases the viscosity and density of the coolant, requiring higher pumping energy than water-based systems. As viscosity rises, fluid friction within pipes increases, leading to higher pressure drops and greater resistance throughout the cooling loop. Pumps must work harder to maintain adequate flow rates, resulting in increased energy consumption and operational costs. To compensate for these effects, proper pump sizing, flow rate adjustments, and the integration of a variable speed pump (VSP) are essential for optimizing efficiency. The following discussion explores how PG 25 affects pumping energy, system performance, and best practices for mitigating increased load in liquid cooling systems.

- PG 25 increases fluid viscosity, requiring more pumping power than deionized water.
- Pump selection must be adjusted to compensate for the increased pressure drop due to PG 25 and the additional energy required.
- Higher energy consumption leads to increased operational costs.
- Variable Speed Pumps (VSPs) can help optimize flow and reduce excess energy usage.
- To minimize frictional losses, it is highly recommended that centrifugal pumps specifically designed for glycol-based fluids be used, along with larger pipe diameters.

It is worth noting that maintaining the PG 25 concentration at the lowest possible level while adapting to system monitoring and operational changes is essential. Exceeding a 30% glycol concentration significantly increases the Power Usage Effectiveness (PUE), resulting in reduced efficiency.

11. Flushing Standards

Proper flushing is a crucial step in commissioning a PG 25 cooling system. It ensures the removal of contaminants, debris, and residual oils that can cause clogging, corrosion, and system inefficiencies. Components should be cleaned and passivated before fabrication or thoroughly cleaned during flushing to ensure system integrity and prevent contamination. Without proper flushing, particles can accumulate in pumps, heat exchangers, and cold plates, reducing heat transfer efficiency and leading to early equipment failure. Flushing is a common challenge, and adherence to recognized industry standards such as ISO 4406 [6], ASHRAE 90.4 [5], and ASTM D3306 [7] is essential for ensuring long-term system performance and reliability.

12. Optimize the Cooling System Design

Even with all the above measures, a well-engineered system layout is crucial for eliminating corrosion.

A. Design Best Practices

- Avoid sharp edges and dead zones where fluid stagnation could occur.
- Use fully welded joints instead of mechanical fittings to reduce leak points, prevent corrosion, and enhance structural integrity. These metal connections are completely fused without the use of mechanical fasteners such as bolts, screws, or gaskets. In liquid cooling systems, particularly those using PG 25, fully welded joints are preferred over mechanical connections because they offer superior structural integrity, leak prevention, and corrosion resistance.
- When welding joints, developing and adhering to specific welding procedures tailored to the material involved is crucial. Each pipe material requires precise welding parameters, filler materials, and shielding gases to ensure structural integrity and corrosion resistance.
- During fabrication and installation, strict adherence to approved welding procedures (WPS -Welding Procedure Specification [12]) is essential. Failure to follow the correct process can lead to defects such as incomplete fusion, porosity, or cracking, compromising the joint's durability and performance.
- Ensure all materials are chemically compatible with PG 25.

B. Commissioning

- Commissioning is critical in designing, installing, and operating PG 25 cooling systems. It ensures that all system components function correctly, meet design specifications, and operate efficiently and reliably. Systems may experience performance issues, premature failures, and increased maintenance costs if not properly commissioned.
- System purging is required when using PG 25 to ensure optimal performance, prevent contamination, and eliminate trapped air. Proper purging is a critical step in commissioning and maintaining a liquid cooling system, helping to prevent corrosion, pump cavitation, and fluid degradation.

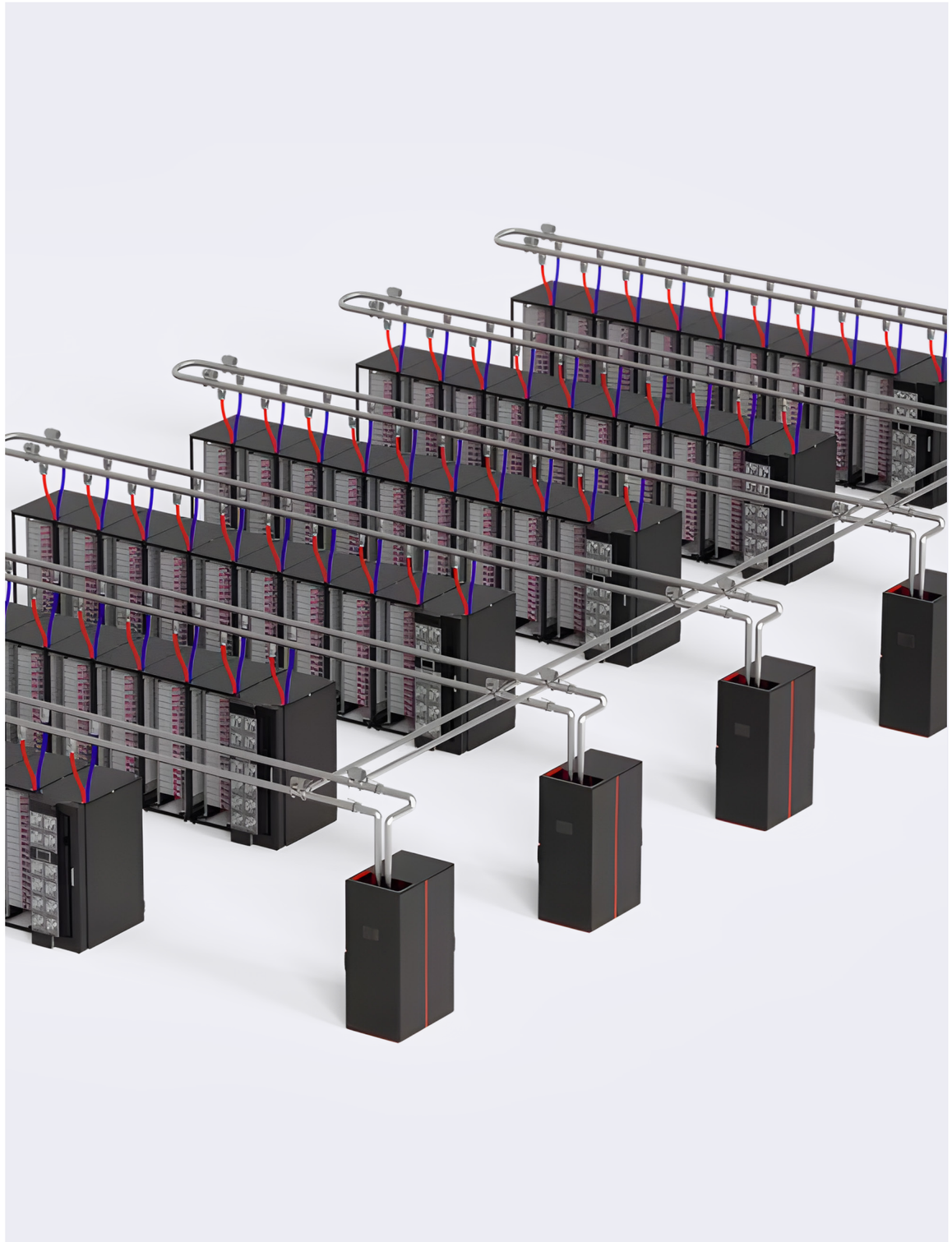
13. Environmental Compliance (non-closed system)

The U.S. Federal Clean Water Act requires that any industrial entity discharging contaminated water to streams and groundwater wells should obtain a National Pollution Discharge Elimination System (NPDES) permit. The NPDES permit limits the quantity of contaminants and flow that can be released into wastewater streams based on the health of the discharge site water systems. Environmental flow and water quality modeling can help data center owners better plan their waste stream and post-coolant life treatment processes to obtain and manage their NPDES permits.

Selecting the Right Coolant
A Thoughtful and Deliberate Process

Choosing the proper coolant for a PG 25-based cooling system requires a carefully considered decision, as it directly impacts system efficiency, longevity, and reliability. Several critical factors must be evaluated, including thermal performance, corrosion inhibition, material compatibility, fluid stability, pumping energy requirements, maintenance needs, and environmental impact. The selected coolant must offer optimal heat transfer, be non-corrosive to system materials, and remain chemically stable over time to prevent degradation or scaling. Factors such as viscosity, biofouling resistance, filtration requirements, and regulatory compliance must be considered to ensure smooth operation and minimize downtime. A well-chosen coolant not only protects system components but also optimizes energy efficiency, reduces maintenance costs, and extends the lifespan of critical infrastructure.

These guidelines are provided for reference only and should be used with a clear and complete understanding of their content. The author, contributors, and the review committee accept no responsibility for any inaccuracies, omissions, or incomplete information. It is the sole responsibility of project owners and engineers to evaluate and ensure the guidelines are appropriate and applicable to their specific project requirements.



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