Why Material Choice Matters in Hyperscale Liquid Cooling

Considering Stainless Steel vs Plastic Manifolds in High-Density Data Centers

Liquid Cooling as Permanent Infrastructure

Once considered a transitional or experimental solution, liquid cooling is now firmly established as a baseline infrastructure in hyperscale data centers. With AI and HPC workloads driving sustained increases in rack power density, coolant temperatures and flow rates exceed the design limits of traditional air-cooled architectures, making liquid cooling the clear choice for quick and efficient cooling in hyperscale data center environments.

This shift is reflected in **ASHRAE's** *Liquid Cooling Guidelines for Datacom Equipment Centers*, which recognizes liquid cooling as a production-grade thermal strategy. As a result, liquid cooling loops are now long-life infrastructure assets with reliability expectations comparable to power distribution and mechanical plant systems.

Within this context, material choice for coolant distribution manifolds is critically important. No longer ancillary mechanical components, manifolds form pressure-retaining interfaces between facility plant, CDU architectures, and rack-level cooling hardware, meaning that the choice of material directly affects mechanical stability, leakage risk, quality assurance, maintenance burden, and long-term system scalability.

Here we consider the pros and cons of the two dominant material choices for manifolds in high-density data centers: stainless steel and plastic.

Scope and Baseline Assumptions

Plastic manifolds have legitimate applications in defined operating envelopes. In low-pressure, low-temperature systems with limited service life and low consequence of failure, engineered polymers can provide advantages in weight, handling, and initial material cost.

However, hyperscale liquid cooling environments increasingly operate outside these constraints. Modern deployments commonly involve warm-water cooling, elevated flow velocities, pressure cycling, chemically treated coolant loops, and service lifetimes measured in decades. Under these conditions, long-term material behaviour becomes the primary engineering consideration, rather than installation-day performance.

While general piping standards such as **ASME B31.3** define requirements for design, manufacture, and traceability, they do not govern material suitability for specialized applications such as datacom liquid cooling. Instead, material selection must be aligned with **ASHRAE** guidance and the specific operating conditions of the cooling loop. However, it is important to note that **ASHRAE**'s *Liquid Cooling Guidelines for Datacom Equipment Centers* does not list polypropylene as a recommended wetted material for the technology cooling system loop.

Many hyperscale data center engineers are now turning to stainless steel piping, which can offer a range of advantages including dimensional consistency, quality assurance, material stability, and chemical compatibility with coolants, as discussed below.

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Dimensional Consistency and Flow Integrity

Plastic piping manufactured via extrusion can exhibit variations in circumferential wall thickness due to gravitational effects during production. While this variation does not typically compromise pressure or temperature ratings, it can result in internal misalignment at fusion joints.

Internal misalignment can affect flow smoothness and introduce localized turbulence, particularly at fusion interfaces where thinner and thicker wall sections meet. In contrast, stainless steel piping provides uniform wall thickness and dimensional stability, supporting more predictable hydraulic performance and cleaner internal flow paths across the full operating envelope.

Joint Quality

Leakage risk in liquid cooling systems is driven primarily by joint performance rather than parent material strength.

Stainless steel enables fully welded manifold architectures that can be qualified and inspected under established standards such as **ASME Section IX** (welding qualification), **ASME B31** and **ASME BPE** piping codes, and **ASTM A380** for pickling. Welded joints provide metallurgical continuity, consistent internal geometry, and support hydrostatic testing, non-destructive examination, and traceable quality documentation.

Plastic systems typically rely on fusion, threaded, compression, or push-fit joints sealed with elastomeric elements. While acceptable in lower-risk applications, these joints can introduce internal beads, flow disturbance, and potential debris capture points. Post-assembly inspection capability is limited, and joint integrity is more sensitive to thermal cycling, vibration, and long-term stress relaxation.

Structural Support and Installation Implications

Plastic piping exhibits lower stiffness and higher susceptibility to deflection than stainless steel. As a result, plastic systems generally require more frequent supports and tighter installation tolerances.

However, stainless steel's higher rigidity allows longer unsupported spans and simpler support strategies. This reduces installation complexity, minimises long-term deflection risk, and lowers maintenance intervention requirements over the system lifecycle.

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Mechanical Stability and Thermal Expansion

Polymeric materials exhibit time-dependent deformation (creep) under sustained load and reduced stiffness at elevated temperatures, as characterized in standards such as **ISO 899-1** (Plastics — Determination of creep behaviour).

Plastic materials also exhibit significantly higher coefficients of thermal expansion than stainless steel. Under temperature cycling, this differential expansion increases stress at joints, supports, and interfaces with connected equipment.

In contrast, stainless steel maintains stable elastic and yield properties across operating temperatures common in liquid-cooled data centers, providing greater resistance to fatigue, creep, and dimensional drift under cyclic thermal and pressure loading (**ASM International**, Properties and Selection: Irons, Steels, and High-Performance Alloys).

Manufacturing Quality and System-Level Alignment

Stainless steel manifold fabrication processes, including welding, passivation, flushing, and leak testing, can be executed to the same standards applied to CDU and plant piping systems. This enables consistent quality control, inspection regimes, and documentation across the entire cooling loop.

However, plastic molding and fusion processes offer limited scope for equivalent QA depth, traceability, or post-manufacture inspection. This disparity becomes increasingly significant as hyperscalers seek deterministic quality assurance across multi-site and multi-region deployments.

Forming Flexibility and System Architecture

Stainless steel can be bent, formed, and configured to accommodate complex routing and integrated system designs while minimising joint count. This supports cleaner architectures and reduces potential leakage pathways.

Plastic piping cannot be formed in the same manner and typically requires additional fittings, tees, or transitions to achieve comparable routing. Increased joint count directly increases long-term leakage exposure and maintenance burden.

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Cost and Lifecycle Considerations

Material cost comparisons are frequently oversimplified. In practice, stainless steel piping is often cost-competitive with plastic, up to approximately 12-inch diameter. At larger diameters, cost differences between plastic and stainless steel narrow significantly.

Market forces are another factor that can make steel more cost-effective than plastic piping. Steel is widely available across global markets, supported by mature supply chains and relatively stable pricing. In contrast, plastic materials are derived from petroleum-based products, making them more susceptible to market volatility and fluctuations in cost.

However, when lifecycle risk, inspection capability, maintenance exposure, and consequence of failure are considered, initial material cost becomes a secondary factor in high-density liquid-cooled environments.

Chemical Compatibility and Coolant Stability

Modern hyperscale liquid cooling loops utilize glycol-based coolants, corrosion inhibitors, biocides, and treated technical water. Long-term material compatibility with these chemicals is essential to maintain loop integrity and corrosion control, with industry guidance from organizations such as **AMPP** and **ASHRAE** emphasizing material compatibility as a critical factor in closed-loop fluid systems.

Stainless steel exhibits predictable corrosion behaviour and has proven, long-term chemical stability with modern coolant formulations when properly specified and passivated. In addition, stainless steels are inherently autopassivating, as noted in **ASTM A967**, Paragraph 3.1.1, “stainless steels are autopassivating in the sense that the protective passive film is formed spontaneously on exposure to air or moisture.” This self-generating chromium-rich oxide layer provides continuous corrosion protection and can re-form naturally if it is locally disrupted during service.

Plastic materials, while often nominally resistant to common coolant constituents, may be more susceptible to polymer degradation or additive leaching over extended service lives.

Industry Practice: Designing for Consequence

In high-density data halls, engineering decisions must consider the consequences of failure as well as the probability. Leakage events inside white space environments carry disproportionate operational and reputational impact.

From an industry best-practice perspective, this drives preference toward materials and architectures that:

- Reduce joint count
- Support inspection and pressure testing
- Provide predictable long-term mechanical behaviour
- Align with plant-level QA standards

As evidenced by the discussion above, stainless steel manifolds meet these criteria more consistently than polymer alternatives in hyperscale liquid cooling applications.

Conclusion

Plastic manifolds remain suitable for defined, low-risk use cases. However, in hyperscale liquid cooling environments characterized by high power density, long service life, pressure and thermal cycling, and high consequence of failure, stainless steel represents the more robust engineering solution.

Material choice in liquid cooling distribution is no longer a procurement optimization exercise. It is an infrastructure reliability decision that directly affects system uptime, maintenance exposure, and lifecycle performance.