

Built to Endure: Why Stainless Steel is the Backbone of High Density Liquid Cooling



Building infrastructure that's not only fit for today's demands but designed to support whatever comes next begins with selecting the right material for the job.

For decades, data center rack densities sat comfortably at around 40kW per rack, making air cooling within controlled environments relatively straightforward, predictable, and manageable. But now, firmly inside the AI era, this sense of equilibrium is rapidly eroding as operators confront a new set of challenges defined by extreme density, accelerated thermal loads, and constant pressure to protect uptime.

Today's massive rack densities mean the most efficient – and increasingly the only viable cooling method – is liquid cooling. Introducing liquid into the data center represents a fundamental shift away from traditional, well-established approaches towards something far more dynamic, complex and, in many ways, less forgiving.

Where a single aisle may have once required around 200kW of cooling, operators are now dealing with aisle densities exceeding 1MW, with entire halls transitioning to liquid-cooled setups. This new normal represents a full-scale infrastructural evolution to deliver liquid consistently across every rack throughout the facility without interruption.

Central to this evolution are the material choices that underpin the durability and performance of the entire cooling system. As facilities become increasingly critical to the digital landscape – representing vast capital investments – protecting equipment from liquid-related risks and maintaining always-on operations must come built into each and every design and planning decision.

When material performance influences everything from reliability and scalability to durability and longevity, selecting the right material for liquid distribution is more than an engineering priority, but central to operational strategy.

Helping to deliver the kind of confidence operators require, Aidan Jones, Tate's Head of Research & Development for the EMEA region, highlights why understanding and evaluating material options for liquid distribution must sit at the center of designing and planning modern, high-density environments.

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Aidan Jones

Head of Research & Development
Tate



High-Density, Even Higher Stakes

When distributing liquid at higher densities and pressures, ensuring that no rack is starved of coolant is critical. Even small inconsistencies in flow can translate into facility-wide operational risks.

“Coolant requirements are typically sized at around 1.5 litres per minute per kilowatt, meaning a 100kW rack requires approximately 150 litres per minute,” explains Jones. “Any drop below this threshold during peak load conditions can result in rapid overheating and potential hardware failure.”

Hydraulic design naturally favours the first rack in an aisle, which tends to receive a greater share of flow, while racks further along the line experience progressively reduced supply. This pattern is simply unfit for purpose in high-density environments where uniform performance is essential.

Achieving consistent distribution requires carefully pressurized ring main systems that ensure adequate flow reaches the very end of every aisle, combined with precise sizing and selection of flow control or flow limiting valves to prevent individual racks from drawing more than their share and leaving others starved of coolant.

Crucially, this level of control is only made possible reliably and at scale when the underlying pipework material can withstand higher pressures, maintain dimensional stability, and minimize frictional losses across the system.

Not All Materials are Created Equal

Given these pressures, material selection plays a defining role. While options such as rubber, plastics including high-density polyethylene (HDPE), polypropylene (PP) and polyvinylidene fluoride (PVDF) as well as copper, and stainless steel are all commonly used, each comes with its own unique properties and limitations that must be carefully evaluated in the context of today's cooling requirements.

Amid AI-driven complexity, many go-to practices and solutions are beginning to show their limitations – particularly as operating temperatures and pressures continue to rise.

“As next-generation AI systems are expected to drive higher inlet and outlet temperatures, additional strain will be placed on materials like plastics, whose durability can decline under elevated thermal conditions, creating potential vulnerabilities in systems operating near their design limits,” says Jones.

Simultaneously, rising rack densities demand greater flow volumes, which often means replacing entire piping networks to handle increased pressure without exceeding maximum allowable limits. This approach is both inefficient and unsustainable for materials that are already designed to operate at their thresholds from day one.

“In this context, stainless steel emerges as an optimal solution, offering the ability to handle operating pressures well beyond both current and anticipated requirements while maintaining structural integrity across a wide range of temperatures,” explains Jones.

Built to Last

Ensuring a leak-proof system is another essential requirement. Stainless steel enables this via fabrication techniques that minimize joints and reduce potential failure points, including forming flanges directly onto pipes, bending tubes rather than relying on multiple fittings, and using collaring methods instead of pre-fabricated components that require extensive welding.

These approaches simply aren't viable for some alternative piping systems that depend heavily on multiple joints and fittings, increasing the likelihood of leaks over time. In environments where even a minor leak can have significant consequences, selecting materials and technologies that reduce risk is essential to maintaining uptime and operational stability.

Corrosion is an equally critical consideration in liquid cooling systems, as any degradation can lead to leaks or contamination that may damage sensitive equipment.

"Stainless steel is naturally resistant to rust," says Jones. "It forms a natural passivation layer when exposed to oxygen. Post-fabrication processes such as pickling and passivation further enhance this protection by restoring and strengthening the material's surface after welding, while the use of treated coolants with biocides or glycol helps prevent biological growth within the piping for long-term cleanliness and performance."

When properly fabricated, treated, and maintained, stainless steel piping can achieve lifespans far outlasting the operational requirements of most data centers. In addition, its non-flammable nature allows it to withstand fire incidents without contributing fuel to the flames or losing structural integrity, preserving critical cooling infrastructure in scenarios where other materials may completely break down.

Nerves of Steel

Specifying the right liquid cooling system isn't only about managing immediate risks. It also requires anticipating future demand, ensuring long-term resilience and scalability. Today's systems must be built to evolve from supporting a limited number of liquid-cooled racks on day one to accommodating entire aisles or halls as adoption expands, all while handling varying densities and operational conditions without fundamental redesign.

"Stainless steel comes with a high-pressure tolerance and inherent strength, allowing systems to operate comfortably below their maximum capacity, typically at around 50 to 60 percent of allowable pressure, with significant headroom for future increases," says Jones.

In contrast, many alternative materials operate much closer to their limits, particularly as temperature rises reduce their pressure tolerance, creating constraints that limit scalability and increase the risk of failure under changing conditions.

This resilience extends to managing the unpredictable nature of modern operations, where operating temperatures may spike due to equipment failure or localized issues. With stainless steel systems capable of withstanding temperatures well beyond normal operating ranges without degradation, this built-in tolerance ensures that systems remain stable under stress.

Dimensional stability further enhances stainless steel's suitability for high-density environments by allowing for controlled expansion under thermal cycling without requiring extensive expansion loops that introduce additional joints and potential leak paths.

In facilities characterized by frequent fluctuations in load and temperature, this stability ensures consistent performance while preserving the structural integrity of the system over time.

Ironclad Value

As investment in large-scale data centers accelerates and budgets come under increasing scrutiny, there can be a temptation to prioritize lower upfront costs by selecting cheaper materials. But viewed against the full lifecycle cost of critical infrastructure, this approach often proves misguided.

“High availability requirements mean that materials requiring frequent monitoring, maintenance or replacement quickly erode any initial savings, particularly when factoring in the broader costs associated with downtime and system disruption,” says Jones.

A comprehensive evaluation must therefore consider not only the cost of materials but also installation, support requirements, and long-term performance. Some materials demand more extensive structural support or insulation, adding hidden expenses that can be overlooked in initial comparisons.

As the industry accelerates with full force, there's a growing shift towards proven, standardized solutions rather than entirely experimental approaches. Materials and methods that have been tested and validated across decades of use in other demanding sectors such as pharmaceuticals, oil and gas, and chemical processing are increasingly valuable in the data center space.

“Stainless steel is supported by well-established codes, fabrication techniques, and certification processes that ensure consistency and quality at every stage – from material sourcing and welding to testing and installation,” says Jones.

This traceability provides operators with confidence in the integrity of the system. Tate reinforces this peace of mind further via its partnerships with suppliers who prioritize quality and performance, ensuring that every component across the system meets rigorous standards and can be tracked throughout its lifecycle.

In response to industry-wide demand for increased speed to market, Tate is also accelerating deployment via its modular solutions that integrate liquid cooling infrastructure with power and connectivity systems, enabling factory-tested assemblies to be delivered on site ready for rapid installation – reducing construction timelines while maintaining high levels of quality assurance.

A Golden Opportunity

Looking ahead, Jones' view for the trajectory of data center cooling is clear: "Liquid cooling is set to become the default rather than an optional enhancement, shaping the design of facilities from the ground up.

"As rack densities continue to rise and power availability becomes an increasingly significant constraint, data centers are likely to evolve towards more compact white spaces paired with expanded mechanical areas designed for maintainability and long-term reliability."

In this context, planning ahead becomes both more important and more challenging. What's certain is that the best strategies will avoid undersizing any aspect of their infrastructure, from pipework and pressure ratings to mechanical systems and spatial design.

Specifying durable and adaptable solutions at every layer of the data center is now at the core of long-term operational success, and nowhere is this more evident than in liquid cooling systems where material choice forms the backbone of performance and resilience.

By investing in materials that offer the right strength, flexibility, and longevity, operators can ensure uninterrupted operations, minimize risk, and reduce the need for costly interventions down the line. Building infrastructure that's not only fit for today's demands but forged to endure whatever comes next begins with selecting the right material for the job.

To find out more or read our white paper on material choice for liquid cooling manifolds, [click here](#).

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