Systems Engineering Technical Reference Manual: Micro-Channel Liquid Cold Plate Deionized Water Velocity Limitations

PRODUCT IDENTIFICATION

Document Reference: SE-TRM-MCLCP-DWV-001

Revision: 2.4

Product Family: Thermal Management — Micro-Channel Liquid Cold Plate (MCLCP) Assemblies

Intended Medium: Deionized Water (DI-W) or DI-W/Glycol blends (≤ 25% glycol by volume)

Applicable Assemblies: Single-phase micro-channel cold plates with copper or aluminum microfins, 0.2 mm to 0.8 mm channel hydraulic diameter, brazed or gasketed construction

This Systems Engineering Technical Reference Manual defines the permissible and recommended deionized water velocity envelope for micro-channel liquid cold plates deployed in telecom, datacenter, and power-electronics thermal loops. It establishes the fluid-dynamic basis for the velocity limitations, quantifies the thermal and hydraulic consequences of exceeding them, and specifies the engineering controls required for compliant deployment.



SYSTEM HARDWARE TOPOLOGY

The micro-channel liquid cold plate is a single-phase, forced-convection heat exchanger in which the working fluid is constrained to a dense array of parallel micro-channels machined or skived into the plate substrate. The thermal topology consists of four coupled domains:

1. Solid conduction domain — base plate and microfins, typically OFHC copper (C11000) or 6061-T6 aluminum with a nickel or conversion coating.

2. Convective interface domain — the wetted micro-channel walls, where the heat transfer coefficient is a strong function of local velocity and channel diameter.

3. Fluid transport domain — inlet manifold, distribution plenum, micro-channel bundle, and outlet collector.

4. External loop domain — facility or rack-level CDU, pump, filtration, and DI-water polishing skid.

Because channel hydraulic diameters are on the order of 0.2–0.8 mm, the flow regime within the micro-channels is laminar to early transitional across the entire practical velocity range. This is the fundamental reason velocity limitations exist: the cold plate operates in a regime where pressure drop scales approximately linearly with velocity while the convective coefficient scales with the cube root of velocity, producing a strongly unfavorable hydraulic-to-thermal trade at elevated velocity.

DATA & CONTROL PLANE CAPABILITIES

Although the cold plate is a passive component, the thermal loop presents a monitoring and control plane that must be engineered to enforce velocity limits:

Flow instrumentation: electromagnetic or Coriolis flow meters with ±1% of reading accuracy, installed upstream of the cold plate manifold.

Differential pressure sensing: 0 – 100 kPa range transmitters across the cold plate inlet/outlet, used to infer velocity and detect channel fouling.

Temperature telemetry: inlet and outlet RTDs (PT1000, Class A) plus component

junction or case thermocouples.

Leak detection: conductive and/or optical sensors in the rack tray and manifold enclosure.

Loop controller: CDU firmware that enforces velocity setpoints, ramps pump speed, and triggers alarms on out-of-envelope operation.

COMPONENT BREAKDOWN

Base plate: machined copper or aluminum, 3–6 mm thick, flatness ≤ 25 µm over the die-attach area.

Micro-fin array: skived or etched fins, 0.15–0.40 mm fin thickness, 0.20–0.80 mm channel width, 1.5–4.0 mm channel depth, aspect ratios of 3:1 to 8:1.

Manifold and plenum: distribution geometry designed to equalize per-channel flow within ± 8%; maldistribution is a primary cause of localized velocity exceedance.

Lid and seal: brazed (CuAg or Ni-based) for hermetic assemblies; FKM or EPDM gaskets for serviceable assemblies.

Fluid ports: G1/4, G3/8, or 8–12 mm push-to-connect; port bore must not be smaller than the manifold throat to avoid artificial velocity restriction.

OPERATIONAL SPECS MATRIX

The velocity limitation for DI-water in micro-channel cold plates is governed by four concurrent constraints: erosion of the wetted surfaces, pressure-drop budget of the loop, pump energy and cavitation margin, and fouling/particulate transport behavior. The following envelope is the engineering basis for this manual.

Recommended continuous operating velocity: 0.5 m/s to 1.5 m/s at the micro-channel cross-section.

Absolute maximum continuous velocity: 2.0 m/s for copper microfins; 2.5 m/s for aluminum microfins with protective coating.

Transient/intermittent ceiling: 3.0 m/s for $\leq$ 60 seconds, not to exceed 100 events per year, provided differential pressure remains below the manifold design rating.

Minimum velocity for thermal stability: 0.3 m/s; below this value, flow maldistribution and stratified heating can produce hot spots exceeding the component thermal design power margin.

Reynolds number at channel scale: approximately 100 – 1,200 across the recommended range, confirming laminar-dominant operation.

Justification for the upper bound: deionized water is aggressive toward copper and aluminum at high shear. Erosion-corrosion initiation in copper micro-channels is empirically observed above approximately 2.2–2.5 m/s, and

in aluminum above approximately 2.8–3.0 m/s; the specified maxima retain a minimum 1.25× erosion margin. Additionally, at 2.0 m/s a 0.5 mm channel produces roughly 35–55 kPa of pressure drop per 25 mm of flow length in a typical manifold-fed plate, which consumes a disproportionate share of the facility loop budget.

TECHNICAL SPECIFICATIONS

Fluid compatibility: ASTM D1193 Type II or better deionized water; conductivity 0.5–5 µS/cm; pH 6.5–8.0; dissolved oxygen ≤ 100 ppb; chloride ≤ 10 ppb; total suspended solids ≤ 1 µm filtration.

Velocity measurement basis: cross-sectional average velocity in the micro-channel bundle, computed as volumetric flow divided by total free-flow channel area.

Pressure drop scaling: $\Delta P \approx k \cdot \mu \cdot L \cdot v / D_h^2$ (laminar Hagen–Poiseuille form), where k is the manifold and entrance/exit loss coefficient (typically 1.3–1.8), µ is dynamic viscosity, L is flow length, and D_h is hydraulic diameter.

Thermal performance sensitivity: convective coefficient scales approximately with v^0.33 in the laminar regime; doubling velocity from 1.0 to 2.0 m/s yields only ~26% improvement in h while quadrupling pressure drop, confirming that velocity is a poor thermal tuning variable beyond the recommended envelope.

Erosion margin: minimum 1.25× between maximum continuous velocity and

the published erosion-corrosion threshold for the wetted alloy.

Cavitation margin: local static pressure at the channel throat must remain ≥ 1.5 × the fluid vapor pressure at maximum loop temperature.

Fouling allowance: design velocity should not fall below 0.5 m/s in loops with particulate risk, to maintain particle transport and avoid sedimentation in the micro-channels.

Parameter	**Specification**
Working Fluid	Deionized water, ASTM D1193 Type II or better; optional ≤25% glycol blend
Recommended Continuous Velocity	0.5 – 1.5 m/s (channel cross-section average)
Maximum Continuous Velocity	2.0 m/s (copper microfins); 2.5 m/s (coated aluminum)
Transient Velocity Ceiling	3.0 m/s for ≤60 s, ≤100 events/year
Minimum Velocity (Thermal Stability)	0.3 m/s; recommended ≥ 0.5 m/s where particulate risk exists
Channel Hydraulic Diameter	0.20 – 0.80 mm
Reynolds Number Range	≈100 – 1,200 (laminar-dominant)
Typical Pressure Drop at 2.0 m/s	35 – 55 kPa per 25 mm flow length
Erosion Margin	≥ 1.25 × vs. published erosion-corrosion threshold

Cavitation Margin	Local pressure ≥1.5× vapor pressure at max loop temperature
Fluid Conductivity	0.5 – 5 µS/cm
Fluid pH	6.5 – 8.0
Filtration	≤1 µm absolute at cold plate inlet
Manifold Flow Distribution	Per-channel equalization within ±8%
Wetted Materials	OFHC copper C11000 or 6061-T6 aluminum; FKM/EPDM seals

REGULATORY COMPLIANCE

IEC 60950-1 / IEC 62368-1 — safety of liquid-cooled IT and telecom equipment, including leak and pressure containment requirements.

Telcordia GR-63-CORE — NEBS physical and environmental criteria for liquid-cooled telecom assemblies.

Telcordia GR-487-CORE — thermal and environmental performance of outdoor electronic enclosures with liquid cooling interfaces.

ASHRAE TC 9.9 — liquid cooling guidelines for datacom equipment, including facility water quality and velocity guidance.

ASTM D1193 — reagent water specification, referenced for DI-water quality control.

ISO 13373 / ISO 10816 — vibration and pump-induced pulsation monitoring in the circulation loop.

RoHS 2011/65/EU and REACH — material compliance for wetted alloys and seal elastomers.

