



LIQUID TO LIQUID CDU TEST METHODOLOGY AND PERFORMANCE RATING

Revision 1.0

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Date: August 2024

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Version Table

Date	Version #	Author	Description
11/01/2024	1.0	All	Initial release

Executive Summary

Liquid cooling is becoming more ubiquitous due to the increasing power and power density of processors and other IT components emitting high amounts of heat. Air-cooling solutions cannot always address thermal challenges of high-performance computing (HPC) devices with high thermal design power (TDP) processors which drives the development and adoption of liquid cooling technologies. Coolant Distribution Unit (CDU) is a key ingredient of the liquid cooling system, and it isolates the facility side of cooling loop from the IT side flow network. Heat transfer occurs inside the CDU, through a heat exchanger, between the heated liquid from the IT equipment and the facility side of liquid cooling loop. This whitepaper provides high-level overview of liquid-to-liquid (L-L) CDU design guidelines and test methodology including cooling performance rating. The paper also includes recommendation on CDU capacity reporting format to ease the communication challenges between product vendors, cooling solution integrators and end users.

Date: August 2024

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1. Introduction

Coolant Distribution Unit is a heat exchange equipment that isolates the IT side of cooling network from the facility loop and controls flow, pressure and temperature of coolant fluid to maintain system temperature at a set point. There are different types of CDU depending on application and other factors. The scope of this whitepaper is to discuss L-L CDU and provide guidelines on test methodology and performance rating. L-L CDU is an integral part of liquid cooling system that circulates coolant fluid in a closed-loop system within the rack and server chassis and utilizes facility water (in full liquid cooling systems) and the air outside the rack to cool the servers. Whether self-contained in-row CDU or integrated in-rack CDU, it must be connected to facility water system through a heat exchanger to facilitate the heat rejection process.

This CDU test guideline and methodology covers some of basic qualification tests, wetted material considerations, fluid servicing and analysis, etc. The whitepaper recommends some of important qualification baselines and performance rating format for CDU manufacturers and end users.

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2. Compliance with Open Compute Project Tenets

2.1. Openness

This whitepaper is devised to share some of the important design and testing considerations for CDU vendors and end users to qualify the product and use for liquid cooling application. The document is put together in collaboration with liquid cooling ingredient vendors, system integrators and end-to-end solution vendors to cover design, manufacturing, and testing aspects of the product. This paper will be published on OCP and open for public access.

2.2. Efficiency

The sharing of this whitepaper on CDU test methodology will provide guidance to suppliers and customers which will help them to improve efficiency in the development process and reduce time to market.

2.3. Impact

The impact of OCP contribution on one of the critical ingredients of technology cooling solution is huge in the proliferation of liquid cooling in data centers. CDU is the most complex component and main part of the IT cooling network which controls coolant flow parameters and heat removal into the facility water infrastructure.

2.4. Scale

The goal of this whitepaper is to share learnings on CDU test methodology and provide a guidance on qualification of new and existing vendors which will help the liquid cooling ecosystem enabling and scaling of the product to be accessible at different Geographic locations.

2.5. Sustainability

OCP contributions like this whitepaper will help to educate the community and open doors for more contributors to join the collaboration effort which will improve scalability and sustainability. Joint efforts on design, manufacturing, testing and deployment will reduce development cost and time as well as improve sustainability through engineering of compatible product/solution that takes the environmental factors into account at all stages of the process.

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3. CDU Development Guidelines

3.1 General Liquid to Liquid CDU Requirements

The data communication (Datacom) equipment should generally accommodate facility water supply temperatures recommended by ASHRAE, based on location, climate and other end user conditions. Table 1 shows liquid cooling equipment and environmental conditions for different infrastructure design options [1]. The maximum allowable pressure supplied to the technology cooling system (TCS) and datacom equipment cooling system (DECS) could be as high as 100 psi (690 kPa) [2], [3]. Therefore, all the ingredients in the TCS should be designed to meet this pressure requirement. To save chiller power and get better cooling efficiency or lower power usage effectiveness (PUE), the best practice is to operate the liquid temperature efficiently and reliably at temperatures well above the ASHRAE recommendations. Some of the datacenter energy optimization methods include use of waste heat from the liquid cooled ITE for district heating and other heat reuse plant applications. The CDU design must be tested and qualified for all operating and environmental conditions. Table 2 shows some of basic requirements of L-L CDU used for ITE cooling in datacenters.

Table 1. ASHRAE TC 9.9 [1]

Liquid cooling class	Typical infrastructure design		Facility water supply temperature °C (°F)
	Primary facilities	Secondary/supplemental facilities	
W17	Chiller/cooling tower	Water-side economizer (cooling tower)	17 (62.6)
W27			27 (80.6)
W32	Cooling tower	Chiller or district heating system	32 (89.6)
W40			40 (104)
W45	Cooling tower	District heating system	45 (113)
W+			>45 (>113)

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Table 2. Key CDU Requirements

Parameter	Value	Table Rationale
Operating Temperature	17 to 65 °C	17 °C: Per ASHRAE, coolant must be delivered to IT equipment at least 2 °C above dew point to avoid condensation
Non-operating Temperature	-40 °C to 85°C	Extreme shipping & handling conditions at high elevation (air shipment) or in hot environment
Relative Humidity	10% to 90%	To verify product stability at dry and wet conditions
Service Life*	10 years	Assuming pump service life (time for 10% of pumps in a population fail for a given boundary condition)
Primary Filter	≤ 200 microns	To remove small particulates in the primary loop.
Secondary Filter	≤ 50 microns	To remove small particulates in a secondary loop

*Actual service life may vary from vendor to vendor, please check with the manufacturer for details including product warranty conditions.

3.2 Basic L-L CDU Design

L-L CDU is a heat exchanger hardware in direct liquid cooling (DLC) system which separates the technology cooling system (TCS) from the facility water system (FWS). It is the brain of DLC system equipped with multiple sensors and control devices to regulate FWS and TCS side of cooling fluid flow and communicates the system status to datacenter operators. There are two main types of L-L CDU based on capacity and deployment, in-rack and in-row.

In-rack CDU – as the name states, it is a rack-mount chassis design with a standard “U” size formfactor (e.g., 4U or 5U etc.) which is directly connected to the rack manifolds and provides cooling to the ITE in the rack. Figure 1 shows an example of in-rack L-L CDU.

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Figure 1 – example of in-rack CDU

In-row CDU – often has larger cooling capacity and supports multiple racks of ITE. Row-based CDU is installed next/near an array of liquid cooled racks and directly connected to TCS flow network manifolds (bottom feed or top feed depending on application). Figure 2 shows a picture of typical in-row L-L CDU.



Figure 2 – example of in-row CDU

3.2.1 Mechanical Design

The outline of L-L CDU is typically aligned to a rack layout to accommodate datacenter scale up and down as well as deployment and servicing. From rack-level accessing standpoint front door or rear door, serviceability is required. Complying with regulatory and safety standards must be considered throughout the product development cycle.

3.2.2 Material Selection

Materials used in the construction of CDU must be compatible to the coolant fluid to avoid contamination, corrosion or other adverse effects in service. Refer to OCP database for details of recommended wetted materials list for use with propylene glycol-based coolants [4] and water-based coolants [5]. These materials must also meet application requirements and comply to safety and environmental regulations.

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3.2.2.1 Pump Selection

Pump(s) selection must consider performance, reliability and compatibility metrics to meet the application requirements. Consult with pump vendor to identify the right pump and accessories for the application. Pump redundancy (N+1 or more) is essential to maintain service during repair or malfunction of one of the pumps. All wetted parts of the pump (internal components) must be compatible with the coolant fluid to avoid contamination or degradation in service. Stainless steel (304/316) pump construction is commonly used for these applications. Friction components like the mechanical face seal are made from wear resistance materials like silicon carbide or tungsten.

3.2.3 Cooling Loop Integration

The quality of cooling loop construction is crucial to have a leak free flow network throughout the product service life. Tube connections and pipe fitting assemblies must be done using proper sealing materials to meet the demands of operating and non-operating conditions. Refer to the product manual during assembling of each ingredient such as pump(s), valves, tube connectors, adapter fittings, filter, expansion tank, sensors, etc. Follow best industry practices to build, test and qualify the CDU. Figure 3 and 4 show internal parts of a rackmount and in-row CDU assemblies.

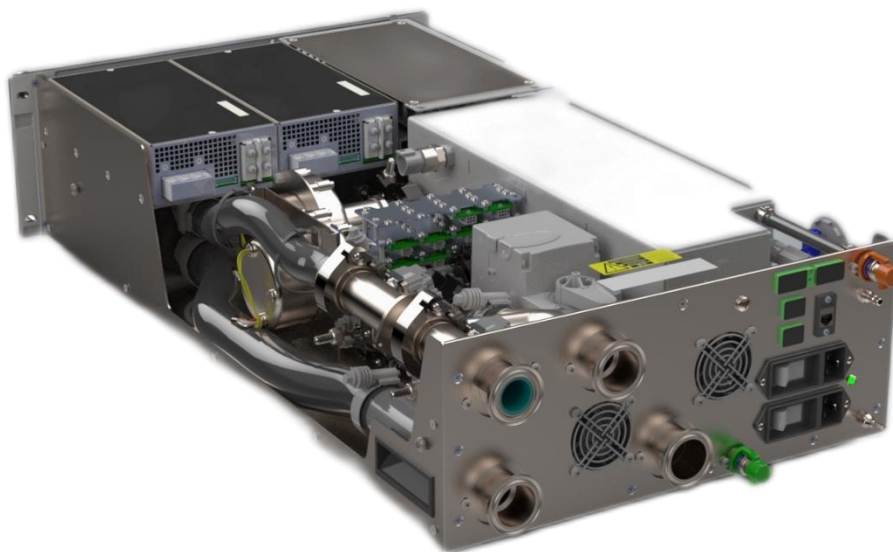


Figure 3 – example of rack-mount CDU assembly

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Figure 4 – example of in-row CDU assembly

3.2.4 Sensors & Controllers

CDU controller is designed to monitor the coolant fluid flow condition and communicate the data to the operator. Sensing devices installed on the flow network provide data on flow conditions (pressure, temperature, flow rate, etc.) to the controller. Based on the CDU setting, there will be system alarms and notifications communicated to the operator if the actual flow conditions deviate from preset values or when abnormal conditions occur. The CDU controller is also equipped with automated safety mechanisms (like cutting power to pump, close/open a valve, etc.) to protect the equipment & operator during accidental failure or coolant leak. Leak sensor rope is commonly used to protect the equipment.

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3.2.5 Quality Control

Quality of the final product is heavily dependent on the quality of each part and subassembly used to build the unit. Therefore, it is critical to pay attention to details of every ingredient used as a building block to make the CDU. Quality control mechanisms must be integrated at every stage of the product development process (from design to material procurement and manufacturing). Therefore, in this section the focus area is postproduction quality control, which is often overlooked.

3.2.5.1 Surface Treatment

Some materials are sensitive to the environment and need surface treatment or protective coating to reduce corrosion, contamination and extend the product service life. Passivation is one of the chemical processes used to create a protective layer on stainless steel parts during post manufacturing process (per ASTM A380/A967). Electroplating process (nickel electroplating or chrome electroplating) is used on some metals (e.g., brass/bronze, etc.) to improve corrosion resistance and other surface properties.

3.2.5.2 Cleaning

Every component used to build a CDU must be thoroughly cleaned to remove manufacturing waste, oil, and foreign object debris (FOD). Air drying is common cleaning process used on manufacturing floor to remove debris or moisture after washing. CAUTION: Compressed air system used for drying process must have a proper filter setup to provide clean air. Every machined component is recommended to be cleaned using steam pressure washing process or in an ultrasonic steam bath to have the best quality and finish before assembly into the final product.

3.2.6 Fluid Servicing

Periodic fluid quality monitoring and servicing is essential to maintain continuous operation without or minimal downtime. Sensing devices installed on the CDU will provide signals/alarms if coolant level is low or leak is detected. In addition, coolant fluid samples can be drawn from the flow network for chemical composition assessment over time and determine if dosing is required to rebalance the chemistry. Follow fluid vendor guidelines to treat the fluid with recommended chemicals.

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3.2.6.1 Filling & Flushing the System

The fluid used to fill and flush the system must be compatible with the coolant fluid used in operation. Consult with coolant fluid vendor for compatibility before using any other fluid or chemical for flushing the system. Regardless of which other fluid is used to purge/flush the system, final flushing must be done using actual coolant fluid before putting the system back online to reduce the amount of dilution. Use of coolant fluid filling/flushing carts are recommended to ease the process if available onsite [6].

3.2.6.2 Filter Servicing

Filter is the last line of defense to prevent solids or FOD which may restrict fluid flow through cold plate microchannels or damage soft parts like O-ring seals. Use of proper filtration system (the right filter material & size) reduces operating power/cost and mean time between failure (MTBF).

3.3 Test Methodology

3.3.1 Mechanical Testing

3.3.1.1 Dimensions

Shape and size of rack-mount L-L CDU should be designed to fit in a standard 19" (EIA-310) rack or ORV3 rack to meet application requirements and for ease of deployment in data centers. Length & width dimensions must comply with rack space requirements and height is determined by components packed inside the enclosure but recommended to adhere to standard "U" size (e.g., 4U, 5U, etc.). In-row L-L CDU on the other hand is large and often conforms to the rack size (e.g., 42U, 48U, etc.) depending on cooling capacity specifications of the application.

3.3.1.2 Cosmetic

Visual inspection is the first line of defense in quality control. Complete visual inspection must be done per manufacturer's first article inspection (FAI) criteria to verify the product appearance meets specifications and has no debris or hazardous materials (like manufacturing waste, cleaning chemicals or FOD).

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3.3.1.3 Structural

CDU development process (from material selection, design, manufacturing to testing) must take structural requirements into account so that the product meets extreme application conditions such as shock, vibration, pressure, etc. Refer to section 3.3.3.3 for more information on dynamic testing. Furthermore, seismic loading is considered during rack and CDU installation in data centers. Follow manufacturer installation and operating manual for details or consult with application engineer or local distributor for guidance.

3.3.1.4 Assembly & Integration

Every component of a CDU must be securely fastened onto the structural members/frames inside the enclosure. Electrical and tube routing must be done properly so that it doesn't obstruct future maintenance and servicing. Rigidity of assembly, tubing and fitting must be tested and qualified for no leak or mechanical damage. Leak sensor routing must be done in accordance with coolant flow path to detect and communicate proactively when leak occurs.

3.3.2 Performance Testing & Reporting

Performance testing of a CDU comprises of ingredient level and system level testing. With ingredient level testing, each component of the CDU including parts on the secondary flow network are tested according to supplier product validation requirements. Pump performance specification, hose and valve rating, etc. are few examples of documentation from ingredient level testing which are often provided by manufactures/vendors. Each component selection must be done in consideration of good performance rating for the application. Then, as part of system level testing, the whole assembly goes through qualification test plans to validate the performance per product specification.

CDU performance definition varies from supplier to supplier due to many features customization incorporated into the product for differentiation. Main reason is the lack of standardization in design, performance rating and reporting of the product. Key parameters of importance when selecting CDU and maybe used for standardization are:

- Cooling capacity
- FWS flow condition (approach temperature, flowrate and pressure)
- TCS flow condition

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- Coolant type (Propylene glycol, treated water, etc.)

3.3.2.1 Thermal Performance

CDU thermal performance depends on several factors, such as heat exchanger design, material, FWS & TCS flowrate and temperature, etc. Figure 5 shows coolant flow diagram through a typical heat exchanger used inside a L-L CDU. Facility water supply temperature recommendation is to be higher than dewpoint to prevent condensation. For lower temperature operating conditions, pipe insulation is used in conjunction with a bypass circulation to avoid condensation. Thermal performance is specified based on approach temperature difference (ATD) and the corresponding heat load supported at a given flow rate. Figure 6 shows approach temperature versus heat load graphs for different FWS fluid inlet temperature conditions.

ATD = (TCS supply temp – FWS supply temp)

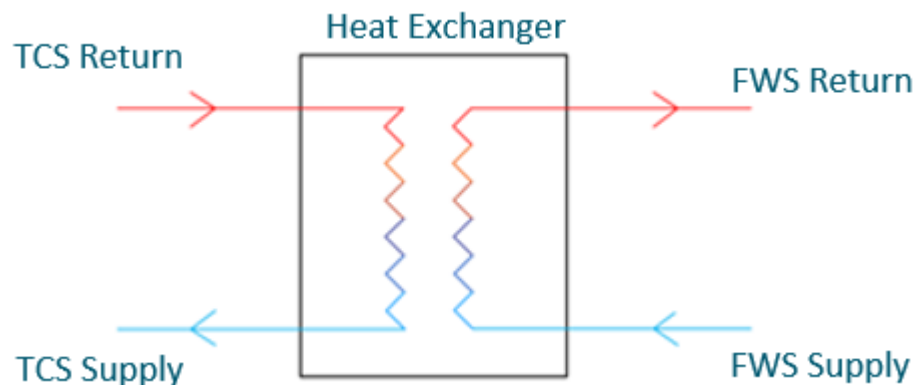


Figure 5 – illustration of cooling fluid flow through liquid-to-liquid heat exchanger

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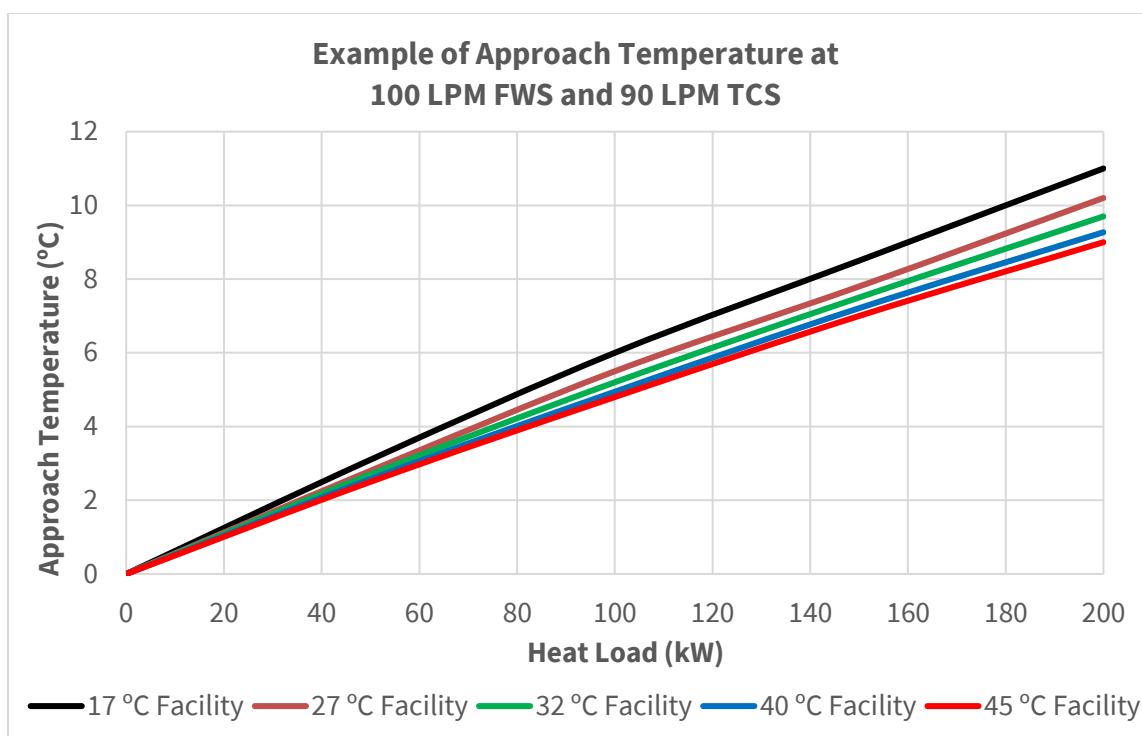


Figure 6 – example of CDU thermal performance curves

3.3.2.2 TCS Pressure Head

Pumping pressure head of TCS flow network must be evaluated to determine the capacity of CDU required to beat the pressure loss (dP) and provide adequate cooling. CDU manufacturers often use redundant pump configurations to overcome total impedance of the flow network and support varying cooling demands. Figures 7 show example of pressure head vs flow (PQ) curves (pumping demand) for a typical CDU.

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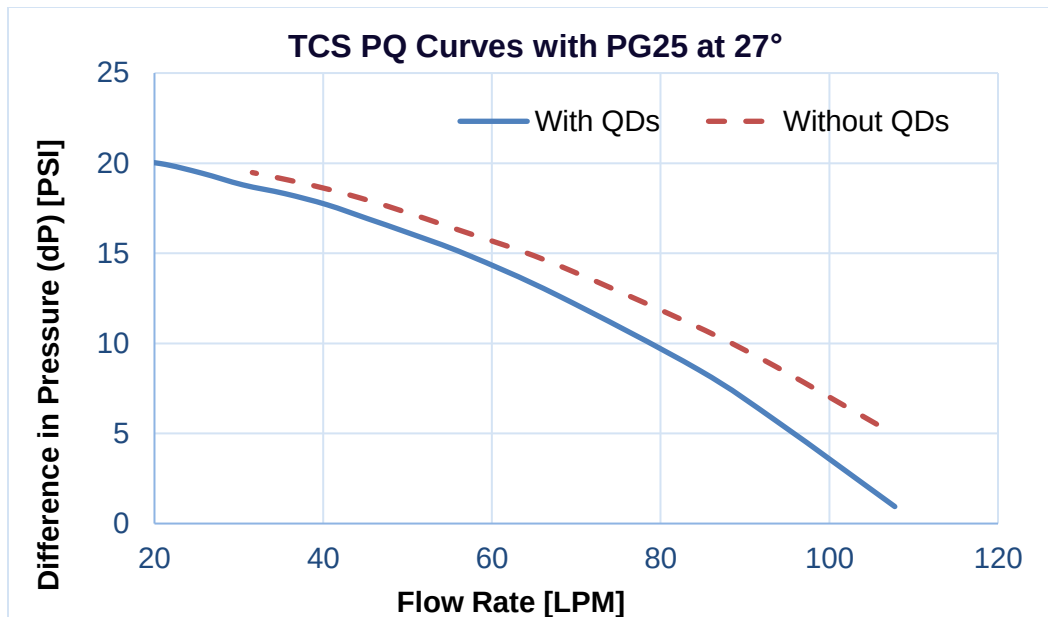


Figure 7 – Pressure head vs flow (PQ) curves for TCS flow network with and without QD

3.3.2.3 FWS Flow Impedance

FWS fluid flow impedance is critical during CDU sizing to verify capability of the equipment for achieving anticipated performance [7]. Facility side of the infrastructure should be able to provide the required flow, pressure and temperature for the CDU to perform as expected. Figures 8 show example of flow impedance curves with and without QDs.

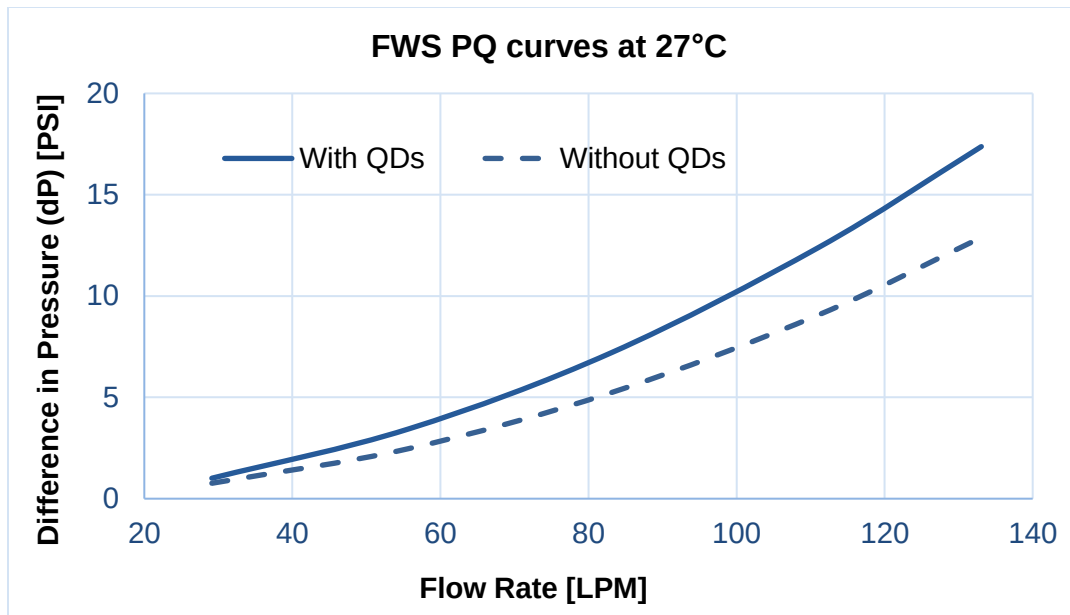


Figure 8 – FWS flow impedance (PQ) curves with and without QD

3.3.2.4 Recommendation on Performance Reporting

CDU performance definition can be standardized on the following key parameters:

- Specify fluid type
 - Water for FWS side of the loop
 - Propylene glycol for TCS side of flow network
- Specify FWS fluid temperature (or ASHRAE water class)
- Recommended flowrate, like, 1.5LPM/kW to support most of chips in the current market
- In-rack CDU capacity rating:
 - X kW where CDU performance meets the following conditions:
 - TCS dP (head) ≥ 25 psi at $X \cdot 1.5$ LPM TCS flow rate
 - FWS dP (impedance) ≤ 75 psi at $X \cdot 1.5$ LPM FWS flow rate
 - ATD = 5 °C to cool X kW, at $X \cdot 1.5$ LPM TCS & FWS flow rate
- In-row CDU capacity rating:
 - X kW where CDU performance meets the following conditions:
 - TCS dP (head) ≥ 40 psi at $X \cdot 1.5$ LPM TCS flow rate
 - FWS dP (impedance) ≤ 75 psi at $X \cdot 1.5$ LPM FWS flow rate
 - ATD = 5 °C to cool X kW, at $X \cdot 1.5$ LPM TCS & FWS flow rate

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CDU rating maybe builds upon by creating a capacity matrix which comprises of ATD and flowrate per kilowatt variables. According to this matrix, cooling performance improvements can be achieved through cold plate optimization and using low flowrates. Lower ATD can also be achieved by system design or CDU performance optimization (see figure 9).

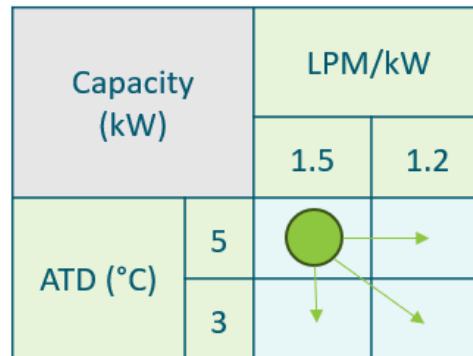


Figure 9 – CDU capacity rating matrix and performance improvement opportunities

3.3.3 Reliability Testing

CDU materials of construction include metals, polymers, elastomers, etc. Therefore, reliability of the product depends on compatibility of all wetted materials with the coolant fluid and perform at the operating conditions of the system [8], [9]. Filtration mechanism must be implemented to keep the fluid clean from contaminants/debris. Typical filter size used in the TCS loop is 25 to 50 μm and the facility side of loop is 150 to 250 μm depending on design or customer requirements. Best practice in CDU design incorporates a hot swappable filter and pump configuration to ease maintenance and servicing.

3.3.3.1 Hydrostatic Pressure Testing

Hydrostatic pressure testing must be performed on the CDU per IEC 62368-1, ASME B31.1/31.3 or equivalent standard to qualify the loop. The CDU must meet normal operating condition and safety test requirements. There should be no leak or deformation on any part of the pressurized system during a post-test inspection. Every mechanical and thermal performance testing must be followed by a pressure test to verify there is no leak or damage per ASTM E1003-13 or other applicable standards.

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3.3.3.2 Chemical Compatibility Testing

All wetted components used in the flow network must be made from materials compatible with the coolant fluid. CDU suppliers are responsible for validating compatibility of ingredients used in the secondary flow network. Corrosion is one of the problems with water-based coolants when used with dissimilar metals in the same flow network. Some polymers and elastomers may also react to the coolant fluid and result in depletion of corrosion inhibitor or leach out to contaminate the fluid. Therefore, CDU manufacturers are recommended to follow wetted materials guidelines often provided by coolant fluid vendors to meet product performance and quality requirements [4], [5]. A low-cost coupon test is often used for new materials to check for compatibility with the coolant fluid. Salt spray testing per ASTM B117 is one the methods used to validate corrosion resistance [8]. For long-term reliability testing, fluid samples can be drawn periodically (at 0 day, 7 days, 14 days, ... etc.) from active flow path of the loop for chemical analysis. Test results from fluid analysis techniques, such as inductively coupled plasma mass spectrometry (ICP-MS), gas chromatography mass spectrometry (GC-MS) or liquid chromatography mass spectrometry (LC-MS) will help to track changes in fluid chemistry (such as corrosion inhibitor concentration and organic material leaching into the fluid), which is one way of evaluating material compatibility. Another test is ion chromatography (IC) which can be used to measure reactive ions in the cooling fluid per ASTM D5827. Conductivity and pH of the fluid must be maintained within the recommended range by the vendor. Fluid degradation mechanism can be determined by testing pH over time per ASTM 1287 & D1121.

3.3.3.3 Dynamic Testing

Shock and vibration resistance testing is critical to validate system integrity and manufacturing/assembly quality per applicable standards like IEC 60068-2-64 or equivalent (for random vibration), 60068-2-27 or equivalent (for mechanical shock), etc. The final assembly must go through dynamic testing to simulate shipping and handling conditions per ISTA or equivalent standards. There should be no physical damage/defect during post-test inspection. Pressure testing must be followed by shock & vibration testing to check for leaks which may result from stresses due to dynamic loading.

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3.3.3.4 Thermal Cycling

The CDU must go through a temperature and humidity cycling test to evaluate for operating and nonoperating (shipping/storage) conditions of the product life cycle as listed on Table 2.

Operating condition test cycle ranges from minimum to maximum temperatures, ramp rate, dwell time, and cycle count (life expectancy). Nonoperating thermal cycle includes fast ramp rate between shipping and storage temperatures, dwell time and cycle count. Thermal performance testing must be followed by pressure testing to detect a leak which may result from thermal stress and deformation.

3.3.4 Typical Regulatory Requirements

CDU suppliers are required to provide product quality documentations to customers from accredited regulatory bodies. Table 4 shows some of the regulatory bodies used to certify the products depending on geography.

Table 4 regulatory requirements

Requirement	Regulatory body	Notes
Safety	IEC 62368-1, IEC 60950-1, UL, ETL, EN, CE, CCC	Varies based on local conditions
EMC (ESD/EMI)	EN 55032/EN 55035 or ETSI-EN300-386 or EN IEC 61326-1	Recommended
Material compliance	RoHS, REACH, WEEE	Recommended

4. Conclusion

This white paper provides general test requirements and methodology for L-L CDU and proposes standardization on CDU performance rating format to ease the communication between vendors and end users. CDU manufacturers and integrators can use this document as a reference to build and validate their product and contribute towards the standardization effort to enable the liquid cooling ecosystem.

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5. Glossary

HPC: High Performance Computing
ITE: Information Technology Equipment
TDP: Thermal Design Power
CDU: Coolant Distribution Unit
L-L CDU: Liquid-to-Liquid Coolant Distribution Unit
DLC: Direct Liquid Cooling
TCS: Technology Cooling System
FWS: Facility Water System
DECS: Datacom Equipment Cooling System
PUE: Power Usage Effectiveness
MTBF: Mean Time Between Failure
FOD: Foreign Object Debris
FAI: First Article Inspection
ICP-MS: Inductively Coupled Plasma Mass Spectrometry
GC-MS: Gas Chromatography Mass Spectrometry
LC-MS: Liquid Chromatography Mass Spectrometry
IC: Ion Chromatography
PQ: Pressure vs Flow Curve
dP: Differential Pressure
QD: Quick Disconnect
ATD: Approach Temperature Difference

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