The Right Terminations for Reliable Liquid Cooling in HPC

Proper specification ensures ease of use, leak-free connections

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High performance computing manufacturers are increasingly deploying liquid cooling in their systems. The engineers responsible for thermal management, therefore, are drilling down into the components that facilitate optimal cooling.

Liquid cooling system components must meet requirements for chemical compatibility, flow rates, and temperature and pressure exposures. Ease of use and reliability over long periods of time are desirable attributes as well. To avoid potential damage to expensive electronic equipment due to leaks, secure drip-free connections are also essential for any liquid cooling system. Considerations related to connectors include install torque, sealability and vibration and shock resistance.

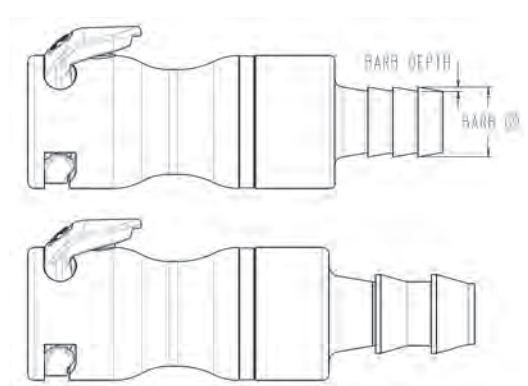
Quick disconnects (QDs) designed and built specifically for HPC applications are now available, simplifying connector selection. Questions remain, however, around which of the many termination options are most appropriate for liquid cooling systems. Intended use, ease of installation and maintenance, operating conditions, durability, and potential for leakage all have bearing on the selection process.

The foundation of a robust cooling loop begins with specifying the right terminations to keep tubing and connectors securely joined. At the QD level, most terminations fall into two categories: barbs for tubing or threaded joints.

TERMINATIONS FOR TUBING AND HOSE

Quick-disconnect couplers with barbed terminations work well for applications where flexible tubing is required. Barbed terminations are designed to grip the inside of tubing. Installation is simple—cut the tubing to length and push it over the termination barbs. During installation, tubing expands over the hose barb termination. As the tubing relaxes to its original diameter, the barb grips and seals it creating a reliable, leak-free connection.

Quick Disconnect (QD) with hose barb termination



Tubing diameter and durometer (hardness) largely determine proper fit of a barbed termination. Factors affecting sealability and grip strength include the barb outer diameter and profile, the barb depth, as well as the number and spacing. The outer diameter will be sized relative to the mating tube to ensure interference and to compensate for variation in the tubing inner diameter. The barb depth creates space for soft tubing to relax into, further increasing the grip and retention force. If barbs are spaced so that the tubing relaxes between each barb, then each additional barb can provide extra grip. Multiple barbs provide more than one sealing surface, which is beneficial if one of the barbs gets damaged.

Because terminations exhibit different strength characteristics for various tubing sizes and grades, installation force and pull-off resistance are additional considerations in the specification process.

The amount of force required to assemble the tubing is primarily driven by the termination type and placement along with the tubing durometer.

For more rigid tubing, termination options such as push to connect or compression styles provide better performance with a lower assembly force.

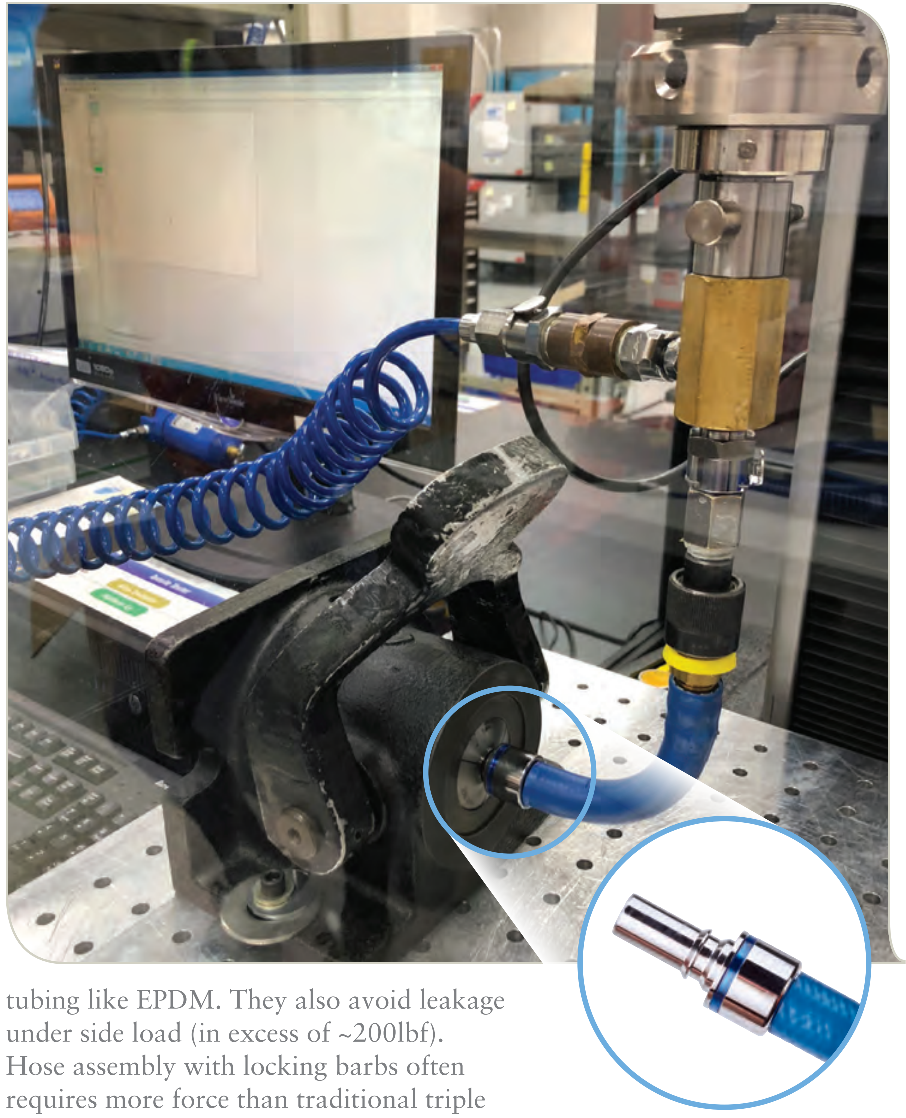
In terms of pull-off resistance, sharp multi-barbed terminations tend to grab when soft tubing is pulled. In contrast, a shallow or rounded hose barb mated with very stiff tubing could allow the tubing to disengage with minimal effort.

Tubing with poor memory—that won't relax—will not grip as well on barbed fittings and will require a clamp. However, incorrectly installed clamps might induce leaks and failures. For example, a tie-type clamp cinched too tightly on soft tubing can lift the tubing away from the fitting creating leaks.

Many types of barbed connections are available, so it is important to find the one that best suits the tubing and the application.

1. Triple barb. Fluid coupling terminations with multiple, shallow barbs are commonly used with lighter weight tubing. The triple barb design incorporates a balance of good retention with redundant sealing points. In applications where high pressures and temperatures or mechanical loading is expected, or the tubing is less flexible, an additional clamp may be necessary to secure the tubing against the barb geometry. Installation and removal of soft tubing with a triple barb termination is a simple manual operation typically requiring no additional tools. For applications where the tubing may be removed repeatedly, an additional clamp can enhance reliability.

2. Locking barb. The locking barb is a good choice in environments where heavy tubing may be exposed to hose or assembly pull (e.g., being bumped or stepped on)—at the front of a server rack, for example. Locking barbs fit securely without the need for hose clamps or ferrules and work well on heavy-duty



Example of side load testing hose with barbed termination

tubing like EPDM. They also avoid leakage under side load (in excess of ~200lbf). Hose assembly with locking barbs often requires more force than traditional triple barbs. Light application of heat or lubricant may ease installation. Typical removal of hydraulic-type hose from this style of termination requires cutting along the length of the barb with a thin blade, taking care not to scratch or damage the barb, especially on any of the sealing surfaces.

3. Compression. Common compression style terminations include a ring or ferrule to mate with rigid tubing, and a nut to thread capture the ferrule against the termination seat. Additional styles of compression fittings include flared, push-fit fittings, and PTF. To secure semi-rigid tubing, ferruleless polytube terminations (PTF) seal the tubing connector interface by threading a nut to compress the tubing against a hosebarb or post on the termination.

THREADED PORT CONNECTIONS

Fluid couplings incorporating a threaded termination provide a robust and reliable connection, primarily at machined ports throughout the cooling loop. Common profiles include parallel thread O-ring boss (ORB) and tapered pipe threads. Threaded terminations are commonly described by a relative pipe inner diameter or equivalent hydraulic flow size. For example, a ¼ NPT or G1/2 make reference to a ¼" or ½" pipe, respectively.

Straight thread terminations for liquid cooling applications will most often incorporate an elastomeric seal to achieve a leak-free connection. To ensure long-term performance and reliability, proper material selection of both the seal, quick-disconnect coupling, and mating material with the fluid media is critical.

Installation of straight thread terminations can be achieved with manual tooling, and in most cases a pressure-tight seal will be achieved as soon as the fitting is fully seated in the port. The amount of installation torque used to secure the joint deserves consideration and will vary depending on the mating materials, presence of fluid or thread-lock, and thread size among other factors. Too little preload and the coupling may loosen over time from use or vibration. Too much and the threads can be damaged, or in cases where galvanic corrosion is a concern, create a high stress area that may be problematic.

Tapered pipe thread terminations on the other hand, do not include an additional elastomeric component. The threads themselves both retain

(Left to right) NPT, BSPT (R), SAE ORB, BSPP (G)

the part and create a seal. With the thread's tapered profile, the male thread acts as a wedge, creating interference as the fitting drives down into the port.

In real-world use, though, a spiral leak path along the joint may still be present due to variation of thread profiles, crests and roots, torque and other elements. For reliable sealing performance, thread tape or additional sealant is recommended to fill gaps between threads, and aid assembly, reducing the risk of thread damage or galling. If thread tape is used, keep in mind that the thickness will affect the installation. Wrapping two to three times around the male thread is typically sufficient without adding too much material.

As with straight threads, proper material selection is key. Choose materials compatible with the cooling fluid, and also any components in contact. Anaerobic thread sealants may chemically attack certain thermoplastics, and excess tape may create debris in the fluid loop.

Given the wedging action upon installation, material selection and installation should be examined to reduce thread damage, or creep and deformation of the female port over time. A common rule of thumb for installing tapered QDs is finger-tight plus an additional one to two turns.

The variability in tapered thread assemblies can make controlling the coupling's installed height and orientation challenging. If product orientation and height are important, consider using a QD with a straight thread termination.

Below are common threaded terminations employed in liquid cooling systems. The list is not exhaustive but provides an overview of the types of threaded connections that can add functionality in specific applications.

1. SAE Straight Thread O-Ring (ORB). This parallel thread termination follows SAEJ1926 – an industry specification for fluid ports utilizing ASME B1.1 thread profiles. It features elastomeric sealing and is commonly used in North America.

The mating female port referenced in SAE J1926-1 requires specific machining to create a chamfered seat at the top that accepts an O-ring, a configuration known as ORB or

COMPARISON

TERMINATION STYLE	REFERENCE	EXAMPLE DESIGNATION	THREAD	MAJOR DIAMETER (INCHES)
SAE	SAE J1926	SAE-4	7/16-20 UN	.4375
BSPP	ISO 1179	G1/4	1/4 -19 BSPP	.5180
NPT	ANSI/ASME B1.20.1	1/4 NPT	1/4-18 NPT	.5400
BSPT	ISO 7	R1/4	1/4-19 BSPT	.5180

O-ring boss. When the fitting is tightened, the O-ring is compressed radially and the seal is located in the pocket within the port, which prevents fluid escape. Users appreciate the more streamlined, protected connection profile that this termination facilitates.

2.NPT (National Pipe Thread). This common tapered thread follows ANSI/ASME B1.20.1. It has been around for many years and is relatively easy to install—just drill and tap a mating port. However, a thread sealant (tape or compound) is required to fill in surface imperfections and create a leak-free seal. The install torque is affected by how much thread sealant applied. Some users also express concerns that sealants can increase system contamination.

Tapered threads in metals such as stainless steel can be prone to galling—welding together by high contact stresses and friction during tightening making the components non-reusable. Hand tightening adds to installation variability and it can be challenging to control the finished height. As a result, thread NPT terminations are often best used in smaller installations, like lab or prototype facilities.

3.G/BSPP (British Standard Pipe Parallel). This straight-thread, metric termination has a 55° flank (opposed to 60°) and Whitworth thread form, and is used most commonly throughout Europe and Asia. Originating from Germany, the parallel thread is denoted with a G for gas, and the tapered thread with an R for Rohr, which translates to "pipe" in English. G threads appear in the U.S., though, in PC gaming or cameras and projectors. The thread profile follows ISO228, and the plug and port follow ISO1179.

While metal-to-metal sealing is covered in the standard specification, the most common sealing method for liquid cooling applications will include an elastomeric seal. The seal will be captured either by an additional ring around the outer diameter, or integrated directly into the base of the QD termination. During tightening into the port, the seal compresses into the cavity created between the fitting body, the inside of the metal ring and the port itself.

G's are often used with cold plate assemblies because the face-type sealing is convenient to maintain a shallow port. Short threads—sometimes just one or two—save space and contribute to a low profile, but make them susceptible to stripping during installation.

4.R/BSPT (British Standard Pipe Taper). Sister to the BSPP thread in thread profile and the NPT in form and fit, a BSPT termination provides a simple, leak-free connection. Consistent with other tapered thread installations, tape or additional liquid sealant is recommended to ensure reliability of the fluid connection. While these threads appear similar, they are not intended to be intermixed with other termination types, such as BSPP or NPT. Doing so will most likely create a leak, potentially irreversibly damage the QD or the mating port.

QDS SPECIFICALLY FOR LIQUID COOLING

All the terminations above are available in quick disconnect couplings, which are among the newer connector options in liquid cooling. QDs allow fast, secure, repeated connections and disconnections

CONSIDERATIONS FOR LIQUID COOLING SYSTEM DESIGN

Pressure – What are minimum and maximum pressures, and the number of times the pressure will cycle between those two points? In liquid cooling of electronics, typical pressures may range from vacuum to 75 psi.

Shock – Will the component be subjected to mechanical shocks or impact that affect product life expectancy?

Vibration – What is the expected level of vibration? Will this vibration cause components to loosen, leak or fail?

Temperature (ambient and fluid) – What extremes will the system be subjected to and how will they affect tubing, connectors and the interface between them?

Contamination – Could contaminants be introduced to the system due to the kind of fitting and/or materials required to create robust seals?

Fluid Velocities – Will the tubing, fitting size and sealing method handle likely fluid velocities at various points within the cooling system and pathway?

Chemical Compatibility – Can components withstand the cooling fluids to which they are regularly exposed?

during both service and use. No tools are required. Integrated non-spill shutoff valves automatically stop flow, reducing spills or pressure loss during disconnection.

For long-lasting performance, look for QDs designed specifically for liquid cooling and ask suppliers for information about their product testing and validation in cooling applications.

While terminations are a critical part of creating a leak-free connection, other important QD factors include:

- **Performance:** Maximum flow rate and pressure, operating temperature, and leak-free, dripless valves. Many QDs feature O-rings. In contrast, X-ring multilobed seals offer better shape retention over time, protection against leakage, greater resistance to debris or foreign contaminants and require less force to connect.

- **Connector material—metal, plastic or a combination:** In the early days of liquid cooling, users turned to the connectors that were readily available: bulky, heavy ball-and-sleeve connectors designed for hydraulic applications and made of copper, brass or stainless steel. All metals are susceptible to oxidation or corrosion over time and mechanical wear of metal components also can result in fluid loss—a significant concern around expensive computing equipment. Newer lightweight, high-performance thermoplastics are non-corrosive and withstand heat and humidity without losing structural integrity. Plastic or metal/poly valves experience lower friction than all-metal valves and are compatible with many coolants. Today, thermal engineers can choose from high-performance metal or thermoplastic QD options, so factors like weight, cost and durability further influence connector choice.

- **Ease of installation:** Some QDs allow one-handed installation and feature user-friendly designs like integrated thumb latches that make connection and disconnection simple. Elbows and swivel joints further simplify connections in tight spaces.

As liquid cooling use grows in HPC, so does the need for knowledge on how to properly design robust, leak-free cooling systems. The right combination of tubing, terminations and connectors will enable system integrity and optimal performance from the point of installation through years of use.

Elizabeth Langer, CPC senior design engineer, specializes in liquid cooling of electronics. In addition to helping CPC's customers develop liquid cooling systems to meet their needs, she also serves on ASHRAE, TC9.9 Committee, which focuses on mission critical facilities, data centers, technology spaces and electronic equipment/ systems. She also is an active member of The Green Grid , which works to improve global IT and data source efficiency. For more information on liquid cooling solutions, call 800-444-2474 or visit www.cpcworldwide.com. Validation reports, technical videos, selection guides and more are available online.

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