

3M™ Two-Phase Immersion Cooling – High Level Best Practices for System Fabrication*

PART 1 - Tank

Material

Except for technology demonstrators, tanks should not be fabricated from plastics as they contain and transfer moisture that becomes a burden on the system desiccant. Tanks can be fabricated from glass but edge sealing is questionable. Ideally tanks are made from welded metal. Ordinary carbon steel (14 gage for smaller tanks, 11 gage for larger ones) has proven effective, but aluminum and stainless can also be used. Metal should be reinforced as needed and powder coated on the interior and sealing surfaces at a minimum to help prevent oxidation from accidental moisture condensation and to provide a margin of safety against short circuiting to the tank walls.

Construction

Perforations for condenser lines can be on the flat top panel surface of the tank to keep all perforations at or above this point, or on the sides which minimizes damage from leaky water lines. If placed on the sides, they should perforate above the liquid line to minimize the risk of fluid leakage. They can be sealed with compression fittings, or minimal use of clean elastomers like butyl rubber or clean pipe thread sealants such as industrial grade PTFE tape or Leak Lock® Blue Joint Sealing Compound¹. Tanks should be insulated to prevent extraneous heat loss to the room and (in the case of high boiling fluids) to minimize risk of burns. Outer skins make a tank more attractive and prevent contact with high voltage relays, etc., if these are present.

Lid & Sealing

Lids can be made from glass or metal. Smaller tank openings are easily sealed with an O-ring and toggle clamps. For larger openings, the force per unit length required for standard O-rings typically means a stiff and very heavy lid or multiple clamps. Since pressure within the tank is typically very low, hollow O-rings² (no need for groove) or inflatable gaskets³ (require a groove) can be used to lessen the mechanical force required to seal.

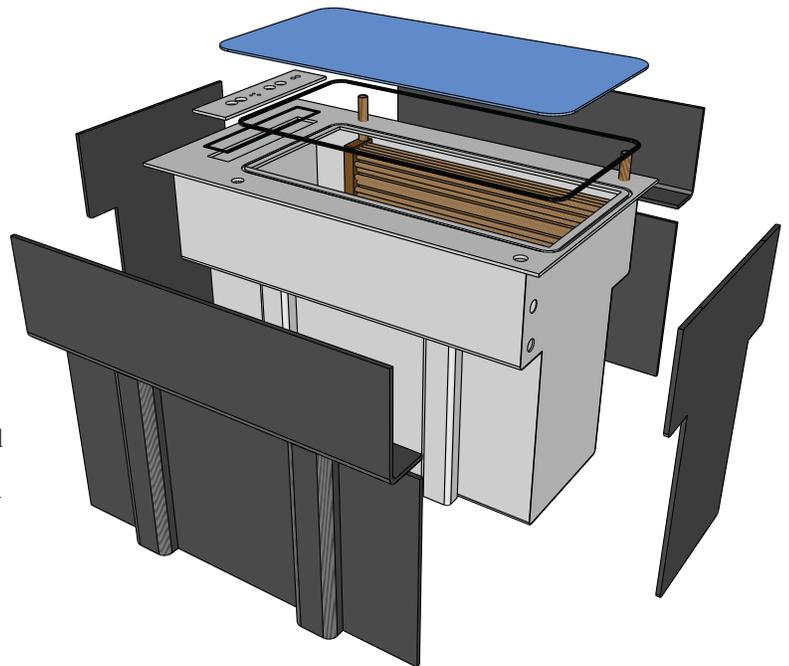


Figure 1. Exploded view of a 200kW Two-Phase Immersion Cooled Tank with skins removed.

80 durometer EPDM or butyl should be used with hydrofluoroether fluids (3M™ Novec™ 7000, 7100 or 7200 Engineered Fluids) and silicone for fluoroketones (3M™ Novec™ 649 or 774 Engineered Fluids) or perfluorocarbons (3M™ Fluorinert™ Electronic Liquids FC-72 or FC-84). These elastomers contain oils that are inevitably extracted in normal use and are a source of fluid contamination. Elastomers should therefore be chosen that are low in extractable content. Pre-cleaning by vapor degreaser may be indicated to “pre-shrink” the elastomer and lessen the organic burden. This will be addressed later in the guide.

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Layout

Water cooled condensers are often placed in “bumpouts” in the tank wall. This permits unrestricted access to and swapping of hardware while minimizing the fluid requirement. Condensers for small systems (a few kW) can be fabricated using radiator technology and appropriate finstock⁴. For larger systems, they should be fabricated as banks of enhanced tubes of the type commonly used in industrial chiller condensers⁵. Optimal designs of either variety will achieve 4+ kW/liter of core volume at 15°C approach temperature difference (fluid to water) and 10°C water rise.

An additional perforation with a removable “accessory plate or port” in the top plate is recommended to accommodate penetrations for IO, power, conduits, etc. Positioning the plate on the top minimizes fluid losses due to imperfect seals on any of these penetrations.

The space above the condenser and below the top plane of the tank is known as the freeboard. This space helps minimize fluid losses due to diffusion and entrainment by moving air when the tank is opened. Freeboard of at least 10cm is recommended. Higher freeboard is better but this must be weighed against power density, system height, accessibility, etc.

Table 1: Overview of Primary Considerations for Two-Phase Immersion Cooled Tank Construction

Consideration	Recommended
Material	<ul style="list-style-type: none"> Welded metal (carbon steel, aluminum, stainless steel) Glass (edge sealing concerns)
Material Finish	<ul style="list-style-type: none"> Powder coated for metals
Perforations	<ul style="list-style-type: none"> For condenser lines and penetrations for IO, power, conduits, etc. Should be above fluid line
Lid	<ul style="list-style-type: none"> Glass or metal material Sealed with o-ring and toggle clamps for smaller tank Sealed with hollow o-rings or inflatable gaskets for larger tanks O-rings 80 durometer EPDM or butyl with HFE fluids; silicon with FK or PFC fluids
Other Tank Considerations	<ul style="list-style-type: none"> Insulated to prevent heat loss Outer skin for safety and appearance Bump-out in tank wall for water-cooled condensers Optimal design will achieve 4+ kW/liter of fluid volume

PART 2 - Computer Hardware Modifications/Preparation

In order to be immersion cooled, mainstream computer hardware requires firmware or BIOS modifications to function in the absence of a fan tachometer signal in an environment hotter than the air normally used to cool it. The OEM is sometimes helpful in this capacity.

As a rule, any device that does not have a heat-sink in air requires no modification when immersion cooled. Examples include memory DIMMs, capacitors, etc. Heat sinks should be removed from all other components. Any additional required modifications are dependent upon the device power density. In practice, any device that requires a copper heat sink to be air-cooled effectively will generally require some kind of boiling enhancement coating to facilitate incipience and increase efficiency. Either organic or metallic boiling enhancement coatings can be used. In the case of most lidded devices, such as CPUs in the 50-120W range, the application of a thin porous metallic boiling enhancement coating (BEC) to the lid by soldering or adhesive is suggested. Thermal grease as well as any packages that use it should not be used as the grease can deteriorate after months of service as the oil carrier is extracted. Bare die devices that have heat sinks or lidded ones that exceed 50-120W will require an optimized heat spreader with the BEC applied to it⁶.

Computer hardware typically contains substantial amounts of residue from manufacturing. Power supplies, compute nodes and switches should all be subjected to a quick vapor degreasing process⁷ with a mild polar solvent such as 3M™ Novec™ 71IPA Engineered Fluid to remove soluble flux residue, mold release, fingerprints, etc. Most cabling is clad with polyvinyl chloride (PVC) that contains 3-30% oil by weight. This oil is inevitably extracted from the PVC in normal use and is a source of fluid contamination. Though the PVC jacket will stiffen, it does not become brittle or fail. Cabling can be pre-cleaned by extended period (24 hr) vapor degreasing to remove most of the oil, but some will remain and must be removed by the fluid conditioning system to keep the fluid healthy. Cabling clad with polyolefin or PTFE is typically quite clean but more difficult and expensive to acquire.

PART 3 – Organic Removal/Fluid Conditioning

If not removed, the hydrocarbon oils found in elastomers, PVC insulation, foams, adhesives, etc. will be solvated by the fluid at low levels and separated by distillation to foul boiling surfaces. It can also diffuse into other materials and cause them to fail. Acid washed activated carbon, similar to the type used in drinking water cartridges, has a high affinity for these materials. Smaller systems can often be cleansed passively by placing carbon filter “bags” in the liquid. For larger systems, the time scale for diffusion of contaminants to the carbon is too slow and forced scrubbing using any automotive fuel pump to deliver fluid through a carbon cartridge is useful. Carbon conducts electricity so it must be filtered. The amount of carbon used should be at least 5× the mass of anticipated contamination; this can be estimated by totaling the elastomeric mass and assuming that 0.1% (if cleaned) to 3% (typical) or even 25% (extreme) of that mass is contamination. Carbon should be replaced after the first week of service and does not need to be replaced subsequently. Active filtration can cease after a few months service.

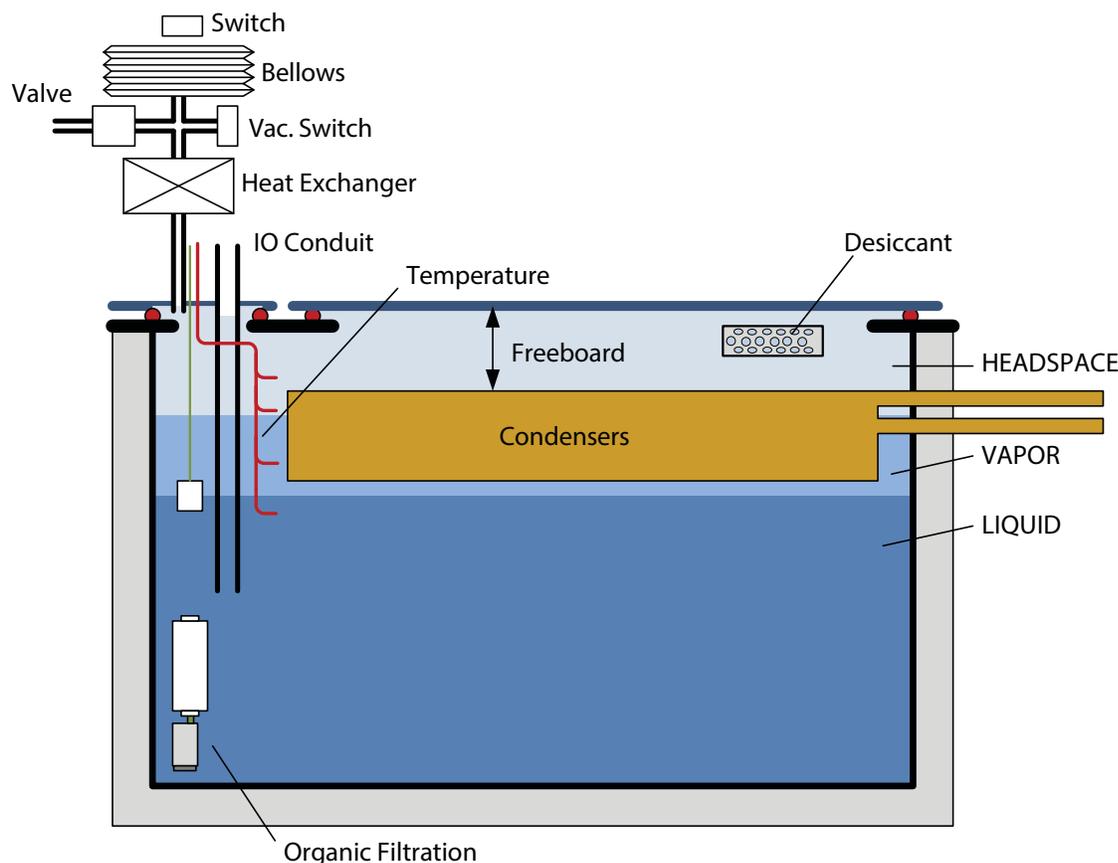


Figure 2. Two-Phase Immersion Cooled Tank set-up

PART 4 – Moisture Management

Two-phase immersion cooling working fluids have low water solubility but can hold from 5-20 parts per million by weight (in fluoroketones and PFCs) to as much as 100 ppmw (in hydrofluoroethers) of water. Upon start-up, this water will migrate to the top of the system into the headspace above the vapor zone. Its concentration in the headspace can rise above the saturation concentration and water will begin to liquefy. Liquid water can cause short circuits and corrosion. A desiccant such as silica gel in a perforated container placed in the headspace will prevent liquefaction of water. A desiccant placed in the liquid or vapor zone will NOT remove water and will actually add water to the headspace. The desiccant mass should be at least 5 times the anticipated water mass. A system should be quite dry after the first day of operation. As long as it remains operating, the desiccant is no longer needed but should be replaced upon start-up whenever the system is allowed to cool.

PART 5 – Vent and Pressure Control

Atmospheric pressure operation is a hallmark of two-phase immersion cooling as it minimizes fluid loss, permits easy access to hardware and eliminates the need for expensive hermetic electrical connectors. Simply venting a tank to atmosphere, however, will lead to unacceptable amounts of fluid loss.

A demonstrated method of maintaining atmospheric pressure is to use a bellows⁸ in conjunction with a mechanical and pressure switch controlling a solenoid valve. This can be done either at the bath or facility level. During start-up when the fluid is degassing, or during subsequent increases in power that cause the vapor zone

to rise, additional gas pressure will build up and the bellows will expand. At the limit of the expansion, the bellows closes a switch, causing the vent valve to open. The venting stream is sometimes passed through a secondary heat exchanger that captures much of the fluid vapor in the vent stream. When the bellows collapses due to a drop in power or a return to steady-state, a vacuum switch closes and causes the vent valve to open and admit air.

PART 6 – Managing IO Penetrations

Sealing has historically been a challenge in implementing two-phase immersion for computer systems. Hermetic connectors for AC power are usually manageable, but those typically required to handle the myriad of conductors and optics in some computing applications tend to be cost prohibitive. The atmospheric pressure operation of a two-phase immersion cooling system permits wires and cables to be passed through a simple conduit that terminates below the liquid level. The liquid creates a “trap” seal that helps prevent rampant egress of vapor and liquid and results in diffusive fluid losses of approximately 1 g-m/cm². This loss is driven to lower levels by potting, if necessary, using low viscosity resins⁹. In some very communication-intensive applications, the PCB of the switch can be potted in such a way that it serves as a pass through for IO.

Part 7 – Other Controls

A float switch can be used to cut power to the hardware in the event that the liquid level gets too low. Temperature sensors in the vapor zone can be used to determine vapor height as it may be useful for regulating water flow to minimize movement of the vapor zone.

A temperature sensor above the condenser will warn to the fluid boiling temperature if the condenser capacity should be exceeded. This and other inputs can be routed through a programmable logic controller to help monitor and regulate the system.

References

¹ <http://www.highsidechem.com/leaklock.html>

² <https://www.youtube.com/watch?v=buyPdRTF0Ss>, <http://www.darcoid.com/includes/hollow-o-rings-spliced.html>

³ http://www.dynamicrubber.com/?gclid=CKLJ5_j6774CFeZaMgodsFcAgw

⁴ Hardware Labs (www.hwlabs.com) is one source for such radiators. Optimal designs require thicker finstock and custom fabrication.

⁵ Contact Florian Hudelmaier, Wieland Copper Products, Wheeling, IL, Direct: (847) 465-6789

⁶ In-depth discussion of boiling enhancement is available in other 3M Documents.

⁷ Various companies can provide short term (cleaning) and long term (extraction) vapor degreasing services.

⁸ https://www.youtube.com/watch?v=oi_iFRAtfus

⁹ http://www.polytek.com/index.php?dispatch=categories.view&category_id=243

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