

3M Technical Paper

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

## Part 1 - Tank

### Material

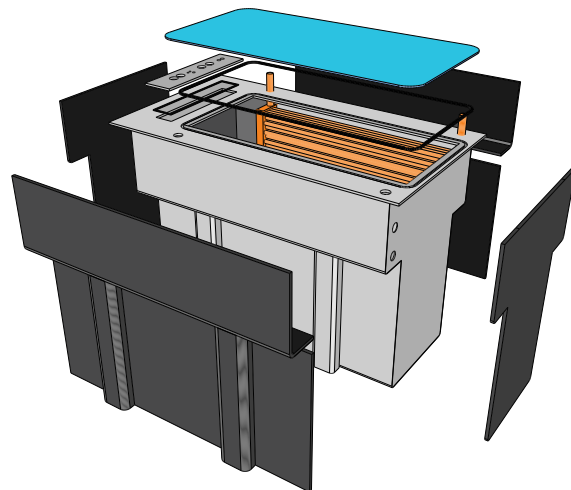
Except for technology demonstrators, tanks should not be fabricated from plastics as they contain and transfer moisture that becomes a burden on the tank's drying system. Tanks can be fabricated from glass but edge sealing of glass panels is questionable. Ideally tanks are made from welded metal. Stainless steel and ordinary carbon steel (14 gage for smaller tanks, 11 gage for larger ones) have been preferred, but aluminum can, in principle, be used. Metal should be reinforced as needed to support hydrostatic pressure of the fluid. Aluminum and carbon steel must be painted or powder coated on the interior and sealing surfaces at a minimum to prevent oxidation from accidental moisture condensation.

### 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 Compound<sup>1</sup>. 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



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

toggle clamps. For larger openings, engineering recommendations for the force per unit length required to make a good seal should be carefully considered and may necessitate numerous clamping points<sup>2</sup>.

80 durometer EPDM or butyl should be used with hydrofluoroether fluids (3M™ Novec™ 7000, 7100 or 7200 Engineered Fluids) and silicone for perfluorocarbons (3M™ Fluorinert™ Electronic Liquids FC-72 or FC-3284). These elastomers contain oils that are inevitably extracted in normal use and are a source of fluid contamination<sup>3</sup>. Elastomers should therefore be chosen that are low in extractable content. Pre-cleaning by vapor degreaser may be indicated to “preshrink” the elastomer and lessen the organic burden. This will be addressed later in the guide.

## 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 finstock. For larger systems, they should be fabricated as banks of enhanced tubes of the type commonly used in industrial chiller condensers<sup>4</sup>. 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.

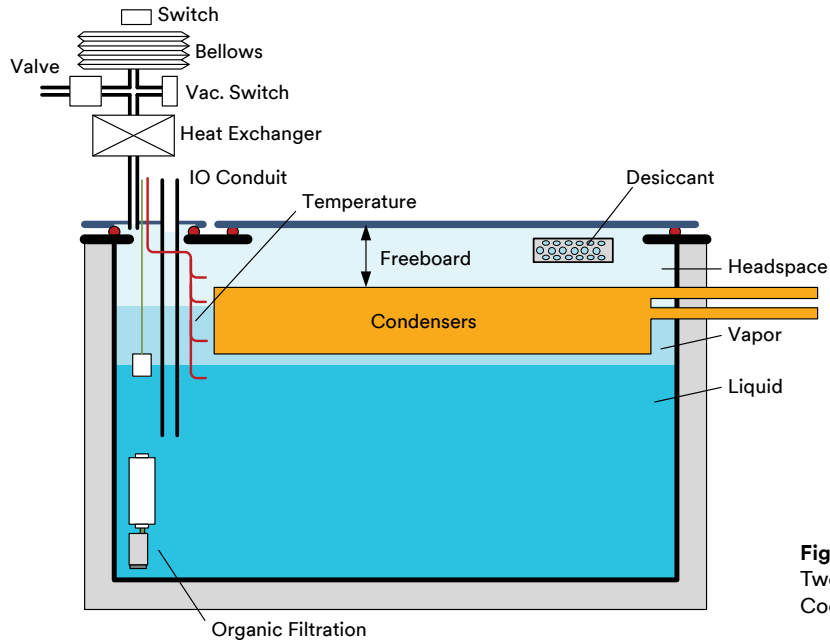
Consideration	Recommended
<b>Material</b>	<ul style="list-style-type: none"> <li>Welded metal (carbon steel, aluminum, stainless steel)</li> <li>Glass (edge sealing concerns)</li> </ul>
<b>Material Finish</b>	<ul style="list-style-type: none"> <li>Powder coated for metals</li> </ul>
<b>Perforations</b>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

## 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 it<sup>5</sup>.

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 process<sup>6</sup> 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.



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

### 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.

### 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 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.

This water can be passed outside the tank through a pervaporative membrane or adsorbed with a replaceable desiccant such as silica gel in a perforated container placed in the headspace. 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. The fluid in an operating system should be quite dry after the first day of operation. Additional water will gradually be liberated from the hardware inside the tank. Relative humidity should always be monitored recognizing that the sensor temperature may not be warmer than the coolest headspace surface.

### 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 bellows<sup>7</sup> in conjunction with a mechanical and pressure switch controlling a solenoid

valve. 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 or regenerable carbon bed that captures some or all 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/cm<sup>2</sup>. This loss is driven to lower levels by potting, if necessary, using low viscosity resins<sup>8</sup>. 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 warm 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.



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