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Frequently asked questions

3M fluids for data center immersion cooling

General Immersion Cooling Questions:

What is immersion cooling?

Immersion cooling is a method for cooling data center IT hardware by directly immersing the hardware in a non-conductive liquid such as 3M™ Fluorinert™ Electronic Liquids or 3M™ Novec™ Engineered Fluids. Heat generated by the electronic components is directly and efficiently transferred to the fluid. This reduces the need for interface materials, heat sinks, fans, shrouds, sheet metal and other components that are common in traditional cooling methods.

What are the benefits of immersion cooling?

Immersion cooling with 3M fluids offers many benefits compared to traditional air cooling, including increased thermal efficiency (i.e., lower PUE), performance and reliability of data centers. Immersion cooling also eliminates the need for complex airflow management. Optimized immersion-cooled data centers can lead to reductions in capital and operating expenses, as well as a reduction in construction time and complexity. The increased compute density from immersion cooling allows for more flexible data center layouts and removes barriers to data center location choices such as areas with high real estate costs or space limitations. Finally, immersion cooling with 3M fluids can help eliminate the tradeoff between water usage, energy efficiency and cost by eliminating the need for chillers with economizers and complex controls used air cooling. This helps eliminate the use of water needed to cool the data center by, instead, utilizing natural water temperatures in many climates to allow for full capacity cooling without evaporation infrastructure.

What is the difference between immersion cooling and direct-to-chip cooling?

Immersion cooling involves directly immersing IT hardware in a sealed but readily-accessible enclosure filled with dielectric liquid. Heat generated by the electronic components is directly transferred to the fluid. With direct-to-chip cooling, fluid never comes in direct contact with the electronics. Instead, direct-to-chip cooling uses pipes to pump a liquid coolant to cold plates that sit on electronic components to transfer heat.

Both immersion cooling and direct-to-chip cooling can be implemented using single-phase and two-phase methods using 3M fluids.

What are common ways in which immersion cooling can be implemented?

There are two common immersion cooling configurations: tank-style and clamshell.

Tank-style immersion cooling uses dielectric fluid as the heat transfer medium in a sealed but readily-accessible tank. This eliminates the need for hermetic connectors, pressure vessels, seals and clamshells. The servers must be vertically installed inside the tank.

In the clamshell design, server electronics are sealed within the server chassis. Dielectric fluid is circulated through the entire server enclosure, removing heat from the electronic components. The clamshell design is typically implemented with servers inserted horizontally into a rack.

When should I consider single-phase immersion cooling? When should I consider two-phase immersion cooling?

There are several key factors worth considering when deciding between single-phase and two-phase immersion cooling.

Single-phase immersion cooling systems feature simpler tank designs and easier fluid containment. Material compatibility and fluid hygiene are also less challenging in single-phase compared to two-phase cooling.

Implementing passive two-phase immersion cooling systems enables greater heat transfer efficiency through the boiling process (through the liquid to vapor phase change) compared to single-phase immersion cooling, allowing for greater power densities with two-phase immersion cooling (up to 250-500 kW/tank). Furthermore, the cooling infrastructure required to support two-phase immersion cooling is typically less complex, as additional adiabatic cooling beyond a dry cooler is not necessary.

What categories of fluids can be used for single-phase immersion cooling?

Both fluorochemicals (or fluorocarbons) and hydrocarbons (e.g. mineral oils, synthetic oils, natural oils) can be used for single-phase immersion cooling. Fluids with a higher boiling point (above the maximum temperature of system) are necessary to ensure the fluid remains in liquid phase.

Considerations when deciding among various fluorochemicals and hydrocarbons include: heat transfer performance (stability and reliability over time, etc.), ease of IT hardware maintenance, fluid hygiene and replacement needs, material compatibility, electrical properties, flammability or combustibility, environmental impact, safety-related issues and total fluid cost over the lifetime of the tank or data center.

What categories of fluids can be used for two-phase immersion cooling?

Fluorochemical fluids, generally with a lower boiling point, are predominantly used for two-phase immersion cooling. Hydrocarbons typically are not used for two-phase immersion cooling systems, as most hydrocarbons are combustible and/or flammable. Therefore, hydrocarbons are typically only used in single-phase applications.

Considerations when deciding among various fluorochemicals include: impact on IT performance (consistency, reliability, etc.), ease of IT hardware maintenance, fluid hygiene and replacement needs, material compatibility, electrical properties, flammability or combustibility, environmental impact, safety-related issues and total fluid cost over the lifetime of the tank or data center.

Product and properties

What heat transfer fluids for immersion cooling are manufactured by 3M?

3M heat transfer fluids are part of a class of materials called fluorocarbons which have properties that are uniquely suitable for heat transfer applications such as immersion cooling of electronics. Commercially available immersion cooling heat transfer fluids from 3M include perfluorocarbons (PFCs) that are available under the brand name 3M™ Fluorinert™ Electronic Liquids, as well as hydrofluoroethers (HFEs) that are available under the brand name 3M™ Novec™ Engineered Fluids. Suitable heat transfer fluids for immersion cooling under these 3M brands are further discussed below, and include:

- PFCs: 3M™ Fluorinert™ Electronic Liquid FC-3283, 3M™ Fluorinert™ Electronic Liquid FC-40, 3M™ Fluorinert™ Electronic Liquid FC-43, 3M™ Fluorinert™ Electronic Liquid FC-3284, 3M™ Fluorinert™ Electronic Liquid FC-72, and 3M™ Fluorinert™ Electronic Liquid FC-70
- HFEs: 3M™ Novec™ 7000 Engineered Fluid, 3M™ Novec™ 7100 Engineered Fluid, 3M™ Novec™ 7200 Engineered Fluid, 3M™ Novec™ 7300 Engineered Fluid, 3M™ Novec™ 7500 Engineered Fluid, and 3M™ Novec™ 7700 Engineered Fluid

3M is continuously developing new fluorochemical fluids that provide additional advantages over existing products or enable new applications.

What are 3M™ Fluorinert™ Electronic Liquids for immersion cooling?

3M Fluorinert Electronic Liquids are a type of fluorochemical referred to as perfluorocarbons (PFCs), which are primarily composed of carbon and fluorine; however, they may additionally contain nitrogen and/or oxygen. (See previous question for list of applicable Fluorinert liquids for immersion cooling.)

3M Fluorinert Electronic Liquids have set the industry standard for heat transfer applications for over 60 years. These fluids are colorless, odorless, non-oil-based, and non-corrosive. Fluorinert liquids are not classified as flammable liquids under the Global Harmonized System of Classification and Labeling of Chemicals (GHS). Further attributes include wide operating temperature ranges, low toxicity, outstanding thermal/chemical stability, and exceptional dielectric properties. 3M Fluorinert Electronic Liquids can be used in single-phase or two-phase immersion cooling systems. They are ideal for data center immersion cooling by virtue of their extremely low dielectric constants and high dielectric strengths.

What are 3M™ Novec™ Engineered Fluids for immersion cooling?

3M Novec Engineered Fluids that have been used for heat transfer applications consist of two types of fluorochemicals: fluoroketones (FKs) and hydrofluoroethers (HFEs). 3M currently recommends using HFE Novec fluids for data center liquid cooling applications (see previous question for recommended list of Novec fluids for immersion cooling).

Like 3M™ Fluorinert™ Electronic Liquids, Novec fluids are primarily composed of carbon and fluorine. The HFE Novec fluids include a hydrocarbon ether segment while the FK fluids include oxygen in a double bond configuration. The 3M Novec brand of fluids is designed to balance performance with favorable environmental and worker safety properties.

Novec fluids are not classified as flammable liquids under the Global Harmonized System of Classification and Labeling of Chemicals (GHS) as they do not display a closed cup flash point. Moreover, Novec fluids are non-oil-based, low in toxicity, and non-corrosive, with good material compatibility and thermal stability. Novec HFE fluids have a low global warming potential (GWP) and zero ozone depletion potential (ODP), giving data center owners an innovative and sustainable solution for their single-phase or two-phase data center liquid cooling (direct-to-chip and immersion cooling) applications.

What is the difference between fluorocarbons, such as 3M™ Novec™ Engineered Fluids and 3M™ Fluorinert™ Electronic Liquids, and hydrocarbons?

Hydrocarbons (e.g., mineral oils, synthetic oils, and natural oils) are primarily composed of hydrogen and carbon, although they may additionally contain nitrogen and/or oxygen. These materials are prone to dissolving hydrocarbon-based polymers and are therefore less likely to be compatible with adhesives, elastomers, and thermal interface materials. Moreover, most hydrocarbons are combustible and/or flammable. Therefore, hydrocarbons may pose an unacceptable risk to safety and infrastructure for many applications, particularly in two-phase immersion cooling Hydrocarbon fluids with sufficiently high boiling points and flash points can be used in some single-phase applications, but they have the disadvantage of being relatively viscous (especially at low temperature) and do not evaporate readily from hardware when it is removed for service.

Fluorocarbons primarily contain the elements fluorine and carbon and may additionally contain hydrogen, nitrogen, and/or oxygen. In organic chemistry, the bond between carbon and fluorine is known as being the strongest single bond, which is why fluorocarbons exhibit high chemical and thermal stability. Neither Novec fluids nor Fluorinert liquids display closed cup flash points and therefore are not classified as flammable liquids under GHS. This provides an additional element of safety in many heat transfer applications including immersion cooling. Unlike hydrocarbons, particularly those with high flash points, both Novec fluids and Fluorinert liquids exhibit low viscosity over a wide temperature range and evaporate cleanly from any surface.

FAQs: 3M fluids for data center immersion cooling

How do 3M™ Novec™ Engineered Fluids differ from 3M™ Fluorinert™ Electronic Liquids? Why would I choose a Novec fluid over a Fluorinert liquid, or vice versa, for immersion cooling?

Novec fluids and Fluorinert liquids have different molecular structures but exhibit similar properties such as being non-ozone depleting, low in toxicity, and low in solvency. However, there are a few points to consider when choosing a fluid for data center immersion cooling applications:

- **Material Compatibility**
  Novec fluids exhibit a higher solvency for hydrocarbon-based materials compared to Fluorinert liquids and thus may have a greater interaction with immersed materials (see section titled *What are the material compatibility considerations for HFE 3M™ Novec™ Engineered Fluids and 3M™ Fluorinert™ Electronic Liquids?*)

- **Environmental Impact and GWP**
  Novec fluids have low global warming potential (GWP) values and shorter atmospheric lifetimes compared to Fluorinert liquids and would be favored in applications where environmental sustainability is important.

- **Electrical Properties**
  In general, the dielectric constant (Dk) values for HFE Novec fluids are greater than those for Fluorinert liquids. The high Dk values for HFE Novec fluids may lead to signal integrity issues for some high-frequency applications where there are immersed electronic components and/or connectors that are not explicitly designed to be utilized in a fluid with a high Dk value. These fluids have been used successfully in cryptocurrency mining applications and may potentially be used in other data center applications if modifications to the IT hardware are made to enable operation in an HFE Novec fluid.

Which 3M fluids are commonly used for single-phase immersion cooling?

3M™ Fluorinert™ Electronic Liquid FC-3283 and 3M™ Fluorinert™ Electronic Liquid FC-40 are commonly used for single-phase immersion cooling. The 3M™ Novec™ Engineered Fluids that are hydrofluoroethers (HFEs), such as 3M™ Novec™ 7500 Engineered Fluid, may also be used, depending on the application. Please consult 3M Tech Service for assistance with selecting the most suitable fluid for your applications.

For more information, please refer to the Data Center Immersion Cooling with 3M™ Fluorinert™ Electronic Liquids Product Selection Guide.

Which 3M fluids are commonly used for two-phase immersion cooling?

3M™ Fluorinert™ Electronic™ Liquid FC-3284 and 3M™ Fluorinert™ Electronic Liquid FC-72 are commonly used for two-phase immersion cooling. The 3M™ Novec™ Engineered Fluids that are hydrofluoroethers (HFEs), such as 3M™ Novec™ 7100 Engineered Fluid, may also be used depending on the application. Please consult 3M Tech Service for assistance with selecting the most suitable fluid for your applications.

For more information, please refer to the Data Center Immersion Cooling with 3M™ Novec™ Engineered Fluids Product Selection Guide.

Will 3M™ Fluorinert™ Electronic Liquids or 3M™ Novec™ Engineered Fluids cause corrosion?

Neither Fluorinert liquids nor Novec fluids are known to cause or accelerate material corrosion by themselves. These fluids exhibit high dielectric strengths (~40 kV at 0.1" gap) and are non-ionic, non-oxidizing and non-reducing in nature. Corrosion in fluorochemical heat transfer systems can generally be linked to either a separate water phase or extraction of corrosive hydrocarbon contaminants (e.g. organic acids from solder flux).

The saturation level of water in a Fluorinert liquid or Novec fluid is usually less than 100 ppm by weight. Water present in the fluid at or below this level has never been linked to significant corrosion. A separate water phase will form when the total water content of the system exceeds the saturation level of the fluid. In this case, the separate water phase may cause rapid corrosion if it comes into contact with metal surfaces, which would also occur in the absence of the fluorochemical fluid.

Dissolved water in a heat transfer application will tend to evaporate and condense on the coldest part of the system (e.g. the lid of an immersion cooling tank). This latent water can be captured with any common molecular sieve or silica gel desiccant sold for refrigeration systems. The saturation level of hydrocarbon contamination (e.g. organic acids) in a Fluorinert liquid or Novec fluid is usually less than 200 ppm by weight. These potential sources of hydrocarbon-based corrosion may be captured using activated carbon cartridges with active fluid pumping (see section titled *How can I mitigate fluid contamination issues?*)

Application and design

What are material compatibility considerations for the hydrofluoroether (HFE) 3M™ Novec™ Engineered Fluids and the perfluorocarbon (PFC) 3M™ Fluorinert™ Electronic Liquids?

Compatibility may be defined as the measure of how stable two or more substances are when in contact with each other. 3M fluids used in immersion cooling are generally inert and therefore, under normal use conditions, do not chemically interact with most materials. However, it is important to consider compatibility when designing a system that will use 3M fluids. Material compatibility with 3M fluids is primarily focused on two physical interactions:

- The extraction of compounds such as plasticizers (e.g., dioctyl phthalate and similar additives) from materials that could migrate to other locations
- The absorption of the fluid into materials, especially fluorinated compounds such as fluoropolymers, that could lead to swelling of elastomers or plastics

The lack of hydrogen-carbon bonds makes PFC Fluorinert liquids a poor solvent for hydrocarbon compounds, meaning Fluorinert fluids are generally compatible with hydrocarbon compounds. In contrast, the molecular structure of HFE Novec fluids gives them a slight affinity for hydrocarbon compounds, which could lead to more pronounced extraction effects. This extracted material can migrate to other locations in a system and impact overall system health and performance. There are recommended methods to manage this. Please contact 3M Technical Service to discuss material compatibility.

What are potential sources of fluid contamination for an immersion cooling system?

Fluid contamination can occur with both single-phase and two-phase immersion cooling systems. Broadly speaking, these contaminants fall into three categories: hydrocarbons, water, and solid particulate. Some common sources of potential hydrocarbon contaminants include: solder flux from printed circuit boards (PCBs) containing surfactants, corrosion inhibitors, and activators; adhesives and lubricants; and plasticizer additives in polymeric cable cladding, seals, and gaskets. Entrained water is found in nearly all permeable materials, including PCBs, polymers, seals, and gaskets. Solid particulate examples include zip ties, paper towel fibers, clothing fibers, dander, metal or plastic shavings, and thread sealants.

The solubility of hydrocarbon contaminants in both Fluorinert liquids and Novec fluids is typically on the order of 200 ppm by weight or less. Water solubility will vary somewhat depending on the fluid being used, but typically it is 100 ppm by weight or less. Solid particulate concentrations may be any arbitrary number since they are not dissolved in the fluid and instead are carried by the fluid during pumping or agitation.

For general guideline on how to mitigate fluid contamination, please refer to the following section titled *What steps can be taken to mitigate fluid contamination?*

It is important to note that the contamination described above comes not from the environment, as in air cooling, but from materials present in the electronics or related hardware. Thus, the system designer has some degree of control over contamination by choosing materials that have low concentrations of extractable content and by pre-cleaning components.

What steps can be taken to mitigate fluid contamination?

There are some general best practices that will help users maintain fluid hygiene by minimizing contamination that might arise during the use of an immersion cooling system:

1. Pre-clean hardware using a vapor degreaser to remove flux, fingerprints, oily residue, etc. and reduce the overall hydrocarbon contaminant level
2. Avoid the use of materials containing extractable hydrocarbon substances to the extent possible

Recognizing that materials containing hydrocarbon contaminants cannot be avoided completely, activated carbon is used as an *in-situ* adsorbent for scrubbing the fluid in both single-phase and two-phase systems. Water contamination can be minimized using adsorbents such as silica gel placed into the headspace region. Solid particulate can be filtered using standard liquid filtration hardware incorporating media such as cellulose, polypropylene, or sintered metal. Please consult 3M Technical Service for additional information.

What are sources of fluid loss in a two-phase immersion cooling tank?

There are loss mechanisms associated with the different phases of operation of an atmospheric pressure, two-phase immersion cooling tank. These losses result from filling and starting the tank, venting due to power fluctuations while operating, parasitic loss from I/O conduits (e.g. tank seals, etc.), and evaporative losses during servicing. Please consult 3M Technical Service for information on how to minimize fluid losses.

What is a boiling enhancement plate? Why do I need it for two-phase immersion cooling?

A boiling enhancement plate is a thin layer of microporous structures, typically a copper and/or silver coating 100-500 microns thick, bonded to a copper plate to improve the thermal performance of a two-phase system. Boiling enhancement plates are recommended for CPUs, GPUs, and certain ASICs and FPGAs to help increase the heat transfer efficiency, the heat transfer coefficient, and critical heat flux in two-phase immersion cooling operations.

Maintenance

How do I manage routine servicing and fluid handling?

Read and follow safety precautions on the product label and safety data sheet (SDS) prior to using 3M fluids. Dispose of collected material in a manner consistent with local regulations and in accordance with the guidance provided in the SDS. General guidelines include the following considerations:

- **Gloves and Eyewear:** Though 3M™ Fluorinert™ Electronic Liquids and 3M™ Novec™ Engineered Fluids are classified as non-irritating to the skin and eyes, good industrial hygiene practices indicate the use of safety glasses with side shields whenever splashing of liquid into the eyes is possible. Incidental and even long-term skin contact is acceptable; however, butyl or nitrile glove protection may be preferred whenever significant or prolonged skin contact with the liquid is expected.
- **Inhalation Protection:** Please refer to the appropriate SDS for specific guideline for inhalation protection.
- **Methods for monitoring concentrations:** Instruments capable of measuring airborne concentrations of 3M™ Fluorinert™ Electronic Liquids and 3M™ Novec™ Engineered Fluids are commercially available from third parties such as Bacharach, Inc. Equipment is available that is capable of measuring concentrations as low as 1 ppmv.
- **Filling and Draining Fluid Drums:** The DrumQuik® PRO system has been successfully used to fill and drain large tanks holding several drums of fluid. Each drum is fitted with a drum insert that is easily sealed. The tank is outfitted similarly. When these are connected to each other through a proper filling system, the liquid lines and headspaces of the two containers are coupled, permitting pumping in either direction. The vent stream created by this process can be treated by various means to mitigate fluid loss during the process. Please refer to the operator's manual for the system that you choose to use.
- **Hot Swapping:** See following section *Can I hot swap my IT hardware with 3M fluids?*

How frequently do I need to change out 3M fluids in the system?

Both the hydrofluoroether (HFE) 3M™ Novec™ Engineered Fluids and the perfluorocarbon (PFC) 3M™ Fluorinert™ Electronic Liquids are generally unaffected by common sources of contamination (e.g. water or hydrocarbons). They are unreactive towards these species and will remain chemically unaltered by their presence. Rather, it is the contaminants themselves that may become problematic at certain concentrations. Therefore, with proper filtration of potentially problematic contaminants, the fluorinated fluid can be used indefinitely. Please refer to the operator's manual for the system that you choose to use.

How do I remove 3M™ Fluorinert™ Electronic Liquids or 3M™ Novec™ Engineered Fluids from my system or parts?

Fluorinert liquids and Novec fluids evaporate cleanly and almost immediately as equipment is pulled out of the immersion cooling tank, leaving virtually no residue.

How can I detect fluid leaks?

A halogen leak detector can be used to detect fluid leaks. These detectors are commonly used to detect refrigerant leaks in automotive applications and are readily available from companies such as Robinair Automotive & HVAC, Bacharach Inc., and INFICON. Check the operator's manual for the detector that you choose to use.

Can I hot swap my IT hardware with 3M fluids?

Data center IT hardware can be hot swapped in both single-phase and two-phase immersion cooling applications. Servicing of hardware in single-phase applications with 3M fluids is managed by opening the lid, extracting the hardware, and allowing it to drip dry as much as possible before removal from the tank area. 3M fluids will tend to "drag out" less than oils owing to their higher density and lower viscosity. Also, unlike oils, residual 3M fluid will evaporate with time leaving the hardware completely dry and without residue.

In two-phase applications, the tank is opened and hardware is extracted from the boiling tank at a few inches per second. Any liquid left on the warm hardware will "flash" as it breaks free from the vapor zone and will be captured by the condenser. The hardware will exit almost completely dry.

Safety Data Sheet: Consult Safety Data Sheet before use.

Regulatory: For regulatory information about this product, contact your 3M representative.

Technical Information: The technical information, recommendations and other statements contained in this document are based upon tests or experience that 3M believes are reliable, but the accuracy or completeness of such information is not guaranteed.

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Electronics Materials Solutions Division
3M Center, Building 224-3N-11
St. Paul, MN 55144-1000
1-800-251-8634 phone
651-778-4244 fax
3M.com/immersioncooling

60-5005-0212-9