Comparison of Dielectric Fluids for Immersive Liquid Cooling of IT Equipment

White Paper 291

Version 2

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Executive summary

Understanding the TCO, material compatibility, safety, environmental impact, IT maintenance and handling characteristics of dielectric fluids are key to choosing the right liquid cooling technology for your applications. Oils and fluorocarbon fluids are two types of dielectric fluids used in immersive liquid cooling technologies. In this paper, we discuss the characteristics and tradeoffs of these two types of dielectric fluids to help data center designers and operators make informed decisions.

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Introduction

There are increasing numbers of liquid cooling technologies available for IT equipment (ITE) from multiple vendors. Each of these is designed to optimize around a combination of attributes including, but not limited to, capital cost, energy cost, serviceability, rack density/compaction, water usage, harsh environment, fan noise/air movement, room layout, etc. How critical each of these attributes is, ultimately depends upon your specific business requirements. The benefits and drawbacks of each of the main liquid cooling technologies are reviewed in White Paper 265, *Liquid Cooling Technologies for Data Centers and Edge Applications.*

One of the key selection criteria when choosing between different liquid cooling technologies is the liquid coolant (i.e., dielectric fluid) itself. Dielectric fluids are nonconductive and remove heat from IT components by direct contact with the electronics. Dielectric fluids used for ITE cooling can be broken into two broad categories:

- Oils
- Fluorocarbons

We use the generic "oils" to category a variety of fluids that have similar characteristics, which includes hydrocarbons, esters, etc. The selection criteria depend on a combination of attributes including, but not limited to, total cost of ownership (TCO), material compatibility, safety, environmental impact, IT maintenance and handling, and heat transfer capability.

In this paper we discuss the main types of dielectric fluids currently used by solution providers, together with their benefits and drawbacks, based on their main characteristics. Table 1 is a simplified summary comparison between the five main attributes of dielectric fluids.

Table 1
A simplified summary comparison between the five main attributes of dielectric fluids

Main attributes	Oils	Fluorocarbons
TCO of fluid	$ - $$	$$$$$
Material compatibility	Poor – Good	Good – Excellent
Safety	Poor – Good	Poor* – Good
Environmental impact	Very Low – Low	Low – High GWP
IT maintenance and handling	Messy	Clean

* Research on PFAS indicates they are harmful to humans.

Note, **heat transfer capability** is an important attribute for fluids, but cannot be quantified unless coupled with the cooling techology the fluid is used with. Thermophysical properties are described later in this paper.

Background of liquid cooling technologies

Not all dielectric fluids are compatible with all liquid cooling technologies. The technology providers recommend or provide compatible fluids. For example, one of the most deployed liquid cooling technologies, single-phase "cold plate" or "direct to chip" (D2C), does not typically use dielectric fluid, although technically possible. Instead, treated water contained within a closed loop, is used to transfer the heat from the chips and other components.

Table 2 illustrates which fluid categories are currently in use for the five most common liquid cooling approaches described in *White Paper 265*. Note that there are variations and hybrid versions of these technologies, so this list is not intended to be exhaustive.

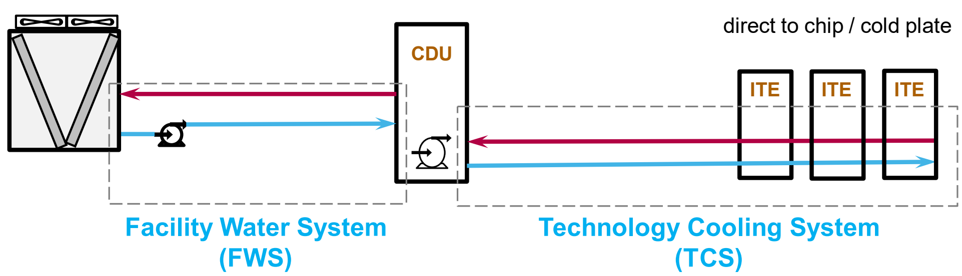
Table 2
Cooling fluids currently used in the most common liquid cooling approaches

Liquid cooling technologies		Cold plate	Dielectric	
		Water	Oils	Fluorocarbons
Cold plate / Direct to chip	Single-phase	Yes	No*	Yes*
	Two-phase	No	No	Yes
Immersive	Tub (Single-phase)	No	Yes	Yes*
	Tub (Two-phase)	No	No	Yes
	IT chassis (Single-phase)	No	Yes	Yes

* Technically possible, but not typically practiced.

In most deployments of liquid cooling in data centers, water is used somewhere in the system to transfer the heat. In direct to chip liquid cooling, it is used directly inside the server, through cold plates, to remove the heat of chips. There are many variations on how to move heat from liquid-cooled servers to the outdoors. Figure 1 shows a simplified architecture for a liquid cooling deployment. ASHRAE Technical Committee 9.9 has done an excellent job working on terminology and specifications for systems in their white paper, *Water-Cooled Servers Common Designs, Components, and Processes*, released in 2019.

Figure 1
Simplified view of a liquid cooling architecture



Water is a very effective heat transfer medium. Its electrical conductivity restricts its use to cold plate technologies, where it does not come into direct contact with the electronic components it is cooling. It is also used by many immersive solutions within TCS loop and FWS loop.

Data center operators have been managing condenser water systems and facility water systems for many years, and they understand water issues such as corrosion protection (uniform, galvanic, crevice, pitting, etc.), fouling, and microbial protection, together with end-of-life disposal very well. However, for liquid cooling deployments, specifically cold plates, where small dripless connectors are used, it's important to understand the requirements of the TCS. Unlike the large water pipes in the FWS, TCS water must flow through cold plates, which in most cases requires tighter tolerances on water properties to avoid clogging.

The **coolant distribution unit (CDU)** provides the important function of separating the FWS from the TCS. Analogous to the function of a distribution transformer in an electrical network, the CDU ensures the water going to the ITE is at the correct pressure, flow rate, temperature, chemistry, wetted materials compatibility, and quality (filtration). Additionally, it maintains the water temperature above the dew point which prevents condensation within the ITE. Some CDUs designed with a Leak Prevention System (LPS) move water through the TCS loop under a vacuum. If a break in the system were to occur, air is sucked into the loop, preventing water from spilling within the ITE. Although not common, dielectric fluids can be used instead of water to prevent damage in an event of a leak. More detailed specifications on the TCS can be found in ASHAE guidelines.

Types of immersive dielectric fluids

The use of fluids with dielectric properties has a long history in various industries, with power transformers, electronics manufacturing and fire suppression being the most predominant. Oils and fluorocarbon fluids are currently the two main categories, with a variety of choices within each. In this section, we describe the choices of each category in detail.

Oils

Industrial use of oil as a dielectric for cooling has its origin in liquid-filled power transformers. Oils have been adopted by liquid cooling solution providers for single-phase dielectrics, particularly in immersive tub systems, which share a similar cooling typology as power transformer designs. The oils are most commonly derived from petroleum or natural gas, and there has been significant work to improve the overall characteristics of these fluids. The most common types of dielectric oils are:

- Mineral / white oils
- Synthetic poly alpha olefins (PAOs)
- Synthetic gas to liquids (GTLs)
- Synthetic esters
- Silicone oil

These fluids are typically clear and as the name implies, oily in nature. They are only used as a single-phase dielectric because of their very high boiling point. Flammability and flash point is an aspect to oil dielectrics that gets a lot of attention. It will be mentioned in the sections below and covered in more depth later in the paper.

Mineral oils have a long history of use for outdoor transformer installations, where fluid availability and low initial cost are prime requirements, and the associated risks due to the flammable nature of this material are well understood and accepted by users and insurers. **White oils**, like mineral oils, are also derived as an inexpensive byproduct of petroleum distillation process, having undergone a further refining process called "hydrotreating", which removes many of the impurities typically found in refined products. Mineral oils have restrictions imposed on their use and containment as a transformer dielectric, and they are generally used in outdoor applications.

An advantage of mineral and white oils is that they can be mixed from different batches and sources providing flexibility during deployments and operations. However, due to large variations in manufacturing, finding detailed technical data sheets (TDS) and material safety data sheets (MSDS) are difficult. Mineral and white oils have been used as a dielectric for immersive server cooling, but material compatibility issues, quality inconsistency, and lower flash point has caused the IT industry to move away from their use.

PAOs and GTLs are in the same class as synthetic motor oils. They have been engineered with improved characteristics over mineral and white oils. These materials often originate from improved transformer dielectrics. With a range of viscosities (lower than petroleum oils) and flammability ratings, they are suitable for use in open and sealed systems (increasing viscosity assists with increasing the flash point, but also impacts heat transfer capability and pumping power).

Compared to mineral and white oils, the PAOs and GTLs have tightly-controlled manufacturing processes which results in fewer impurities while providing greater resistance to oxidation, water absorption, and improved material compatibility. These kinds of oils are also more biodegradable in contrast to mineral and white oils. The price is higher than mineral oil, but lower than the fluorocarbon fluids.

Synthetic esters have recently gained popularity as a replacement to mineral oil in transformers. Esters can be derived from plants or synthetically produced, have good environmental characteristics and very similar performance characteristics as PAOs and GTLs. Their chemistry characteristic allows for slightly better viscosity to flashpoint ratios and good resistance to oxidation.

Silicone oil is used as a transformer oil and is specified for indoor use due to its relatively high flash point of 268°C (514°F) compared to mineral oils. It has a bit higher kinematic viscosity that comes with this higher flash point. It has not seen much use in ITE liquid cooling. It can absorb water like mineral oil and contains methyl polysiloxanes which generates formaldehyde at around 149°C (300°F), and also not biodegradable.

Fluorocarbon fluids

The use of fluorocarbon dielectric fluids for industrial applications have its origins in manufacturing of semiconductor devices, their testing, and the operation of electronics. They effectively replaced deionized (DI) water/glycol fluids in electronic fabrication, testing, assembly, and operation, which had previously been used for this purpose in the 1990s. Other versions have also been used as fire suppression agents. These fluids are manufactured by major chemical companies, and the technical data sheets (TDS) and MSDS data are readily available and guaranteed.

There are four main fluorocarbon molecules in use for liquid cooling:

- Perfluorocarbons (PFCs)
- Perfluoropolyethers (PFPEs)
- Hydrofluoroethers (HFEs)
- Fluorketones (FKs)

For the purposes of this paper, we can categorize PFCs and PFPEs into one group due to similarity of properties. All of these fluids have high dielectric strengths, and high thermal and chemical stability. They have no flash point, making them immune to flammability issues. All of these compounds can be formulated for a wide range of boiling points, e.g. from 50°C (122°F) through to 270°C (518°F). The low boiling points such as 50°C (122°F) are used for two-phase liquid cooling while the higher boiling points are used for single-phase liquid cooling.

One of the characteristics of these materials is relatively high vapor pressures, which means that admins can work on the IT equipment almost immediately after draining or removing it from the dielectric. Evaporation rate is higher with the lower boiling point materials, therefore using higher boiling point fluids at more moderate temperatures make it possible to reduce evaporation losses significantly. The PFCs have a long history for computer cooling which goes back to early supercomputers. The HFEs and FKs have been developed more recently to address environmental concerns, which can provide much lower Global Warming Potentials (GWP) with FKs having a GWP less than 1.

Heat transfer characteristics

Here we broadly describe the heat transfer characteristics of different fluids discussed above. System designers look for fluids that can capture heat quickly and move it away easily. There are a variety of thermophysical properties to consider. Among them are:

- Density: Mass per unit volume. This is the weight of a material, measured in kilograms per cubic meter (kg/m^3), or grams per cubic centimeter (g/cm^3).
- Specific heat capacity: The amount of energy required to increase the temperature of a given mass of material. This is measured as joules per kilogram per degree Kelvin [J/(kg*K)], or joules per gram per degree Celsius [J/(g*ºC)]. This represents how much energy a material can absorb or release during temperature changes.
- Thermal conductivity: The rates at which heat passes through a specified material. This is measured as watts per meter per Kelvin [W/(m*K)]. Metals are typically good conductors of heat while air is a good insulator. A higher number means the temperature will conduct more quickly.
- Kinematic viscosity: A measure of a fluid's internal resistance to flow under gravitational forces. This is commonly measured as centistokes (cSt), which is also equivalent to a square millimeters per second (mm^2/s). A lower number is less viscous and flows more easily. This has an impact on the energy needed to move or pump a liquid and should also be considered if cold starts at low temperatures is a possibility, especially for edge applications.

Table 3 provides a list of common single-phase dielectric fluids and their properties, along with reference materials (water, air, and copper) for comparison. All forms of liquid cooling provide much better heat transfer performance over air. Performance of the cooling system cannot be determined solely by these fluid characteristics because how the fluid is technically applied in a system has a great impact on its suitability.

There are two other thermophysical properties to consider:

- Boiling point: The temperature at which a fluid changes from a liquid to a gas. For two-phase immersive liquid cooling, designers must choose a fluid that will boil to maintain a desirable temperature. For current IT systems, this is about 50°C-60°C (122°F-140°F). For single-phase immersive liquid cooling systems, the fluid boiling point must be high enough to ensure it remains a liquid.
- Latent heat of vaporization: Heat required to convert a unit mass of a liquid into vapor without a change in temperature. This is measured as kilo joules per kilogram (kJ/kg). This is applicable to two-phase applications.

Table 3
Thermophysical properties of fluids used in ITE liquid cooling solutions

Material types		Density (g/cm^3) @20°C	Specific heat capacity [J/(kg*K)]	Thermal conductivity [W/(m*K)]	Kinematic viscosity (cSt)
Oils	Mineral / white oils	0.84	1670	0.130	9.6
	Synthetic oils	0.80 - 1.0	1900 – 2200	0.130	3.0 – 9.0
Single-phase fluorocarbons	PFCs	1.8	1100	0.065	0.8 – 2.2
	PFPEs	1.7 – 1.8	2300	0.065	0.6 – 11.0
	HFEs	1.4 - 1.8	1050 – 1150	0.067	0.7 – 2.5
	FKs	1.6	1100	0.059	0.4
The following are reference materials for comparison					
Water		0.998	4200	0.610	0.658
Air (dry)		0.0012	1000	0.026	-
Copper		8.9	375	385	-

Comparison between immersive dielectric fluids

Currently, there is no perfect fluid that provides the best price and performance for all applications. For immersive dielectric fluids, five key attributes described below are useful to help determine the best fit for an application and provide a starting point for discussions with liquid cooling solution providers.

TCO

The TCO of an immersive dielectric fluid includes initial cost and operating cost.

Initial cost: Mineral oils have the lowest initial cost among dielectric fluids. However, they are less frequently used due to material compatibility and flammability issues. Synthetic oils can be roughly double the initial cost of mineral oils. Fluorocarbons are the most expensive and can be five to ten times the cost of synthetic oils. Different cooling technologies require varying amounts of fluid. A metric commonly used is liters per kW of IT load. Your technology provider can tell you how much is needed and its cost.

Operating cost: This includes costs due evaporation and lifespan. Oils have a very low rate of evaporation, and the losses are negligible. Both single-phase and two-phase fluorocarbon fluids will evaporate when they are open to the atmosphere. These systems are typically sealed to prevent this. Fluid providers estimate a well-sealed two-phase immersive liquid cooling system can experience 1-2% fluid losses per year.

The other factor for operating cost is the life span. Nearly all dielectric fluids listed in this paper have good stability and will not breakdown easily when well maintained and will typically outlive the ITE they are cooling. Synthetic oils vary in life span from 10-20 years from date of manufacture, while fluorocarbon fluids can have more than a 30-year life span. All fluids used today have good dielectric strength for use in IT equipment. Impurities introduced in manufacturing or operations are the main concern for lowering dielectric values. ITE components should be cleaned and free of contaminants before immersion. Sufficient care should be taken during operations and maintenance to prevent contamination. All dielectric liquids are fairly robust and "clean room" conditions are not necessary. Testing frequency of dielectric strength is variable, based upon how often the IT systems are opened up. Hydrocarbon fluids might become yellow as they age, but this has no impact on their performance.

Compatibility

Fluid compatibility with IT equipment is one of the most common concerns when considering immersive liquid cooling. There are two main considerations; the first is that the materials within the IT equipment are non-reactive with the dielectric fluid, and the second is that the IT components will perform as needed.

Materials compatibility: Oils have received a bad reputation from the early usage of mineral and white oils. For example, one problem was that o-rings, used to seal capacitors in PSUs, swelled and failed due to incompatibility with oils. Today, synthetic oils such as poly alpha olefins (PAOs), gas to liquids (GTLs), and esters are highly refined and have improved material performance. The main considerations for oils include the stiffening of polyvinyl chloride (PVC) clad cables, incompatiblility with some thermal greases, and incompatiblity with label adhesives. These issues are overcome by using nitrile rubber-clad power cables, using indium foil instead of thermal grease for heat sink mounting, and either removing paper labels or covering them with clear expoxy or tape. Integrators with experience in oils are familiar with these procedures.

Fluorocarbon-based fluids overall have a very good material compatibility. PFCs and PFPEs are extremely stable molecules and have the best compatibility, which have been used in the manufacturing of IT equipment for over 50 years. HFEs and FKs can have slight interactions with hydrocarbon compounds within the IT equipment and cables. Manufactures recommend using charcoal filters in both single-phase and two-phase fluorocarbon applications to account for this.

Technology compatibility: At the time of this writing, most immersive liquid-cooled ITE are converted from air-cooled SKUs. Not all ITE components are compatible with immersive liquid cooling. The most obvious example is fans, which are removed or disabled in immersive liquid-cooled systems. To prevent alarms, the system basic input output system (BIOS) is updated or fan simulator circuits are installed. Spinning hard disk drives (HDDs) must be helium-filled sealed models. Solid-state drives (SSDs), however, are compatible, have been gaining in use, and are now common in immersive applications.

Network connectivity is another area to ensure your requirements are compatible with the technology. High frequency quad small form-factor pluggable (QSFP) connections might have signal degradation in some fluorocarbon fluids. Fluid-tight fiber optic connections are recommended since all immersive fluids might refract light, causing signal degradation. Also, for two-phase immersive liquid cooling, the heat sinks must be replaced with spreader plates to enhance heat transfer during boiling.

There are an increasing number of integrators and server OEMs who are capable of converting air-cooled servers for immersive liquid cooling. At the time of writing, natively-designed, immersive-ready servers have just started to become available on the market. This is expected to increase along with adoption.

Safety

The safety of immersive dielectric fluids includes human safety and flammability. **Human safety:** Oils pose little health risks to humans during normal operation when they are handled properly. Harm from inhalation and contact is minimal. Most manufactures recommend nitrile gloves when working with fluids to avoid contact with the skin and contamination of the fluids, although not necessary. Some types of fluorocarbon fluids (e.g., Fluorinert, Novec[1]) are categorized as per- and polyfluoro-alkyl substances (PFAS)[2], which might be harmful to humans and the environment. There are emerging regulations on limiting the use of PFAS and tracking releases in some regions of the world. For example, the U.S. Environmental Protection Agency (EPA) have taken a series of actions to address PFAS[3]., while the European Chemical Agency (ECHA) published a proposal to ban the use and production of PFAS. In the future, these regulations could be used increasingly as a reference by other regions. As a result, two-phase immersive liquid cooling is not recommended until non-PFAS fluids are developed.

Flammability: It's important to understand the definitions around flammable and combustible liquids, to ensure the terms are used properly and do not cause unnecessary confusion. **Table 4** provides short definitions of flammable liquids based on National Fire Protection Association (NFPA).

Table 4
NFPA flammable liquid definitions

Term	NFPA definition*
Flammable liquid	Any liquid that has a closed-cup flash point below 37.8ºC (100ºF).
Combustible liquid	Any liquid that has a closed-cup flash point at or above 37.8ºC (100ºF).
Flash point	The minimum temperature of a liquid at which sufficient vapor is given off to form an ignitable mixture with the air, near the surface of the liquid or within the vessel used.
Fire point	The lowest temperature at which a liquid will ignite and achieve sustained burning when exposed to a test flame (*Fire point is always higher than the flash point*).

* *2018 edition. Definitions shorten for brevity.*

NFPA Hazard Identification System

Fluorocarbons used for immersive cooling do not have a flash point or fire point and pose no combustion risk. Oils are combustible, with mineral and white oils having the lowest flash point of about 115ºC (239°F) and synthetic oils for immersion cooling range up to over 200ºC (392°F), with viscosities increasing for the higher flash points. These oils have fire and flash points well above the temperatures that are likely to be encountered from the immersive liquid-cooled ITE during normal operations and are technically classified as a combustible liquid, not flammable. Most synthetic oils have a NFPA hazard rating of 0-1-0 (as shown in **sidebar**). Blue with value 0 means there is no health hazard, and red with value 1 means that the flash point is above 93ºC (200°F) and yellow with value 0 means stable[4]. Engage with local inspectors and your insurance company when planning on large deployments of any dielectric fluid.

[1] 3M announced they would exit all PFAS manufacturing by the end of 2025.

[2] PFAS are a group of synthetic chemical compounds that are used widely in society. They are described as "forever chemicals", which are man-made organic compounds that have been used in consumer products since the 1940s. PFAS can be categorized into perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS), perfluorohexanesulfonic acid (PFHxS) and perfluorohexanoic acid (PFHxA).

[3] Published rules to report PFAS releases and released a framework to prevent unsafe new PFAS from entering the market.

[4] https://www.acs.org/content/acs/en/chemical-safety/basics/nfpa-hazard-identification.html

Environmental impact

Sustainability has become a top priority for most data center operators and understanding the environmental impact of dielectric fluids is important selection criteria. If these fluids were released into the environment, the main considerations are: Ozone Depletion Potential (ODP)[5], Global Warming Potential (GWP)[6], and contamination of soil and groundwater.

ODP and GWP: Both oils and fluorocarbon fluids have zero ODP. Oils have zero GWP while the fluorocarbon fluids have a GWP. Because of the stability of PFCs and PFPEs, they have a long life in the atmosphere and have GWPs values in the thousands. HFEs and FKs are engineered to have lower GWP values in the range of single digit (for FKs) to hundreds. Fluorocarbon liquids should always be used in sealed systems to ensure minimal release to the atmosphere. They should also be reclaimed at decommissioning and recycled or disposed following local environmental laws and regulations, stewardship obligations and guidelines in the product safety data sheets.

Contamination of soil and groundwater: Oils do not evaporate but can cause soil or groundwater contamination if released in large quantities. Most synthetic oils are classified as biodegradable, but spills should be contained and cleaned up.

IT maintenance and handling

Liquid cooling technologies require changes to operation procedures within a data center. The scope of changes depends on the adopted technologies. Data center operators continue to strive for workforce efficiency and maintaining ITE is an important part of that. Operation considerations vary based on fluid types and technologies.

For all immersive types, if the system is being run for maximum energy efficiency, the dielectric temperature can be 50-60ºC (122°F-140°F), which makes the ITE hot to touch. After powering off or removing the IT from the dielectric fluids, the system will cool to comfortable levels within minutes. For reference, the Occupational Safety and Health Administration (OSHA) defines touch safety below 60ºC (140°F). Nitrile gloves are recommended when maintaining fluid cleanliness and also for worker comfort. There are differences in oils and fluorocarbon fluids when maintaining ITE. Horizontal immersive cooling tubs require lifting equipment to safely remove heavy ITE vertically out of the tub while the chassis-based immersion systems can be racked out and put on a service cart, like heavy air-cooled ITE. Below are some of the main considerations.

Main considerations for oils

- Oils do not evaporate, so the ITE is typically serviced on a tray above the tank, or within the chassis for chassis-based immersive liquid cooling, allowing excess oil to drip back into the system.
- Tanks should be installed on catch bases or other containment to ensure any leaked fluid is captured.
- If more significant service needs to be done on a workbench, the servers from a tank system should be placed in a bin for transport, while the chassis-based immersive systems should have their fluid pumped out, and then moved.

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[5] Ozone Depletion Potential (ODP): European EA; US EPA

[6] Global Warming Potential (GWP): European EA; US EPA

- Components that need to be returned for repair or replacement should be cleaned and dried. System Suppliers usually recommend or provide cleaning agents to remove the oil residue.
- When packaging ITE systems for return, they should be sealed in large plastic bags.

Main considerations for fluorocarbons

- The ITE removed from the system dries quickly, which makes servicing similar to air-cooled systems.
- Since the fluid evaporates easily, systems should remain sealed and only opened for short periods of time to minimize losses. This is especially true for low boiling point fluids in two-phase systems.
- Charcoal filters should be maintained more frequently during initial operation, then less regularly.

Table 5 is a summary comparison between the five main attributes of dielectric fluids.

Table 5

A detailed summary comparison between five main attributes of dielectric fluids

Main attributes		Oils	Fluorocarbons
TCO		Low initial cost, and low operating cost due to a very low rate of evaporation. Life span can be 10-20 years, with low grade mineral oil on the low end and well-maintained synthetics on the high end.	Much higher initial cost, which can be five to ten times that of synthetic oils, and higher operating cost due to evaporation. Well maintained fluid can have a life span over 30 years.
Compatibility	Materials	Bad reputation from the early usage of mineral and white oils, but the new synthetic oils are highly refined and have improved material performance. PVC cables and thermal grease should be reviewed.	A very good material compatibility overall. Charcoal filters are recommended for removing hydrocarbon compounds.
	Technology	Fans are removed/disabled, and HDDs must be sealed, helium filled. SSDs have good campatibility. Sealed fiber optic connections are recommended.	Fans are removed/disabled, and HDDs must be sealed with helium filled. SSDs have good campatibility. QSFP connections might have signal degradation. Sealed fiber optic connections are recommended. Spreader plates are recommended to replace heat sink for two-phase.
Safety	Human	Little health risks from inhilation and contact during normal operation. Nitrile gloves are normally recommended when working with the fluids.	Some types of fluorocarbon fluids are categorized as per- and polyfluoroalkyl substances (PFAS), which might be harmful to humans and the environment.
	Flammability	All are combustible to some degree, but most hold an NFPA 0-1-0 classification and will not combust under normal conditions.	Fluorocarbons have no flash or fire point, making them immune to flammability issues.
Environmental impact		Zero ODP and zero GWP. Many fluids are bridgeable. Soil and groundwater contamination a concern if released in large quantities.	Zero ODP but GWP can a range from single digit (FKs) to thousands. PFCs and PFPEs have a long life in the atmosphere, contributing to their high GWP.
IT maintenance and handling		Messy since it is hard to clean and dry. Recommended to be installed on catch base or other containment to ensure any leaking oil is captured.	Clean as a result of the fluid drying quickly. Systems need to be well sealed and maintenance is minimized to prevent evaporation.

Conclusion

Selecting the right fluids for immersive liquid cooling is not straightforward and must be taken into context of the technologies and applications. Synthetic oils are cost effective and come with a good environmental profile, but their oily characteristic makes ITE maintenance and handling much different than traditional data centers. Fluorocarbon fluids come at a cost premium but have good material compatibility and ITE maintenance and handling is much like traditional data centers, since the fluid evaporates quickly. But fluorocarbon fluids have environmental profiles and are harmful to humans which might not align with company or regulation guidelines. The five key attributes of fluids including TCO, compatibility, safety, environmental impact, and IT maintenance and handling will help guide conversations with technology providers. Fluid manufactures are continuing research and development on improving the characteristics and cost of fluids, making this a dynamic technology area.

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- 3M Immersion Cooling
- Engineered Fluids
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- Iceotope
- MiVolt
- Open Compute Project (OCP) Immersion Cooling Sub-project
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