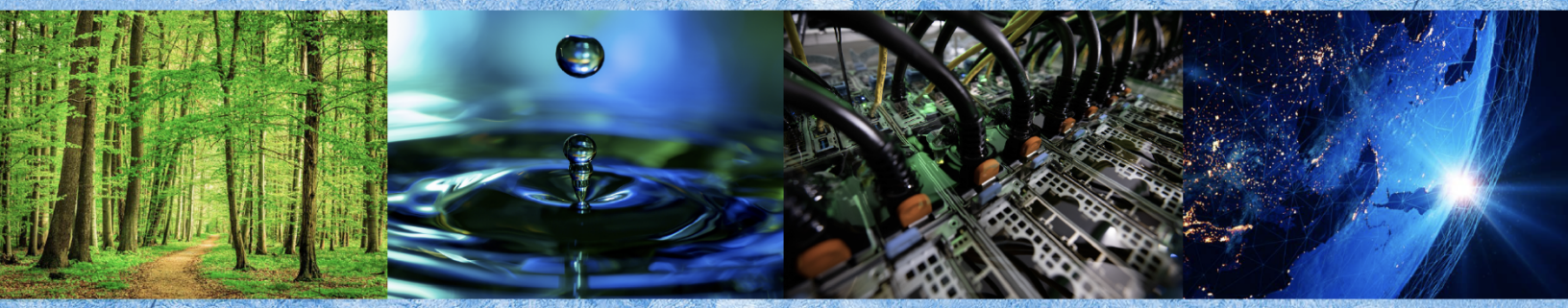
White Paper

Enhancing Data Center Performance

with Immersion Cooling and Precision-Engineered Fluids



GRC
THE IMMERSION COOLING AUTHORITY®

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White Paper

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Executive Summary

Immersion cooling has emerged as one of the most effective ways to efficiently address increasingly hot data centers, and selecting an optimal fluid is a key part of that solution. But when it comes to choosing the best fluid for any given operation, one size definitely does not fit all.

This paper discusses in detail the many important fluid selection criteria for immersion cooling deployments. It also presents valuable resources that can help IT professionals simplify the process and make the best decision to suit their operational goals and green initiatives.

Immersion Cooling: The Fluid Factor

Given the growing thermal challenges posed by advanced CPUs and GPUs, many experts agree that immersion cooling has become the superior solution for data centers worldwide.

An important component of this approach is the fluid itself. In fact, individual fluid properties can have a major impact on critical data center metrics such as performance, infrastructure integrity, and longevity, along with sustainability. As detailed in our white paper, The Future of Immersion Cooling, fluid optimization is a key success factor in the quest to utilize 1000W and higher chips.

However, data center operators should be aware that not all single-phase immersion cooling fluids are the same. Furthermore, fluid specifications can be confusing, making it hard to choose which is right for your equipment and operational goals.

A pioneer of single-phase immersion cooling since 2009, GRC and its staff of experts can help you sift through the details and find the best fluid for your application. We produced this paper to give you an understanding of fluid selection basics and set you on the right path for your decision-making process.

Through our ElectroSafe® Fluid Partner Program we rigorously vet and test fluids from many trusted vendors to give you confidence. This program is your assurance of quality, performance, reliability, and sustainability.

A Word About OCP Specifications

Many but not all of the fluid properties mentioned in this paper have corresponding Open Compute Project (OCP) specifications. The OCP is an organization that evaluates designs of data center products and publishes qualitative and quantitative standards. Their fluid specifications were developed in collaboration with industry experts both in and outside of the OCP.

Individual fluid properties have a major impact on critical data center metrics such as performance, infrastructure integrity and longevity, along with sustainability.

Minimum Critical Fluid Requirements

Certain fluid properties are critical to maintaining an optimal data center operating environment.

Fluid Thermo-Physical Thresholds

Flash Point
Flash point describes fluid flammability and the temperature beyond which combustion becomes likely in the presence of an ignition source. This standard is set by local and national regulators.

For example
- 150° C is a common requirement for North America and Europe
- There are other flash point specifications unique to specific regions

Observance of this threshold is critical to maintaining the safety of data center equipment and personnel.

Auto Ignition Temperature
If the fluid and air interface reach the auto ignition temperature defined by IEC 62368-1 at > 300° C, combustion could occur.

Pour Point
Because viscosity varies with temperature, fluids with warmer pour points may not be suitable for some environments due to heightened failure rates. Conversely, data centers in warmer climates may not be as restricted. The current OCP specification for pour point is ≤ -30° C.

Density/Viscosity
Where weight load is concerned, it should be noted that single-phase immersion cooling systems do not require raised floors. However, GRC systems can easily be installed on raised floors, making them an ideal solution for an HPC pod/hybrid data center deployment.

From a cost and weight perspective, racks should be designed to minimize fluid volume. As a criterion for data center floor loading, hydrocarbon-based fluids typically would not exceed 900 kg/m3, whereas fluorinated fluid density is roughly double, increasing the floor load. The reference temperature for density is 25° C.

Pump power is another reason to specify density. The denser the liquid, the harder the pump must work to move the fluid through the system.

Electrical Resistivity
To prevent damage to electrical components, fluid must not be electrically conductive. Electrical resistivity is defined by ASTM D1169 (Volume Resistivity/specific electrical resistance) and must be greater than 2.0 GΩm for virgin fluids and greater than 0.2 GΩ m throughout the life of a fluid.

Dielectric Strength
This describes the maximum electric field that a fluid can withstand without undergoing electrical breakdown and becoming electrically conductive. Recommended strength over fluid lifetime is > 6 kV/mm.

Saybolt Color (ASTM D1500 or D156)
Fresh immersion fluid should be less than or equal to a (1) on the ASTM D1500 standard and should be monitored for significant color changes over its service life. Note that fluid color can change due to degradation, or for more benign reasons.

Acid Number (ASTM D974)
Look for changes in chemical identity, primarily Total Acid Number (TAN), but also color and viscosity. OCP TAN spec is conservatively set at ≤ 0.01 mg KOH/g for hydrocarbon class fluids. Other fluid classes have higher or lower TAN requirements. Immersion adopters should monitor upcoming revisions of the OCP Base Specification for Immersion Fluids as there is movement within the OCP Community to realign TAN requirements to meet needs of IT Equipment instead of representations of various fluid base components.

Material Compatibility

Understanding whether and how a candidate fluid is compatible with exposed data center hardware is key to avoiding damage to or excessive wear on that material. It's also critical to maintaining system reliability.

Customarily, parts suppliers had been hesitant to warranty immersed components until more data were available. Today this has changed as many ITE providers, such as Dell Technologies, Supermicro, and Penguin Solutions are fully supporting immersion servers, and designing servers specifically for immersion. Even Intel has provided a warranty rider for customers wishing to immerse processors in immersion cooling systems.

Fluid Properties That Directly Impact Performance

These properties are generally recognized as driving data center performance.

Specific Heat
Higher specific heat values can help heat absorption and dissipation.

Thermal Conductivity
Higher thermal conductivity enhances heat transfer efficiency.

Coefficient of Thermal Expansion
A lower value suggests better volumetric stability, which is useful for wider operating ranges.

Viscosity/Density
See the previous section for details on these properties.

Figures of Merit (FOM) That Help Rank Fluids

Figures of Merit are values attributed to a device, system or method to measure its relative utility. Three FOM are particularly helpful in single-phase immersion fluid selection. As applied in this paper, FOM1 and FOM2 are experimental correlations based on natural and forced convection, respectively.

Natural Convection (FOM1)
FOM1 is a measure of fluid performance under natural convection and is an important aspect for determining fluid effectiveness. Based on FOM1, OCP ranks fluids into two categories: > 35 for Tier 1 and > 45 for Tier 2.

Forced Convection (FOM2)
FOM2 is based on forced convection and is independent of fluid viscosity. FOM2 for single-phase immersion liquids is > 19.

Viscosity (FOM3)
Viscosity heavily influences convective heat transfer.

Lower viscosity fluids

- Result in greater flow and are generally desirable
- Promote easier convective motion of fluid
- Are best for heatsinks with higher fin density thus offering more area for heat dissipation

Higher viscosity fluids

- Reduce the flow that develops through the heatsink
- Are best for heatsinks with fewer, thicker fins, thus reducing heat dissipation area

Note that pump specifications and viscosity at a lower temperature should be considered together to ensure pumps can work with higher viscosity liquids. An operating temperature lower limit of 0 °C is recommended to ensure pumps are capable of pushing coolant to the immersion system.

GRC's ElectroSafe Fluid Partner Program Testing Goes Above and Beyond

GRC believes fluid selection involves more than simple compatibility testing and consideration of thermophysical properties. Fluid degradation, safety, and sustainability should be factored in as well.

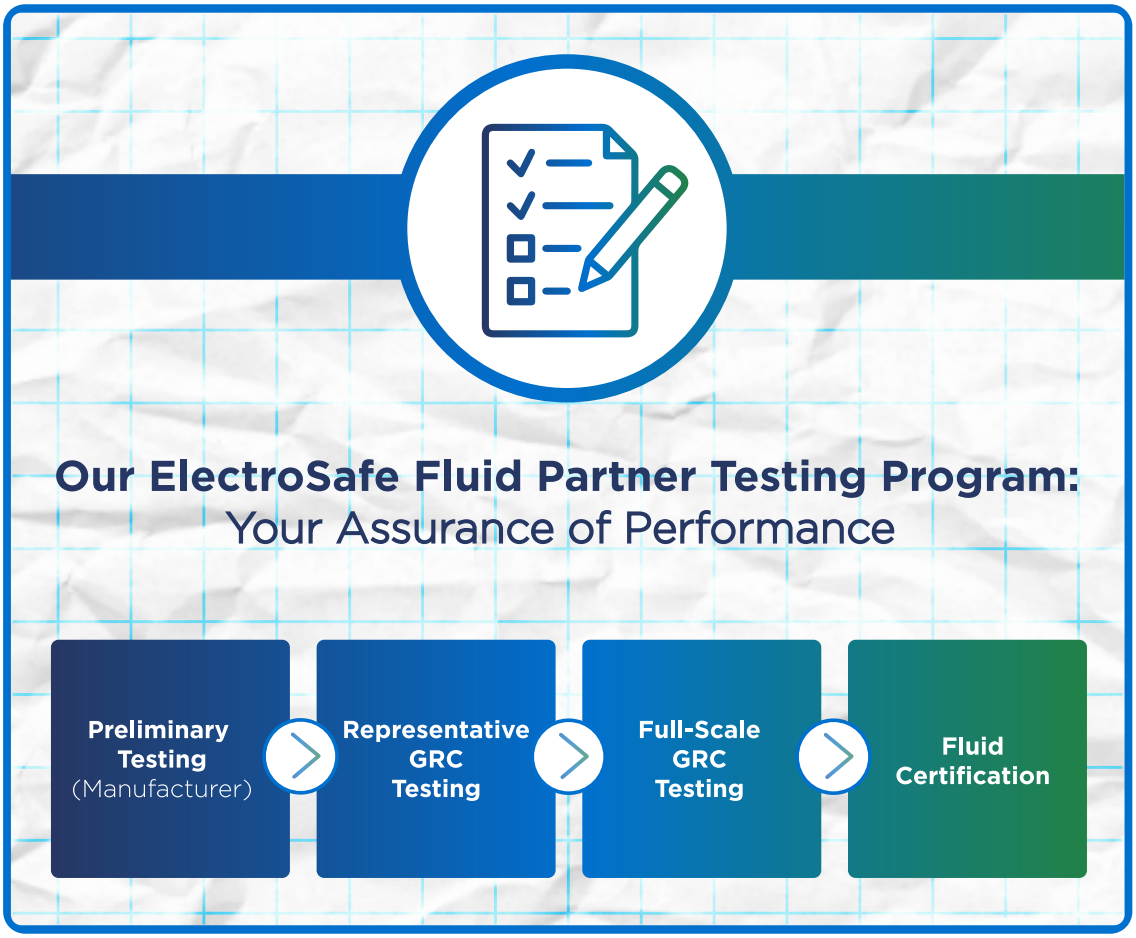
Preliminary Testing by the Manufacturer
Before their products can be accepted into our ElectroSafe Fluid Partner Program, we require manufacturers to conduct: a) detailed in-house compatibility testing according to OCP guidelines; and b) thorough in-house fluid degradation tests to certify that the following properties are above the NRTL and OCP recommended thresholds:

- Dielectric strength
- Resistivity
- Flash, fire, and auto-ignition points
- Acid number

Once they pass this test, we then carefully evaluate the candidate fluid in our labs.

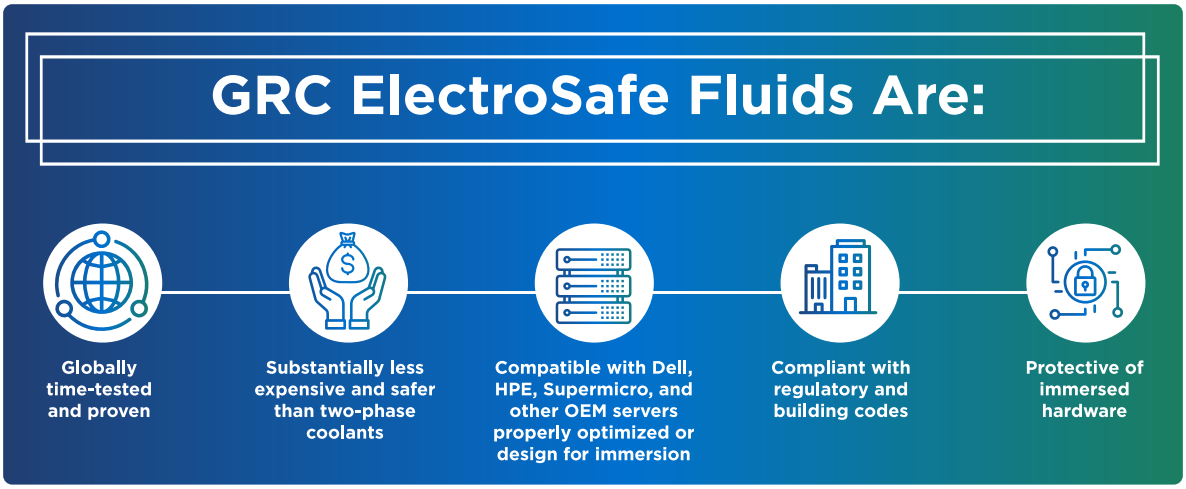
Representative GRC Testing
Before deploying the fluid in a GRC system, we conduct material compatibility tests at elevated temperatures for at least 14 days using IT modules and/or proxy materials. Fluid samples are collected before and after the test and are examined in a third-party lab for thermophysical properties.

Full-Scale GRC Testing
If a fluid passes representative testing, we deploy it in a GRC system and test it with servers for several weeks. We then send the fluid to a third-party lab to test changes over time in dielectric strength, D1, color, and acid number per ASTM standards. These tests help determine the fluid's potential lifespan according to its ability to resist degradation under normal operating conditions.



Next, thermal stability tests are done under higher-than-expected operating conditions to speed results and reveal the fluid's long-term performance potential. For safe and efficient operation, the fluid must retain thermophysical properties over time and temperature.

Given our experience and learnings gained through this stringent testing regimen, GRC makes these further recommendations to help you choose a single-phase immersion cooling fluid:



Sustainability
According to the OCP, sustainable immersion fluids should be formulated for a long operational lifetime and have the following properties:

- Conformance to safety and regulatory compliance
- Low Global Warming Potential (GWP)
- Zero Ozone Depletion Potential (ODP)
- Low toxicity and flammability
- Low equivalent values of carbon footprint “kg CO2-eq per liter” in a lifecycle analysis
- Readily biodegradable
- A defined End-of-Life (EOL) treatment

Health and Safety
Going beyond OCP and Intel guidelines, we recommend that fluid not have an associated inhalation hazard (LC50 < 5 mg/l) nor be released to air in any significant quantities under normal conditions of use.

Due to environmental and health concerns, fluorinated liquid coolants are facing increasing regulation; with major suppliers like 3M already exiting the market, it's crucial to assess future costs and fluid availability before adopting these cooling technologies.

Thermal Performance
The thermal performance of any given fluid depends on a variety of factors beyond its intrinsic characteristics. These include server and heat sink type, form factor, TDP, and flow pattern. In some cases, fluids with a higher FOM1 tend to work better, whereas in others, a higher FOM2 is beneficial.

Introducing ENEOS Single-Phase Immersion Cooling Fluids

A strategic supplier in GRC's ElectroSafe Fluid Partner Program, ENEOS offers a line of high-quality single-phase immersion cooling fluids designed to meet the energy economy, performance, sustainability and regulatory compliance demands placed on today's data centers. Like all offered by our program, ENEOS fluids are fully vetted and tested to meet or exceed our customers' expectations.

ENEOS Product Formulations

Green Fluid Formulation
Made from renewable sources, ENEOS's Green Fluid Formulation offers eco-friendliness, reduced emissions, effective lubrication, and efficient cooling to ensure optimal data center performance.

Features and Benefits

- ENEOS Carbon Neutral Immersion Fluid supports the mitigation of scope-3 emissions
- A low acid number maintains a stable acidity level over time and safeguards the long-term integrity, reliability, and sustainability of data center infrastructure
- A FOM1 Tier 1 specification adherence provides natural convection cooling

High Cooling Performance Fluid
By pushing the boundaries of heat dissipation, ENEOS's High Cooling Performance Fluid delivers not only superior efficiency but also longevity to handle increasing computational demands.

Features and Benefits

- Excellent thermal dissipation: attains or exceeds the under-development benchmarks of FOM1 Tier 2 (natural convection), establishing a new threshold for cooling efficiency
- In contrast to basic fluids, advanced thermal properties ensure enduring performance under varying temperature conditions
- Consistent heat management helps create a reliable and uniform cooling environment to promote long-term operational efficacy

Immersion J (Japan-Specific Fluid)
Tailored expressly for Japan's unique regulatory environment, this fluid offers not only unparalleled thermal stability but also compliance with the stringent standards of the region.

Features and Benefits

- With a flash point exceeding 250° C (482° F), this fluid surpasses the minimum legal requirements of Japan's regulations
- Compatibility with a diverse range of materials such as PBT, PA66, PCB FR4, stainless steel, nickel-plated stainless steel, and more
- Ensures reliable, long-lasting performance by mitigating acid-induced degradation

ENEOS Fluids Recommended Applications & OCP Specifications

Typical Properties[1]	Units	OCP Spec[2]	Immersion J	High Cooling Performance	GREEN Fluid
Targeted Application			Japan Market Requirements	Max Cooling Efficiency	Carbon Neutrality
Primary Fluid Features			High Flash Point	High FOM1 Low Viscosity	Sustainable Impact
Density	g/cm³ (15° C)	<2.000	0.837	0.809	0.819
Kinematic Viscosity	mm²/s (40°C)	-	34.8	9.19	19.8
Pour Point	°C	< - 30	-15	-35	-45
Flash Point	°C	> 150	254	196	248
Auto Ignition Temperature	°C	> 300	> 300	> 300	> 300
Acid Number	mgKOH/g	≦ 0.01	0.01	0.01	0.01
OCP FOM1 *(Natural Convection)*	(25°C)	> 35 (Tier 1) > 45 (Tier 2)	30.8 (-)	46.2 (Tier 2)	36.8 (Tier 1)
OCP FOM2 *(Forced Convection)*	(25°C)	> 19	34.8	33.5	34.6
Carbon Footprint		-	Normal	Normal	Excellent

1. These characteristics are representative of typical fluid and not presented as manufactured specifications
2. OCP Base Specification for Immersion Fluids, Revision 1.0, Version 1.0, December 01, 2022.

Immersion Cooling Fluid Selection — Simplified

Clearly, there's a lot to consider when choosing the right single-phase immersion cooling fluid for your data center. It's also easy to be intimidated by the many selection criteria and scientific standards.

Fortunately, you don't have to undertake the challenge alone. Instead, you can rely on GRC's immersion cooling expertise and our rigorous ElectroSafe Fluid Partner Program to guide you toward the best decisions to meet your operational goals and sustainability initiatives.

Learn more about GRC immersion cooling systems and ENEOS' ElectroSafe-certified fluids.

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