



OPEN
Compute Project



SERVER COMPONENT IMMERSION MATERIAL COMPATIBILITY TESTING

Version 1.5, June 2026

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Revision History

Date	Version #	Author(s)	Description
June 10, 2026	1.5	Brian Kinkade	Fix PDF links
June 4, 2026	1.5	Brian Kinkade	Must and shall removal
May 19, 2026	1.5	Brian Kinkade	Added Material to Title since there are IT design considerations not covered within.
April 10, 2026	1.5	Brian Kinkade	- Formatted to OCP whitepaper template. - Section 1.2 “Scope and Non-Requirements” were added. - Section on the compliance with Tenets was added. - Conclusion, Glossary and Definitions were added.

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1 Introduction

To support the wide-ranging application needs of the data center end users, server Original Equipment Manufacturers (OEMs) provide options for integrating a variety of individual components supplied by many different vendors. Each server component option may be composed of several different bulk materials such as plastics, elastomers, metals, adhesives, and inks.

Server components' safety and functional performance can become compromised from exposure to a dielectric immersion fluid due to the degradation of materials within the component. Additionally, server components can contaminate the immersion fluid without impacting the performance of the component being tested or the fluid performance properties. This contamination has the potential to adversely impact other server components through secondary reactions such as corrosion.

To address these risks the objective of this white paper is:

- To standardize the compatibility testing of functional server components to identify server component/base-fluid combinations where the safety and performance of the server component is not outside of vendor production acceptance specifications.
- To identify fluid contaminants extracted from server components during compatibility testing.

The content of this whitepaper describes the server component compatibility test flow, as shown in Figure 1.



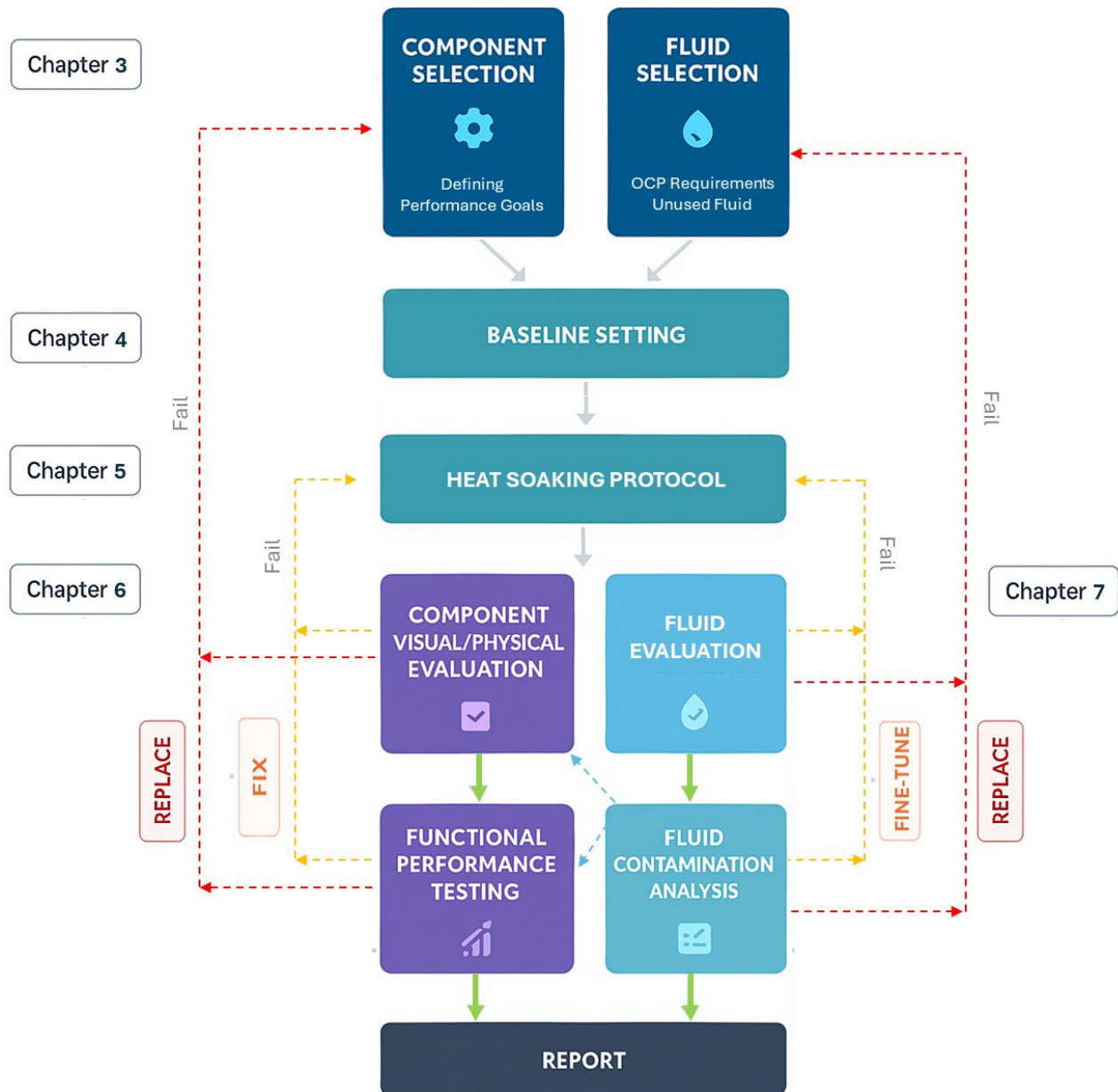


Figure 1. Server Component Compatibility Test Flow.

1.1 Related Documents & Workstreams

This white paper expands the guidance from [Material Compatibility in Immersion Cooling](#) and is intended to test functional server components composed of multiple bulk materials that will be integrated into a system before the system is tested for its thermochemical reliability. The guidance and methodologies for assessing the thermochemical reliability of the Information Technology (IT) hardware during its service lifetime is addressed in the [Thermochemical Reliability Workstream](#).

We also reference the minimum requirements for immersion cooling fluids as defined in the [Immersion Requirements Document V2.1](#).

1.2 Scope & Non-Requirements

This document provides guidance for conducting component (and associated material) compatibility evaluations in the context of immersion cooling environments. The intent of this document is to support consistent test structuring, reporting, and interpretation across the Open Compute Project (OCP) community.

This document does not define mandatory requirements, acceptance thresholds, certification criteria, or qualification procedures. Results generated using the guidance described herein should not be interpreted as certifying compatibility, guaranteeing fitness for use, or establishing service life. Material and component compatibility outcomes are dependent on the specific operating environment, exposure duration, and test conditions under which evaluations are performed.



2 Compliance with Open Compute Project Tenets

2.1 Openness

This whitepaper was written in a community workstream that invited all members of the immersion community to participate. The contributors were diverse and represented immersion community leaders, fluid vendors, server component suppliers, and even end users.

2.2 Efficiency

- This whitepaper expands upon the guidance provided in: [Material Compatibility in Immersion Cooling](#).
- Immersion cooling itself contributes to improved water efficiency, excellent power efficiency, while increasing compute capacity.

2.3 Impact

One challenge facing immersion cooling is the potential material compatibility impacts on the individual server components and the potential contamination of the immersion cooling fluid. This whitepaper outlines a simple approach to properly evaluate and mitigate these potential risks. It provides guidance for server component and fluid providers to feel comfortable that their products are compatible for immersion cooling of servers.

2.4 Scale

- Ease of implementation by server component OEMs was considered at every step of this document.
- The testing guidelines are designed to minimize testing expense and complexity where possible.

2.5 Sustainability

- Immersion cooling supports responsible use of energy and water, thereby minimizing environmental harm.
- This whitepaper helps to reduce the potential material compatibility and fluid contamination risks, thereby contributing to improved server reliability and longevity.



3 Component & Fluid Selection

The chapter aims to ensure full preparation before beginning the testing. This includes clearly defining the test objectives, completing a risk assessment on the component from potential material incompatibilities, and defining the success criteria of the testing.

The following topics will be discussed:

- The types of server components and their primary function.
- The types of base fluids and relevant immersion characteristics.
- How to set functional performance goals of both server components and fluids before and after the testing.

3.1 Server Components

Server components provide a variety of functions and, thus, have a variety of functional performance goals from simple (e.g., a label that needs to be easy-to-read and adhered to its related component) to complex (e.g., a GPU chip being able to provide a certain compute performance during operation).

Component categorization by criticality of function is essential for effective risk mitigation, asset management, and resource allocation. For the listed server components, the criticality of function is described in Table 1.

Testing should prioritize the following risk categories while considering both the likelihood of failure and the potential for gradual performance degradation over time

1. Safety-critical components
2. Regulatory compliance requirements
3. Capital Expenditures risks (cf. component failure)
4. Operational Expenditures risks (cf. hardware downtime)



Table 1. Non-exhaustive prioritized list of server components and failure risks.

Server Component	Potential Degradation Mechanisms	Potential Functional Criticality	Recommended Monitoring
Cable Assemblies	Stiffening and embrittlement of sheathing Cracking of insulation Change in dielectric insulation	Safety Power Signal Integrity	Mechanical dimensions Hardness Fluid contamination
Connectors, Sockets, Standoffs, Clips, Spacers	Risk related to changes in relative permittivity (Dk) of the fluid. Changes in dimensions from swelling hardening/cracking of clip/latch.	Safety Power Signal Integrity	Mechanical dimensions Softening/hardening Fluid contamination
Power Supply	Conformal coating (polymeric) Wire insulation materials	Power Safety	Fluid contamination
Electrolytic Capacitors, Coin cells	Seal material swelling (EPDM)	Safety Power	Visual
Thermal Interface Materials	High softening Crumbling Washing out Lower thermal performance	Performance	Visual & thermal performance
Microchips	Electrical/thermal degradation Packaging material compatibility	Performance	Visual and performance monitoring (electrical characteristics)
Relays	Risk related to changes in relative permittivity (Dk) of the fluid Unsealed relays response time change from fluid ingress	Signal Integrity	-
Printed Circuit Board Assembly, Motherboard	Risk related to changes in relative permittivity (Dk) of the fluid Copper corrosion Shorts	Signal Integrity	Fluid contamination
Optical Fiber Assemblies/Optical Transceiver Component	Stiffening of PVC (cracking) Changes in optical performance	Signal Integrity	Mechanical dimensions Hardness Fluid contamination
Solder	Halides leading to electrolytic metal halides with metal exposure.	1P: low risk 2P: high risk	Halides ppm concentration
Tape/Labels Adhesives	Higher with single-phase fluids	Lower	Clogging of flow channels
Labels Inks	Higher with single-phase fluids	Lower unless critical for regulatory purposes	Discoloration of fluid, contamination
Heatsink	Low temperature solder incompatibility Surface coatings	Low	Fluid Contamination
EMI Foams /Gaskets	Changes in dimensions Hardness	Low	Mechanical dimensions Hardness
Chassis/Fixtures	-	Low	-
Electrical Components	Low	-	-



3.2 Immersion Fluids

Multiple fluid chemistries are appropriate for use in immersion cooling applications. The different categories, descriptions and requirements recognized by the OCP Immersion community, are detailed in: [Immersion Requirements Document V2.1](#).

Useful material compatibility data per fluid category can be found in: [Material Compatibility in Immersion Cooling](#).



4 Baseline Setting

4.1 Server Component Considerations

To increase the probability of success, it is recommended to:

- Confirm that the server component is composed of bulk materials are compatible with the selected base chemistry as outlined in Appendix of [Material Compatibility in Immersion Cooling](#).
- Confirm that all the materials of the server component can withstand the planned heat soak temperature.

Before Soak

Before soaking these server components, it is important to determine the post-soak functional performance goals in consultation with the server and/or component vendor. In that respect, document the baseline functional performance of the server components before soaking in the fluid. These values are defined as component performance metrics “ t_0 , x ”.

- If the server component has been designed for “dry in air” and getting tested for “immersed” performance, then it is acceptable to set the air-cooled production quality acceptance criteria: “ t_0 , *air*” .
- If the server component has been designed/optimized to work “immersed” , it is recommended that the baseline functional component test should be done “wet in air” or “immersed” and should be noted “ t_0 , *wet in air*” or “ t_0 , *immersed*” , respectively.

It is recommended to store - at least - one pristine component as a control sample.

Component Baseline

To be able to detect changes to the component based on the soak, you will need to have data on three different types of component samples:



1. “Component Control”: not heated or soaked
2. “Reference Component”: heated but not immersed
3. “Component Soaked”: heated and immersed in fluid

Detailed procedural guidelines can be found in Chapter 5.

4.2 Immersion Fluid

Before Soak (“ t_0 ”)

The relevant fluid properties can be found in the Technical Data Sheet provided by the fluid vendor. The selected dielectric immersion fluid should meet the minimum unused requirements as outlined in the [Immersion Requirements Document V2.1](#).

It is recommended to retain 1.0L of unused fluid heated but not exposed to the component for testing to understand the changes to the fluid after being heated but not exposed to the server component during the soak procedure with the server component samples. This fluid control sample should be stored in a closed recipient made of inert material such as glass or stainless steel. The recipient should be stored at room temperature in a clean and aerated place.

Fluid Baseline

To be able to detect changes to the fluid that are based on the component soak process, you will need to have data on three different types of fluid samples:

1. “As-Received Fluid”: unheated, without exposure to component.
2. “Fluid Control”: fluid heated to soak temperature without the component.
3. “Component Soaked Sample”: fluid after component samples were soaked.

Detailed procedural guidelines can be found in Chapter 5.



5 Heat Soak Protocols

5.1 Aim

The protocol described in this chapter is focused on elucidating material incompatibility phenomena to assess potential component degradation and/or fluid failures as a thermochemical quality risk assessment. This protocol is not meant for server reliability assessment that will reside in the whitepaper from the [Thermochemical Reliability Workstream](#).

5.2 Baseline

To understand potential degradation mechanisms that result from interactions between the component and the immersion fluid it is essential to understand any failure mechanisms that result from degradation due to heat and/or oxidation in air. If this data is available from high temperature reliability testing of the component, it can be leveraged as the air baseline.

The test results from the component and fluid baseline testing (as described in Chapter 3) should be compared against the results from the corresponding component soak testing process. Any failure mechanisms that are observed as a result of the immersion soak testing process described below but are not observed from the high temperature air baseline test should be investigated as potential component material incompatibility risks.

It is highly recommended to perform multiple samples to report the standard deviation of any observed component degradation.

5.3 Single-Phase Immersion Fluids

You should document the following characteristics of the heat soak process so that the test can be repeated if needed:

1. Heat soak temperature
2. Heat soak duration
3. Fluid mass/volume
4. Sample mass



5. Soaking vessel type
6. Visual appearance: ideally photograph of component before soaking

The following conditions are recommended for single-phase fluid testing:

- Heat soak temperature: $80^{\circ}\text{C} \pm 2^{\circ}\text{C}$.
- Heat soak duration: 14 days.
- Fluid mass/volume:
 - Minimum set by FMEA fluid testing requirements: approximately 0.8L.
 - The sample should be fully immersed, but with just enough fluid to cover the sample.
 - Multiple components can be soaked if additional fluid volume is needed.
- Component sample mass: measured before and after the soak to detect fluid absorbed.
- Closed soaking vessel: inert material (glass, stainless steel), dimensions.
- Pictures, taken before and after the soak.

Sample(s) should be fully immersed with just enough fluid to cover the sample. Sample(s) that have density lower than the fluid can be weighed down with inert materials (glass or stainless steel).

Note that reporting out the sample to fluid mass ratio is important for comparing results.

5.4 Two-Phase Immersion Fluids

For testing small server components, Soxhlet extraction (based on reflux-condensation-siphoning loop) or testing under boiling conditions is recommended. For testing larger server components, using a two-phase immersion tank or similar setup equipped with heaters to maintain the fluid at the boiling point are recommended.



You should document the following characteristics of the heat soak process so that the test can be repeated if needed:

- Test configuration
 - Soxhlet
 - 2-Phase immersion tank
- Heat soak duration
 - OCP fluid guidelines stipulate running Soxhlet testing continuously for 48 hours, but tests can be prolonged, up to 7 days.
 - For longer tests, ensure the chiller setting is cold enough on the condenser to sufficiently condense the fluid, as well as that the fluid heater setting is not too high above the boiling point to minimize fluid loss.
- Sample to fluid mass ratio:
 - Not applicable for Soxhlet due to exposure of the component to freshly distilled fluid only.
 - 1% maximum recommended for 2-Phase immersion tank testing.
- Component sample mass: measured before and after the soak.
- Pictures, taken before and after the soak.



6 Component Testing

Server component testing can involve a variety of functional tests depending on the functional performance goals and potential thermochemical failure modes of the components. Nonetheless, all server components should first go through a visual and physical inspection before functional testing.

6.1 Visual Inspection

The component is removed from the immersion fluid. After draining, a low-pressure air stream can be used in a containment box to remove oil.

Visual inspection is completed before using absorbent, fibreless wipe or solvent to remove residual fluid. Solvent removal should be pre-tested on pristine material to ensure any impact on observations or measurements are noted, including removal of surface or change of appearance. Please refer to the [Immersion Fluids Cleaning workstream](#) and whitepaper for more information.

The ideal visual inspection would include a “Before” and “After” picture using the same camera and sample positioning with an integrated scale bar; with the sample only cleaned with fibreless wipe to remove residual fluid. Lighting should not be affected by changes in daylight or office lighting. With this level of detail, image analysis might detect changes barely seen by the human eye. Attention should be paid to changes in material color, cable routing, unshielded (damaged) cables, capillary action (interior cable), material rigidity (stiffness), kinking of hoses/cables, displacement of components/assemblies, loss of component marking/labels and corrosion signs. If any irregularities are observed, detailed high-resolution pictures should be taken.

6.2 Physical Inspection

The physical characteristics of material before and after the test should be recorded as follows:

- Weight changes (%)
- Volume changes (%)
 - Define shrinkage (negative value) or swelling (positive value)
- Dimensional changes (%): length, width, height, diameter



- Hardness changes (Shore Hardness scale point change) or any other relevant mechanical properties

All parameters should be measured by the appropriate scale that covers the range of the measurement.

6.3 Component Functional Testing

Functional testing relies on the component production specifications and/or capabilities and potential thermochemical failure modes. Guidance should be provided by the component vendor and should be in line with the baseline testing described in Chapter 3. Such an approach should allow an unambiguous component performance evaluation.

Each component follows an industry-specified design qualification testing process, which is typically complex, as well as a simplified process for production quality testing. If production quality testing is expected to identify issues related to material compatibility, this level of testing is considered acceptable. However, if the supplier prefers not to disclose their production quality test methods, relying on a set of industry accepted test procedures is also sufficient.

It is important to document the test procedure(s) used for functional testing to support repeatability and reproducibility by others, as well as, for testing across multiple base fluids.

6.4 Component Failure Root Cause Analysis

If the component fails performance testing or visual/physical inspection, attempt to identify the specific sub-component or material responsible for the failure. Seek guidance from your component vendor and, if necessary, engage a third-party root cause analysis laboratory. Additionally, the analytical techniques in “*Chapter 6, Table 3*” are recommended to assess whether fluid contamination may have contributed to the issue or provide additional data to understand the root cause of the component degradation.



7 Fluid Analysis

This Chapter aims at the following objectives for fluid analysis after the heat soak:

- Identifying fluid contamination that might affect other server components.
- Diagnosing the cause of server component compatibility failures based on the fluid contamination levels.
- Identifying the impact of contamination on the fluid performance.

The proposed methodology for fluid analysis is shown in Figure 2.

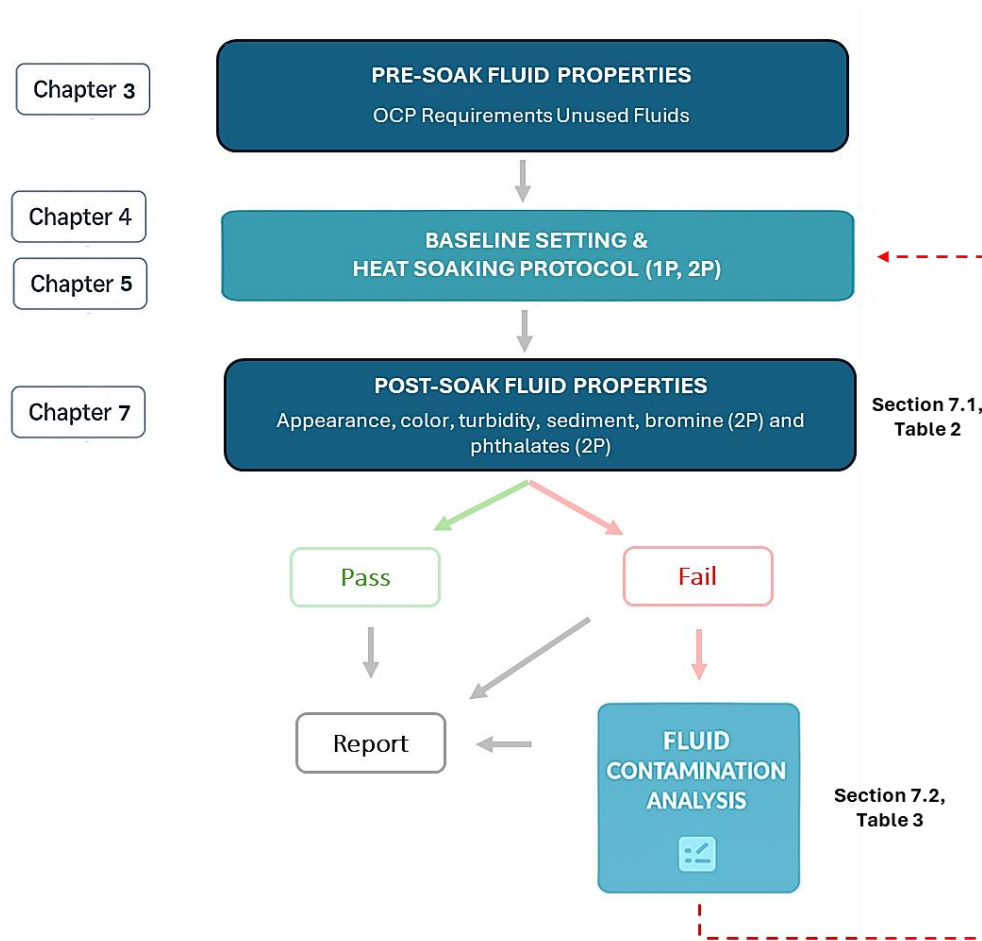


Figure 2. Proposed Fluid Analysis Workflow.



7.1 Fluid Requirements

You should record at least the following primary properties of the pre-soak versus post-soak immersion fluid: (1) appearance, (2) color, (3) haze and (4) sediment.

- Appearance
 - A general visual assessment of the fluid.
- Color
 - The observed shade of the fluid, assessed against a standardized color scale.
- Turbidity
 - A measure of the cloudiness of the fluid.
- Sediment
 - Solid particles that have settled out of the fluid and are visible at the bottom of a container.

For two-phase fluids, the content of bromine and phthalates should be quantified as well. For each of the properties listed, the recommended standard methods are given in Table 2.

Table 2. List of proposed fluid property methods that are simple and non-specific for detecting potential contamination.

Property	Unit	Method	Condition	Fluid	Notes
Appearance		ASTM D1524	Visual	1P, 2P	
Color		ASTM 156 ISO 221	Visual	1P, 2P	NOTE: Color change may also be due to antioxidant additive functioning as expected
Turbidity		ASTM D4176	Visual	1P, 2P	
Sediment		IEC 60422 AHRI 700	Visual	1P, 2P	
Bromine	ppm		ICP-OES/MS	2P	
Phthalates	ppm		LC-MS/GC-MS	2P	



Additionally, the post soak immersion fluid should meet the minimum requirements as outlined in [Immersion Requirements Document V2.1](#). Any change should be noted and considered when evaluating/selecting server components for immersion.

If the characteristics of the post-soak immersion fluid remain unchanged, or if changes occur but still comply with OCP requirements, the fluid can be approved for this specific component (pass). Conversely, if the fluid properties fail to meet OCP requirements, the fluid is deemed incompatible with the tested component(fail).

In cases where fluid properties change significantly, it is recommended to apply more specialized analytical methods to determine the origin of these changes (see Section 7.2).

7.2 Fluid Contamination Analysis

Because fluid contamination from individual components can potentially impact the thermochemical reliability of a full immersion solution due to secondary reactions with other components in the system, a comprehensive report of all detected contaminants should be prepared.

The report should include the contaminant type, the standard method used, and quantitative data (such as the contamination level). It is strongly recommended to consult the fluid vendor for guidance and validation in the identification and characterization of contaminants.

For the sake of completeness, Table 3 provides a non-exhaustive list of how to identify various contaminants.



Table 3. Non-exhaustive list of potential contaminants along with recommended test methods.

Fluid Contaminants	Methods	Comments
Sulfur	- ASTM D5453 - ASTM D4294 /D2622	May trigger metal corrosion.
Halides	- ASTM D5808 - ASTM D7359	May form metal halides. Electrodeposition.
Solder flux residue	- ASTM D974 - Ion chromatography (weak organic acids) - ASTM D2989 (2P)	- Cosmetic appearance - May cause lowered dielectric properties.
Metal ions	- ICP-OES - ICP-MS	May cause lowered dielectric properties.
Plasticizers	- LC-MS - GC-MS (*)	(*) GC-MS may be less appropriate to detect plasticizers given their very high boiling points.
Particles	ISO 4406	May cause short circuits upon functioning.
Dyes/Adhesives	- GC-MS - LC-MS	Losing labels. May cause color changes.
Water	- ASTM D1533 - IEC 60814 - AHRI 700 (2P)	May cause lowered dielectric properties.
Organic Acids	- GC-MS - ASTM D3327 - ASTM D5827 or AHRI 700 (2P)	- May trigger metal corrosion. - May explain the increased total acid number.
Conformal Coating	- ASTM 156 ISO 2211 (color) - GC-MS - LC-MS	Reduced adhesion of conformal coating
Polydimethylsiloxane (PDMS)	- ASTM D7889 - LC-MS	-

For guidance on the most appropriate analytical techniques to detect molecular-level fluid degradation, consult your fluid supplier.



8 Component Performance Test Examples

What follows is our documentation of component testing plans developed within this workstream. Plans are to continue to add to these examples to help the industry develop a knowledgebase of recommended component testing procedures.

8.1 Cable and Connector Assemblies

Connectors and electrical components have the same quality acceptance test as baseline based on end user criteria. It is important to characterize the component as either “wet in air” or “Immersed”. Document and use the approach that is most applicable to the component.

Cables:

- Acceptable flex, twist, pull: BS EN 50525-2-21
- Capillarity testing
- Electrical performance: UL 60320/IEC 60320

Connectors:

- Mate/UnMate and Mechanical Forces
- Connectors and electronic components can rely on the EIA, Telcordia, and UL standards for pre and post evaluation. Such as millivolt readings or other product specific requirements. (UL486A, EIA-364-1000, GR-1217-CORE as examples)
 - LLCR (Low Level Contact Resistance)
 - DWV (Dielectric Withstand Voltage)
 - Applied Current T-Rise
 - Signal Integrity Performance
 - Inductance
 - Capacitance



- Characteristic impedance
- Crosstalk, near end and far end
- Propagation delay
- Skew between pins of differing path length within the connector
- Insertion loss
- Return loss
- Other electrical performance parameters may also be required

8.2 Optical Transceiver Components

For the optical transceiver connector components (single or multi-mode optics), one can do the evaluation on optical SI analysis (such as BERT, eye diagram analysis) for pre and post condition, to determine if there is a fluid migration into the optical connectors and cause signal drops or instability in signal transmission.



9 Conclusion

This white paper addresses a central challenge in the adoption of immersion cooling for data center hardware: the need to systematically understand and manage component and associated material compatibility across a diverse and evolving hardware ecosystem. As server architectures incorporate increasing material diversity and operate under more demanding thermal and electrical conditions, uncontrolled material-fluid interactions represent a potential risk to both component functionality and fluid integrity.

To address this challenge, the document consolidates community knowledge and establishes a structured, repeatable framework for evaluating component compatibility in immersion cooling environments. Key inputs include component criticality assessments, baseline characterization of components and fluids, and controlled heat soak testing under defined operating conditions. These inputs are coupled with standardized inspection methods and fluid analysis techniques to identify component/material degradation mechanisms, fluid contamination pathways, and secondary interaction risks. The resulting outputs provide consistent, comparable data that can be used to inform component selection, risk prioritization, and system-level decision making without prescribing qualification thresholds or certification outcomes.

The guidance presented herein reflects the current state of industry understanding while remaining intentionally non-normative, enabling broad applicability across different hardware designs, fluid chemistries, and deployment scenarios. As immersion cooling continues to scale into new compute classes and longer service lifetimes, the methodologies described in this document establish a foundation for ongoing data generation, cross-vendor collaboration, and refinement of best practices. Future work within the OCP community is expected to build on this foundation by expanding component coverage, incorporating field-return insights, and further strengthening the linkage between component compatibility data and long-term system reliability.



10 Glossary

The OCP Immersion Project maintains a consistent set of terms across the Immersion project documentation set. The most recent definitions can be found in this [harmonized glossary](#).

Below are document specific terms not defined in the harmonized glossary.

Acceptance Criteria

Predefined conditions under which a material or component is considered compatible.

Chemical Interaction

Any chemical reaction or physical change resulting from contact between a cooling fluid and a material.

Compatibility Limitation

A documented boundary or condition under which compatibility is not claimed.

Degradation

A change in material properties resulting in reduced performance relative to initial condition.

Discoloration

A visible change in material color resulting from fluid exposure.

Embrittlement

A reduction in material ductility or toughness resulting from environmental exposure.

Exposure Duration

The cumulative length of time a material or component is in contact with a cooling fluid under defined conditions.

Extraction

The removal of constituents from a material due to contact with a fluid.



Fluid Additive

A chemical constituent intentionally included in a fluid formulation to modify its performance characteristics.

Mass Change

A measurable increase or decrease in material mass after fluid exposure.

Operating Environment (Compatibility Context)

The defined set of temperature, pressure, electrical, and atmospheric conditions under which material compatibility is evaluated.

Swelling

An increase in material volume resulting from absorption of a fluid.

Test Coupon

A standardized sample of material used for compatibility testing.

Wetted Component

Any component or material surface that is in direct contact with the cooling fluid during normal operation.



11 References

The Immersion sub-project enables community driven activities focused on facilitating OCP and industry progression of immersion cooling. Within the Cooling Environments (CE) group, this project also facilitates harmonization among other sub-projects and various other industry platforms.

Relevant information on the Immersion sub-project and associated workstreams can be found here: [Cooling Environments/Immersion - OpenCompute](#).



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13 About Open Compute Foundation

The Open Compute Project (OCP) brings at-scale innovations and hyperscaler best practices to all, spanning technology domains from the data center to the edge, and the technology stack from silicon, to systems, to site facilities and services. The international OCP Community is made up of organizations and people from hyperscale and Tier-2 cloud data center operators, communications providers, colocation providers, diverse enterprises, and technology vendors. The OCP Foundation fosters collaboration within the Community to tackle market challenges in an array of OCP Projects that create open contributions such as specifications, designs, and more. The OCP Solution Provider Program then recognizes the application of those contributions in compliant products, solutions, and data center facilities and services with designations like OCP Inspired, OCP Accepted and OCP Ready. With the tenets of openness, impact, efficiency, scale and sustainability, the OCP engages and educates thousands of engineers every year through many events and webinars. Across many initiatives the OCP Foundation and Community are meeting the market today and shaping the future.

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