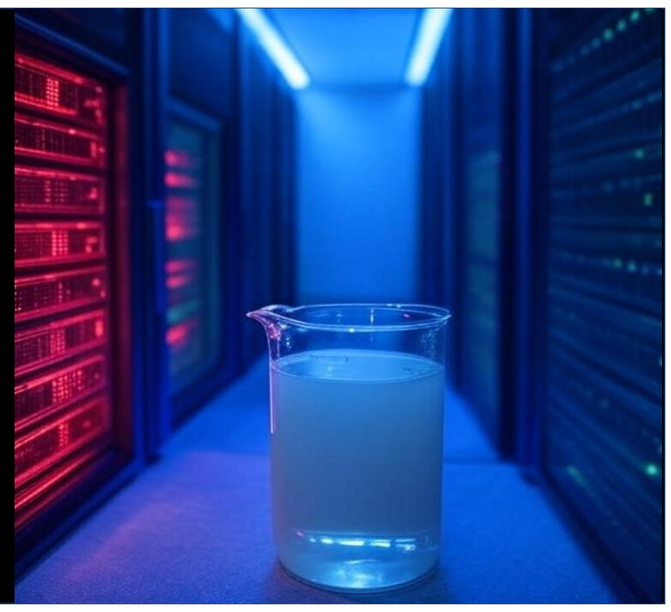
Nano-dielectric oils for Immersion cooled Data centers



Author: Sana Fateh (s.fateh@synano.eu)
Synano B.V., Delft, The Netherlands

Introduction

Increasing demand for high capacity due to AI and HPC workloads

Less space for hyperscale DC → Increasing rental costs

Emergence of Immersion cooled DC

High power density DC = more capacity in less space

Limitations of immersion cooling:

- ❑ Dielectric oils form the major thermal resistance
- ❑ Low thermal conductivity and Specific heat capacity
- ❑ Trade-off between viscosity and flash point (performance vs safety)
- ❑ Current oils already reaching capacity with high power GPU/CPU

Mitigation:

- ❑ Fewer servers per rack
- ❑ Adopt Nano-oils for increased heat transfer

Advanced Nano-Oil Solution

Synano has developed highly stable nano-additive suspensions to enhance the thermal performance of the conventional immersion oils by upto 20%. Nano-additives are suspensions of nanoparticles (metal, metal oxide, graphene) in oil-based liquids, added to immersion oils in certain ratios to improve thermal and physical properties of the base oil.

Unique chemical formulations customized for different base oils → Highly stable suspensions. No agglomeration of nanoparticles. → HTC boosted by up to 20%, due to enhanced thermal conductivity, micro convection and low viscosity → Enhanced breakdown voltage and higher flash point. Increased safety.

Performance improvement by Nano-additives

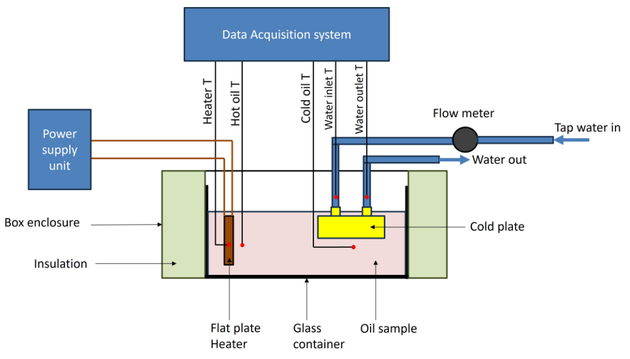
Enhancement in Thermal and physical properties of mineral and PAO-2 based oils after adding nano-additives are as shown below in the table.

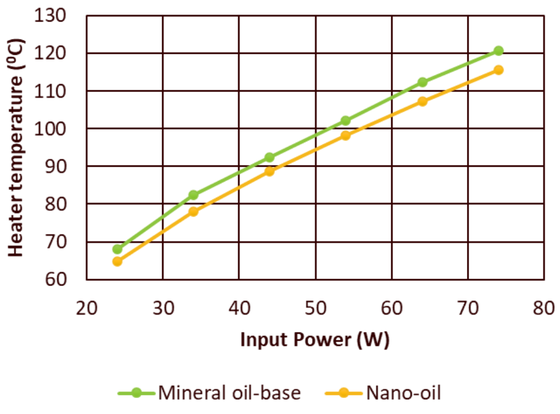
Property (unit)	Mineral oil + Nano additives	PAO-2 + Nano additives
Thermal conductivity (W/mK) @40^{0}C	12% increase	8% increase
Kinematic Viscosity (cSt) @40^{0}C	23% reduction	Same as base
Density (g/cm^3) @40^{0}C	0.5% increase	1.5% increase
Specific heat capacity (J/kgK) @40^{0}C	3.3% increase	1% increase
Breakdown Voltage (KV)	2X higher	50% higher
Flash point (^{0}C)	180^{0}C	170^{0}C
Dielectric constant	2.1	2.12
FOM Values		
FOM-1 (Natural convection)	25% higher	6% higher
FOM-2 (Forced convection)	9% higher	5% higher
FOM-3 (Pump power)	25% decrease	0.5% decrease

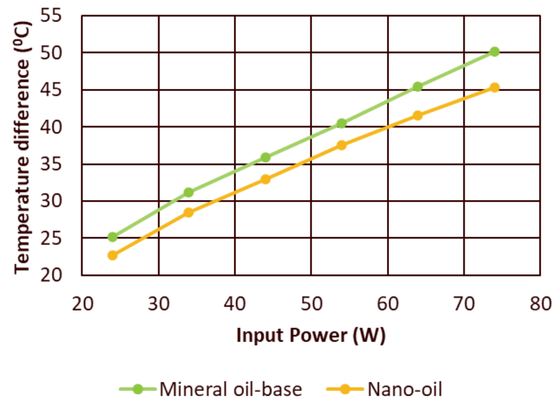
Experimental Validation

A natural convection test was conducted to compare conventional mineral and Nano-oils:

- ❑ Heater temperature reduced by **5°C** at 74W power for Nano-oil compared to pure mineral oil.
- ❑ **5°C reduction in temperature difference between heater and oil**, demonstrating reduced thermal resistance.







Impact & Benefits

A 20% increase in Heat transfer coefficient results into:

- ✓ **20% higher power density** in same area footprint
- ✓ **Increased Revenue** for Data center owners
- ✓ **Reduced CAPEX/OPEX** - plug-and-play solution without hardware change
- ✓ **Improved sustainability** - aligns with EU 2030 targets - 55% GHG reduction
- ✓ **Enhanced reliability** - lower failure risks
- ✓ **Heat reuse potential** - higher outlet temperatures

Challenges

- Long-term performance
- Electromagnetic interference and signal integrity effect
- Material compatibility
- Market acceptance

Next steps

- Accelerated aging tests and chemical stability assessments
- Collaborative projects within OCP to test electric and thermal performance
- OCP-led standards and guidelines to provide benchmark for material selection to minimize risks

References

[1] "Global Data Center Trends 2024," www.cbre.co.uk, Jun. 24, 2024. Available: https://www.cbre.co.uk/insights/reports/global-data-center-trends-2024. [Accessed: 2025-02-11].
[2] Amin, Danial, et al. "Recent progress and challenges in transformer oil nanofluid development: A review on thermal and electrical properties."IEEE Access 7 (2019): 151422-151438.
[3] Huang, Zhengyong, et al. "Electrical and thermal properties of insulating oil-based nanofluids: a comprehensive overview." IET Nanodielectrics 2.1 (2019): 27-40.
[4] Ahmad, Furkan, et al. "State-of-art in nano-based dielectric oil: A review." IEEE Access 7 (2019): 13396-13410.
[5] Ahuja, Sandeep et. al. "OCP Base Specification for Immersion Fluids"- Revision 1.0, Version 1.0., 2022.