Single-Phase Liquid Immersion Cooling
Marine and Off-shore Applications

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What is SLIC for Electronics Cooling

SLIC : Single-phase, Liquid Immersion Cooling

The full immersion of electrical devices directly into single-phase dielectric heat transfer fluid that is either passively circulated by the natural convection of the heated coolant or actively circulated by pumping the dielectric coolant through and around the electrical device being cooled.

Single-phase

- A single-phase coolant does not boil or undergo a phase change at anytime during the cooling process. This eliminates all pressure, fumes, vapors, and corrosion due to micro-cavitation created by a coolant's state transition from liquid to gas.

Liquid

- The coolant is a Newtonian fluid and can be circulated and transported within the system at very low pressure and low flow rates using standard inexpensive hoses, pipes, pumps, and cooled with radiators, dry coolers, or heat exchangers.

Immersion

- Direct immersion of electronics in a non-electrically conductive (dielectric) engineered coolant such that no protective cover, enclosure, coatings, or other means of insulation is required to be applied to the electrical circuits, chips, or device.

Cooling

- The removal of thermal energy from a device through absorption by a dielectric coolant and transfer to a heat rejection device or heat reuse appliance through the circulation of the coolant without the use of compressors or phase change.

SLIC is simply the most efficient and cost-effective means to cool all high-power electronics.

About Engineered Fluids

Specialized developer of Single-phase Liquid Immersion Cooling Solutions

High-Performance Biodegradable, Non-Toxic, Non-Corrosive Dielectric Coolants

BitCool®- Dielectric Immersion Coolants designed specifically for ASIC based miners

- Supports all ASIC Crypto-mining devices

ElectroCool®- Dielectric Immersion Coolants for Semiconductors and Servers

- Server / CPU / GPU / SSD / DRAM
- Lasers / LEDs / RF Amplifiers / Tubes / Processors / RADAR
- Battery / Fuel Cell cooling for Power Generation (Solar / Wind / Conventional) in stationary electrical storage applications

AmpCool®- Dielectric Immersion Coolants for Batteries, Electric Motors and Hydraulics

- Electric motors & motor controllers
- Hydraulic power transmission and actuator systems
- Battery and Fuel Cell cooling in hybrid and electric vehicles

SubmergeDeep® - Dielectric Pressure Compensation Fluids and Coolants for Subsea Applications

- Remote Operated Vehicles, Submarine Cables, Subsea Oil and Gas Downhole rigging
- Battery, chargers, electric motor, LED lighting, and hydraulic manipulators.

Products for protecting and cleaning electronic equipment during and after immersion

VoltCool® Additives - Highly Concentrated Transformer Oil Protection

- Power & Distribution Transformers, Switch Gear, AC & DC feeder lines
- Anti-oxidation and Corrosive Sulfur Stop Additives for use with hydrocarbon transformer oils

Dielectric Solvents – Safe and Effective Removal of Dielectric Fluids and Mineral Oils

- Fully dielectric solvents for use with all electronics and immersion cooling systems

ElectroCool® Dielectric Coolants

High Performance Coolants designed for efficient cooling of electrical devices

Industries & Applications for Dielectric Coolants:

Aerospace

- Aeronautic and space instrumentation and radar cooling

Automotive & Marine

- Electric motors & EM controller cooling & lubrication
- Battery charger / invertor / shore power & battery cooling
- Kinetic Energy Recovery Systems (KERS) cooling and hydrostatic energy transfer
- Undersea pressure compensation and lubrication for submersibles

Power and Transmission Engineering

- Transformer Cooling

Semiconductor & Communications

- Electronics Immersion Cooling - CPU / GPU / FPGA / SSD and servers
- Amplifiers, Power Vacuum Tubes, & RF Transmitter cooling
- Optical & Laser Diodes cooling

Marine & Off-Shore Applications

The Marine and Off-Shore Applications of SLIC

The marine environment is harsh and SLIC is the answer to reliability

Marine Vessels

- Shore Power Systems
- Marine Battery / Chargers / Invertors
- Marine Electronics, Servers & Accessories
- Satellite Communications

Port Applications

- Shore Power Pedestals
- Power Chargers for hybrid / all electric ship batteries (ferries, near shore cargo)

Off-Shore Applications

- Oil & Gas Off-Shore Rigs – Servers and control systems
- Battery Power Systems

Key SLIC Advantages for Marine Applications

1. *Footprint – SLIC reduces the total compute onboard footprint by 70%*
2. *Power Utilization – PUE of <1.03 vs >3.00 for similar density*
3. *Compute Density – up to 200kW per 2sq/meter*
4. *System Reliability – >3x improvement in Mean Time Between Failures*
5. *Reduced Maintenance – No fans, no compressors, no filters, no A/C, no dehumidifiers*
6. *Increased Fire Safety – Dielectric Coolant protects batteries and equipment from shorts*
7. *COTS Electronics & Servers – Use state of the art hardware instead of hardened devices*
8. *No Noise Operation - No fans means 0db during operation*
9. *Heat Re-use – Electronics provide efficient water and floor heating onboard*
10. *Full Environmental Protection – Fully sealed systems provide the ultimate in marine environmental protection with greater efficiency*

Trends in the Marine Industry Driving SLIC

The transition to "smart vessels" and hybrid electric power systems

Smart Vessels

- Similar to the smart vehicle transition occurring on land, marine architects are adding increasingly complex compute on-board to enable more autonomous, safer and more energy efficient vessels
  - Navigation, Situational Awareness, Radar, Communications, Fuel & Engine Management, Sail Trim, System Control and Monitoring, Video Monitoring, Monitoring and Alarm, and Entertainment Storage and Streaming
- The harsh marine environment requires purpose specific "Marine Servers" utilizing specialized materials design that are marine specific, but today's systems ultimately rely on on-board air conditioning and specific placement to avoid the marine (salt, humidity, temperature, water, etc.) environmental hazards
- These devices are expensive and often lag industry performance by 12-18 months due to limited production volumes

Hybrid Vessels and Electric Power Systems

- Increased focus on fuel efficiency and reduction in green house gas emissions
- IMO 2020 banned shipping vessels using fuel with a sulfur content higher than 0.5 percent, compared to levels of 2.7 - 3.5% at present
- The transition to hybrid electric ships requires large battery and charger systems on scale with grid storage battery systems, yet design for ruggedized marine use with fast charge / high discharge C-rates

Maintenance Reduction Through SLIC

All marine electronics fail due to thermal loads and harsh environments

SLIC reduces electronics failures and maintenance by:

1) Fully shielding the electronics from all environmental impacts using low-cost sealed enclosures filled with Engineered Fluids' hydrophobic Dielectric Coolant
2) Removing fans and other air-cooling infrastructure from the system, thereby improving reliability by removing the components with the lowest MTBF
3) Removing heat uniformly across the entire electronic device, thus providing a homogenous thermal environment based on a dielectric coolant with 1600x the thermal density of air
4) Eliminating all hot spots and allowing temperature management down to a ½ degree C across the entire device, prevents heat stress on all components
5) All electronics can be placed in secure, easy to maintain, locations independent of air ventilation and separate from the crew and passenger areas.

Use of Lithium-ion Batteries in Marine Applications

Li-ion batteries pose a serious safety threat when in contact with water

With the increasing use of large capacity, high voltage Li-ion batteries for house loads and power applications, the safety issues related with Li-ion has become a serious consideration for marine architects and vessel owners.

- https://shipinsight.com/articles/a-small-ferrys-battery-fire-deserves-global-attention
- https://www.marinelog.com/coastal/ferries/coolant-leak-likely-caused-battery-room-fire-in-hybrid-ferry/
- The Norled ferry *Ytterøyningen,* built in 2006 and **converted to battery-hybrid in 2019**, was in regular operation, running on its diesel engines when the fire started. The twelve passengers and three crew members were evacuated to shore. Next morning there was an explosion below deck in the battery room.
- The most probable cause of the fire was a leakage in **the battery system's liquid cooling circuit into the battery**. Findings indicate that a 0.05USD twisted gasket, intended to seal the cooling plate outside of a battery module was the cause of the leakage. The leakage of the water cooling created **arcing between battery's pack 1kV DC** electrical components igniting the fire. The fire was further fueled by **ethylene glycol components from the coolant which drove the battery modules into thermal overload**.
- The incident was further escalated to the use of the **seawater sprinkler system** for a short period of time, which among other things, caused several short circuits.

Marine Use Cases for SLIC

SLIC Application – Marine Electronics Cooling / Protection

SLIC enables use of high-powered electronics in the most difficult environments

Today, on-board air-cooled electronics must either be placed in locations with fully conditioned air-flow or utilize specialty environmental packaging which increases cost and prevents the use of state-of-the-art electronics in the marine environment.

SLIC provides the ability to:

- Place state-of-the-art electronics anywhere within a ship, air-flow is not necessary
- Use existing liquid heat exchangers, water pumps, and common flexible hoses for cooling
- Increases the cooling capacity and simplify the device cooling infrastructure
- Eliminate all ancillary air systems required for electronics cooling
- Eliminate the need to evacuate the devices' waste heat into the operating environment of the crew and passengers, thereby reducing the need for comfort cooling and noise.

SLIC Application – Marine High-Density Compute

SLIC enables a tremendous leap forward in the speed and density of compute in marine environments with increased reliability and reduced maintenance

Taking advantage of SLIC technology allows a dramatic reduction in size and weight of electronics, while simultaneously increasing the speed, density, and lifecycle

SLIC provides the ability to:

- Increase compute speed by up to 6x
- Decrease electronics footprint and form factor by up to 8x
- Eliminate complex, maintenance intensive air-cooling systems
- Decrease overall power usage by up to 50% allowing power to be repurposed for other uses
- Allows the use of off-the-shelf electronics in the harshest environments with no need to harden electronics for extreme environmental conditions
- Reduce maintenance by eliminating the sources of common hardware failures and by providing a pristine homogenous thermal operating environment

SLIC Application – Marine Battery & Power Sources

- Servers and other electronics require tremendous amounts of power
- Alternators, Generators, Invertors and Batteries all must be cooled in order to operate at peak capacities and remain in peak operational state over long periods of time
- Alternators and Generators on large vessels can be subjected to high stress use and are typically air or water cooled. Both of which present implementation challenges
- Batteries, especially lithium metallic and similar batteries, require a constant uniform temperature to operate efficiently and to extend their operational lifecycles
- SLIC cooling solutions solve these challenges:
  - By allowing continuous cooling and lubrication of alternators and generators and allow them to be situated in on-board locations that can be far more easily shielded from the environment.
  - Battery cooling using SLIC is far more effective than air, cold-plates, or water and uses common off the shelf components already used on-board ship.

Military / Naval Use Cases

Naval Use Case: Submarines

Based on discussions with US sub commanders Engineered Fluids identified the following opportunities for the use of SLIC on board submarine fleets:

- The majority of electronics' waste heat onboard submarines is exhausted into the air-conditioned environment requiring a tremendous amount of comfort air conditioning during non-alert operations in order to maintain an effective working environment
- During alert operations, air-conditioning systems are shut down to eliminate fan and air-flow noise which is easily detectable. This results in temperatures which readily exceed 100F in the crew quarters, further exasperating an extremely stressful work environment
  - https://www.public.navy.mil/NAVSAFECEN/Pages/acquisition/heat_stress.aspx#common
- With SLIC all waste heat from the electronics can be silently removed from the working environment of the submariners during all modes of operation
- In addition, SLIC can provide an effective means of cooling battery systems in a silent manner thereby increasing run time and decreasing detection

Naval Use Case: Surface Ships

Based on discussions with US naval shipyards Engineered Fluids identified the following opportunities for the use of SLIC on-board naval surface fleets:

- Today's naval vessels are literally floating data centers utilizing tremendous compute resources for ship management, detection and senor control, weapons operation, targeting, communications, control, etc.
- All of these electronics which are air-cooled require that they are either hardened for use in harsh marine environments or placed in locations on-board ship that are serviced with air conditioning, de-humidifiers, filters, and other high maintenance systems.
- Using SLIC, all of air handling space and systems can be vastly reduced resulting in better space utilization, reduction in power requirements, relocation of equipment, simplified maintenance, and the ability to use common off the shelf electronics.
- In addition, SLIC can dramatically increase the on-board compute power while reducing weight and space resulting in a reduction in fuel requirements and on-board sparing.
- https://www.public.navy.mil/NAVSAFECEN/Pages/acquisition/heat_stress.aspx#common

ENGINEERED FLUIDS

High Performance, Biodegradable Single-phase Dielectric Coolants

The ultimate in marine electronics protection, crew and environmental safety

Engineered Fluids vs. the Competition

Our Dielectric Coolants are the safest and most effective on the market

Characteristic	EF ElectroCool™	Organic Esters	Silicone Oil	Shell GTL Base Oil
Dielectric Strength (ASTM 1816)	**60kV**	75kV[(2)]	35kV	25kV
Relative Heat Capacity (Air = 1)	**1,610**	1,470	1,105	1,170
Environmental Impacts[1]	**GWP=0**	GWP=1	**GWP=0**	**GWP=0**
10+ year Operating Life (Guaranteed)	**Yes**	No	No	No
Health and Safety (Food Grade Certification)	**Yes**	No	No	No
Biodegradable and Non-toxic	**Yes**	**Yes**	No	No
Non-corrosive to Metals	**Yes**	No[(3)]	**Yes**	Corrosive Sulfur
Material Compatibility with Electronics	**Yes**	No[(4)]	**Yes**	No
Hydrophobic and Water Displacing	**Yes**	Highly Hydroscopic	**Yes**	Hydroscopic
Easy to Clean / Remove from Devices	**Yes**	**Yes**	No	**Yes**
Purpose-Built, Tested and Guaranteed	**Yes**	**Yes**	No	No
Material Compatibility Guarantee	**Yes**	No	No	No
Immersion Device Warranty Available	**Yes**	No	No	No
5yr and 10yr Characteristic Warranties Available	**Yes**	No	No	No
Cooling Systems are Simple, Quiet, and Clean	**Yes**	**Yes**	No	No

ElectroCool® Dielectric Coolants

ElectroCool Dielectric Coolants are the highest performance biodegradable, non-toxic dielectric thermal management fluids available.

ElectroCool Coolants feature the broadest material compatibility, highest safety, and widest useful temperature range.

Download Information on ElectroCool:

- Technical Data Sheets
- Safety Data Sheets
- Characteristics by Temperature

Product ID		EC-100	EC-110	EC-120	EC-130	EC-140
Typical Application		General electronics cooling with excellent material compatibility	Outdoor and sealed system electronics cooling and insulation	Enterprise grade cooling of servers, semiconductors, and electronics	Data center cooling of servers, GPUs, semiconductors, and electronics	High temperature semiconductor & electronics cooling and insulation
Fluid Behavior		Non-Compressible, Isotropic, Newtonian				
Appearance		Clear				
Dielectric Strength		>60kV				
Resistivity (ohm-cm)		$>1x10^{14}$				
Dielectric Constant		2.3	2.3	2.1	2.2	2.3
Refractive Index n_D^{20}		1.462	1.440	1.442	1.453	1.465
Pour Point (°C)		-55	-57	-66	-57	-54
Flash Point (°C)		180	150	157	135	280
Density, g/cc @ 15.6°C		0.8133	0.7980	0.7980	0.8244	0.9300
Coefficient of Thermal Expansion, volume/°C		0.00068	0.00068	.00067	0.00066	0.00070
Kinematic Viscosity (cSt)	0°C	47.12	27.43	18.99	12.12	794.61
	40°C	9.58	6.43	5.02	3.72	66.46
	100°C	2.68	2.00	1.70	1.41	9.53
Thermal Conductivity (W/m*K)	0°C	0.1396	0.1382	0.1383	0.1404	0.1601
	40°C	0.1373	0.1359	0.1359	0.1374	0.1584
	100°C	0.1339	0.1325	0.1325	0.1329	0.1561
Specific Heat (J/g*K)	0°C	2.0540	2.0608	2.0608	2.0577	2.0460
	40°C	2.2032	2.2121	2.2121	2.2090	2.1912
	100°C	2.4270	2.4388	2.4390	2.4355	2.4090
Global Warming Potential		0	0	0	0	0
Biodegradability (28 Days)		>93%	>96%	>96%	>98%	>50%
Materials Compatibility Warranty		Yes	Yes	Yes	Yes	Yes
Product Operational Warranties (Yrs) [1]		0, 5, 10	0, 5, 10	0, 5, 10	0, 5, 10	0, 5, 10
Shelf Life (Yrs) [2]		5	5	5	5	5

SLIC Videos: Engineered Fluids' Video Channel

https://vimeo.com/channels/engineeredfluids

You can also visit our Vimeo Video Channel to see:

- Live Demonstrations of our products
- Discussions with live customers Q&A
- Explanations of use cases
- Customer feedback on our products

You can also subscribe to our channel to get notified when we post new materials!

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