High performance battery cooling by innovative immersion cooling systems

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Agenda

01 | What drives BEV direct cooling
   | Market trends, technology drivers, battery immersion cooling

02 | Challenges of immersion cooling dielectric fluids
   | Integration, efficiency, safety

03 | Dielectric fluid development process
   | Formulation, simulation and testing

04 | FUCHS BluEV technology promise
   | FUCHS BluEV integrated solution portfolio
What drives BEV direct cooling
Market trends, technology drivers, battery immersion cooling
Electric cars to triple market share in Europe amid COVID-19, researchers say

France Hits Record 19.2% EV Share In December — Up Almost 6× Year On Year

UK’s EV Market Share Jumps To 16% In November — Overtaking Diesel

EV sales triple in Germany, disrupting market with 11% share

Source: ACEA
01 Market trends
Dynamics in published consulting agencies studies
01 Technology driver
Ultra Fast Charging Challenge

- High energy density
- Up to 50kW dissipation loss!
- Safety optimization
- Maximum efficiency
- Condition monitoring requires homogeneous cell temperature

Source: Porsche AG, Taycan Turbo S
01 Battery Immersion Cooling
How and why?

- Battery immersed with cooling fluid
- Insulating dielectric fluid is derived from transformer fluid
- Highest heat transfer capability
- Homogeneous battery cell temperature
- Increased safety
01 Battery immersion cooling
FUCHS BEV applications

- Contact coating for charging socket
- Noise cancelling in the interior
- Contact grease and cleaners for electric connections
- Thermal fluid for power electronics
- Cutting oil for electrical sheets in E-Motor
- Metal working fluids for production of E-Motor and transmission
- E-Drive oil for E-Motor and transmission
- E-Drive CV Joint grease
- Compressor oil for heatpump / air condition
- Electric steering greases
- Low noise grease for ventilators and pumps
- Drawing oils for copperwire
- Bearing and sealing greases for E-Motors
- Cleaners in battery production processes
- Forming oils for battery cell cups or battery cases
- Corrosion protection for battery housing
- Thermal fluid for battery
Challenges of immersion cooling dielectric fluids
Integration, safety, efficiency
02 Integration

Multiple temperature levels in BEV components

Key challenges

- Thermal management for performance and lifetime
- Heating and cooling

- Cooling only
- High gradients, intermittent

- Cooling and heating
- ICE waste heat non existent

- Cooling only
- Hotspots

Operating temp (°C)
<table>
<thead>
<tr>
<th>Type</th>
<th>Air</th>
<th>Water-Glycol</th>
<th>Refrigerants</th>
<th>Dielectric Fluids</th>
</tr>
</thead>
<tbody>
<tr>
<td>Description</td>
<td>Direct cooling by airflow around cells</td>
<td>Indirect cooling through pipe and heat exchanger system</td>
<td>Indirect cooling by expansion of refrigerant in heat exchanger system</td>
<td>Direct cooling by fluid flow around cells</td>
</tr>
<tr>
<td>Advantages</td>
<td>Low cost of system</td>
<td>Fluid already available at car production sites</td>
<td>High heat transfer rates</td>
<td>No additional heat exchanger system inside battery needed</td>
</tr>
<tr>
<td></td>
<td>Low specific heat capacity of air = low efficiency</td>
<td>Conductive fluid in high voltage environment needs higher safety efforts</td>
<td>High Power and high pressures required</td>
<td>Highest energy density</td>
</tr>
<tr>
<td></td>
<td>Loud</td>
<td>Smaller contact surface to cells = low efficiency</td>
<td>Only cooling, separate heating system required</td>
<td>Highest efficiency and cooling capability</td>
</tr>
<tr>
<td></td>
<td>High space demands</td>
<td></td>
<td></td>
<td>Fluid either environmentally harmful, expensive and heavy or flammable</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Higher fluid volume</td>
</tr>
</tbody>
</table>
# 02 Integration

## Thermal management media for direct cooling of batteries

<table>
<thead>
<tr>
<th>Coolant</th>
<th>Direct Cooling</th>
<th>Cost</th>
<th>Energy Efficiency</th>
<th>Heat Transfer</th>
<th>Electrical Conductivity</th>
<th>Fire Resistance</th>
<th>Weight</th>
<th>Ecology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water / Glycol</td>
<td>✗</td>
<td>++</td>
<td>++</td>
<td>++</td>
<td>- -</td>
<td>+</td>
<td>-</td>
<td>++</td>
</tr>
<tr>
<td>Hydro Fluoro Ethers</td>
<td>- -</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>- -</td>
<td>-</td>
<td>- -</td>
</tr>
<tr>
<td>Heat Transfer Oils</td>
<td>+</td>
<td>--</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Transformer Oils</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>++</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Dielectric Thermal Fluids, designed for Batteries</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>
02 Safety

- Low flammability
- Robust and homogeneous cooling, no thermal peaks
- Effective cooling results in less risk of thermal runaway
- New China GB/T standard 38031 for BEV safety

*min. 5 minutes!*
02 Efficiency
Heat transfer Comparison of thermal fluids using efficiency indices

**Thermal fluid**
- thermal conductivity
- heat capacity
- density
- viscosity

**System and operation**
- design, geometry, operation parameters
- cooling surface area $A$
- temperature difference $\Delta T$
- flow regime (laminar/turbulent)
- forced convection / 2-phase
- materials, surfaces, coatings, …

Efficiency is influenced by a combination of caloric and hydraulic fluid characteristics

\[ \dot{Q} = \alpha \cdot A \cdot \Delta T \]

\( M_{\text{eff}} \)
02 Efficiency

Heat transfer models laminar and turbulent flow

\[ M = \frac{\rho^a \cdot \lambda^b \cdot C_p^c}{\mu^d} \]

\[ M_1 = \frac{\rho^{0.33} \cdot \lambda^{0.67} \cdot C_p^{0.33}}{\mu^{0.17}} \]
- simple model
- laminar flow
- pump energy neglected

\[ M_2 = \frac{\rho^{0.40} \cdot \lambda^{0.20} \cdot C_p^{0.40}}{\mu^{0.20}} \]
- advanced model
- laminar flow

\[ M_3 = \frac{\rho^{0.80} \cdot \lambda^{0.67} \cdot C_p^{0.33}}{\mu^{0.47}} \]
- advanced model
- turbulent flow

* also described as Mouromtseff number

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03 Dielectric fluid development process
Formulation, simulation and testing
03 Formulation
Hydrocarbon based dielectric fluids offer best overall performance

Dielectric Immersion cooling fluids

- FUCHS Thermal Fluid
- Heat Transfer Oil
- Transformer Oil
- Hydrofluorether
## 03 Formulation

Products made to measure: Comparison of thermal fluids

![Graph showing comparison of thermal fluids](image)

### Properties

<table>
<thead>
<tr>
<th>Properties</th>
<th>Hydrofluoroether</th>
<th>Aromatic heat transfer oil</th>
<th>Mineral heat transfer oil</th>
<th>FUCHS dielectric fluid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kin viscosity 40°C / mm²/s</td>
<td>-</td>
<td>16.5</td>
<td>44</td>
<td>5</td>
</tr>
<tr>
<td>Density 20°C / kg/m³</td>
<td>1.618</td>
<td>1.044</td>
<td>0.870</td>
<td>0.808</td>
</tr>
<tr>
<td>Thermal conductivity 20°C / W/(m*K)</td>
<td>0.065</td>
<td>0.131</td>
<td>0.133</td>
<td>0.154</td>
</tr>
<tr>
<td>Specific heat capacity 20°C / kJ/(kg*K)</td>
<td>1.129</td>
<td>1.6</td>
<td>1.88</td>
<td>2.1</td>
</tr>
</tbody>
</table>
Testing

Comparison of thermal fluid formulation strategies

- Hermetic module casing
- Battery cells immersed in dielectric liquid
- Circulating cooling liquid, controlled in temperature / flow / pressure
- Specific flow pattern around battery cells, flow channels arranged in parallel
03 Testing
Comparison of thermal fluid formulation strategies

- U-shape flow:
- Enhanced thermal and safety performances
03 Simulation
Comparison of thermal fluid formulation strategies

- Flow simulation that combining heating and flow calculation
- Speeds and pressure pattern of the flow in-between prismatic cells in immersion cooling
03 Testing

Comparison of thermal fluid formulation strategies

- EXOES designed a module made of dummy cells
- 1x actual LTO cell (Toshiba SCiB 10Ah)
- Surrounded by 35x dummy heating cells
- 26x temperature sensors enclosed
## 03 Formulation

**Testing: Material compatibility (Construction polymers, sealants)**

<table>
<thead>
<tr>
<th>Construction polymers (examples) acc. to ASTM D3455</th>
<th>Sealants (examples) acc. to ISO 1817: 2015-02</th>
<th>Tested properties (examples)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Polycarbonate (PC)</td>
<td>Fluorocarbon rubber (FKM)</td>
<td>Shore D hardness / Ball indentation hardness</td>
</tr>
<tr>
<td>Polyphenylene sulfide (PPS)</td>
<td>Alkyl acrylate copolymer (ACM)</td>
<td>Strength</td>
</tr>
<tr>
<td>Polyamide - Polycaprolactam (PA6)</td>
<td>Hydrogenated acrylonitrile butadiene rubber (HNBR)</td>
<td>Strain at strength</td>
</tr>
<tr>
<td>Polybutylene terephthalate/ Acrylonitrile styrene acrylate (PBT/ASA)</td>
<td>Ethylene acrylic rubber (AEM)</td>
<td>Stress at break</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Strain at break</td>
</tr>
</tbody>
</table>
FUCHS global footprint
Covering all applications and regions
We have relied on continuity, reliability and proximity – for more than 85 years."
# FUCHS global footprint

**FUCHS PETROLUB SE at a glance**

- **Established 3 generations ago as a family-owned business**
- **More than 5,400 employees**
- **Preference share is listed in the MDAX**
- **No. 1 among the independent suppliers of lubricants**
- **Approx. €2.6 bn sales in 2018**
- **The Fuchs family holds 55% of ordinary shares**
- **A full range of over 10,000 lubricants and related specialties**
- **58 companies worldwide**
01 FUCHS BluEV product line
Customized 360-degree solutions
04 FUCHS global footprint
Covering all applications: BEV product portfolio

Contact grease for electric connections
Coolant for power electronics
E-Drive oil for E-Motor and gearbox
Axle grease for high torque
Compressor oil for heat pump / air condition
Grease for E-Motor
Corrosion inhibitor for battery housing
Battery coolant

Products, which are needed independently from propulsion method are not shown
04 FUCHS global footprint
Covering all applications: HYBRID product portfolio

New generation engine oils for downsized hybrid engines
Compressor oil for heat pump / air condition
Grease for belt tensioner
Grease for starter / generator

Battery Coolant
Corrosion inhibitor for battery housing
Axle grease for high torque / low temp
Contact grease for electric connections
E-Drive Oil for Hybrid gearbox
E-Motor bearing grease

Products, which are needed independently from propulsion method are not shown
Thank you for your attention.