Thermal management for batteries in E-mobility applications

Alessandro Bizzarri, Priatherm on behalf of Batenburg Mechatronica
Company overview – relator presentation

• **Batenburg Mechatronica**
  • Focus on smart components:
    • Precision resistors and capacitors
    • Sensors and connectors
    • Thermal management (cooling & heating – foils, etc.)
  • [www.batenburg-mechatronica.nl](http://www.batenburg-mechatronica.nl) (Rotterdam & Zaventem)

• **Priatherm**
  • Thermal management solutions:
    • Product manufacturing (air and liquid cooling)
    • Engineering services – simulations - testing
    • Technology development - innovation
  • [www.priatherm.com](http://www.priatherm.com) (Ferrara - IT)
  • I’m ALESSANDRO BIZZARRI, General Manager, Thermal Engineer
Hybrid and Electrical Vehicles

• Micro Hybrid (start / stop)
  First introduction in a commercial car by Mahindra & Mahindra (India, May 2000)

• Mild Hybrid (support to thermal engine → K.E.R.S.)
  Suzuki Baleno, Audi A7 and A8 Sportback, La Ferrari (HY KERS)

• Full Hybrid (medium hybrid capabilities + electric launch)
  Toyota Prius, Ford Escape

• Plug-in Hybrid (full hybrid capabilities + electric range)
  BMW i3, Mercedes-Benz C350e, VW Golf GTE

• Full Electric Vehicles (No thermal engine)
  Nissan Leaf, Renault ZOE, Tesla Model S
Hybrid and Electrical Vehicles

Source: Continental Automotive
Energy storage – Cells shape
Overview of cell types for HEVs

<table>
<thead>
<tr>
<th>Large - Prismatic</th>
<th>Large - Pouch</th>
<th>Small - Cylindrical</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pros</strong></td>
<td><strong>Form factor</strong></td>
<td><strong>Cheap &amp; commoditized</strong></td>
</tr>
<tr>
<td>Best scalability, High cycle life</td>
<td>Expensive and hard to scale</td>
<td>Need sophisticated BMS</td>
</tr>
<tr>
<td><strong>Cons</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Currently expensive</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Main cell maker</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Samsung SDI, Panasonic, BYD, EnerDel, ATL, PEVE, LEJ</td>
<td>AESE, LG Chem, SK Innovation</td>
<td>Panasonic</td>
</tr>
<tr>
<td><strong>Market share (volume)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>26%</td>
<td>49%</td>
<td>25%</td>
</tr>
<tr>
<td><strong>Market share (sales)</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>33%</td>
<td>54%</td>
<td>13%</td>
</tr>
<tr>
<td><strong>Main auto OEM</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Toyota, Mitsubishi, Honda, BMW, VW, Audi, Chrysler, BYD, Ford</td>
<td>Nissan, GM, Ford; Renault, Daimler, Hyundai, Volvo</td>
<td>Tesla</td>
</tr>
</tbody>
</table>
Battery Thermal Management

Heat in a battery cell is produced by:

1. The resistance of the various cell components (electrode, cathode, anode, etc.); Joule heating, which can be minimized by cycling the cells at low currents.

2. Entropic reactions within the cell (exothermic reactions within the cell due to the transfer of ions and electrons).
Battery Thermal Management

Temperature is one of the most critical factors in designing and operating batteries for HEVs.
Thermal Runaway in a Lithium-Ion Battery

1. Heating starts.
2. Protective layer breaks down.
3. Electrolyte breaks down into flammable gases.
4. Separator melts, possibly causing a short circuit.
5. Cathode breaks down, generating oxygen.
Thermal Management - Air cooling

Outside Air Ventilation

Outside Air → Battery Pack → Exhaust

Fan

Cabin Air Ventilation

Outside Air → Cabin Air → Battery Pack → Exhaust

Vehicle heater and evaporator cores

Return → Fan

Heating/cooling of Air to Battery – Outside or Cabin Air

Outside Air → Battery Pack → Exhaust

Auxiliary or vehicle heater and evaporator cores

Return → Fan

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POWER ELECTRONICS 2018
Active Air cooling – Ford Escape Hybrid 2012

FORD Escape (Plug-in Hybrid)
• 10 kWh Nickel-Metal-Hydride (NiMH) battery pack
• Air cooled
NISSAN Leaf (Full electric)
• 40 kWh Lithium-ion battery pack.
• 192 Lithium ion cells (48 modules)
• 303 kg total weight
Passive Air cooling – Nissan Leaf BMS (Battery Management System)
Air cooling, at least without an advanced BMS like Nissan Leaf, is not suitable for most recent high performance applications due to the power density required and the inability to cope with a wide range of ambient temperatures.

<table>
<thead>
<tr>
<th>Pro</th>
<th>Con</th>
</tr>
</thead>
<tbody>
<tr>
<td>All waste heat eventually has to go to air</td>
<td>Low heat transport capacity</td>
</tr>
<tr>
<td>Separate cooling loop not required</td>
<td>More temperature variation in pack</td>
</tr>
<tr>
<td>Low mass of air and distribution system</td>
<td>Connected to cabin temperature control</td>
</tr>
<tr>
<td>No leakage concern</td>
<td>Potential of venting battery gas into cabin</td>
</tr>
<tr>
<td>No electrical short due to fluid concern</td>
<td>High blower power</td>
</tr>
<tr>
<td>Simple design</td>
<td>Blower noise</td>
</tr>
<tr>
<td>Lower cost</td>
<td></td>
</tr>
<tr>
<td>Easier maintenance</td>
<td></td>
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</tbody>
</table>
Thermal Management – Liquid cooling

Ambient cooling

Active dedicated cooling/heating

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Liquid cooling – GM Thermal Fin®

**Chevrolet Bolt EV**
- 60 kWh Lithium-ion battery pack.
- 288 Lithium-ion “POUCH” cells
- 435 kg total weight

- Coolant: Water + Ethylene Glycol Mixture
**Liquid cooling – Tesla Model-S**

**TELESA Model S**
- 85 kWh Lithium-ion battery pack.
- 7104 CYLINDRICAL Lithium ion cells (16 modules wired in series)
- 504 kg total weight
- Coolant: Water + Ethylene Glycol Mixture

![Tesla Model S image]

![Tesla patent cooling tube diagram]

1 Model S battery module (16 total)

Glycol coolant in

Glycol coolant out

18650 battery cells
Liquid cooling – F150 “La Ferrari”

Ferrari F150
- 120 kWh Lithium-ion battery pack
- 120 Lithium ion cells in 8 modules
- 140 kg total weight

- Coolant: Water + Ethylene Glycol Mixture
## Liquid cooling

<table>
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<tr>
<th>Pro</th>
<th>Con</th>
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</thead>
<tbody>
<tr>
<td>Pack temperature is more uniform - thermally stable</td>
<td>Additional components</td>
</tr>
<tr>
<td>Good heat transport capacity</td>
<td>Weight</td>
</tr>
<tr>
<td>Better thermal control</td>
<td>Liquid conductivity – electrical isolation</td>
</tr>
<tr>
<td>Lower pumping power</td>
<td>Leakage potential</td>
</tr>
<tr>
<td>Lower volume, compact design</td>
<td>Higher maintenance</td>
</tr>
<tr>
<td></td>
<td>Higher viscosity at cold temperatures</td>
</tr>
<tr>
<td></td>
<td>Higher cost</td>
</tr>
</tbody>
</table>
Design guidelines: input data

• Cells shape (+ modules geometrical configuration)
  Prismatic; Pouch; Cylindrical

• Weight constraints and battery location

• Cooling media available on board
  Water (+ antifreeze, anticorrosion…); Oil, Bi-phase fluids…

• Inlet Fluid Temperature

• Thermal Interface Materials
  Graphite, Phase Change Materials…

• Surface vs. Tab cooling
Conclusions

From 2020 onwards the utilization of conventional gasoline engines is expected to be decreased and it will have been disappeared by 2050. Lithium-ion batteries represent the most prevalent storage device in EVs and HEVs and their study is attracting more and more interest.

A well-designed temperature regulation of Lithium-ion batteries is a basic requirement to get optimized efficiency from electrical engines.

Keeping the temperature within the desired range and low temperature gradients can guarantee furthermore a longer battery life time and better energy efficiency.

Thermal management topics have to be investigated by a team of experts involving batteries manufacturers, electrical engineers and thermal management specialists, since from the earlier stages of the design process.
Question?

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www.priatherm.com
**Kom naar onze open huis!**

Op donderdag 6 september openen wij onze deuren en nodigen wij u van harte uit om een kijkje te nemen in onze productieafdeling, electronica-afdeling en onze nieuwe ESD ruimte. Daarnaast zijn er demonstraties. We sluiten de dag feestelijk af met een borrel.

Bent u er ook bij? Meldt u zich nu aan en we ontmoeten u graag 6 september!

**Locatie**
Stolwijkstraat 33
3079 DN Rotterdam

Aanmelden kan via onze website: [batenburg-mechatronica.nl/open-huis](http://batenburg-mechatronica.nl/open-huis)