3D thermal simulation of a buffer battery for an industrial fuel cell vehicle

GT conference
Oct. 15th 2020
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e-Mersiv “why”

Our mission: accelerate EV transition thanks to high performance batteries

1. **Immersion cooling** to reach very high C-rates

2. **Advanced BMS** to enable higher safety and longer lifetime

e-Mersiv batteries to be used in BEVs and HEVs (including FCEVs):

- Whenever the **Power to Energy ratio is higher than 3**
- Whenever the **ultra fast charging in less than 10 minutes** is required
- Whenever conditions are **severe: hot/cold weather and long lifetime**
e-Mersiv in a nutshell

➢ **Joint Venture** of:
  • EXOES, expert in thermal management systems for vehicles
  • Startec Development, expert in batteries and BMS

➢ 2x locations in **Bordeaux** area

➢ A task force of **50x people**

➢ Internal capabilities:
  • BMS, battery pack & cooling systems design
  • Manufacturing
  • Tests: full performance, abusive and aging

➢ Seasoned team
  • 20-year experience in Li-ion batteries
  • 11-year experience in fluids used for thermal management
Last achievements of the team

- Complete battery packs using different types of cells: form factors & electrochemistry: Li-Ion / Na-Ion / LTO...
- Complete BMS development and manufacturing
- High energy or high-power battery packs developed
Focus on Battery immersion cooling
A large variety of technologies

Criteria to make a choice:
- Cost
- Weight
- Cooling loop
- System performances
- Manufacturing process
- Etc.

Example of a loop
The cooling fluid

- 2x categories: Oils and refrigerants
- Some criteria are listed below to choose the right fluid after extensive tests:

<table>
<thead>
<tr>
<th>Cost / kg</th>
<th>Density</th>
<th>Heat Transfer coefficient</th>
<th>Viscosity</th>
<th>Dielectric properties</th>
<th>GWP ODP</th>
<th>Water acceptance</th>
<th>Material compatibility</th>
</tr>
</thead>
</table>

- Extract of potential fluid suppliers:
### Immersion-cooled products under development

- **3x different products for 3x different markets**

<table>
<thead>
<tr>
<th>details.</th>
<th>Peak C-rate ch. / disch.</th>
<th>Average C-rate</th>
<th>Densities At pack level</th>
<th>Cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Powerfull electric vehicles</strong></td>
<td>10C / 10C</td>
<td>10C rms</td>
<td>130 Wh/kg 1,250 W/kg</td>
<td>Liquid</td>
</tr>
</tbody>
</table>
| - 230 Wh/L  
- designed for large batteries  
- Cell-to-pack  
- Dielectric cooling loop <40°C  
- NMC 21700 cells | | | | |
| **Hybrid or Full electric racing** | 40C / 100C | 40C rms | 80 Wh/kg 3,400 W/kg | Pumped-2-phase |
| - 800V  
- Dielectric cooling loop @60°C  
- LCO Pouch cell | | | | |
| **Powerfull hybrid vehicles (incl. FCHEV)** | 40C / 40C | 8C rms | 30 Wh/kg 1,250 W/kg | Up to Pool boiling |
| - 30,000 Cycles  
- Attractive TCO  
- Air cooled possible, or water loop @25°C  
- LTO prismatic cell | | | | |

**Ex:** Energy 2,15kWh Peak Power charge 21,5kW / discharge 21,5 kW

**Best trade-off between energy and power densities**
**Ex:** Energy 2,15kWh Peak Power charge 86 kW / discharge 215 kW

**Best trade-off between densities and lifetime**
**Ex:** Energy 2,15kWh Peak Power charge 86 kW / discharge 86kW
Simulation of a buffer battery for FCEVs
Use case: industrial FCEV

- An industrial vehicle running 24h/7d
- Equiped with a small fuel cell (FC)
- With repetitive power peaks (10x power of the FC)

- Ratio of energy required on power is:
  - 10C peak
  - and 6C rms!

Stringent requirements on both Lifecycles & Thermal performances
The cell: LTO prismatic

➢ LTO 23Ah 2.3V
➢ LxLxH = 115x22x105 mm
➢ 100 Wh/kg
➢ Up to 20C rms
➢ 1000A for 1sec
➢ 15,000 cycles (EOL 80%, 25°C, 100% DOD)
Cooling options simulated

- we defined the following scenarios for the cooling architecture:
  - Cooling fluid inlet: 25°C
  - Ambient temperature: 25°C
  - Initial temperature: 25°C

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Cooling configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>#0</td>
<td>No cooling</td>
</tr>
<tr>
<td>#1</td>
<td>Bottom cold plate</td>
</tr>
<tr>
<td>#2</td>
<td>2x lateral cold plates</td>
</tr>
<tr>
<td>#3</td>
<td>Full immersion</td>
</tr>
</tbody>
</table>
The cell model

**Casing / Tabs / Collectors**
- Aluminium
  - $\lambda$ [W/m²/K]
  - $C_p$ [J/kg/K]
  - $\rho$ [kg/m³]

**Electrolyte**
- $\lambda$ [W/m²/K]
- $C_p$ [J/kg/K]
- $\rho$ [kg/m³]

**Insulator**
- $\lambda$ [W/m²/K]
- $C_p$ [J/kg/K]
- $\rho$ [kg/m³]

**Jelly Roll**
- $\lambda_Z$ [W/m²/K]
- $\lambda_{XY}$ [W/m²/K]
- $C_p$ [J/kg/K]
- $\rho$ [kg/m³]
The cell model details

- Conductive components are meshed (GEM 3D)
- Insulators are modeled with a single conductance

3D Finite Element

Thermal conductance (W/m²/K)

Cold Plate / Immersion

Casing

Insulator L

Insulator R

Collector L

Collector R

Collector Sheet

Collector Sheet

Electrolyte

JellyRoll

Heat dissipation rate

Cold Plate

Aluminium

λ [W/m²/K]

Cp [J/kg/K]

ρ [kg/m³]
The complete model

➢ The system is simplified to a single cell
➢ The external heat transfer is modeled by a constant heat transfer coefficient $h$.
➢ The busbar connection is neglected
The complete model

Domains:
- Thermal domain (3D FE Thermal resolution)
- Electrical domain (0D Joule heating calculation)

Electrical domain
- Transfer heat production result
- Transfer back element temperature

Thermal domain
3D cell result
(t = End of simulation)

Scenario
#1 BOTTOM
#2 LATERAL
#3 FULL IMMERSION

Cooling configuration
#1 BOTTOM
#2 LATERAL
#3 FULL IMMERSION

NB: Cooling fluid at 25°C
Jellyroll Temperatures

JELLYROLL TEMPERATURE [°C]

Scenario | Cooling configuration
--- | ---
#0 | NO COOLING
#1 | BOTTOM
#2 | LATERAL
#3 | FULL IMMERSION

Only the immersion cooling allows to keep the jelly roll under the max temperature.

Max temperature limit to prevent from lifetime degradation of an LTO cell.

NB: Cooling fluid at 25°C
Conclusion

Work done:

- 3D thermal simulation of a battery cooled by immersion
- Benchmark with a battery cooled by water/glycol cold plates
- Not presented: simulation of a thermal runaway propagation in both case

The appropriate cooling system was selected:

- Ability to simulate transient behavior with « normal » computers (only 16Go RAM – full 3D CFD did not work out – early trials led to computer black out !)

The module design was enriched thanks to the simulation
- Sensitivity studies on parameters (intercell distance, flowrates, fluid viscosity, ...)

Prior to do destructive tests, the thermal runaway behavior was checked
Thanks for your attention!

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