The end of range anxiety thanks to fast charging and immersion cooling in BEVs

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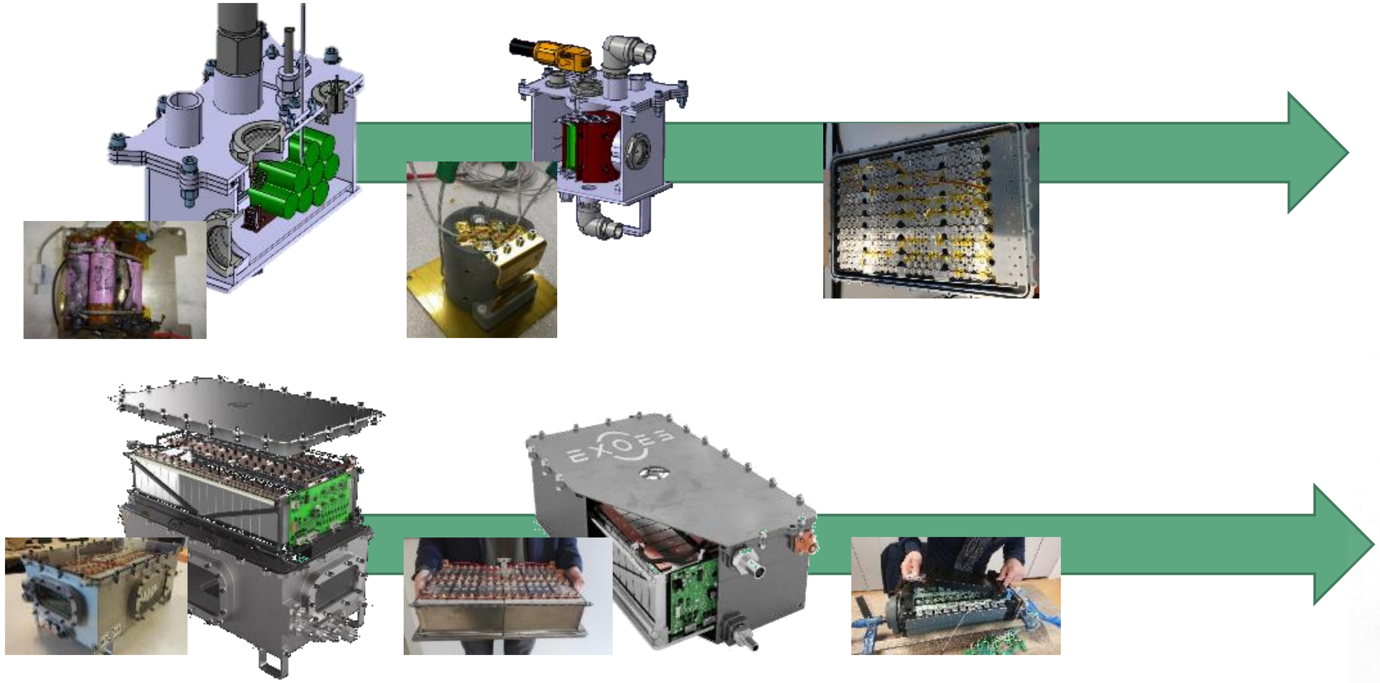
EXOES - Introduction

30x people in Bordeaux

simulating, prototyping and testing batteries cooled by immersion

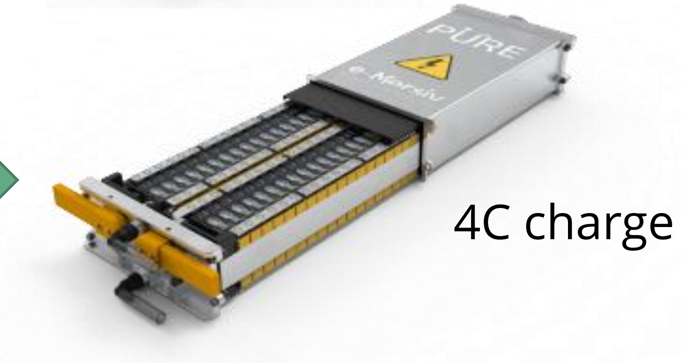
and much more...

Past battery developments



Pending designs

7Crms



4C charge

Range anxiety

- For long trips, 2x possible paths:

Large battery
100kWh

4h driving - 500km →

Charge
25km/min
20min

Small battery
Fast charging
50kWh

2h driving
250km →

Fast charge
25km/min
10min

2h driving
250km →

Fast charge
25km/min
10min

Economically and environmentally, fast charging makes sense

Technical reminder:
C-rates, heat generation & immersion cooling

- **What is « C-rate » for a battery ?**

C-rate $= \frac{Power}{Energy} = \frac{Current}{Capacity} = \frac{A}{Ah}\ [h^{-1}]$

→ Ex: 4C means ¼ hour charging time for 100%

- **How C-rate impacts the heat generation ?**

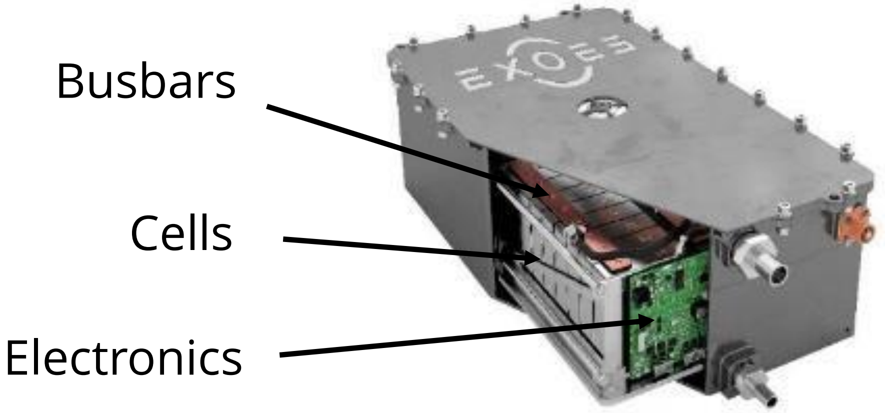
Joule heating due ohmic resistance: $Heat = Resistance\ x\ Current^2$

→ Ex: 4C charge heats 4x more than 2C

Current battery cooling systems cannot absorb so much heat

Representative testing of improved cooling system

What is immersion cooling?



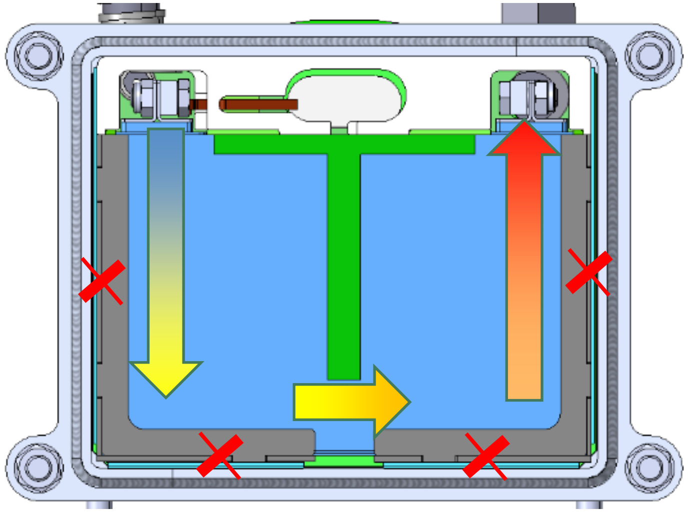
- A sealed battery flooded with a dielectric fluid in direct contact with the cells
- Thermal runaway propagation is prevented
- Low consumption of cooling system (pump & chiller)
- Cooling of busbars

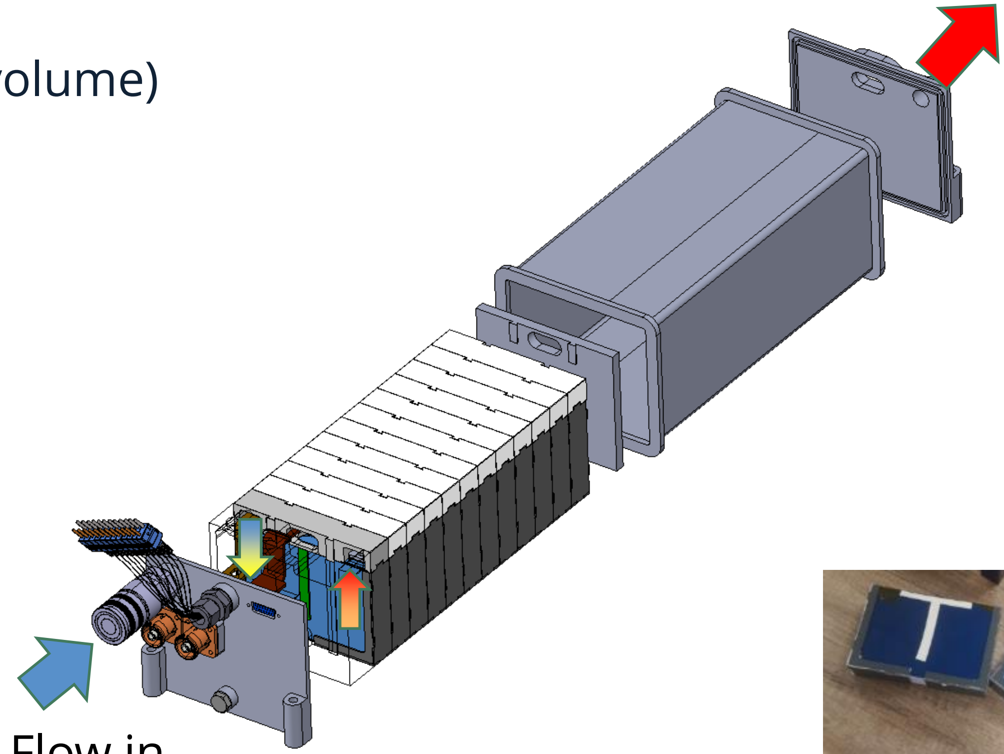
We developed a specific battery module cooled by immersion with prismatic hard-case cells

- 2.2 kWh
- Fully instrumented
- To validate :
  1. Cooling performance
  2. Fast charging capability
  3. Safety behavior during a cell thermal runaway

Module design and flow path

- 50Ah NMC523 prismatic cells – 2p6s
- All cells are hydraulically in parallel with common inlet and outlet manifolds
- U-shape flow along the wide faces of cells
- 1.5mm space between cells for fluid circulation
- quantity of fluid in the module : ~1.2L (25% of cell volume)
- Designed for hydrocarbon-based coolant

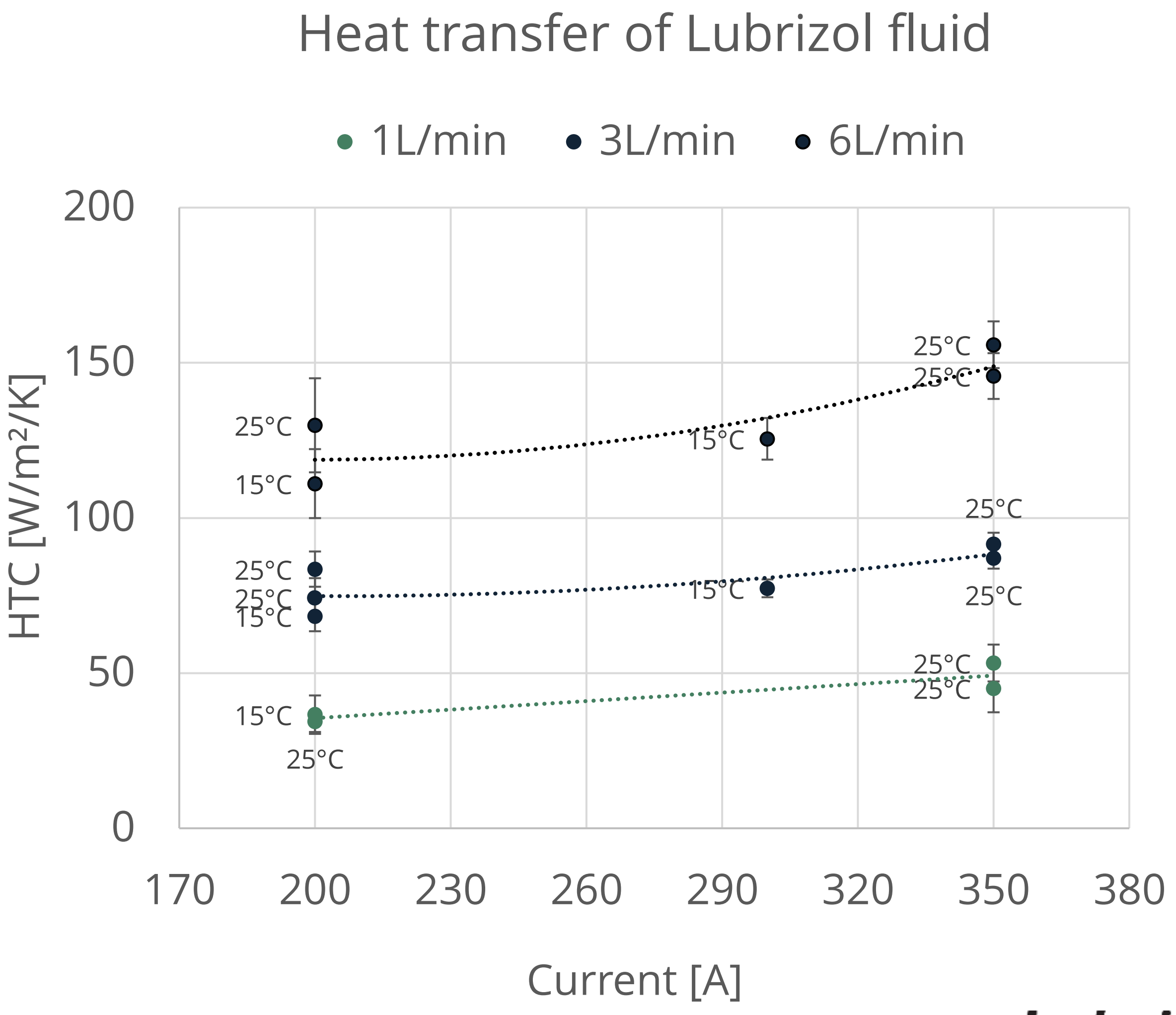




Heat transfer properties at module level

- $\text{HTC x Surface}_{cooled} \text{ x } \Delta T_{\text{fluid to cell}} = Heat_{cells\ \&\ busbars}$
- The Heat Transfer Coefficient (HTC) is highly dependent on flow rate
- A higher temperature lightly increases HTC on the range 15-25°C
- C-rate has a visible influence on HTC (mean fluid temperature increase with C-rate)

With this battery design & fluid
Up to 150W/m²/K

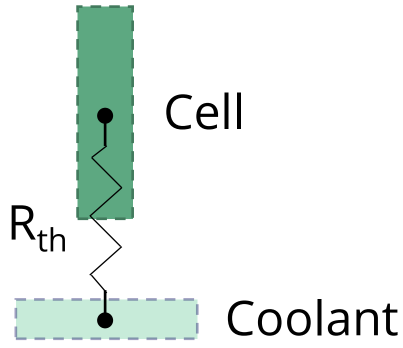


Data are courtesy of Lubrizol

Why immersion cooling ?

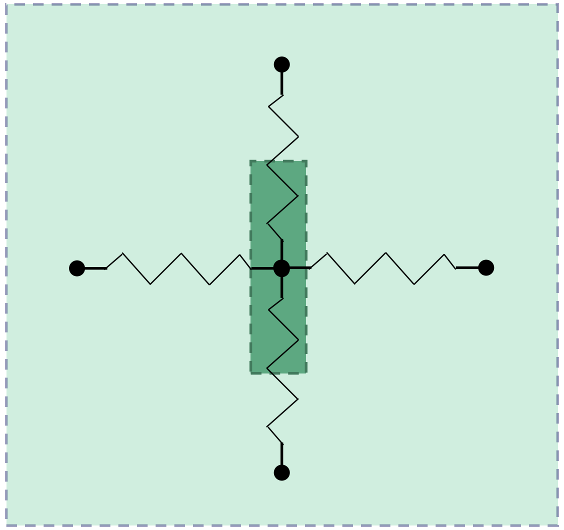
Immersion reduces the battery thermal resistance for better cooling:

Cold plate cooling:



Thermal resistance typ. 0.8 K/W*
& busbar not cooled

Immersion cooling:



Thermal resistance typ. 0.2 K/W*
& hot spots cooling

Immersion cooling is an enabler of fast charging

*: Calculated on prismatic cell – PHEV2 format

Real driving assessment: Fast charge + US06 (EPA)

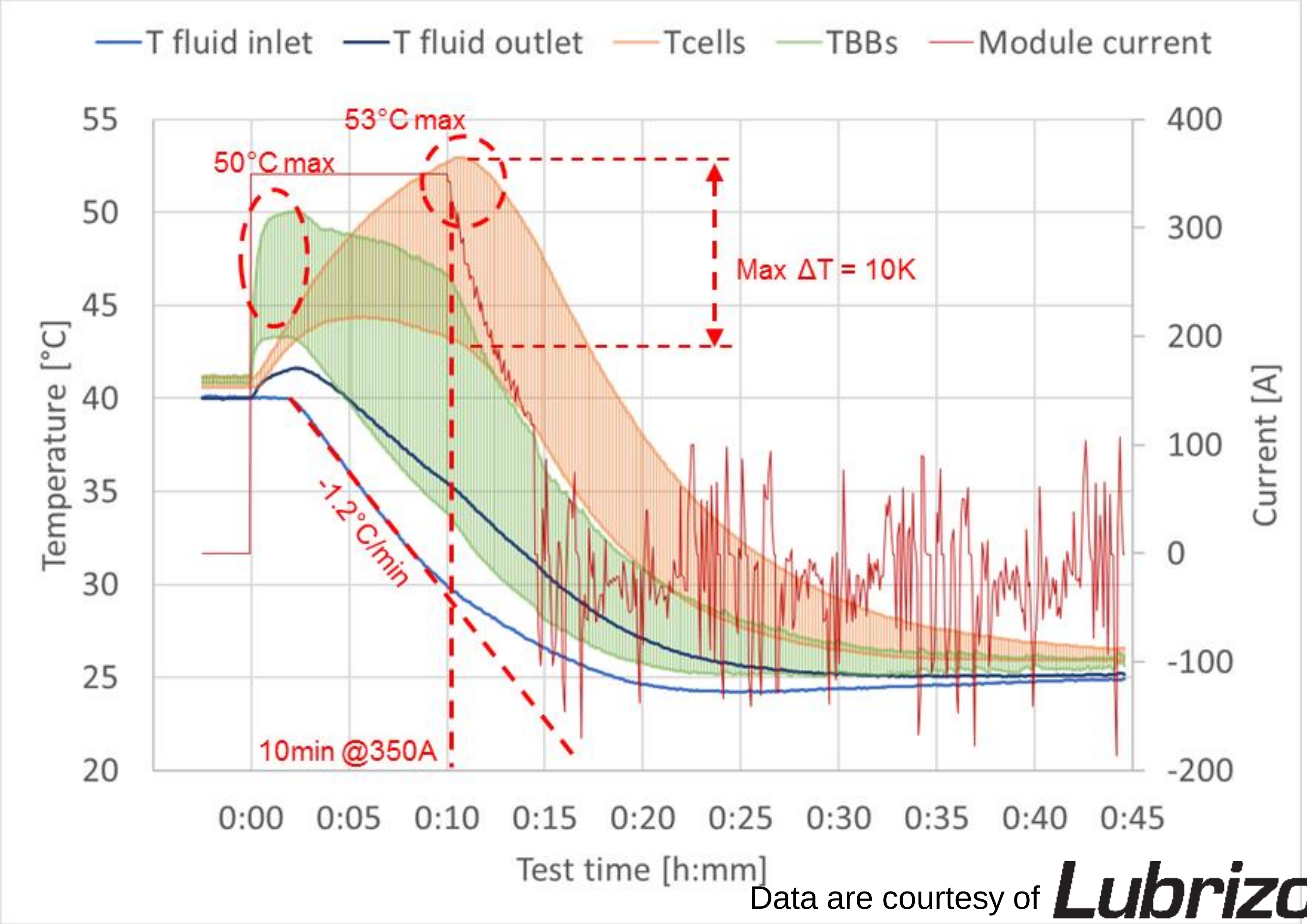
Test conditions:

- Initial temperature 40°C
- 3.5C charge from 5 to 65% (~10min)
- Cooling at 6L/min and 25°C
- Followed by a US06 cycle

Results:

- max cell temp. <53°C
- max busbar temp. <50°C
- max ΔT on cells <10K
- duration above 35°C <23min

3.5C charge accessible with immersion cooling
&
No active cooling required during normal driving



Data are courtesy of Lubrizol

Assessment of the propagation of a thermal runaway thanks to a nail penetration test (NPT)

Gas safety line

Pass-through for thermocouples

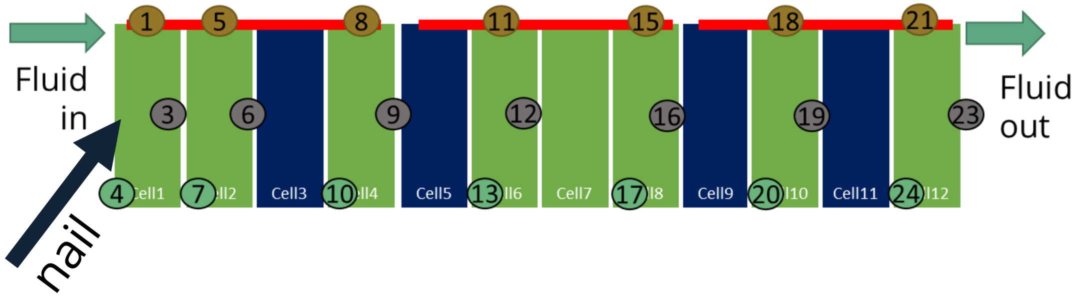
Module terminals

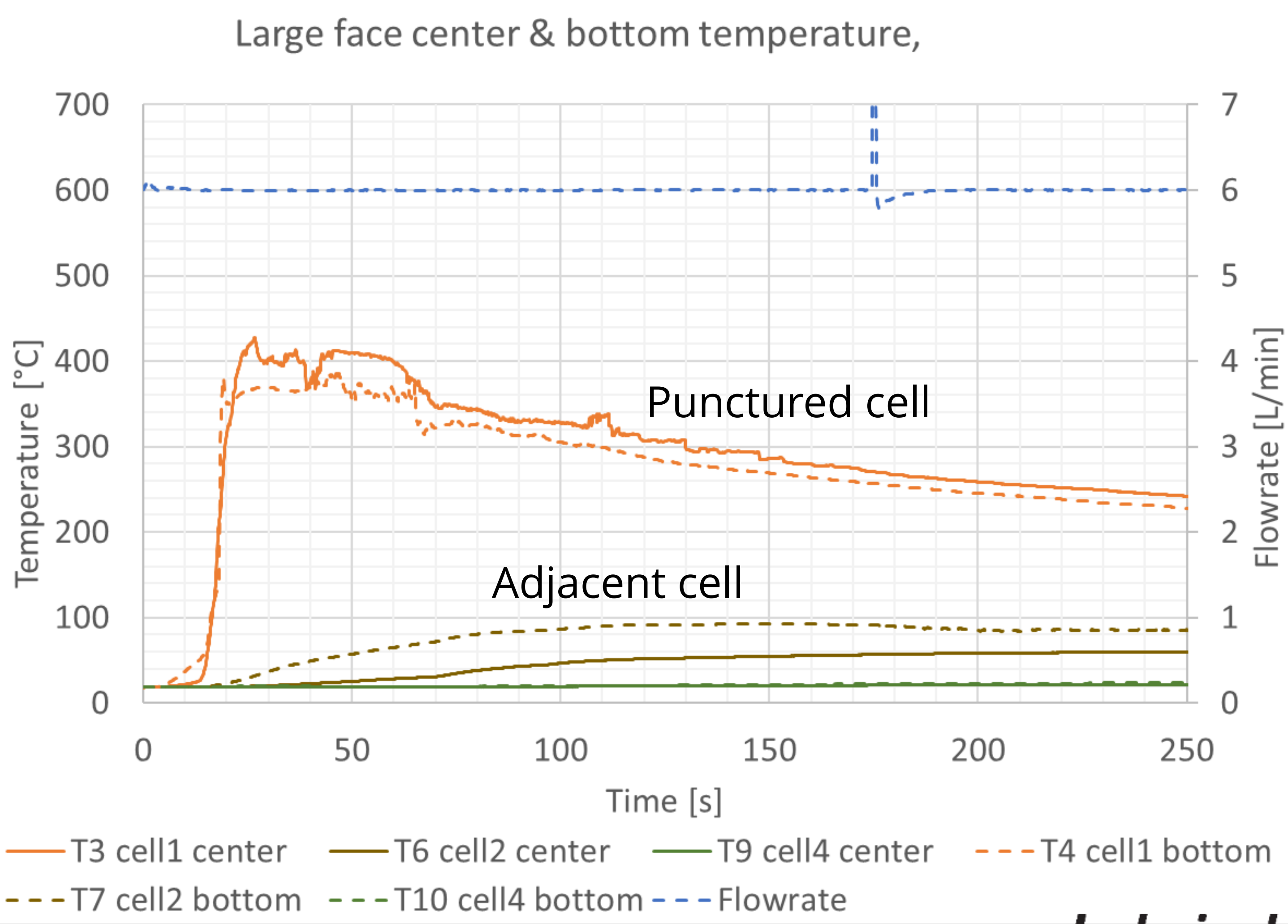
Nail

The cooling prevented the fire propagation

- Punctured cell temp. increased up to 400°C in 20s after the vent break.
- Constant flow rate @6L/min
- Adjacent cell temp. increased up to 92°C within 150s

No propagation to the adjacent cell





Data are courtesy of Lubrizol

The adjacent cell suffered but did not burn

- Adjacent cell partially discharged in the punctured cell until its internal fuse melt
- Gases were generated in the cell leading to swelling

<table>
<tr><th>Cell#</th><th>Electrical continuity</th><th>Voltage* [V]</th><th>Mass [g]</th><th>Swelling [mm]</th></tr>
<tr><td>1</td><td>yes</td><td>0</td><td>758</td><td>+8/-7</td></tr>
<tr><td>2</td><td>no</td><td>0</td><td>870</td><td>+12</td></tr>
<tr><td>3</td><td rowspan="10">no</td><td rowspan="2">3.1</td><td>863</td><td>+0</td></tr>
<tr><td>4</td><td>862</td><td>+0</td></tr>
<tr><td>5</td><td rowspan="2">3.1</td><td>866</td><td>+0</td></tr>
<tr><td>6</td><td>863</td><td>+0</td></tr>
<tr><td>7</td><td rowspan="2">3.1</td><td>864</td><td>+0</td></tr>
<tr><td>8</td><td>864</td><td>+0</td></tr>
<tr><td>9</td><td rowspan="2">3.2</td><td>865</td><td>+0</td></tr>
<tr><td>10</td><td>861</td><td>+0</td></tr>
<tr><td>11</td><td rowspan="2">3.1</td><td>863</td><td>+0</td></tr>
<tr><td>12</td><td>861</td><td>+0</td></tr>
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Lots of ashes

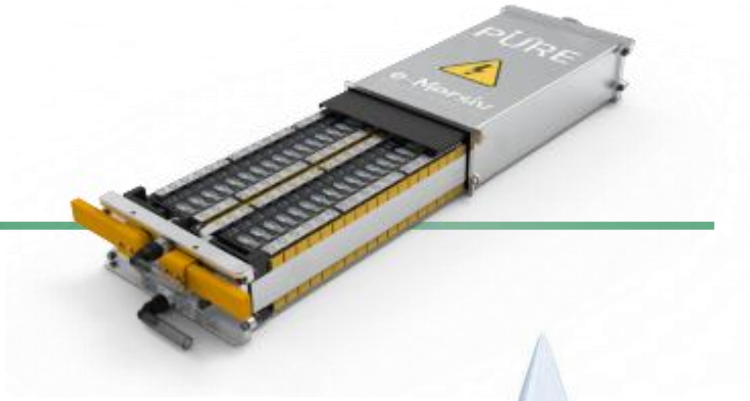
Puffy adjacent cell

Battery design to be improved for greater robustness

* measured after a complete discharge process and a several days of relaxation

Data are courtesy of Lubrizol

Conclusion



- We have demonstrated that immersion allows:
  - | Increased thermal performances
  - | Increased safety levels
  - | No extra cost nor weight compared to current battery designs

  → **Immersion is a promising technology to enable fast charging**

- **The cooling fluid becomes a key component**:
  - | The fluid has to be:
    - Good heat-transfer fluid
    - Robust dielectric properties
    - Easily pumped at all temperatures
    - Safe: not flammable & environment friendly
  - | Methods to be defined to select and characterize the fluid
    - Avoid over-engineering due to engine oil or transmission standards (higher temperature / gears /...)
    - Use standards from different domains (electric transformers / air compressors / ...)
    - Specific tests to be built or methods to be adapted
    - Define relevant accelerated aging test

Exoes' contact in China

THANK YOU

FOR YOUR ATTENTION

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Questions

Special thanks to Lubrizol for sharing data