Battery Thermal Management: Immersive Cooling and Next Generation Dielectric Fluids

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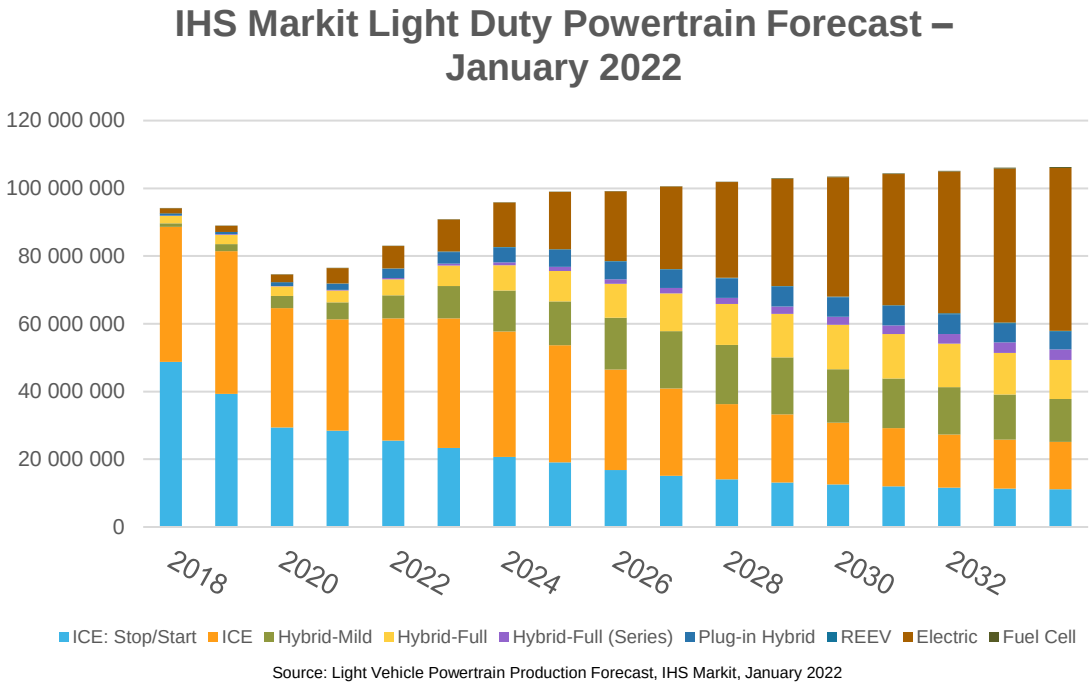
Electric Vehicle Outlook

- New powertrains growth driven by electrification
- Internal combustion engines production peaked in 2018
- Extending battery life directly impact total cost of ownership



Source: Light Vehicle Powertrain Production Forecast, IHS Markit, January 2022

EV Fast-Charging, C-Rate and Heat Generation

Range added per 10-minute charge

4Km	7Km	22Km	49Km	343Km
3.7-7.7kW Charger	7.7kW Charger	22kW Charger	50kW Charger	350kW Charger

Definition of C-Rate

$$C = \frac{Charging\ Power}{Battery\ Capacity} = h^{-1}$$

C-Rate	Charge Time
0.25	4 hours
1	1 hour
3.5	17 minutes

Heat Generation

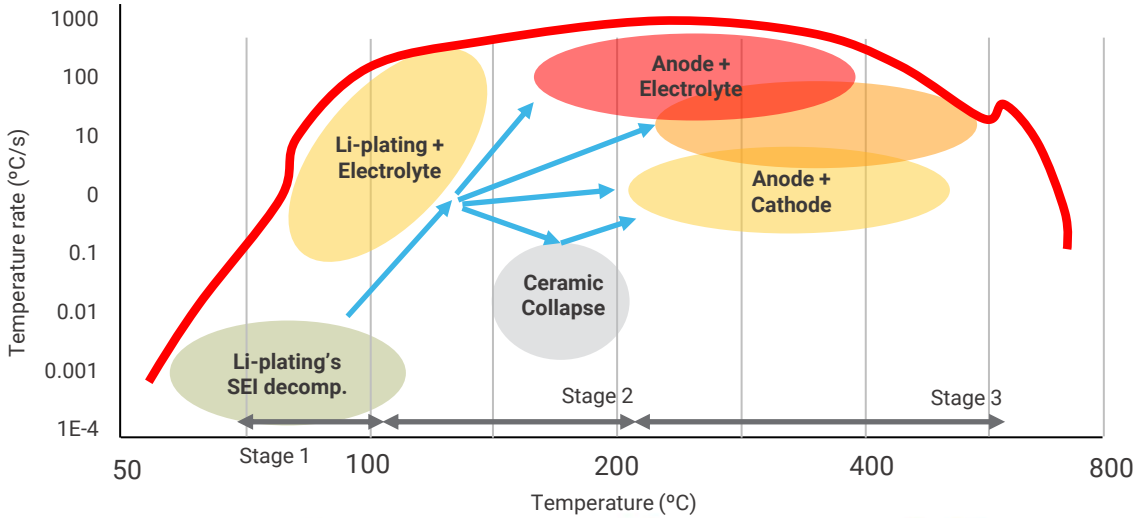
$$Heat = Current^2 * Resistance$$

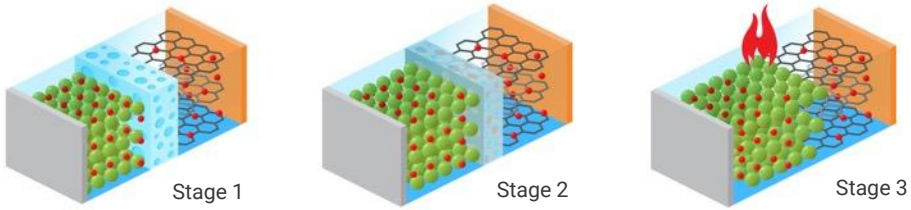
EV Charging Basics: How Long It Will Take To Replenish Range? (insideevs.com)

Charging speeds and outcomes are indicative. Actual charging speed and vehicle battery capacity depends on the vehicle being harged. Actual results will vary from vehicle to vehicle.

Temperature Degradation of Li-ion Battery

- High/low temperatures degrade batteries leading to failure and thermal runaway
- Thermal management of batteries is key to maintain safe operation
- Rapid charging creates more heat and challenges to maintain safe battery operation

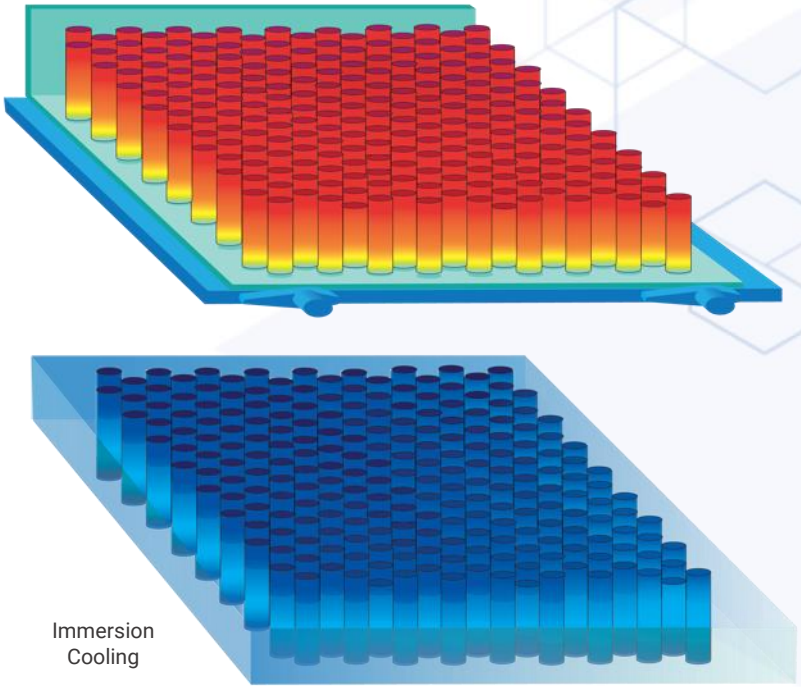




Lithium-ion battery fast charging: A review - ScienceDirect

Immersion Cooling as a Solution

- Direct coolant contact with cells improves heat transfer, reducing peak temperature, enabling smaller bus bars and smaller battery packs
- Provides more uniform cooling across entire battery pack to increase battery lifetime
- Can prevent propagation of thermal runaway

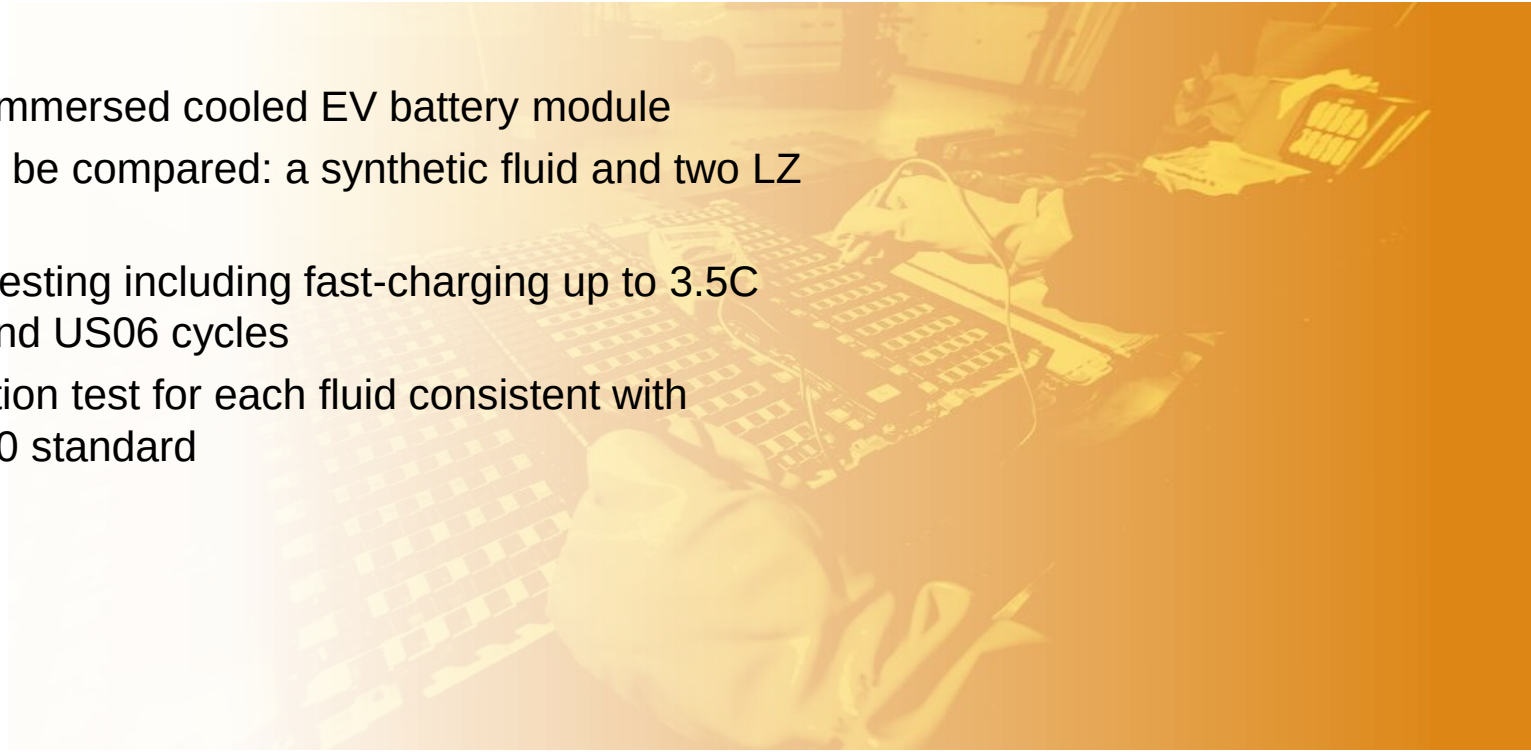


The Importance of the Heat Transfer Fluid

- Heat transfer performance is key enabler of this technology
  - Enables fast-charging and improves battery pack longevity
  - Improves safety by mitigating thermal runaway (TR) and cell-to-cell propagation
- Material compatibility is essential in system design
- Solution is fluid and hardware dependent
  - Fluid heat transfer capability and flow dynamics
  - Fluid-Hardware material compatibility
  - Hardware design to ensure optimal heat transfer and mechanisms to handle gas production during TR

Immersion Cooled Testing

Scope of External Testing with Exoes



- Testing of an immersed cooled EV battery module
- Three fluids to be compared: a synthetic fluid and two LZ fluids
- Performance testing including fast-charging up to 3.5C using WLTP and US06 cycles
- A nail penetration test for each fluid consistent with GB38031-2020 standard

Test Fluids

	Lubrizol TMF01**	Lubrizol TMF02**	Synthetic
Viscosity (cSt)	1.9	2.5	7.9
D92 Flash Point (ºC)	72	104	149
Specific Gravity	0.76	0.78	0.79
Specific Heat (J/g-K)	2.101	1.885	1.948
Thermal Conductivity (W/m-K)	0.106	0.122	0.136
Dielectric Strength (MV/m)	22.2	27.4	-
Boiling Range (ºC)	203 - 250	210 - 259	214 - 368
D97 Pourpoint (ºC)	-40.0	-42.0	-73

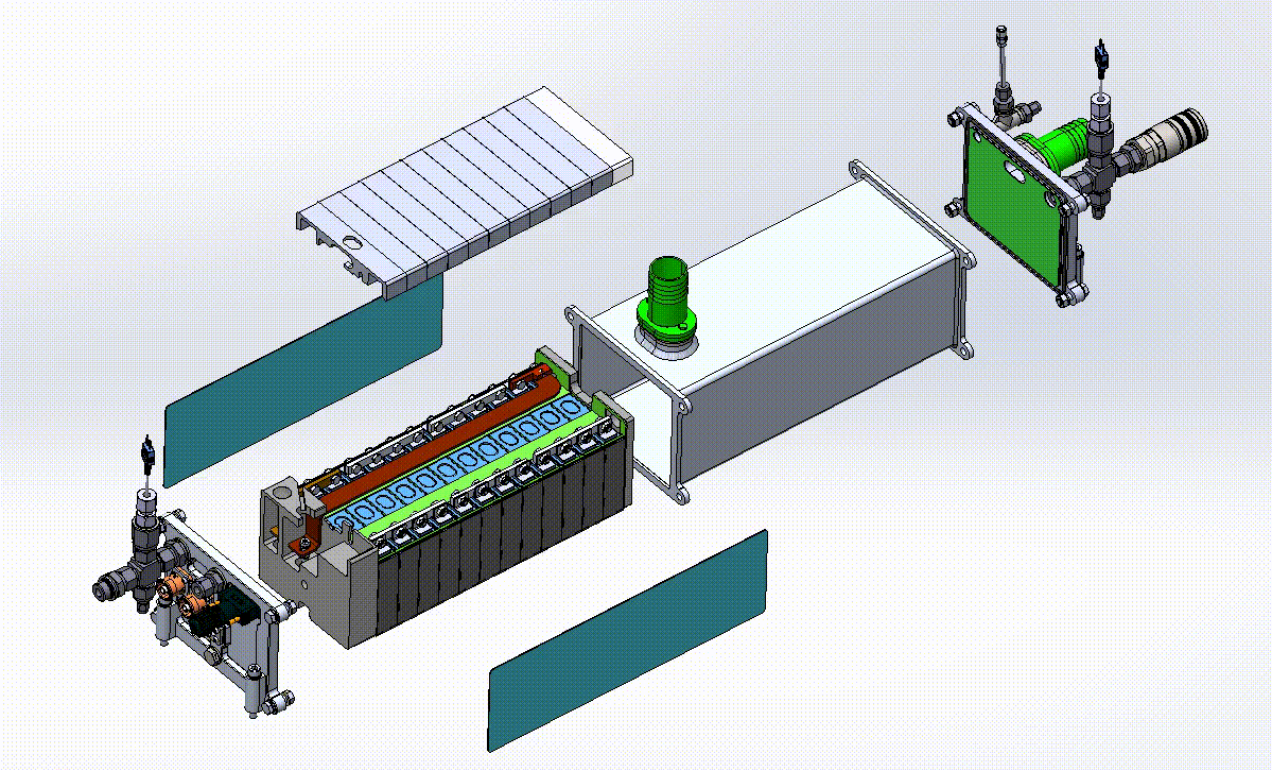
***All measurements at 25ºC**
**** TMF: Thermal Management Fluid**

Performance Testing Parameters

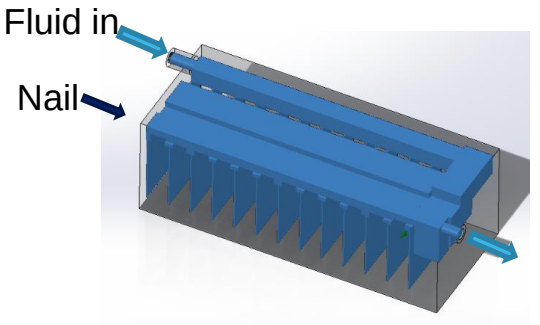
Test #	Description	System Initial Temp [°C]	Fluid Temp [°C]	Flow Rate [LPM]	Charge Rate	Discharge Rate
0	SoC + DCIR + OCV Evaluation	25	-	-	C/3	C/3
1	Sensor Cal	25	25	3	0	0
2,3,4	Pressure Drop	-	0,25,40	6	0	0
	DC-IR Cell Resistance	-	0,25,40	6	3.5C	3.5C
Ref	SoC + DCIR + OCV Evaluation	25	25	1	1C	1C
5	Steady State Thermal Evaluation	-	15,25	1,3,6	2-3.5C	2-3.5C
Ref	SoC + DCIR + OCV Evaluation	25	25	1	1C	1C
6	SoA C-rate Nominal Temp	25	25	1,3,6	2C	1C
7	High C-rate Nominal Temp	25	25	1,3,6	3.5C	1C
Ref	SoC + DCIR + OCV Evaluation	25	25	1	1C	1C
8	Cold Start High C-rate Low Flow	0	25	1	3.5C	1C
9	Cold Start High C-rate High Flow	0	25	3	3.5C	1C
10	Hot Start High C-rate Low Flow	40	25	3	3.5C	1C
11	Hot Start High C-rate High Flow	40	25	6	3.5C	1C
Ref	SoC + DCIR + OCV Evaluation	25	25	1	1C	1C
12	Cold Start + 3x WLTP	0	25	3	3.5C	WLTP Cycle
13	Cold Start + 3x US06	0	25	3	3.5C	US06 Cycle
14	Hot Start + 3x WLTP	40	25	3	3.5C	WLTP Cycle
15	Hot Start + 3x US06	40	25	3	3.5C	US06 Cycle
Ref	SoC + DCIR + OCV Evaluation	25	25	1	1C	1C

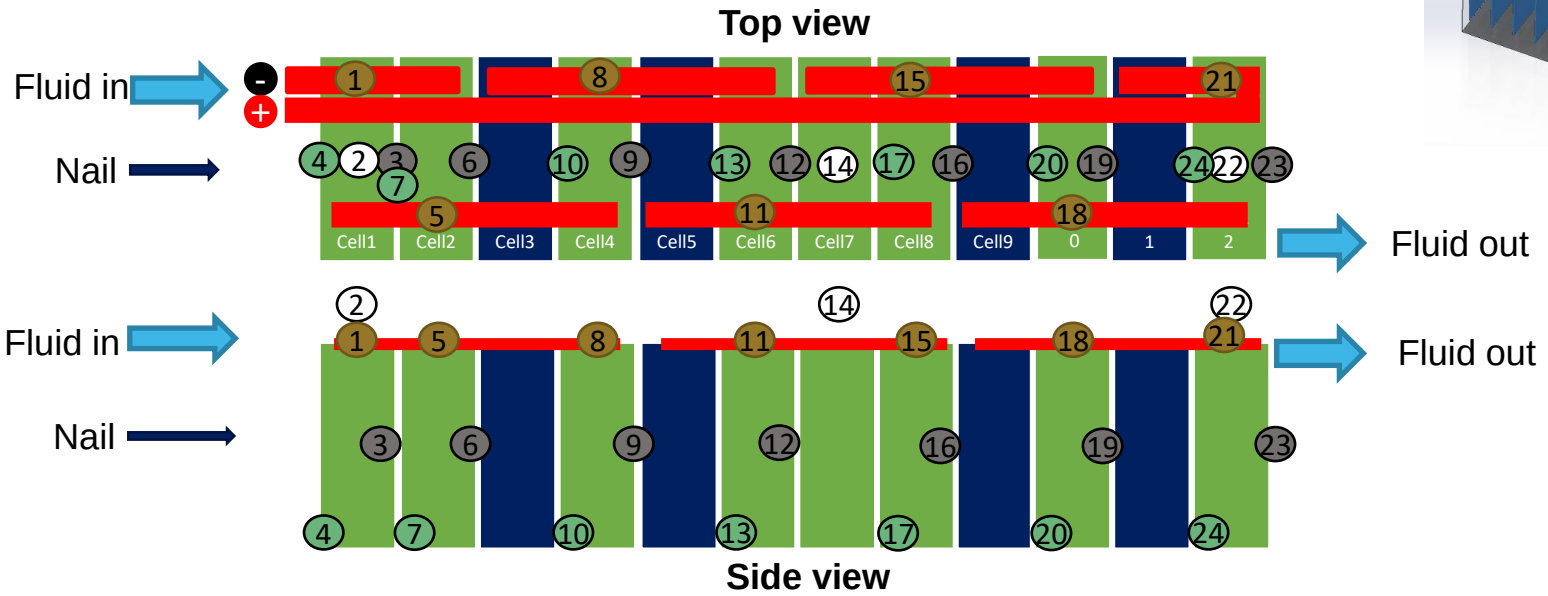
The Testing Module

- 12 Prismatic Cells
- 50 Ah cells in 2P6S
- 1.5 mm spacing between cells
- 1.2 L module fluid volume



Testing Module – Instrumentation





Legend: Thermocouple

Non Measured cell

Measured cell

Busbar

Thermocouple location:

Bottom

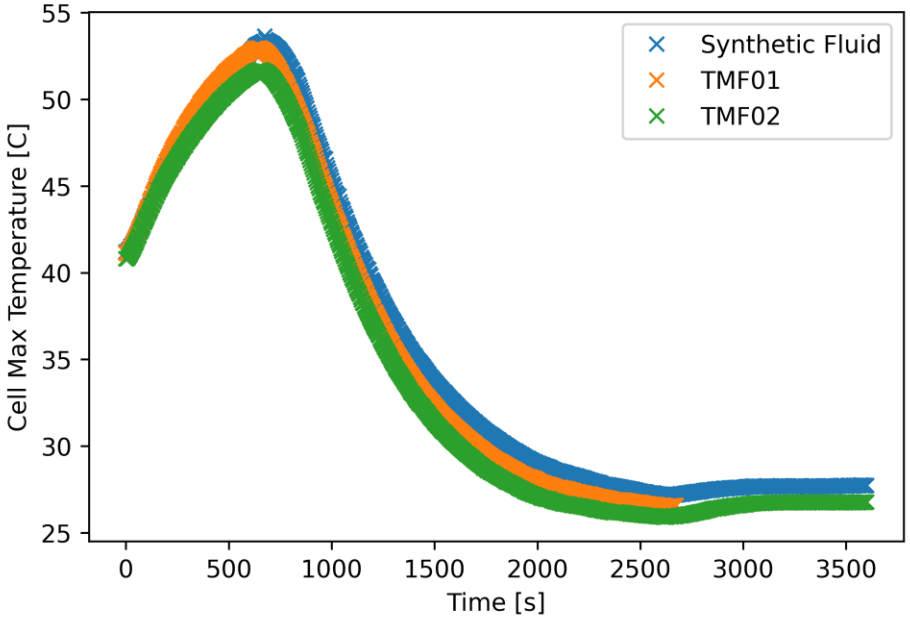
On vents

Busbar

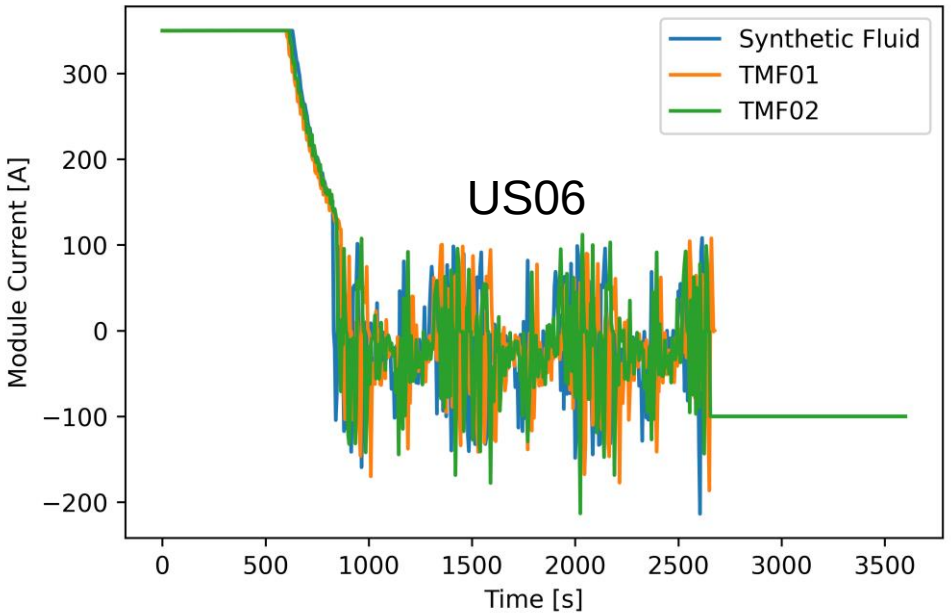
Middle

Performance Testing Results

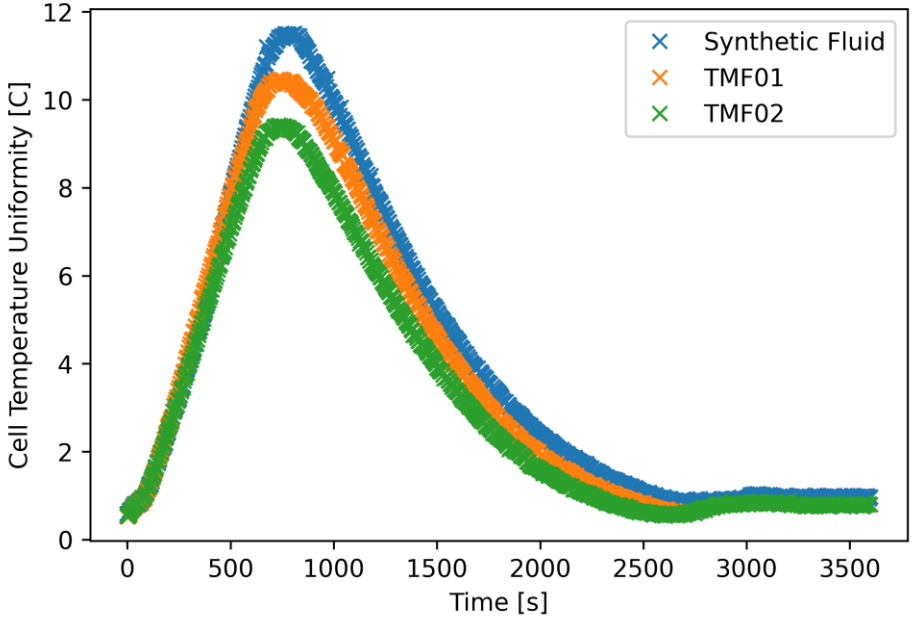
Performance Test Results – Cell Temperature



3.5C Charge



Performance Test Results – Cell Temp Uniformity



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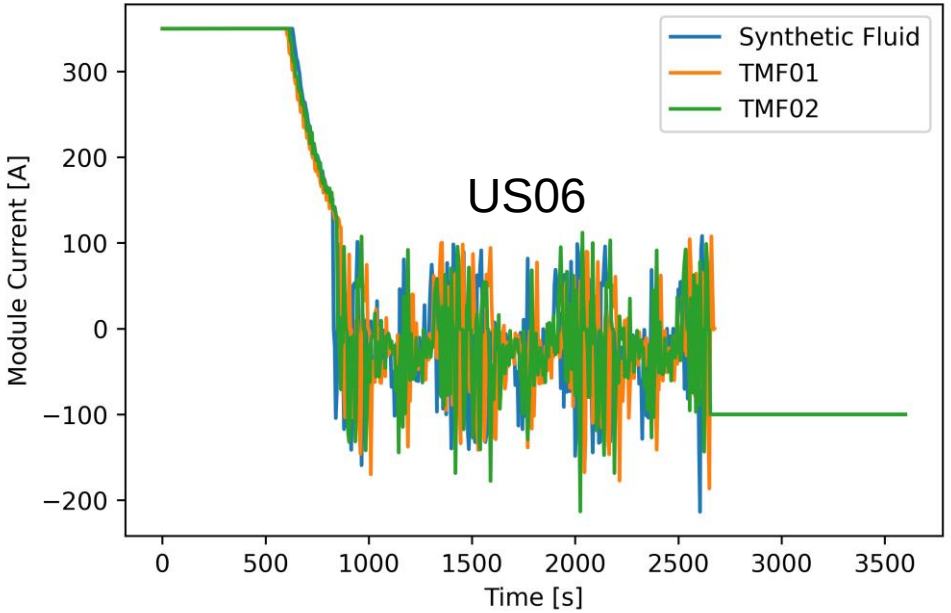
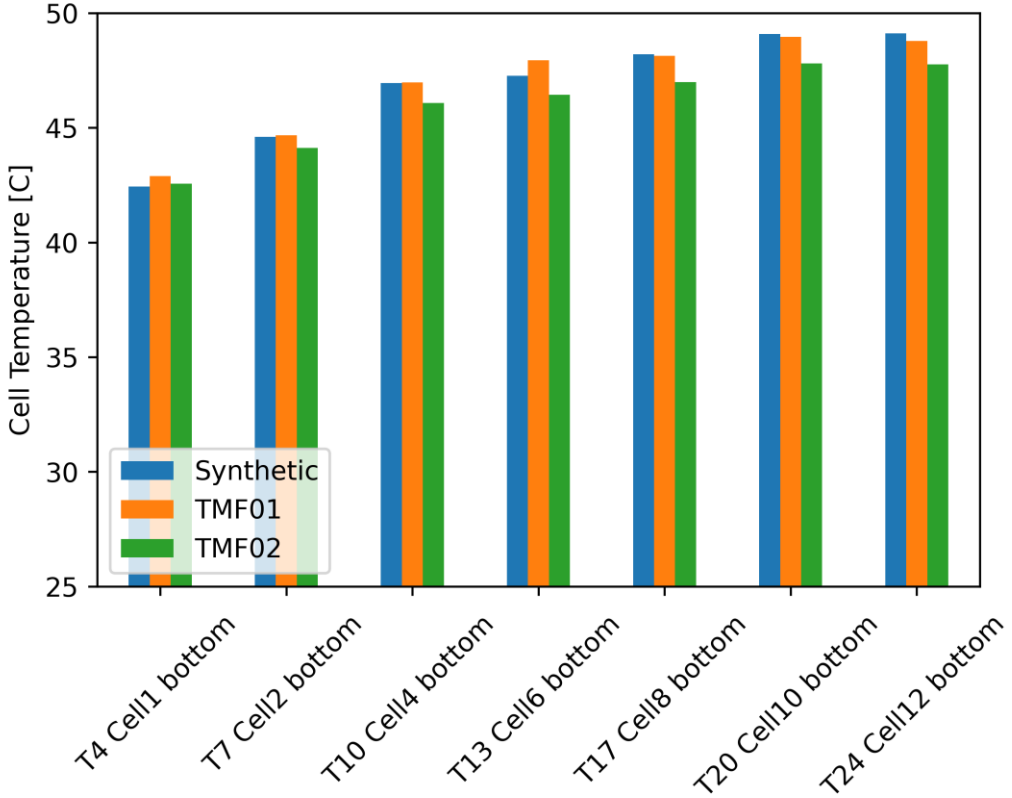
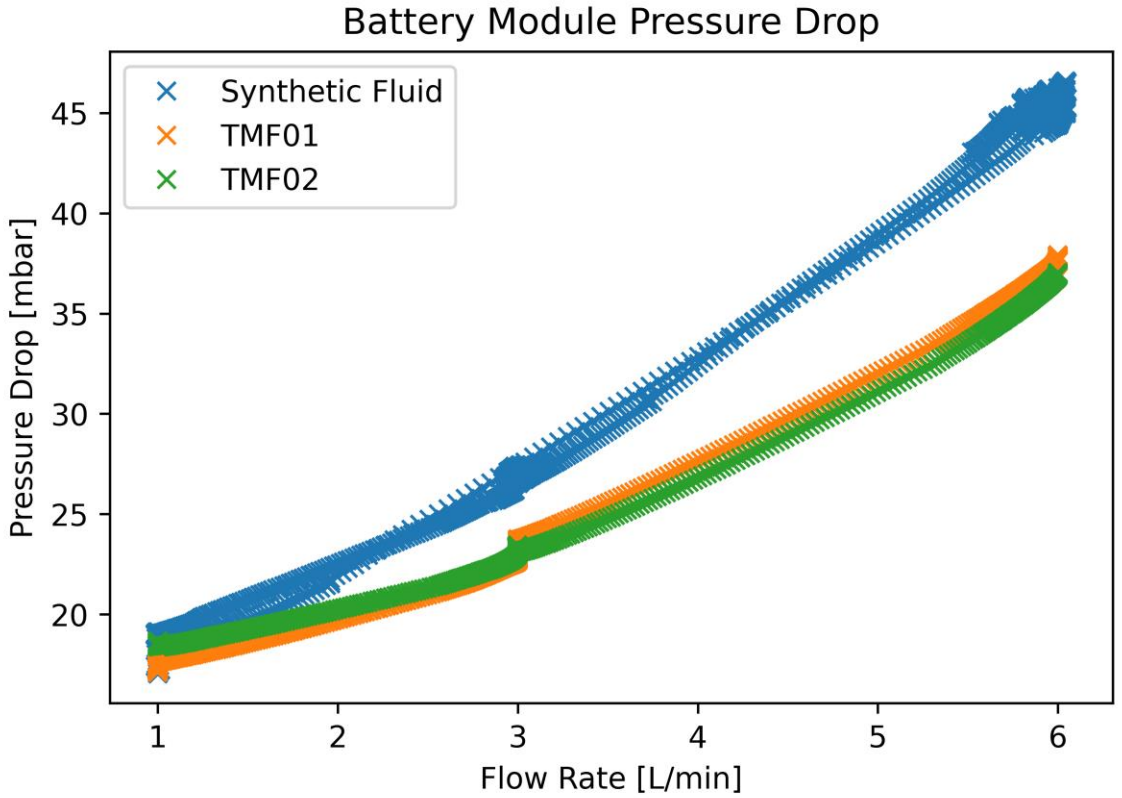


Performance Test Results – Cell Temperature Profile

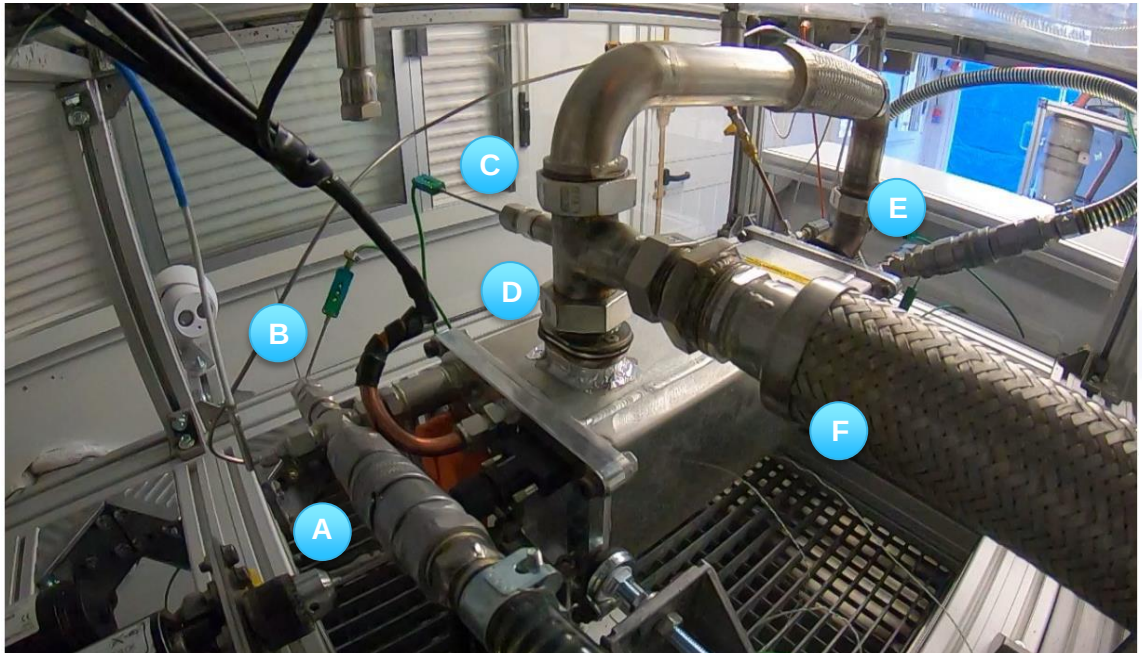


Performance Test Results – Pressure Drop



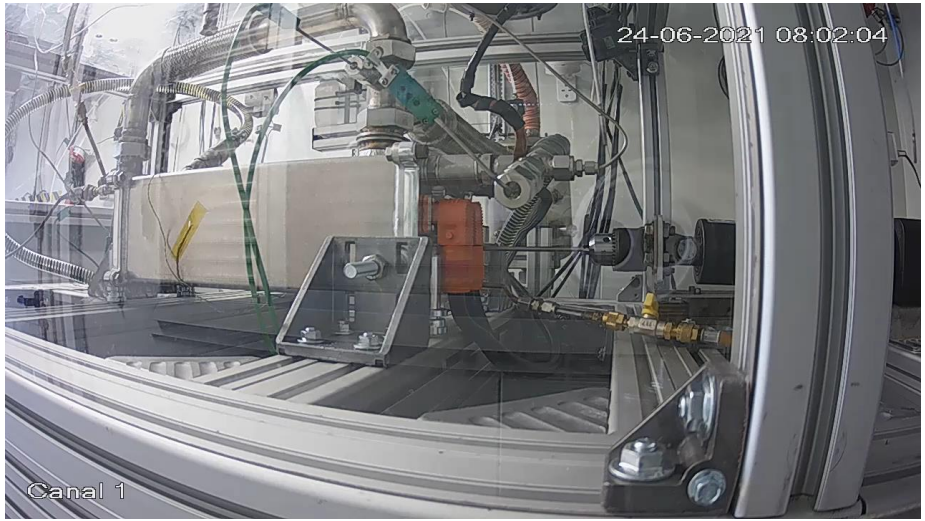
Nail Penetration Test

Nail Penetration Test – Setup

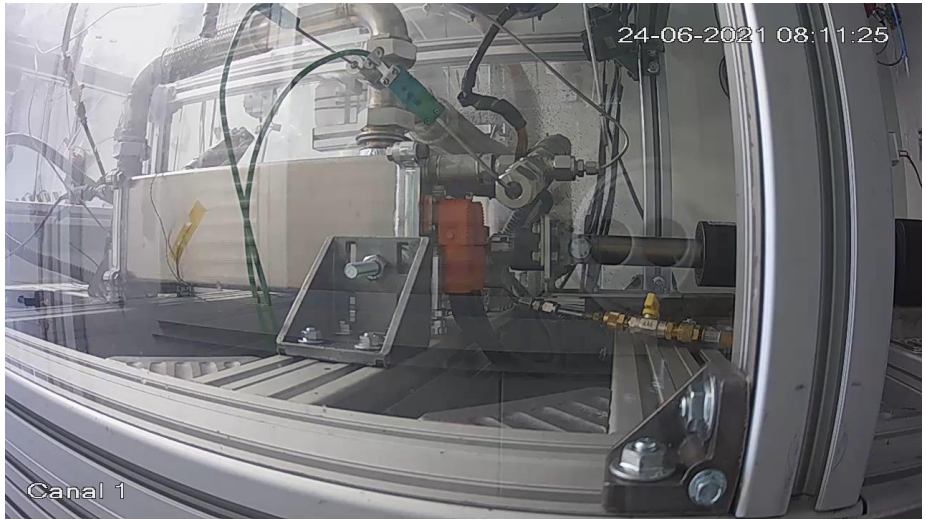


- **A** Nail
- **B** Inlet + Thermocouple
- **C** Gas Thermocouple
- **D** Burst Disc
- **E** Outlet + Thermocouple
- **F** Gas Vent Line

Nail Penetration Videos – Synthetic Fluid

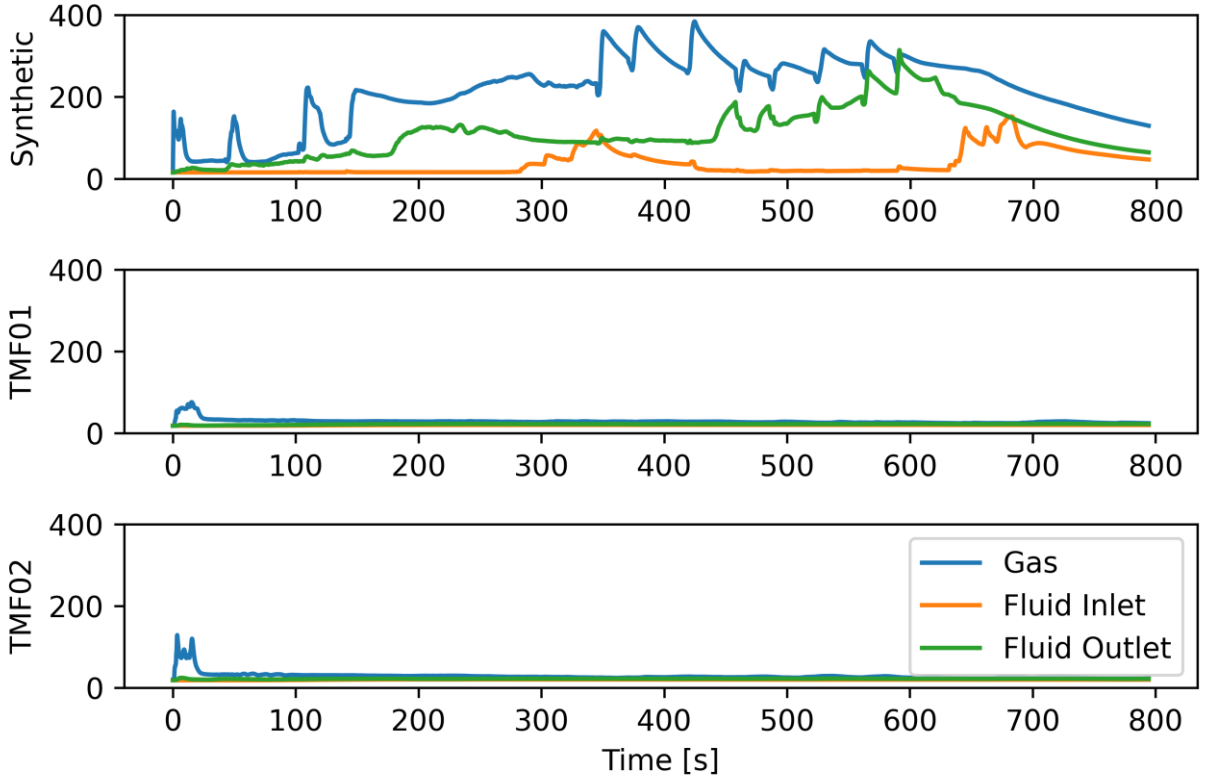


Test Start

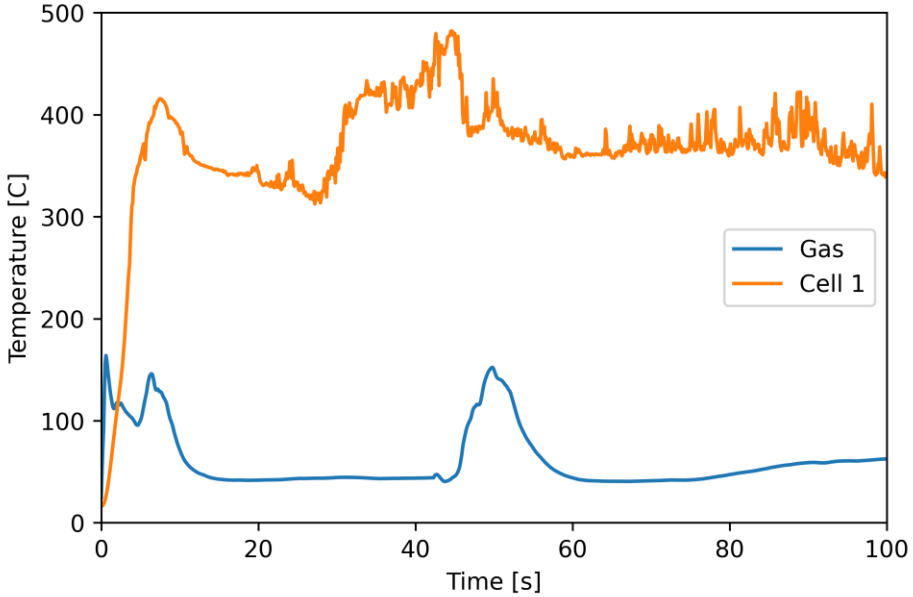


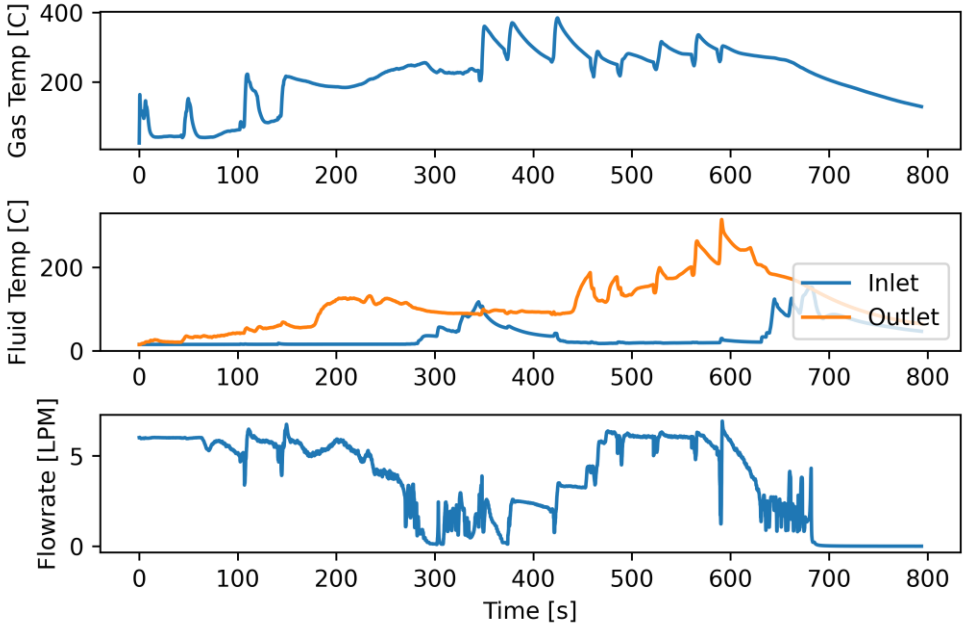
Module Failure

Nail Penetration Test – Results

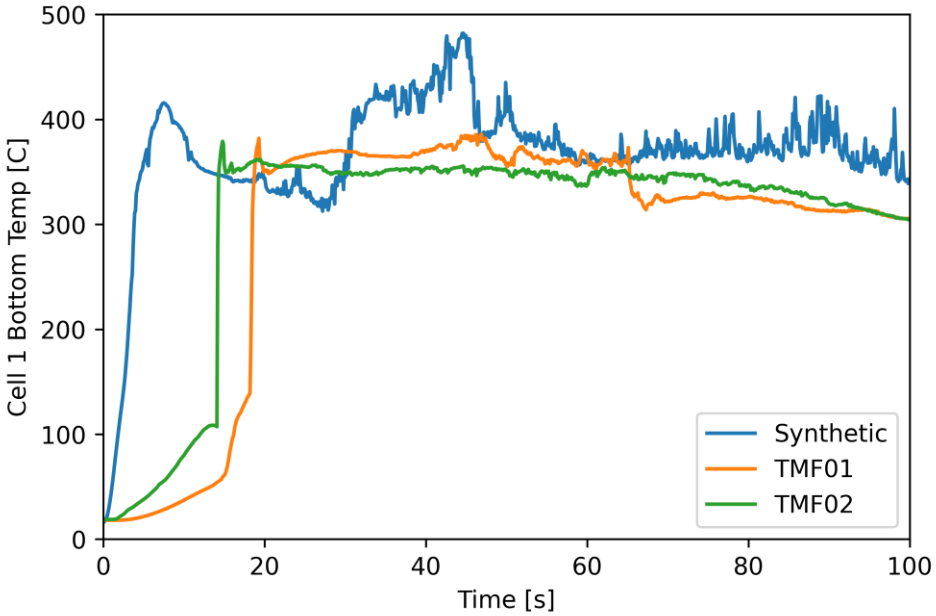


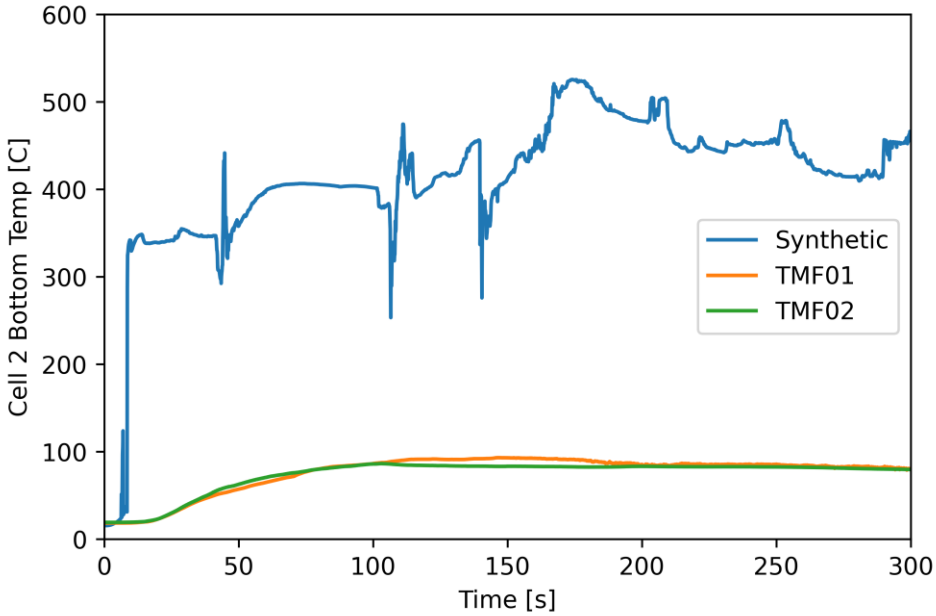
Nail Penetration – Synthetic Fluid Test





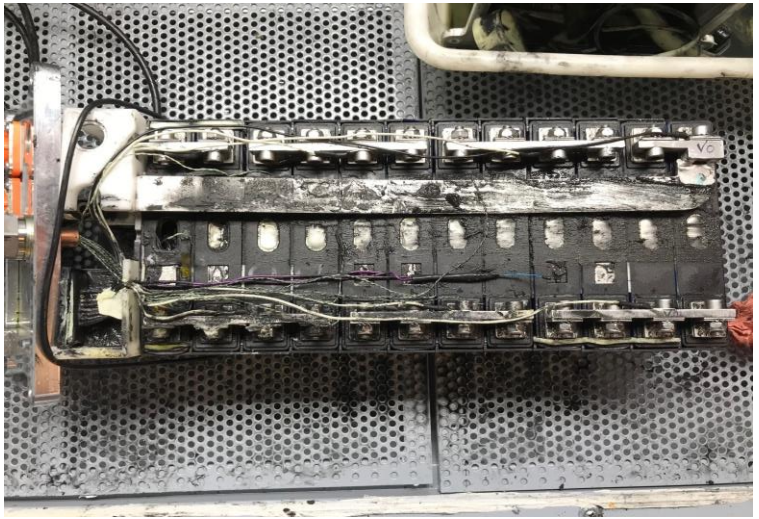
Nail Penetration – Cell Temperature Comparison





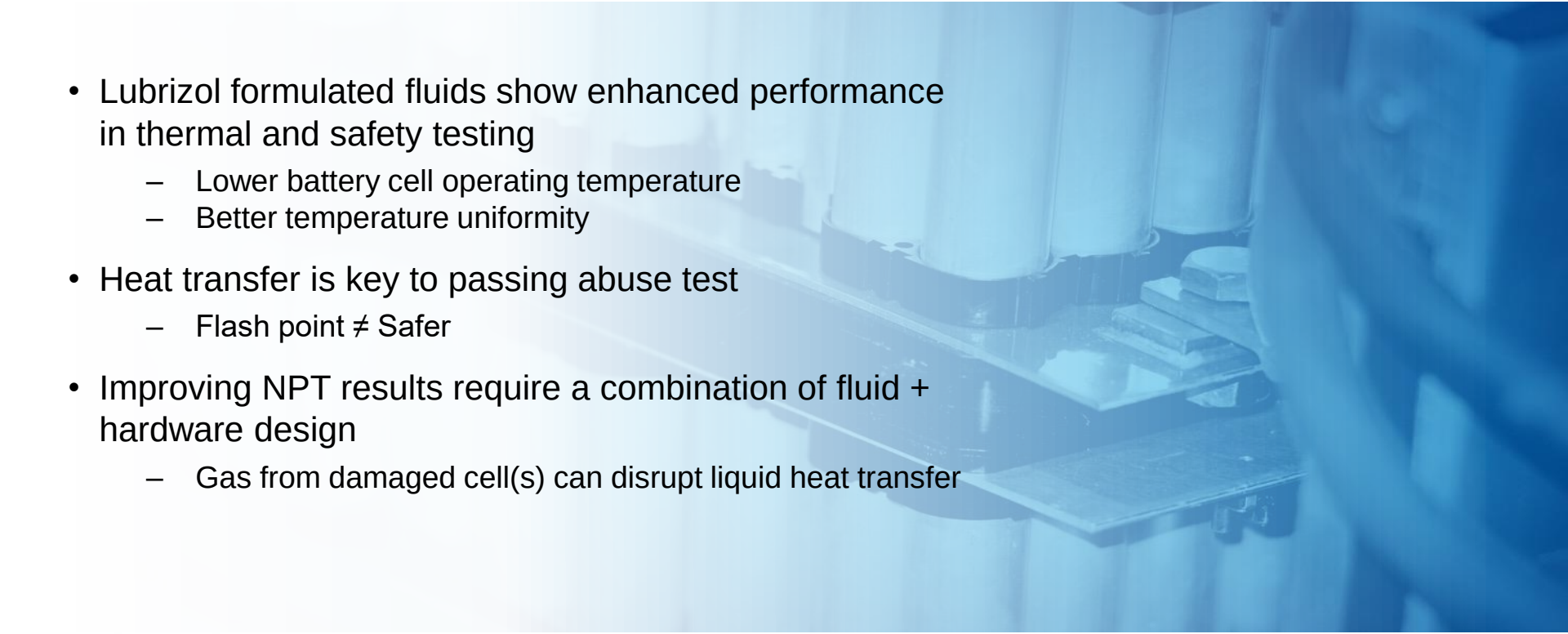
Nail Penetration Postmortem

Synthetic



Lubrizol TMF02

Summary



- Lubrizol formulated fluids show enhanced performance in thermal and safety testing
  - Lower battery cell operating temperature
  - Better temperature uniformity
- Heat transfer is key to passing abuse test
  - Flash point ≠ Safer
- Improving NPT results require a combination of fluid + hardware design
  - Gas from damaged cell(s) can disrupt liquid heat transfer

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THANK YOU!

Thermal Management for EV/HEV

Thermal Management Fluids for e-mobility

As hybrid electric vehicle and electric vehicle markets continue to expand, so does our range of solutions that optimize performance. Our specialized thermal management fluids enable efficient performance and durability of batteries and electronics prone to high temperature degradation.

For more details scan this link or visit www.lubrizol.com/Thermal-Management

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