Battery Pack Design with Immersive Cooling using GT-SUITE and GT-Converge

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SMART TECHNOLOGY FOR SMARTER MOBILITY

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Valeo : automotive supplier and partner to automakers worldwide

17.3BN
Total sales

103,300
employees

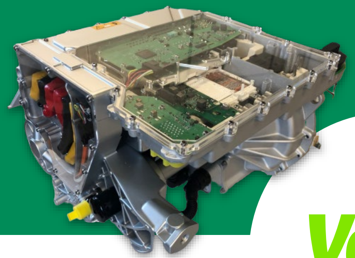
31
countries

64
R&D centers

#1
IN ELECTRIFICATION

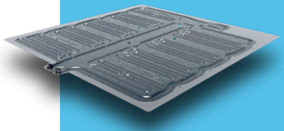
#1
IN ADAS

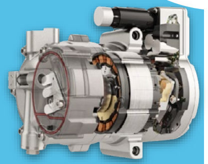
POWERTRAIN

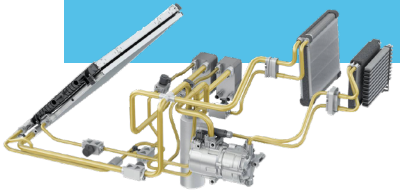


COMFORT & DRIVING ASSISTANCE

THERMAL







VISIBILITY

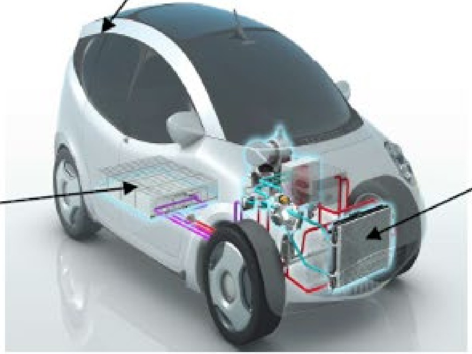
01

Introduction : Battery Thermal Management System

Introduction : Thermal Systems for EV functions

- **Cabin comfort**
  - → Welcome comfort
  - → Cabin cooling in summer : Electrical air conditioning
  - → Cabin heating : Additional Heating using
    - – HV heating completed by direct/Indirect heat pump
    - – Recovery from battery & powertrain heat losses

- **Battery thermal management**
  - → Pre – Heating for power availability or quick charging
  - → Cooling when charging
  - → Cooling during e-drive



- **Powertrain cooling**
  - → Cooling of e-motor & electronics
  - → Waste heat recovered for cabin heating

→ **Energy Efficiency for optimium vehicle range**
→ **Thermal loops interaction for better energy recovery**
→ **Modular solutions for easier diversity management**

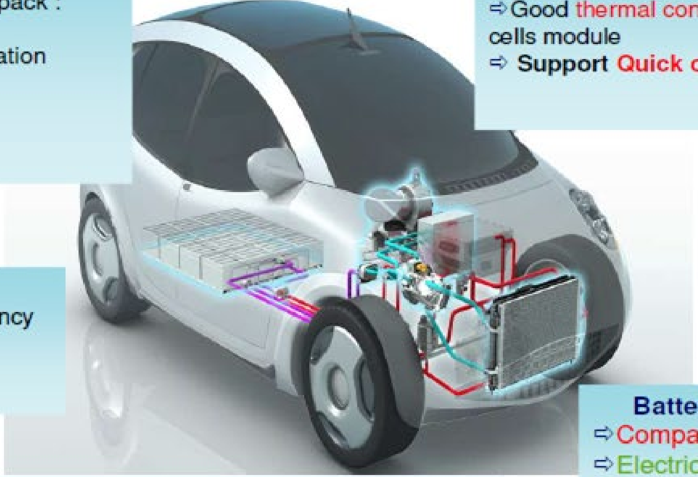
Introduction : Battery Thermal management Market Drivers

Reliability/Durability/safety

⇨ thermal repartition in battery pack : DT°cells<5K
⇨Mechanical resistance to vibration /shock
⇨Internal Cleanliness for compressor/pump
⇨Leak free (glycol)

Performance

⇨Heating & Cooling for 10°<T°cells<35°C
⇨Good thermal contact between cooler & cells module
⇨ **Support Quick charging trend**



Impact on EV range

⇨ Thermal energy efficiency
⇨Weight reduction

Battery Pack integration

⇨Compact & flat solution
⇨Electrical insulation

Cost

⇨Competitive System solution
⇨Lightweight design
⇨Standarization , modular design for HEV/PHEV/EV

Introduction : Battery trends & impact on Thermal management

Battery Heat rejection & Thermal needs for BTM at cell level depends on:

- Chemistry - Cathode composition (LFP, NMC, NCA)
- Electrolyte - liquid / hybrid / SS (solid-state)
- Physical design of the cell: dimensions anode - cathode (thickness,...)
- Charging Kinitics (Fast Charge / Ultra Fast Charge)

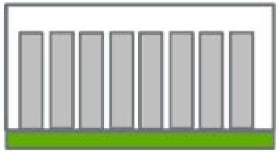
Battery C-rate = Power / Energy = Current / Capacity = A/Ah **[** h^{-1} **]**

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

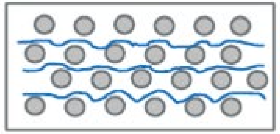
Relationship between Heat rejection and C-rate

Heat rejection = Resistance x Current² → 4C charge heats 4x more than 2C !

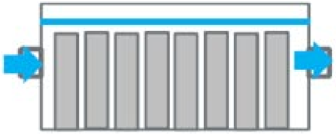
Battery Cooling Methods



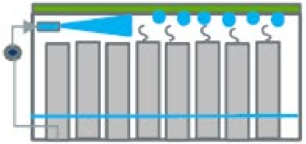
External plate cooling



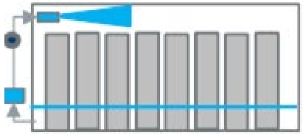
Internal plate cooling



Immersive cooling



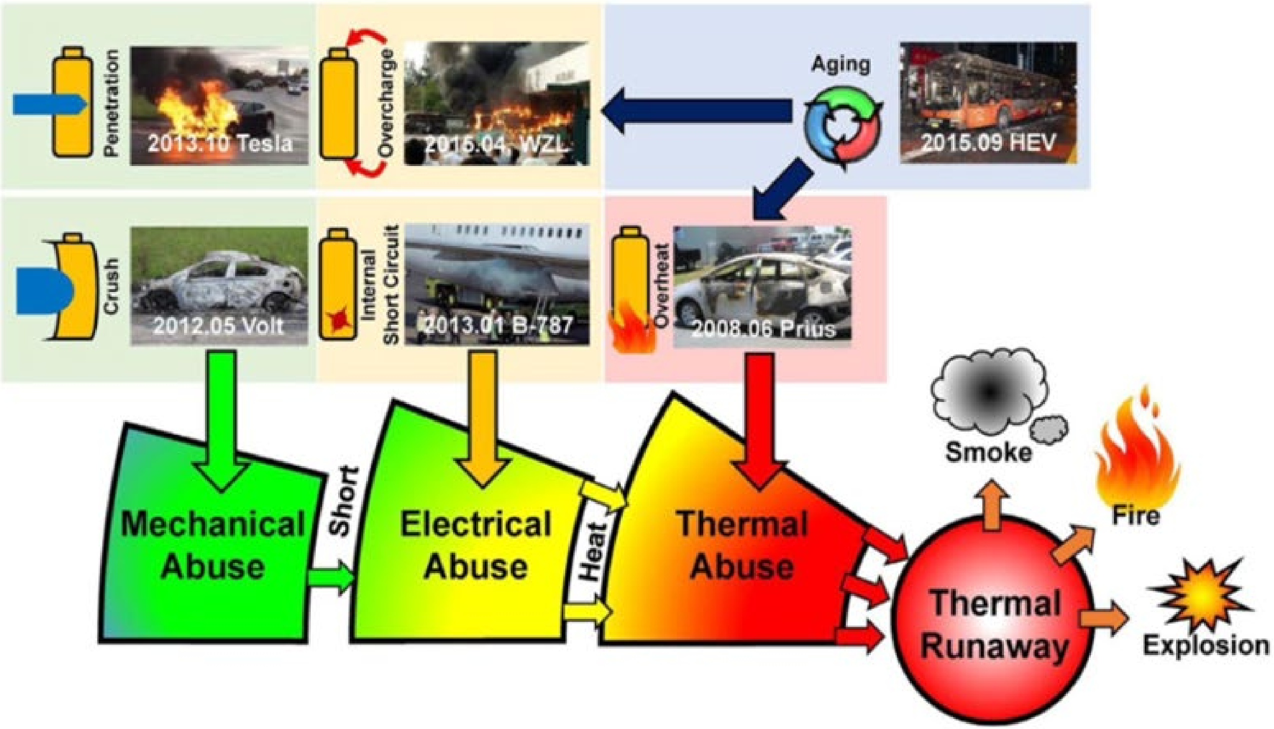
Diphasic cooling



Monophasic cooling

Immersive Cooling solution evaluated

Thermal Runaway Causes and Effects



Source : IFP Energies Nouvelles

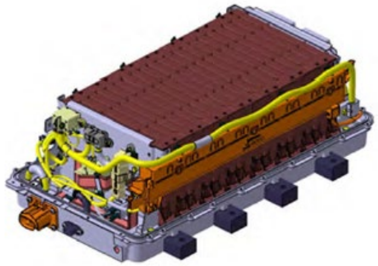
02

Simulation Methodology with GT-Suite and GT-Converge

Simulation Objective

Evaluated a design of immersion cooling during thermal runaway
Sensitivity study on several parameters

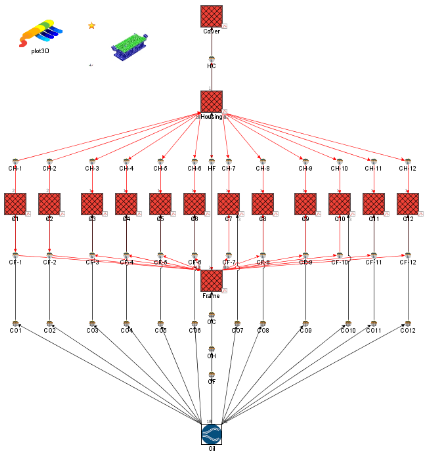
- Gap between cells
- Fluid characteristics
- Fluid flow rate



Pack example

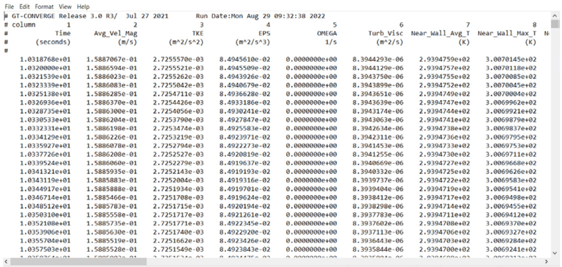
CFD Model on GT- Converge

Target is to get the convective heat transfer coefficient h.
For each fluid, 3 flow rate computed 150 / 300 / 500 l/h



Model GT-Converge

$$P = hS(T_{wall}-T_{fluid})$$



```
File  Edit  Format  View  Help
# GT-CONVERGE Release 3.0 R3/  Jul 27 2021      Run Date:Mon Aug 29 09:32:38 2022
# column         1              2              3              4              5              6              7              8
#             Time    Avg_Vel_Mag            TKE            EPS          OMEGA      Turb_Visc Near_Wall_Avg_T Near_Wall_Max_T  N
#        (seconds)          (m/s)      (m^2/s^2)      (m^2/s^3)            1/s        (m^2/s)            (K)            (K)
#
    1.0318768e+01  1.5887067e-01  2.7255570e-03  8.4945610e-02  0.0000000e+00  8.3944293e-06  2.9394759e+02  3.0070145e+02
    1.0320000e+01  1.5886594e-01  2.7255521e-03  8.4945509e-02  0.0000000e+00  8.3944129e-06  2.9394757e+02  3.0070118e+02
    1.0321539e+01  1.5886023e-01  2.7255262e-03  8.4943926e-02  0.0000000e+00  8.3943750e-06  2.9394755e+02  3.0070085e+02
    1.0323339e+01  1.5886083e-01  2.7255042e-03  8.4940679e-02  0.0000000e+00  8.3943899e-06  2.9394752e+02  3.0070045e+02
    1.0325138e+01  1.5886285e-01  2.7254711e-03  8.4936628e-02  0.0000000e+00  8.3943651e-06  2.9394749e+02  3.0070004e+02
    1.0326936e+01  1.5886370e-01  2.7254426e-03  8.4933186e-02  0.0000000e+00  8.3943639e-06  2.9394747e+02  3.0069962e+02
    1.0328735e+01  1.5886300e-01  2.7254056e-03  8.4930241e-02  0.0000000e+00  8.3943174e-06  2.9394744e+02  3.0069921e+02
    1.0330533e+01  1.5886204e-01  2.7253790e-03  8.4927847e-02  0.0000000e+00  8.3943063e-06  2.9394741e+02  3.0069879e+02
    1.0332331e+01  1.5886198e-01  2.7253474e-03  8.4925583e-02  0.0000000e+00  8.3942634e-06  2.9394738e+02  3.0069837e+02
    1.0334129e+01  1.5886226e-01  2.7253219e-03  8.4923971e-02  0.0000000e+00  8.3942311e-06  2.9394736e+02  3.0069795e+02
    1.0335927e+01  1.5886078e-01  2.7252794e-03  8.4922273e-02  0.0000000e+00  8.3941453e-06  2.9394733e+02  3.0069753e+02
    1.0337726e+01  1.5886208e-01  2.7252527e-03  8.4920819e-02  0.0000000e+00  8.3941255e-06  2.9394730e+02  3.0069711e+02
    1.0339524e+01  1.5886060e-01  2.7252279e-03  8.4919637e-02  0.0000000e+00  8.3940669e-06  2.9394727e+02  3.0069668e+02
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    1.0355704e+01  1.5885519e-01  2.7251662e-03  8.4923426e-02  0.0000000e+00  8.3936443e-06  2.9394703e+02  3.0069284e+02
    1.0357503e+01  1.5885528e-01  2.7251549e-03  8.4923843e-02  0.0000000e+00  8.3935844e-06  2.9394700e+02  3.0069241e+02
```
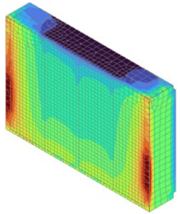

GT file to get Area, Heat Rejection and Wall Temperature



ParaView to get Fluid Temperature

	Nusselt					
	Fluid 1	Fluid 2	Fluid 3	Fluid 4	Fluid 5	Fluid 6
500 l/h	5,4	6,9	6,2	6,2	5,3	6,7
300 l/h	4,6	6,0	5,6	5,6	5,1	5,7
150 l/h	4,1	5,3	5,3	5,3	4,6	4,8

From 3D to 1D

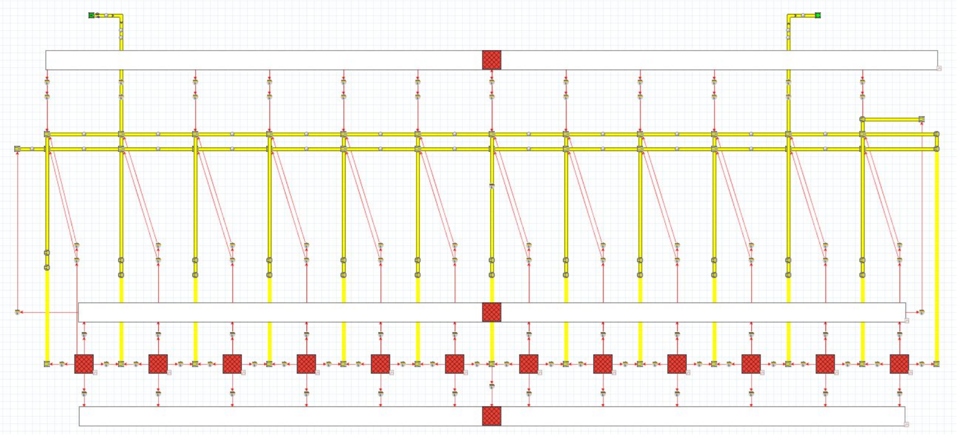
Why going to 1D :

- Lower computational cost, allowing parameter studies and DOEs
- Can be integrated in a system simulation with rest of vehicle
- Boundary conditions are easily changed

Only the fluid part is converted to 1D (with 1D Navier-Stokes), the thermal part remains 3D FE.
And the convective heat transfer coefficient comes from the CFD.

⇒ The 1D-3D approach allows the best balance between accuracy, flexibility and computational cost

1D Model in GT : thermal runaway propagation



GT model is operational :

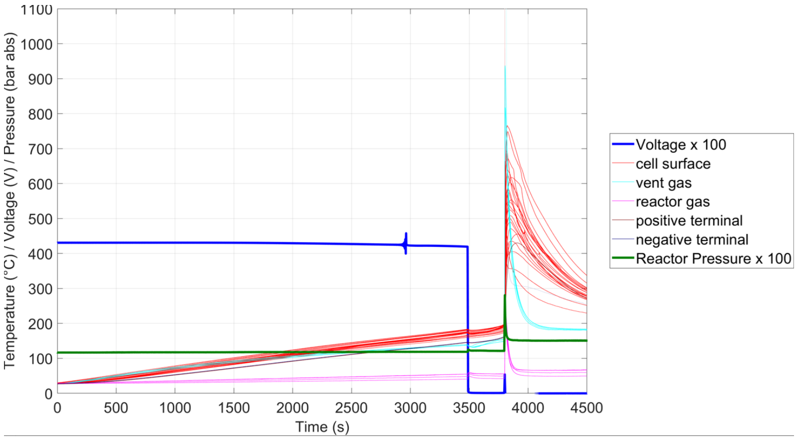
- 1D Navier Stokes on fluid with h coming from CFD
- Full 3D FE for thermal elements

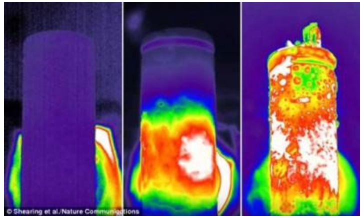
Target is to put one cell (cell 6 in the middle) in thermal runaway (by imposing heat rejection) and check what is the temperature of neighbouring cell
⇒ do we have propagation or not ?

What if we change flow rate ? Change fluid ? Change gap between cells ?

Thermal Runaway on 1 Cell

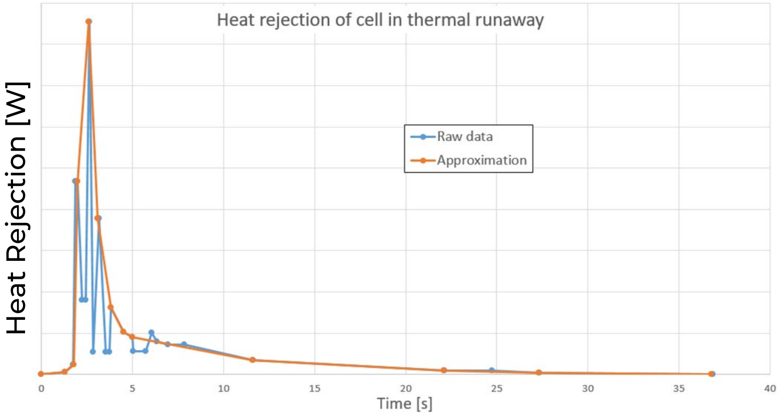
We imposed heat rejection of the cell undergoing thermal runaway, so we need to know how much that is.
Calorimetric test is the answer.





Thermal Runaway Example

Thermal runaway started when surface cell temperature reached 180°C



Heat rejection of the cell can be extracted from the temperature as function of time

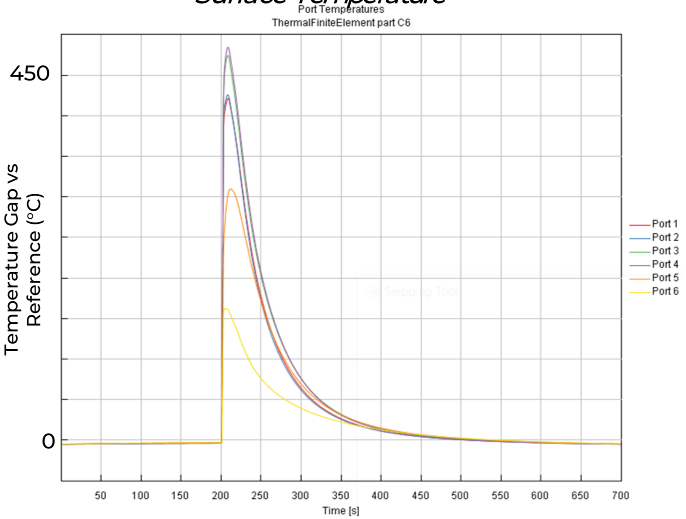
04

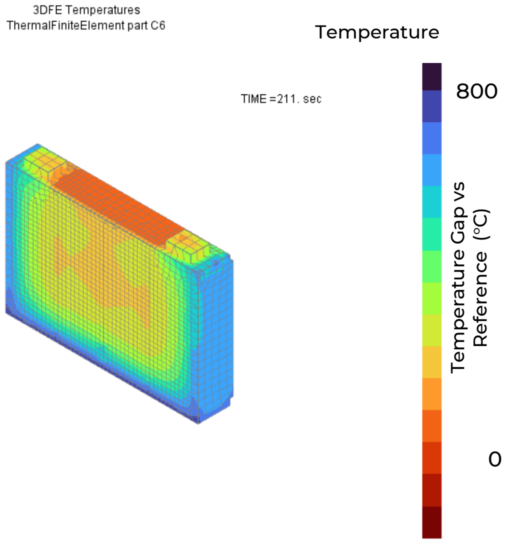
Synthesis / Results

Results on cell 6

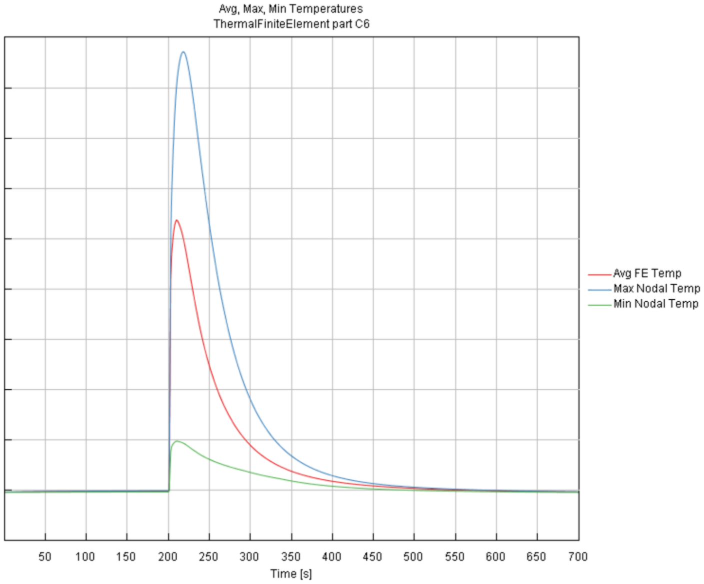
Cell 6 is the one undergoing thermal runaway.
Checking that the model is working.

Surface Temperature





Cell Volume Temperature (Min/Max/Avg)



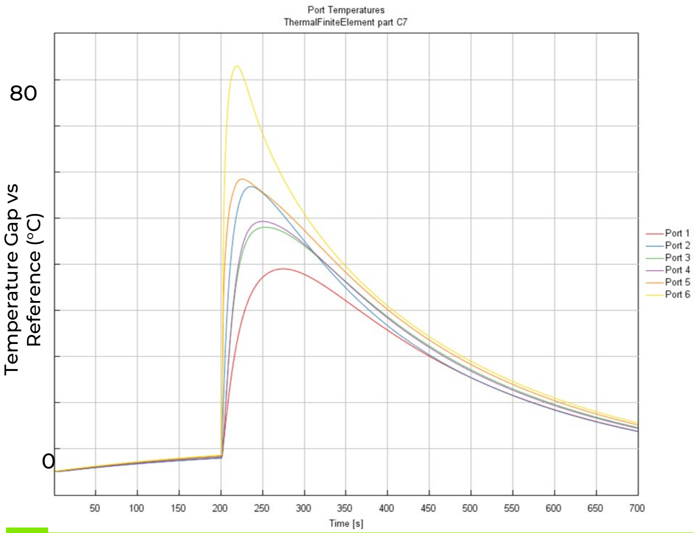
Material is anisotropic so each face has different temperature.
Average cell temperature is +250°C with hot spots at +800°C versus reference temperature
Total energy released is ~900 kJ

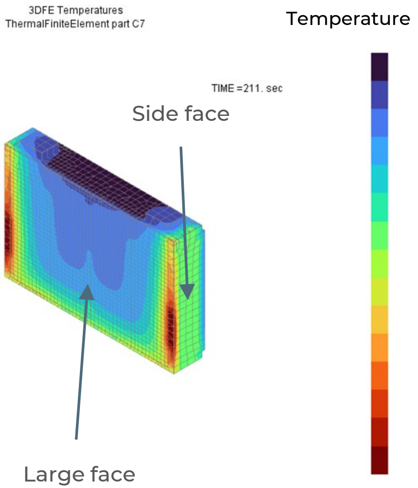
First Results - Reference simulation

- Gap 2 mm
- Flow rate 500 l/h
- Fluid 1
- Cell 6 goes in TR (with heat rejection imposed) at t=200s
- h coefficient based on CFD

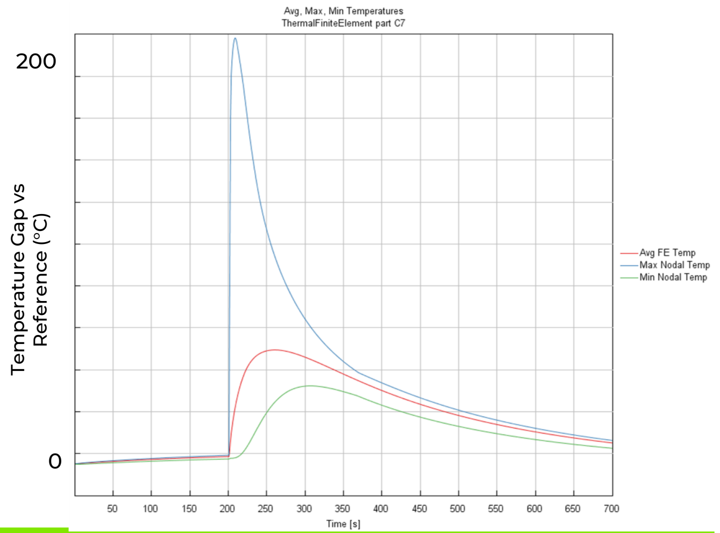
Results for cell 7, closest cell :

Surface Temperature



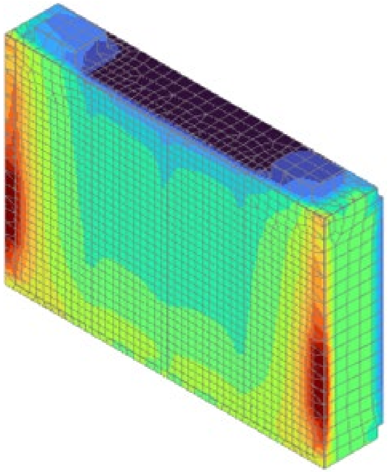


Cell Volume Temperature (Min/Max/Avg)



Maximum temperature is +195°C on the corners
Large face average is +54°C and side face average is +80°C

Results - impact of flow rate and gap



Sensitivity study on flow rate and geometry :

- Fluid 1
- Gap 1 / 2 mm
- Flow rate 150 / 500 l/h

Max Relative Temperature

		FLOW	
		150 l/h	500 l/h
GAP	1 mm	80	76
	2 mm	83	80

Avg Side Face Relative Temperature

		FLOW	
		150 l/h	500 l/h
GAP	1 mm	75	55
	2 mm	64	54

Avg Large Face Relative Temperature

		FLOW	
		150 l/h	500 l/h
GAP	1 mm	193	187
	2 mm	199	195

Higher flow rate improves all temperatures, especially the large face temperature.
Larger gap improves a lot the large face temperature at low flow but has almost no impact at high flow - with small negative impact on maximum temperature and side face temperature.

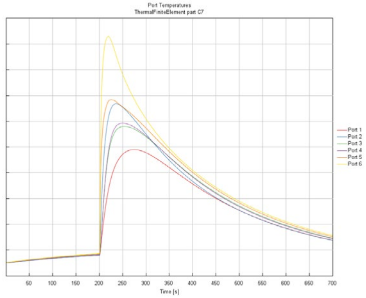
Results - impact of fluid

6 different fluids to compare

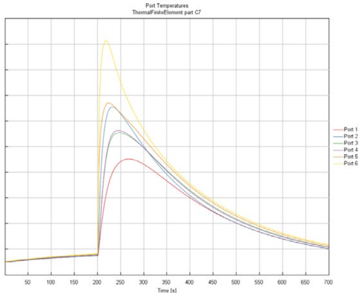
- 2 mm gap
- 500 l/h

	Max Rel. T	Large Face Rel. T	Side Face Rel. T
Fluid 1	195	54	80
Fluid 2	192	52	78
Fluid 3	193	52	79
Fluid 4	193	53	79
Fluid 5	195	53	80
Fluid 6	192	55	79

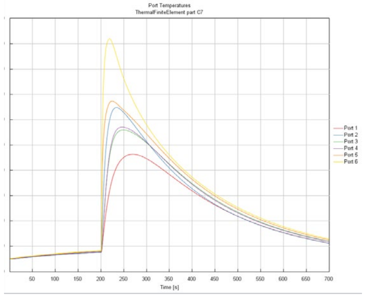
Fluid 1 :



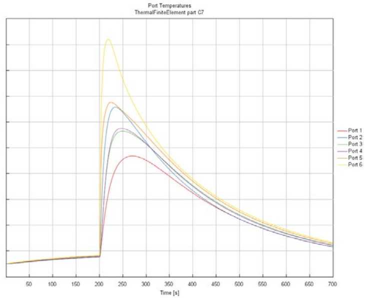
Fluid 2 :



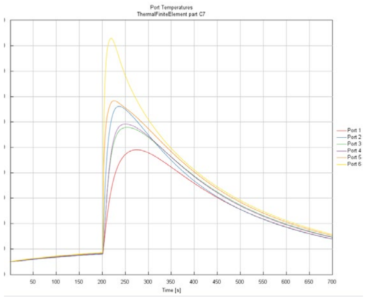
Fluid 3 :



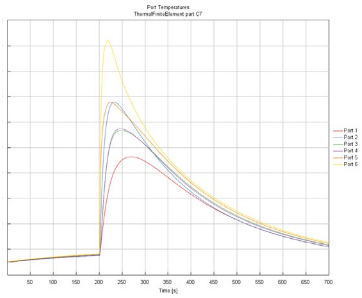
Fluid4 :



Fluid 5 :



Fluid 6 :



Very small impact of fluid on heat transfer
Can be explain by negligible h difference compared to the huge energy release

Next step and perspective

Improvement of model accuracy :

- Refine cell model by adding tab and aluminium casing.
- Replace imposed heat rejection with a complete chemical model using AutoLion

Main limitations of model :

- Venting of cell is ignored
- Fluid stayed liquid : no boiling, no burning

Further studies :

- Different routings of fluid
- Replacing immersion cooling by spray cooling

Thanks for your attention

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SMART TECHNOLOGY
FOR SMARTER CARS