

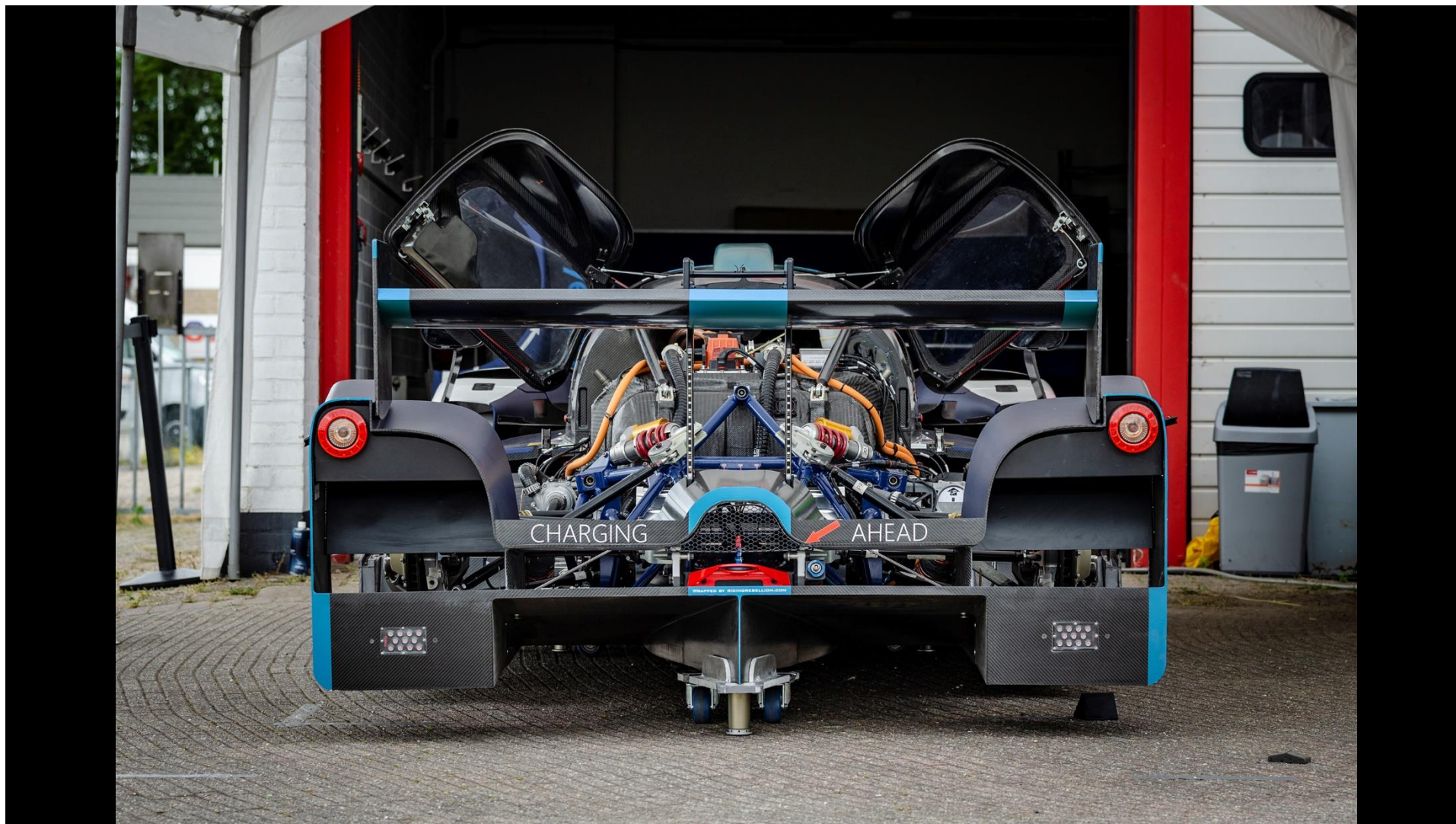
Right Implementation of Liquid cooling in electrically powered transport applications

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Optimal Thermal Solutions B.V.

Overview

- Introduction
- Thermal design for electrical vehicles
 - Thermal challenges
 - Battery structure
 - Example
 - Battery cooling
- Conclusion

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Thermal challenges battery cooling

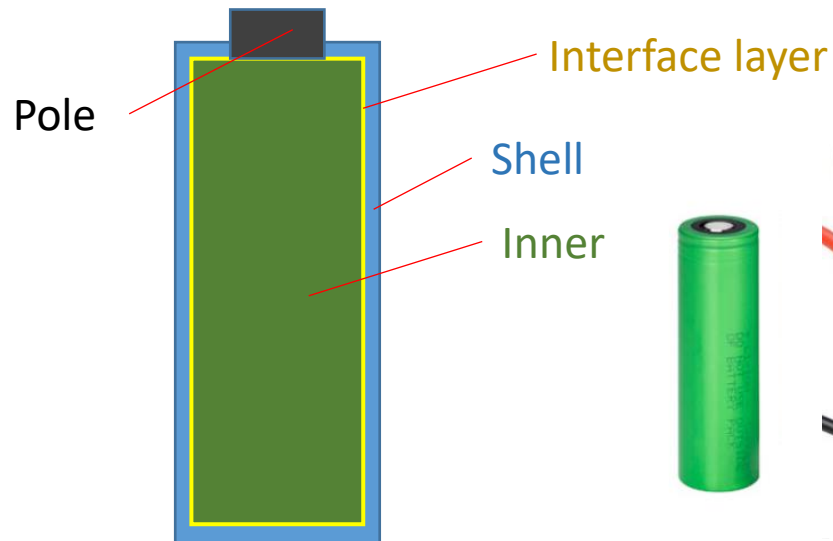
- Battery performance heavily effected by internal temperature and temperature differences between cells and modules.
- Heat generated by:
 - Reaction heat Q_r
 - Polarisation heat Q_p
 - Joule heat Q_j
- $Q_t = Q_r + Q_p + Q_j$
- Joule heating in the busbar, interconnects and in the cells
- Keep temperature uniform at 35-40°C max

For more interesting data see paper:

Study on the thermal interaction and heat dissipation of cylindrical Lithium-Ion Battery cells
21-24 August 2017 ICAE2017, 21-24 August 2017 By Yuqi Huang and others

Battery structure

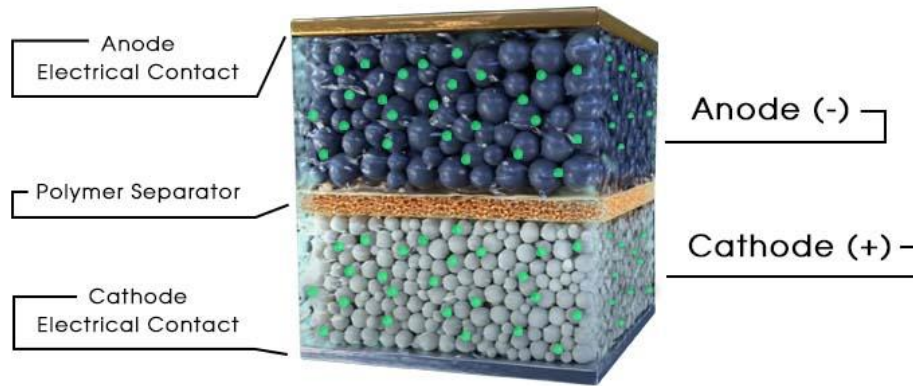
- The heat generated in the battery has to conduct from inside to outside via the poles and the housing
- The shell is in most cases thin metal aluminium or other.
- In most cases air-layer (isolator) between battery inner and outer shell



Battery structure

Lithium/ Lithium-Metal

Lithium-Ion Batteries



Solid-State Lithium-Metal Batteries



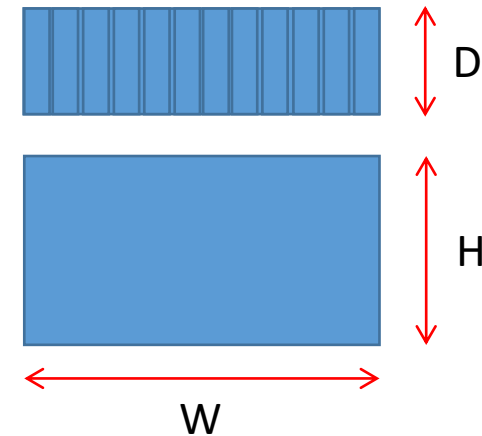
- Internal buildup will result in the location of heat and location of hotspots.
- The materials used will determine how well the conduction path is from inside to outside

<https://www.flashbattery.tech/en/>

Example

- Assume battery electrical resistance is 1.5mOhm (3P4S spec sheet) fast-charge with 200A (50A/cell) versus 400A(100A/cell)
- $P_d = 200^2 * 0.0015 = 60W$ / module, assume the full battery pack exist out of 48 modules, $P_d = 48 * 60 = 2880W$
- $P_d = 400^2 * 0.0015 = 240W$ assume the full battery pack has 48 modules, $P_d = 48 * 240 = 11520W$
- Fast charging and dis-charging has a large impact on dissipated power
- Example module: W470D140H250

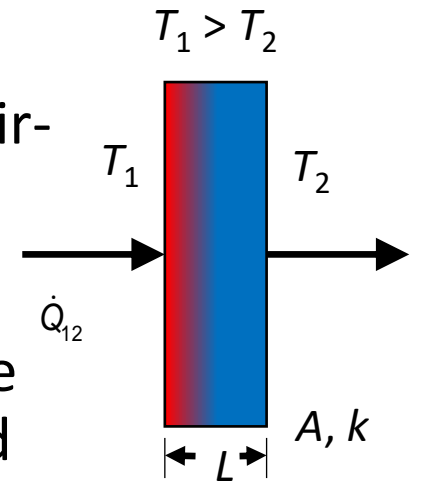
Note only joule heating accounted



Battery cooling

- Cooling via conduction from internal to the outside
 - Via the walls (between inner and outer shell in most cases a thin air-layer)
 - Via the pools
- Temperature difference between internal and external depends on the internal structure of the battery – how well can the heat be conducted

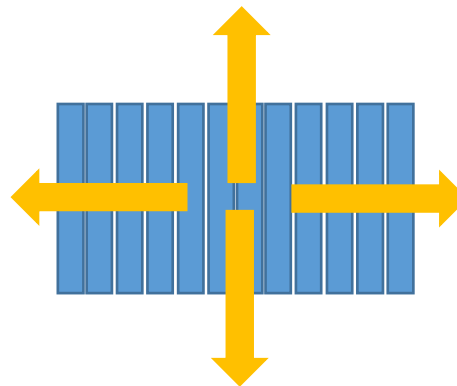
➤ $R_{\text{conduction}} = L / k \cdot A$



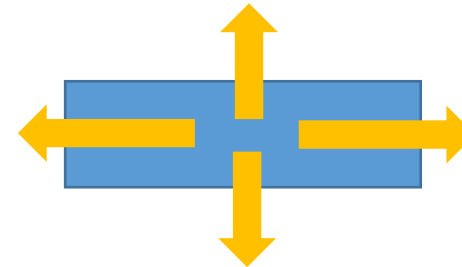
$$\dot{Q}_{12} = \frac{kA}{L}(T_1 - T_2)$$



Frontview



Topview



Module placed on Cold-Plate

- In most cases rather poor conduction path, some batteries has aluminium plates to conduct the heat
=> but those are **too thin** (1mm) to be effective!
- In between base of battery and cold-plate make use of gap-filler material to improve conduction path
- Don't use “the small plate” cooling enhancement in combination with high charge/ discharge current – cooling not effective enough!

$$R_{\text{conduction}} = L / k * A$$

Assume:

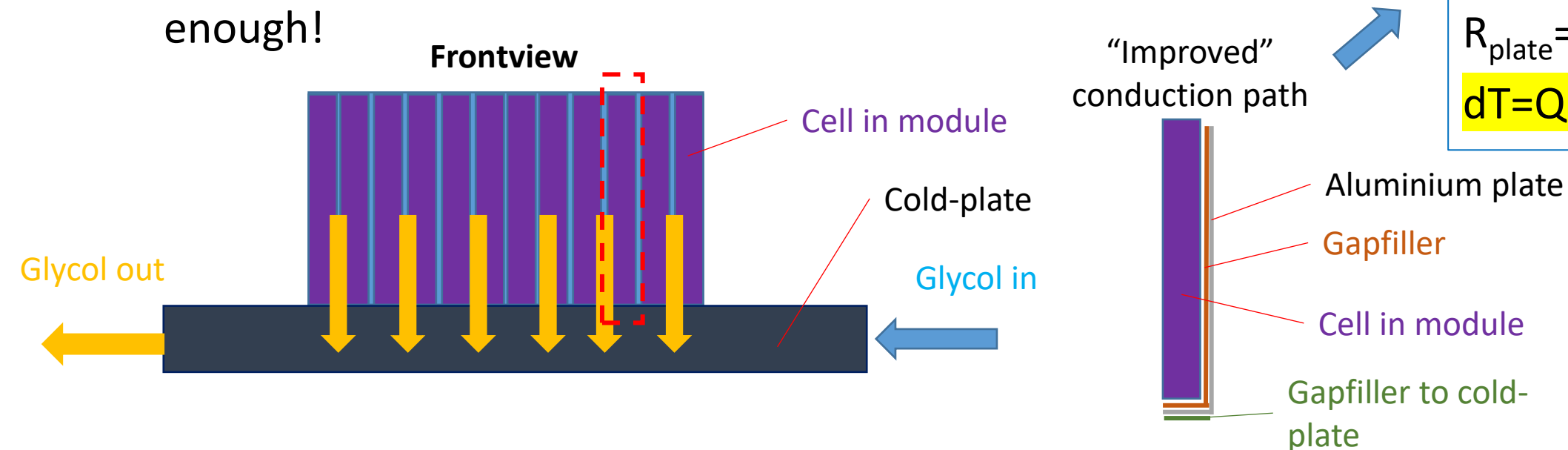
$$L = 250/2 \text{ [mm]}$$

$$k = 224 \text{ W/mK (1050A)}$$

$$A = 1 * 140 \text{ mm}$$

$$R_{\text{plate}} = 4 \text{ K/W}$$

$$dT = Q * R = 60 * 4 = 240 \text{ K}$$



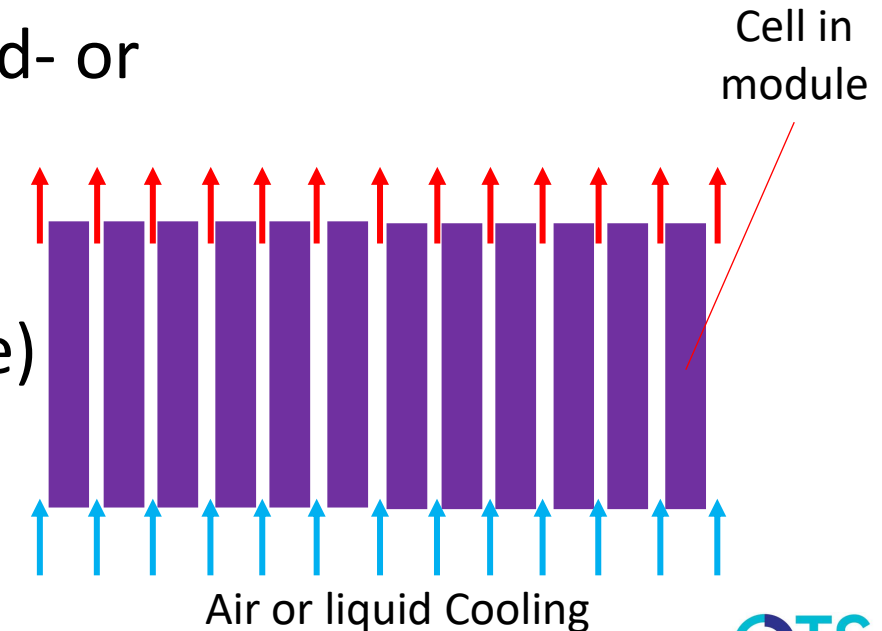
Side cooling module

- Is cooling of every cell from the sides be effective?
- Spacing required between the cells for air-, liquid- or conduction cooling

$$R_{\text{convection}} = 1/(h \cdot A) \text{ (Fluid – air/ liquid)}$$

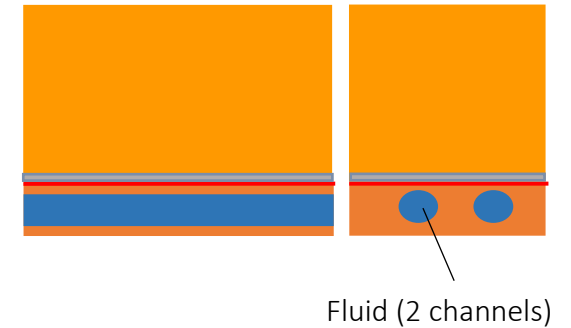
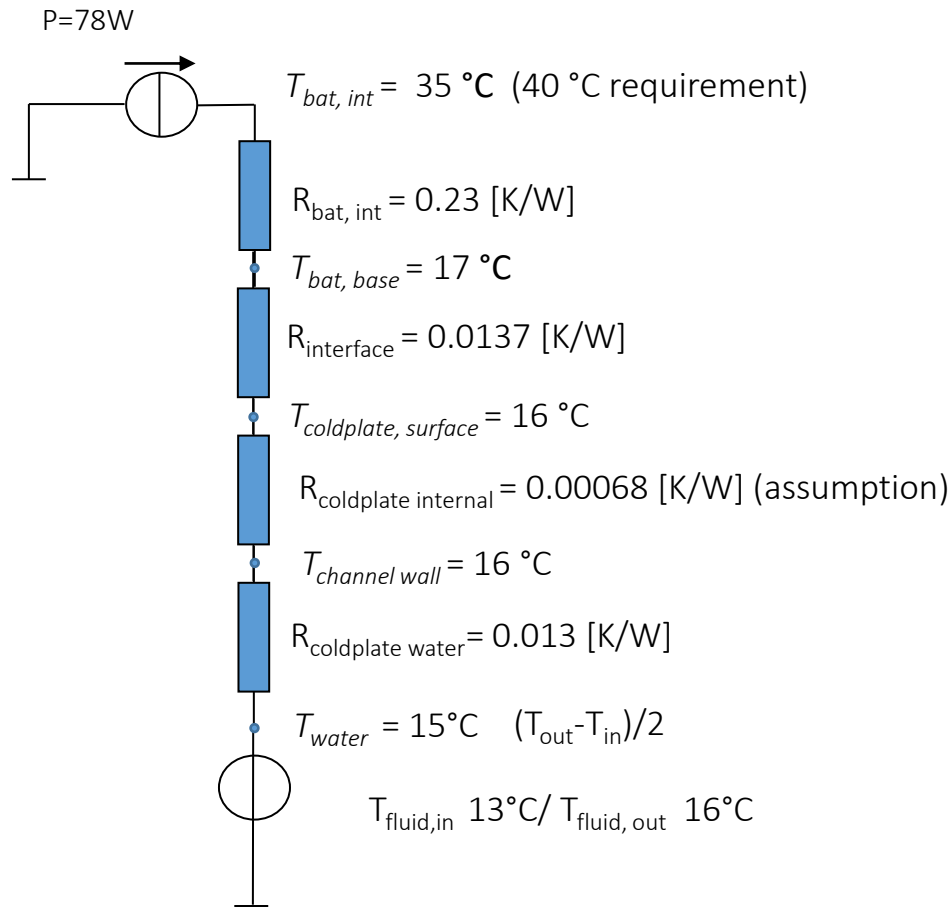
$$R_{\text{interface}} = h' / A \text{ (interfaces, TIM, e.g. gapfiller/ paste)}$$

		Case 1	Case 2	Case 3	Case 4	Case 5
Parameter	Units	natural conv.	forced conv.	forced conv.	Gapfiller 1 to coldplate	Gapfiller 2 to coldplate
Material/	[-]	air	air	water/	40mil@3W/	100mil@3W/mK
H _{cell}	[mm]	250	250	250	250	250
D _{cell}	[mm]	140	140	140	140	140
A	[mm ²]	35000	35000	35000	35000	35000
h	[W/m ² K]	5	14	2500	1400	700
h'	[cm ² ·°C/W]				7.1	14.3
R	[K/W]	5.71	2.04	0.01	0.02	0.04
Q	[W]	60	60	60	60	60
dT	[K]	343	122	0.7	1.2	2.4



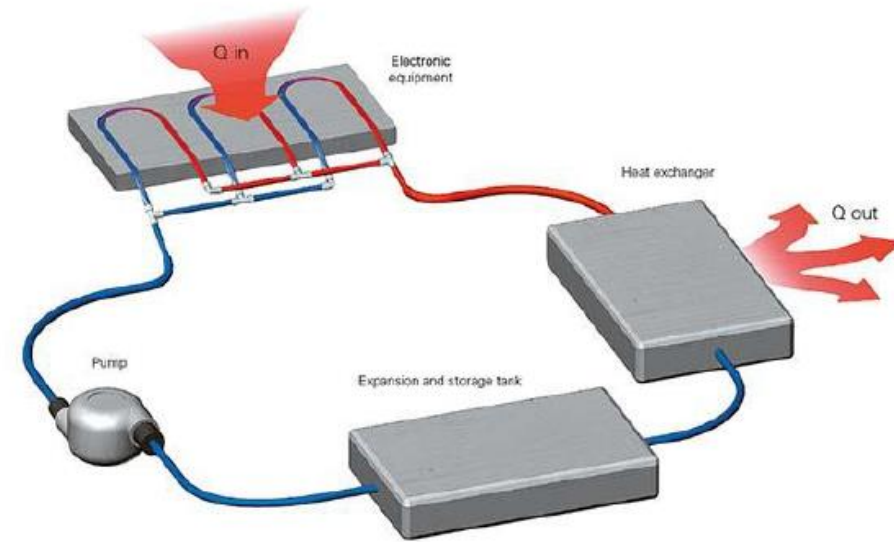
Cooling circuit battery – example calculation

Fluid Temp.	[C]	14	14	14
Fluid Temp.	[K]	287.15	287.15	287.15
Density	[kg/m³]	1001	1001	1001
Specific heat	[J/kg.K]	3660	3660	3660
Conductivity	[W/m.K]	0.5	0.5	0.5
Dynmaic viscosity	[kg/m.s]	1.9E-03	1.9E-03	1.9E-03
Prandtl	Pr	8.3	8.3	8.3
Flow rate	[L/min]	11	11	11
Flow rate	[m³/s]	0.00018	0.00018	0.00018
Diameter	[mm]	10.00	13.00	10.00
Diameter	[m]	1.0E-02	1.3E-02	1.0E-02
Area	[m²]	7.9E-05	1.3E-04	7.9E-05
Velocity	[m/s]	2.33	1.38	2.33
Reynolds	-	12167	9359	12167
Reynolds, 10'x	-	4	4	4
Nusselt no.	-	86	70	86
Heat transfer coefficient	[W/m².K]	3959	2469	3959
Channel Length per battery	m	0.280	0.280	0.280
# of channels	[-]	2	2	2
channel length	[m]	0.56	0.56	0.56
Resistance	[K/W]	1.4E-02	1.8E-02	1.4E-02
Power	[W]	156	156	156
ΔT _{wall-fluid}	[K]	2.2	2.8	2.2
ΔT _{fluid out-in}	[K]	0.23	0.23	0.23
Friction	-	0.030	0.032	0.030
Pressure drop	[Pa]	4594	1321	4594
Pressure drop diff. Factor	-	REF	0.3	1.0

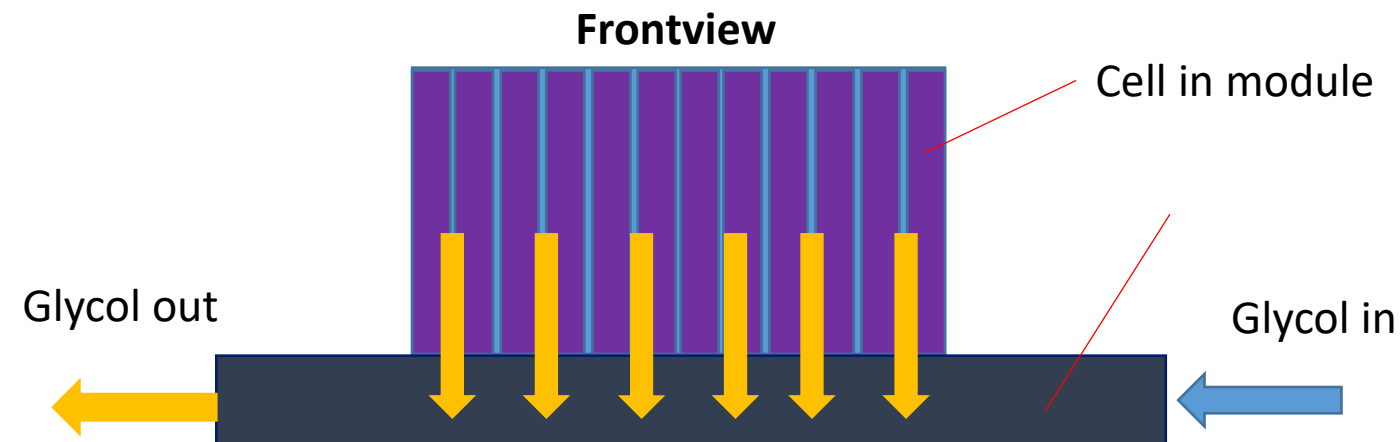


Cooling circuit battery

- Cold-plate (heat from battery into cold-plate into liquid)
- Pump (move of heat via liquid)
- Expansion tank ($T_{\text{fluid}} \uparrow$, $V_{\text{fluid}} \uparrow$)
- Heat exchanger (move heat from liquid into the air) direct (radiator) or via active cooling – refrigeration/ Peltier

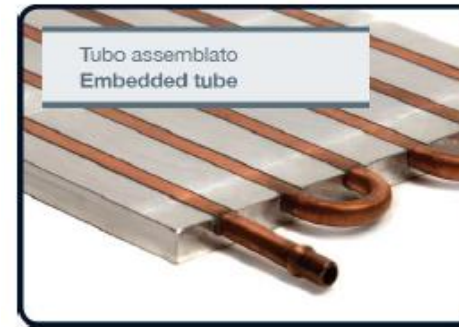
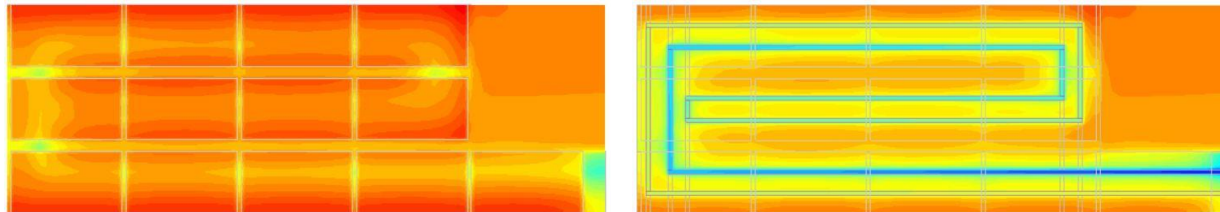


With courtesy of MeccAL



Cold plate design

- Cold-plate (optimize cooling channels)
- Different manufacturing techniques



	Embedded Tube	Gun Drilled	CAB Brazed *	Fusion
Advantages	+ Price + Coolant Corrosion Resistance	+ Cooling Channel layout flexibility + Uniform cooling of the 2 mounting surfaces	+ Thermal Performance + Cooling Channel layout flexibility + Uniform cooling of the 2 mounting surfaces	+ Price + Coolant Corrosion Resistance + Uniform cooling of the 2 mounting surfaces
Disadvantages	- Thermal Performance - Cooling Channel layout flexibility - Not uniform cooling of the 2 mounting surfaces	- Coolant Corrosion Resistance	- Price - Coolant Corrosion Resistance	- Tooling Cost - Thermal Performance

* This can also be done with STIR-friction welding technique

With courtesy of MeccAL

Pump, Expansion & storage tank Heat exchanger

- Radiator with pump & tank
- Chiller with pump, tank and refrigeration system to cool below ambient

WL5000

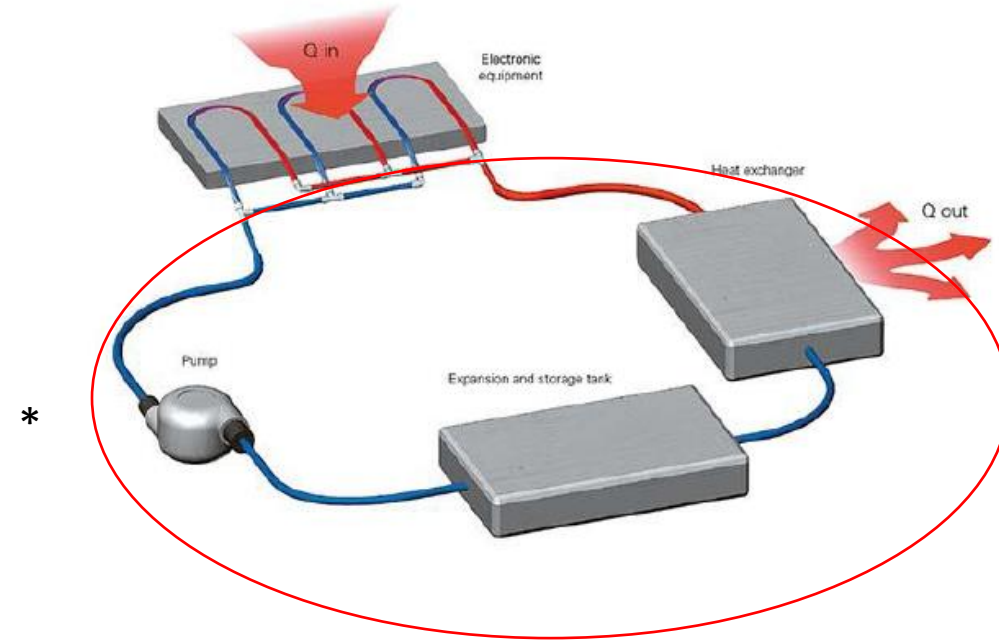


HEX

NRC5000



Chiller



With courtesy of Laird Thermal Systems and MeccAL

Conclusion

- Thermal simulation will give insight in the full 3D of the thermal behaviour of the Battery, battery charger, power electronics both in solid and in fluid.
- Easy to do what if then analyses to make the right decisions during the design.
- Electrical and thermal experimental testing required to come-up with a good thermal model and behaviour of the battery/ accu
- Build proto type
- Reduce of design risk, come to the most optimal design, reduce of cost

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