UNIVERSITAT POLITÈCNICA DE VALÈNCIA

Clean Mobility & Thermofluids

Numerical research on conjugate heat transfer for batteries at CMT

ERCOFTAC Spring Festival
16th May 2024

Xandra Margot[1], Kundan Kumar, Cem Karaca[2]

[1]CMT-Clean Mobility & Thermofluids
Universitat Politècnica de València. Spain

[2]Departamento de Ingeniería
Università degli Studi di Perugia. Italy

Contents

INTRODUCTION

➢ Objective

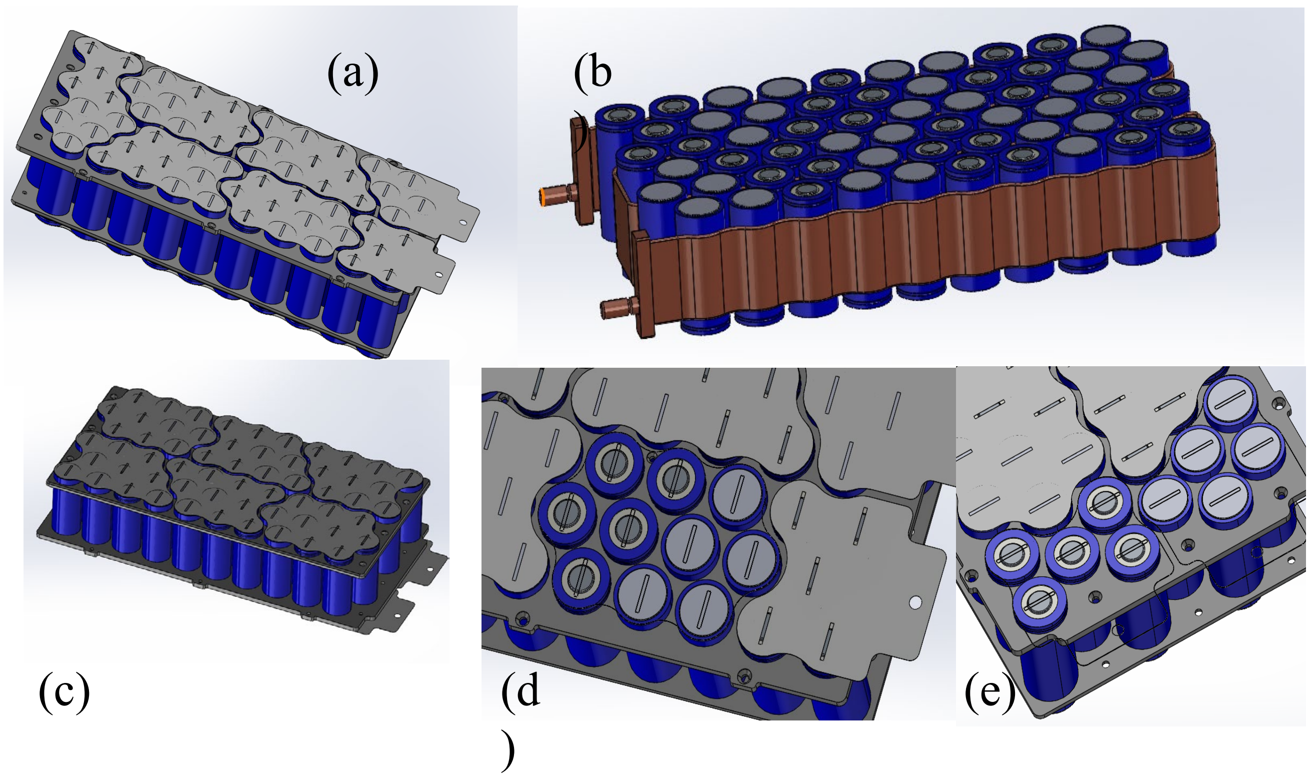
Study of a battery pack side cooling system for an e-bus.

➢ Methodology

- **Calculation of heat generated by a battery cell / module:**
  - Calculate parameters for cell model (equivalent conductivities)
  - Apply model to calculate heat generation for different charge/discharge rates (C-rates) of the module
- **Set-up of CFD-CHT model for one cell with side cooling**
- **Flow characterization of side cooling plate:**
  - CFD to determine pressure drop in function of mass flow rate, vaidation
  - Use cell model results as boundary conditions for CFD-CHT calculations of cooling plate efficiency (heat transfer, coolant temperature evolution)
- **CFD-CHT simulations with small representative module to determine cooling efficiency at various operating conditions:**
  - Analyze cells temperature evolution for different C-rates, coolant mass flow rates, ambient temperatures, …
- **Validation with full module / pack**

MODULE DEFINITION

- The connections of the module are arranged according to a 12S 5P configuration.



The group of 5 cells in parallel is connected on the other face to the next group of 5 cells →

- **12S 5P** electrical configuration
- **Nickel** connection tabs

CELL CHARACTERIZATION

- To design the cooling system , the first step is to characterize the heat generated by the module, i.e. by each cell.
- The cells are 32700 Li-ion, whose properties are given in the table.

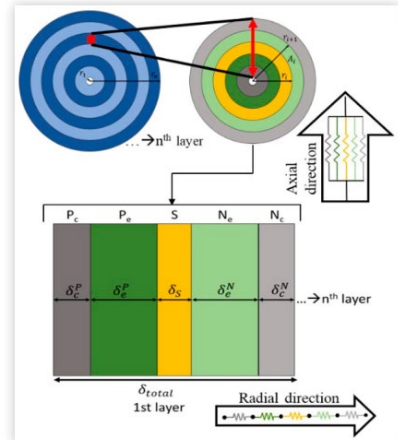
Characteristic	Value
Nominal Capacity	6 Ah
Nominal Voltage	3.2 V
Maximum Voltage	3.65 V
Minimum Voltage	2 V
Maximum continuous discharging current	33 A (5.5C)
Maximum continuous charging current	36 A (6C)
Maximum discharing temperature	65 ºC
Maximum charging temperature	65 ºC
Diameter	0.032 m
Length	0.070 m

Parameters needed for the cell model

- Thermal conductivity in axial and radial directions calculated with the different materials conductivities and thicknesses of the jelly roll.

$$k_{rad} = \frac{\ln\frac{r_n}{r_1}}{\sum_{i=1}^{n-1}\frac{\ln\frac{r_{i+1}}{r_i}}{k_i}} = 0{,}2\,\frac{W}{mK}$$

$$k_{ax} = \frac{\sum_{i=1}^{n-1} k_i * A_i}{A_{total}} = 32\,\frac{W}{mK}$$



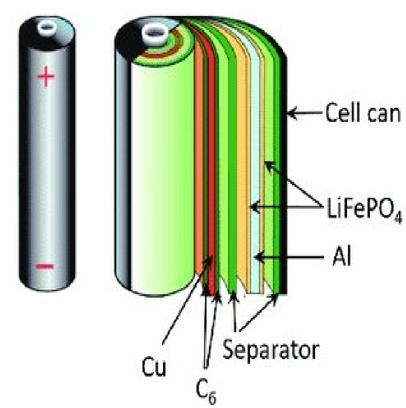
- Positive and negative electrical conductivities

$$\sigma_{eq,\ positive} = \frac{\sum_{i=1}^{n-1}\sigma_{i,P_c} * A_{i,P_c} + \sum_{i=1}^{n-1}\sigma_{i,P_e} * A_{i,P_e}}{A_{total(P_c,P_e)}}$$

$$\sigma_{eq,p} = 1{,}62\,.10^6\ S/m$$

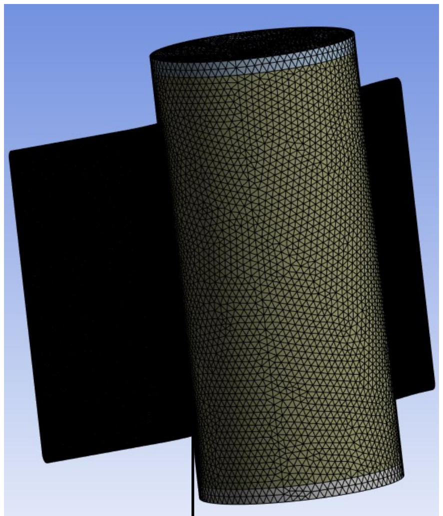
$$\sigma_{eq,\ negative} = \frac{\sum_{i=1}^{n-1}\sigma_{i,N_c} * A_{i,N_c} + \sum_{i=1}^{n-1}\sigma_{i,N_e} * A_{i,N_e}}{A_{total(N_c,N_e)}}$$

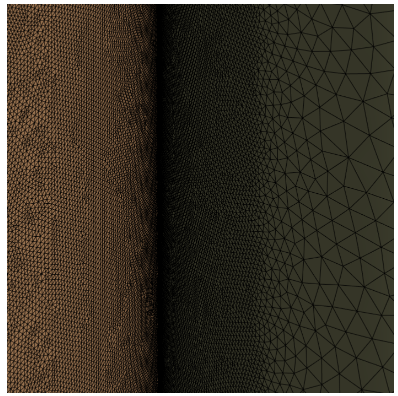
$$\sigma_{eq,n} = 1{,}49.\,10^6\ S/m$$



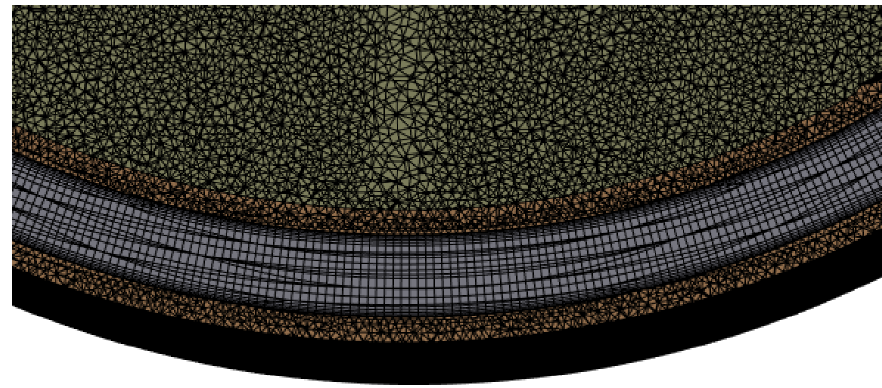
SET-UP OF ONE-CELL CFD-CHT MODEL

➢ One cell model meshing:





Contact zone between cell and coolant plate



Contact zone between cell and coolant plate (cross-section)

- **Mesh generation:**
  - To avoid high number of mesh cells in the contact zones, a *contact mesh sizing* has been separately defined at the contacting surfaces

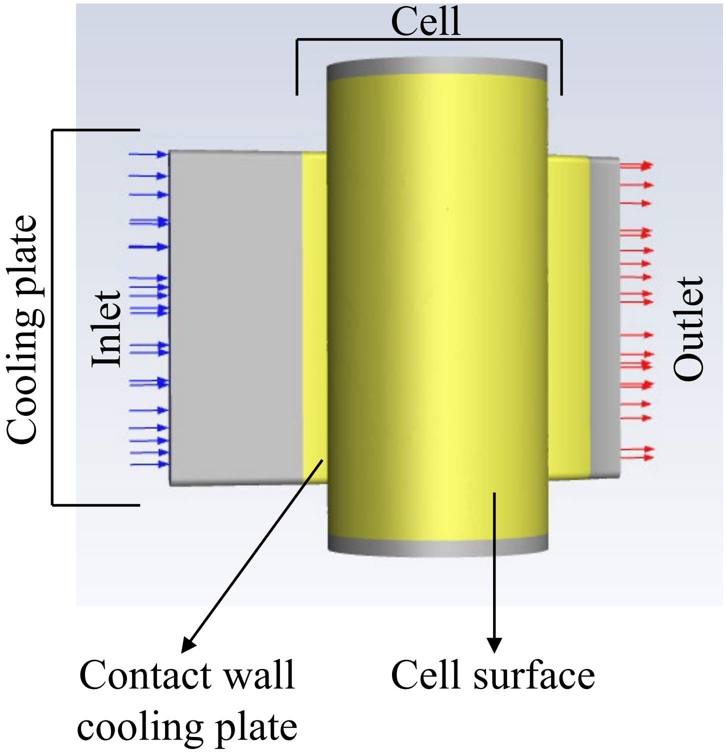
Number of nodes	5,661,214
Number of elements	23,437,214

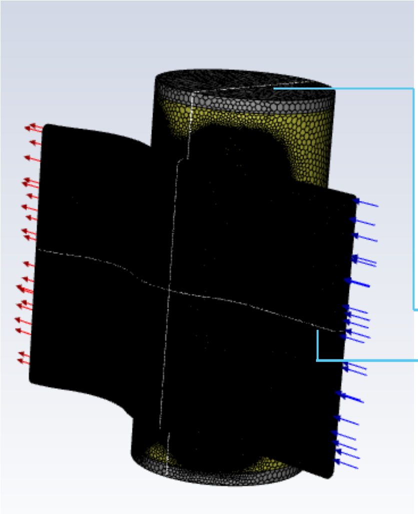
SET-UP OF ONE CELL CFD-CHT MODEL

➢ Boundary conditions:

- For cell:
  - 2C discharging condition
  - Ambient temperature: 293.15 K
- For cooling plate:
  - Inlet mass flow: 7.5 L/min (4.83 m/s)
  - Inlet fluid temperature: 293.15 K

  Fluid was assumed completely stabilised inside the cooling plate.

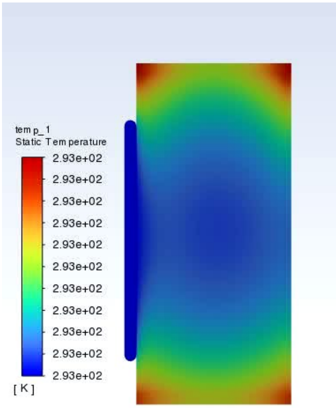


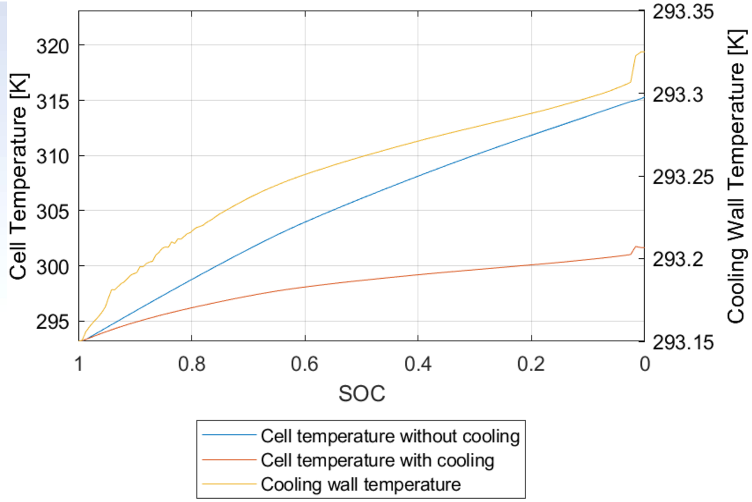


- The white line in the image represents two planes, which were created to observe the temperature distribution between cell and the cooling plate
  - One in vertical direction (considering the centre of the cell)
  - Second in horizontal direction (considering the centre of the cooling plate)

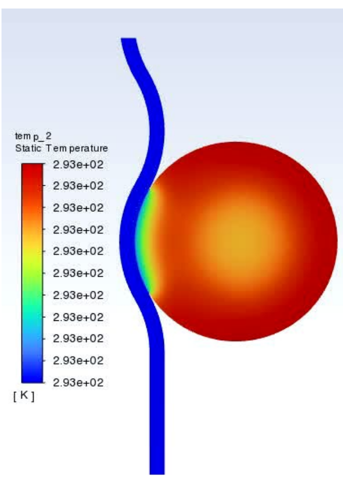
SET-UP OF ONE CELL CFD-CHT MODEL

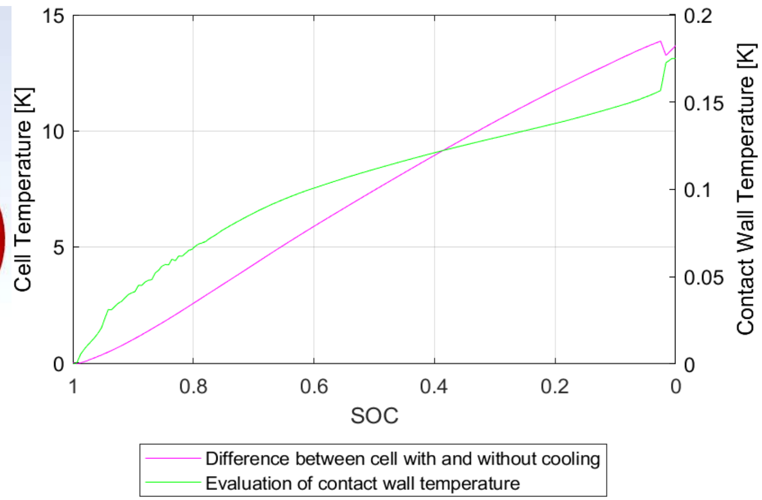
➢ Results of one cell CFD-CHT model





- Cell Temperature at SOC = 0
  - Without cooling plate = 315.32 K
  - With cooling plate = 301.64 K
  - Difference between with and without cooling plate = 13.68 K

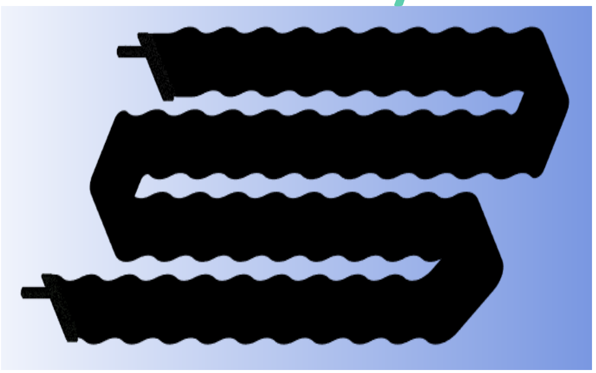


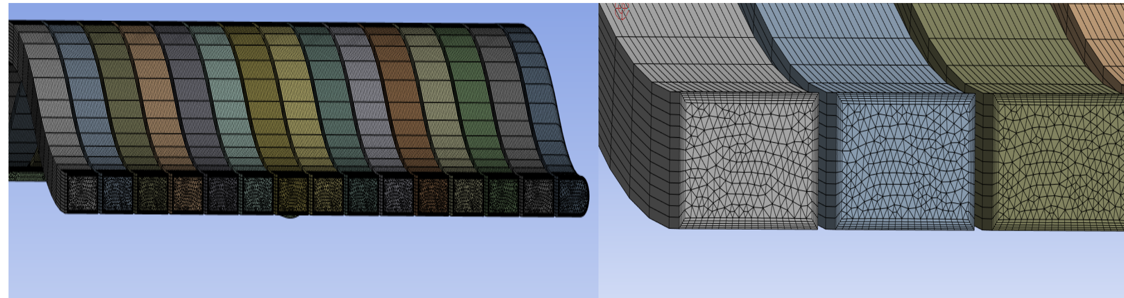


- Coolant contact wall temperature at SOC = 0
  - 293.32 K
  - Total rise in wall temperature from SOC 1 to 0 = 0.17 K

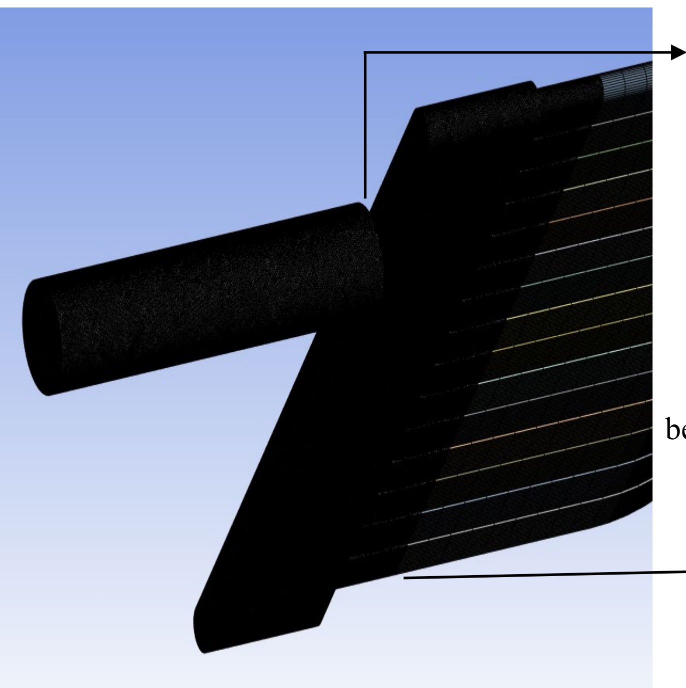
COOLING PLATE FLOW ANALYSIS

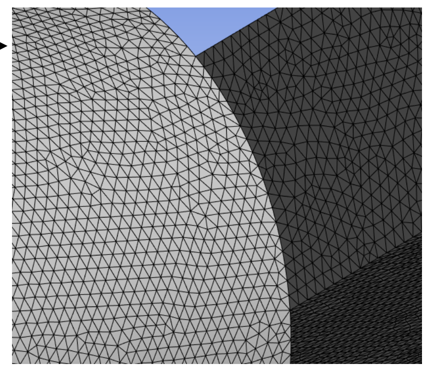
➢ Geometry and meshing of cooling plate



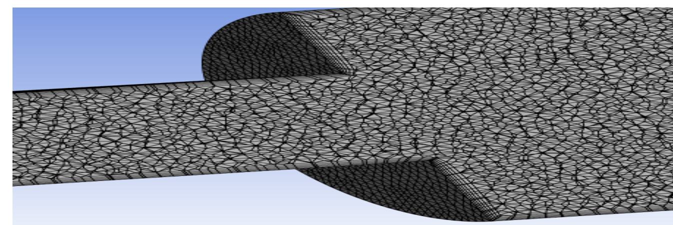


Mesh on and in the channels

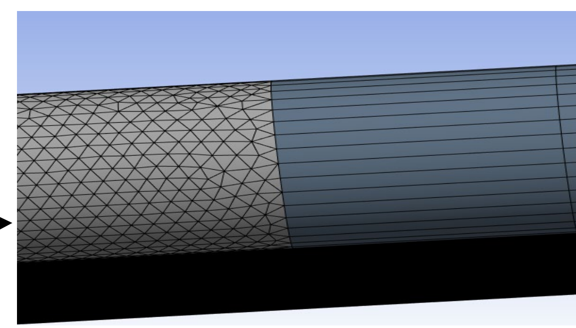




Nodes connection and meshing between the circular inlet/outlet and the plenum



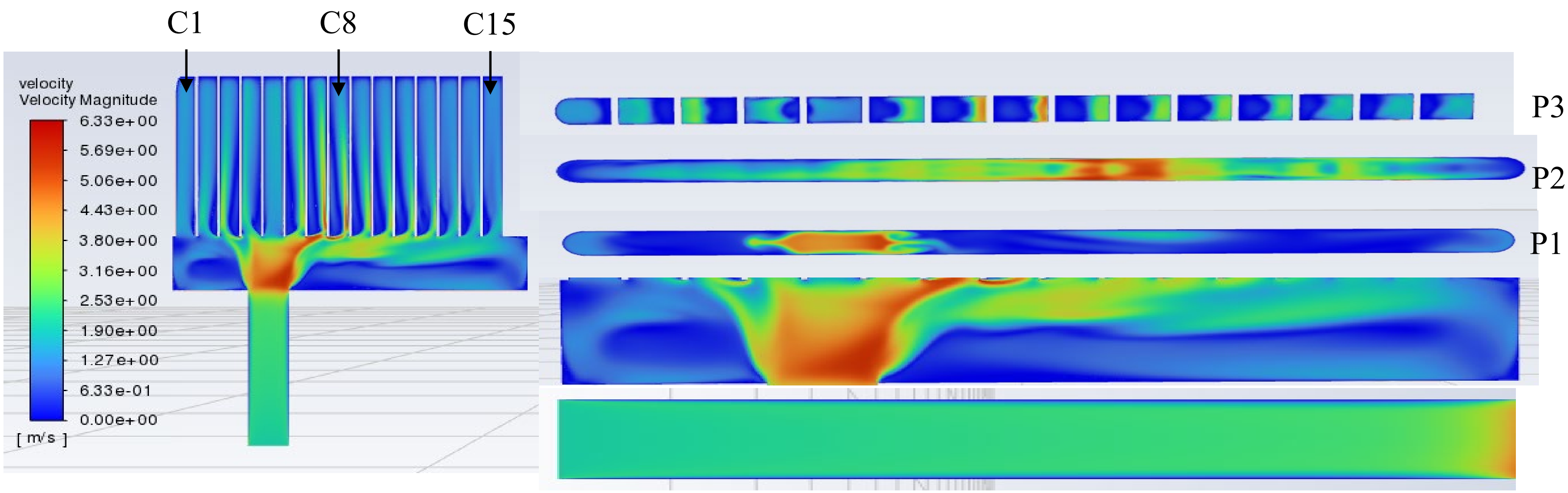
Crosscut-section between the circular inlet/outlet and the plenum

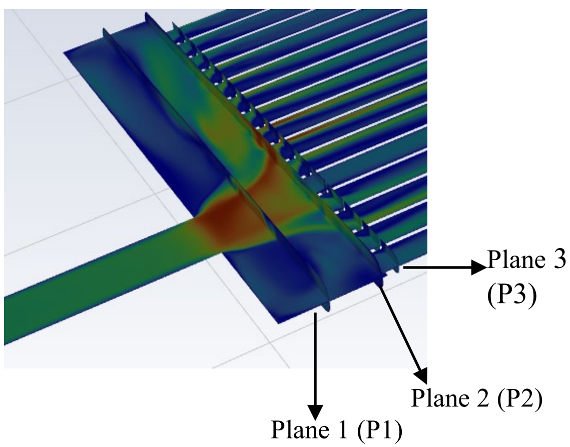


Nodes connection and meshing at the plenum and the channels

Element size: 0.13mm
Number of nodes: 14082067
Number of elements: 29626041

➢ Boundary conditions and velocity field at inlet





Boundary conditions:

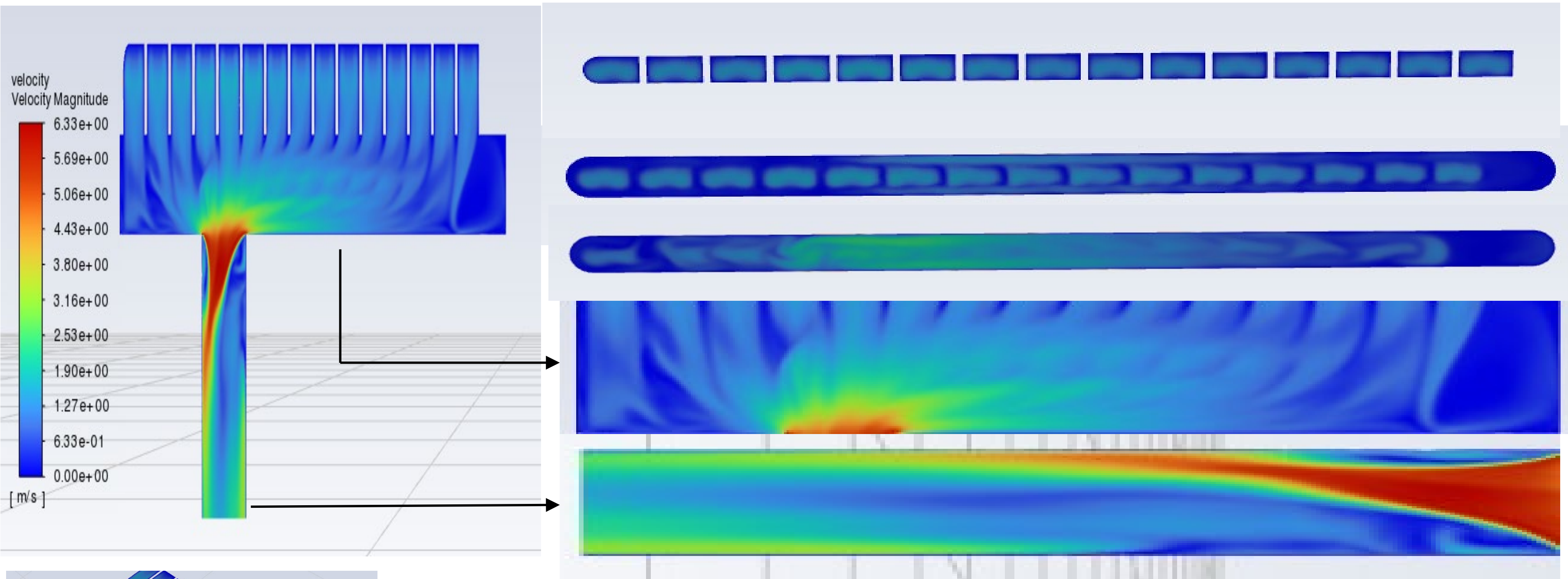
Inlet mass flow: 3.27 L/min

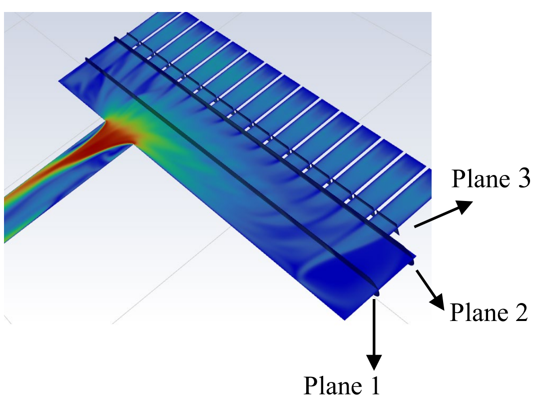
Fluid inlet temperature: 293.15 °C

Heat flux on the refrigerant walls: 910 W/m^2

Coolant: Water Glycol Properties at 20°C	
Density(kg/m3)	1082
Viscosity (kg/m s)	0.00487
Specific heat (J/kg K)	3260
Conductivity (W/m K)	0.402

➢ Velocity field at outlet





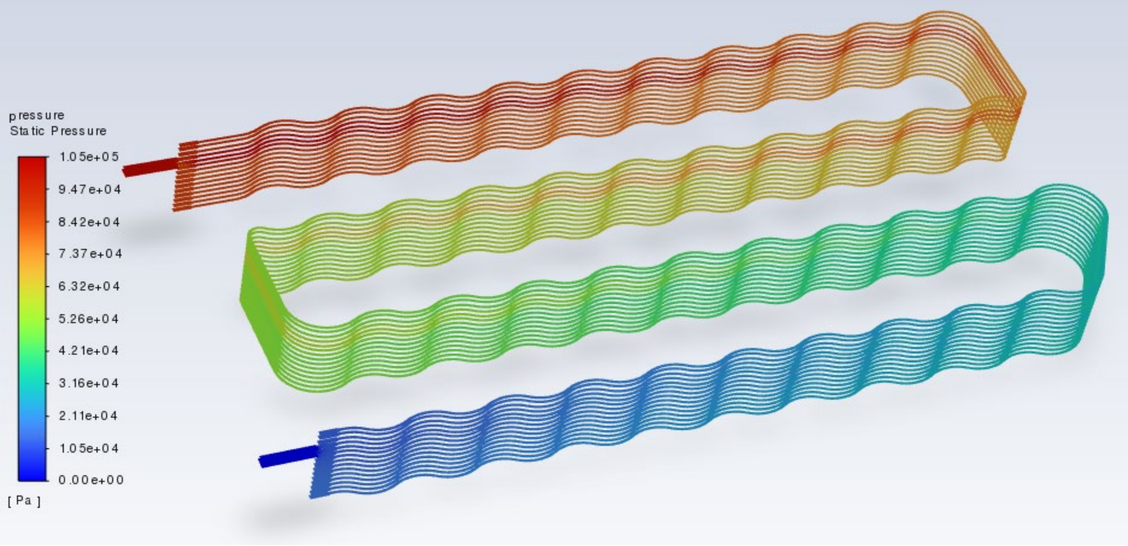
Results at outlet

Fluid velocity: 2.11 m/s (3.27 L/min)

- Due to the change in geometry, higher velocity can be seen at the entrance of the outlet
- The velocity stabilises as it moving towards the end of the outlet

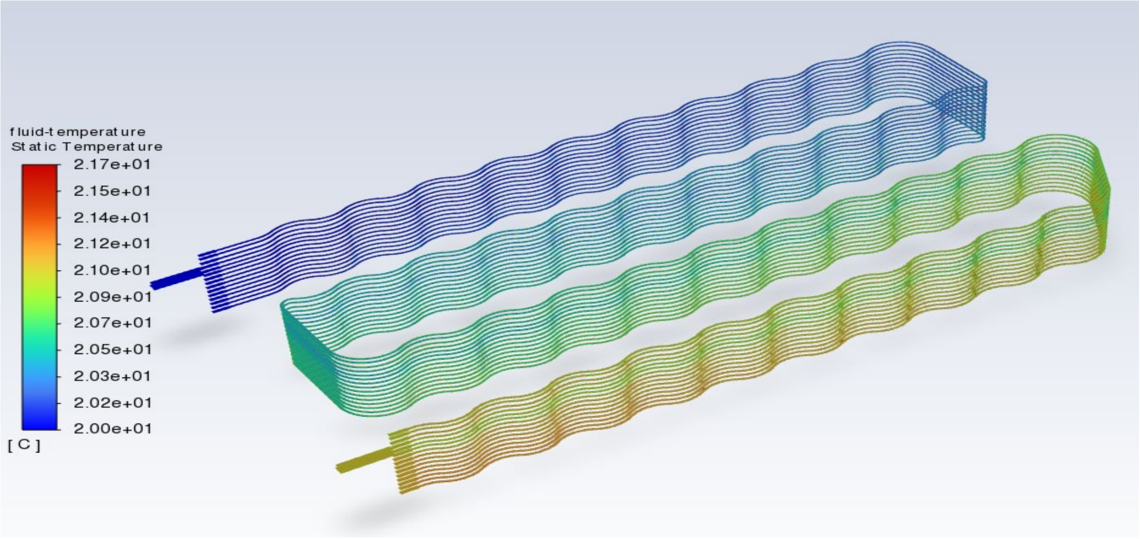
COOLING PLATE FLOW ANALYSIS

➢ Pressure field and fluid temperature in cooling plate

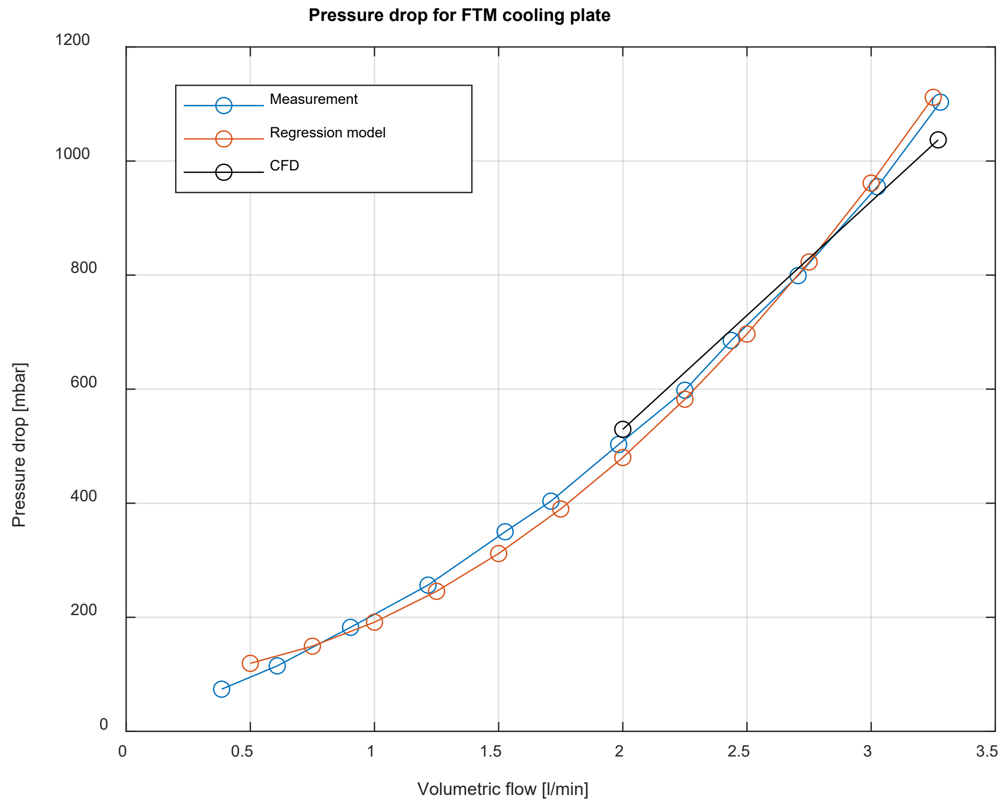


- Pressure gradient difference along channels due to the position of the entry
- The overall pressure drop along the cooling plate **1.03 bar**

- The temperature increase of the coolant between inlet and outlet is **0.88 K.**
- The fluid temperature at the outlet is **294.03 K.**
- Estimated heat transfer coefficient is **850.16** $\boldsymbol{\frac{W}{m^2\ K}}$



➢ Validation with experimental measurements



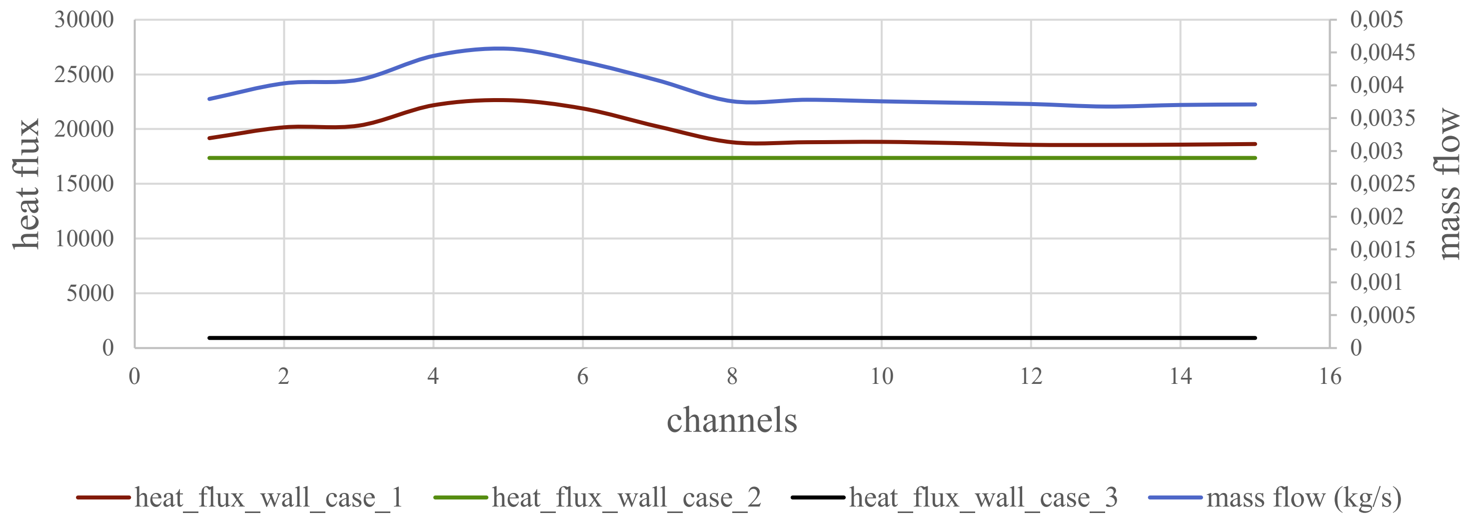
- Good agreement between CFD and experiments.
- Maximum difference found is 6% for 3,27 L/min.
- Differences probably due to micro-channels internal geometry.

Flow rate (L/min)	2	3,27
Temperature at outlet (K)	21,72	20, 88
Pressure loss (bar)	0,53	1,03
Heat transfer coefficient (W/m^{2}K)	611,52	850,16

COOLING PLATE FLOW ANALYSIS

➢ Results of heat transfer through cooling plate wall

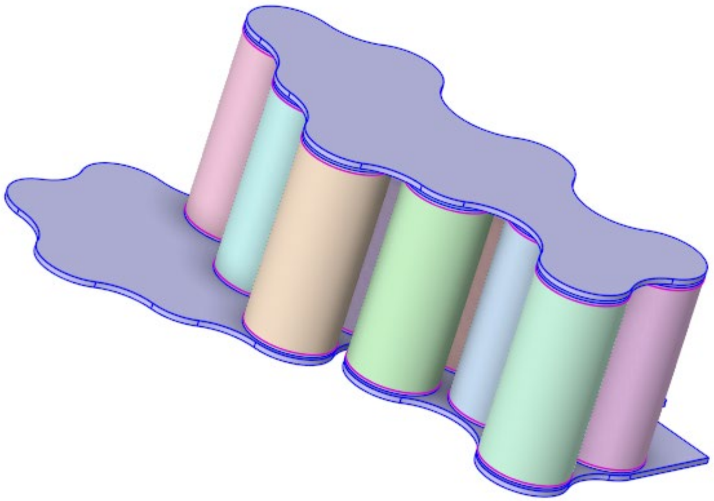
Cases	Boundary conditions	Fluid outlet temperature (°C)	Heat flux (W/m^2)	Average heat transfer coefficient (W/(m2 K))
Case 1 (base case)	Inlet flow rate: 3.27 L/min Fluid inlet temperature: 20 °C Wall temperature: 40°C	39.75	17350	851.53
Case 2	Inlet flow rate: 3.27 L/min Fluid inlet temperature: 20 °C Heat flux: 17350 W/m^2	39.67	17350	997.09
Case 3	Inlet flow rate: 3.27 L/min Fluid inlet temperature: 20 °C Heat flux: 910 W/m^2	21.03	910	158.6

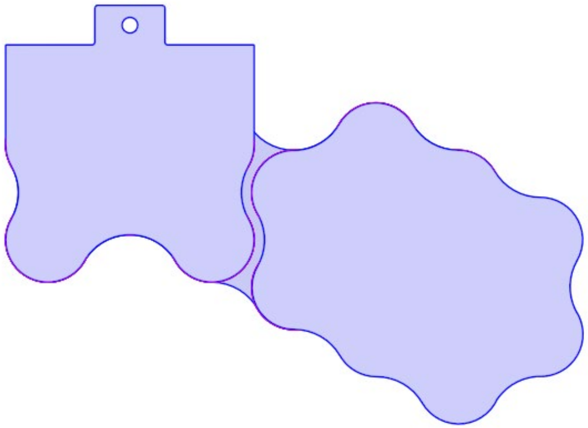


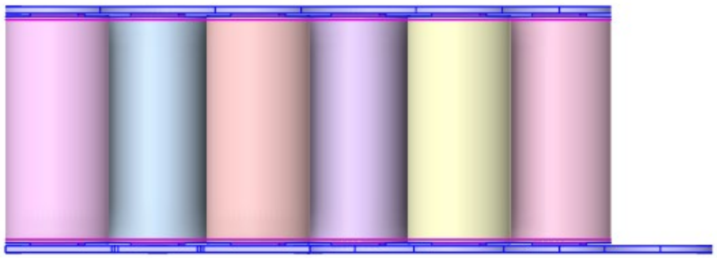
STUDY FOR SMALL MODULE

➢ Small representative module geometry

- Small 5P2S module representative of the e-bus battery pack module: same cells and connectors, same distribution.



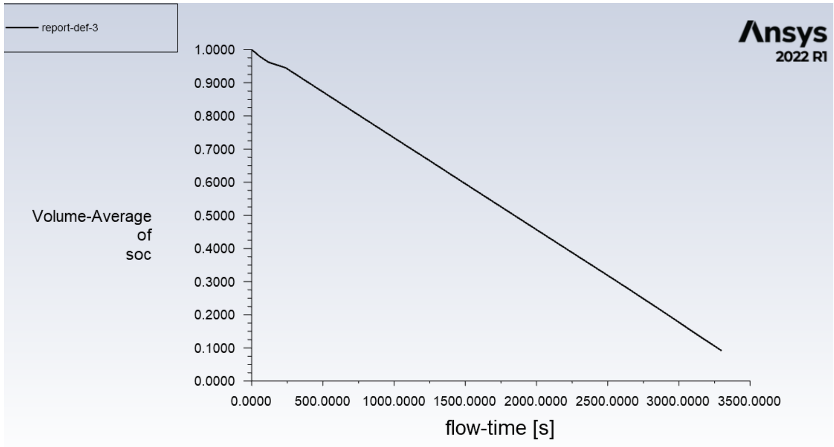




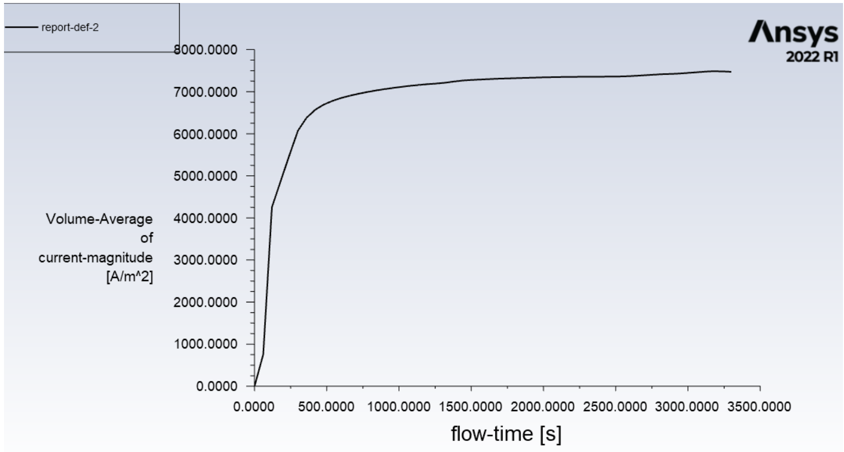
STUDY FOR SMALL MODULE

➢ Results of CFD-CHT model for small module

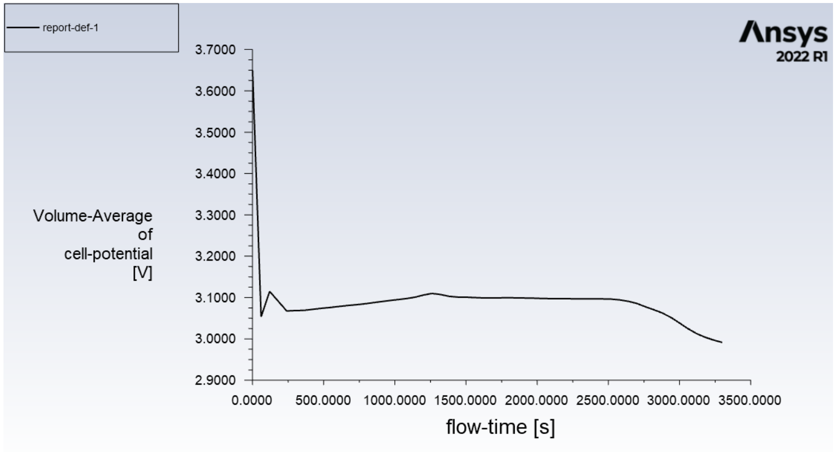
- Voltage max value is set at 3.65V and min at 2V (for SOC 0).
- Current is 6 A for each cell which equals 1C discharge rate.
- 60 hours CPU for one simulation on a Workstation.



SOC evolution during 1C discharge



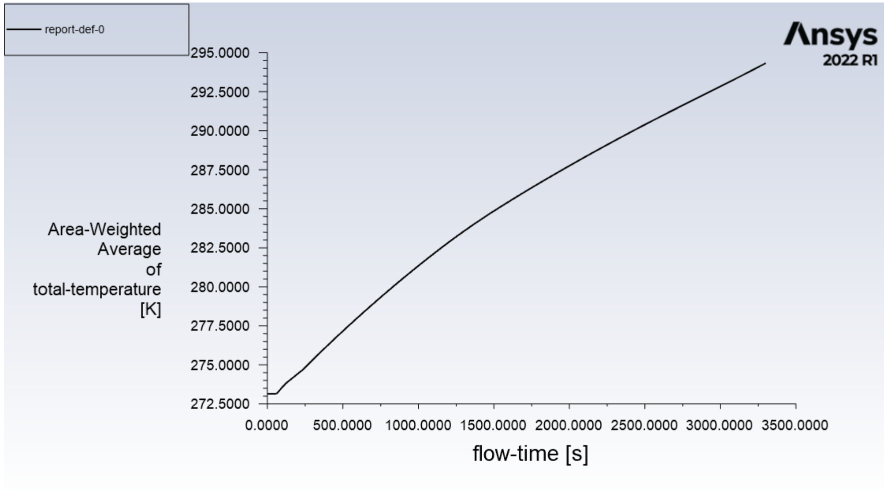
Cell voltage evolution during 1C discharge

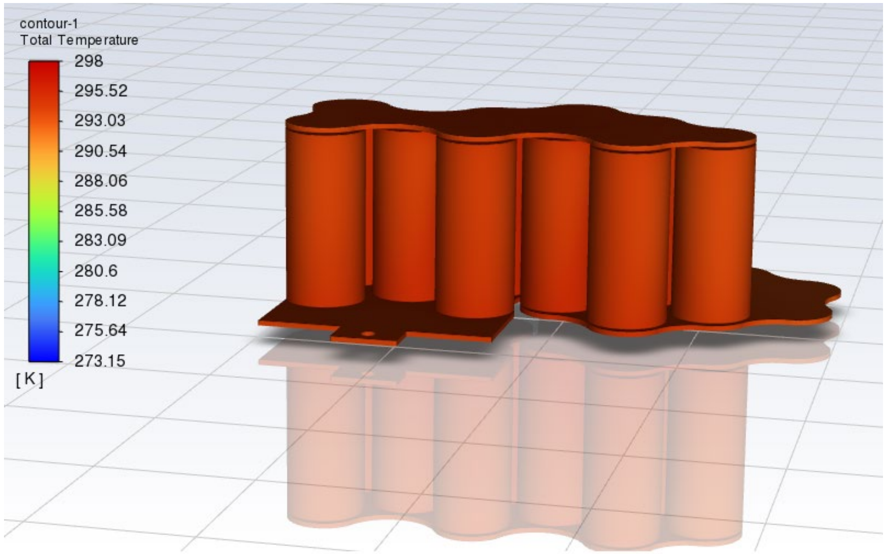


Current voltage evolution during 1C discharge

STUDY FOR SMALL MODULE

➢ Results of CFD-CHT model for small module



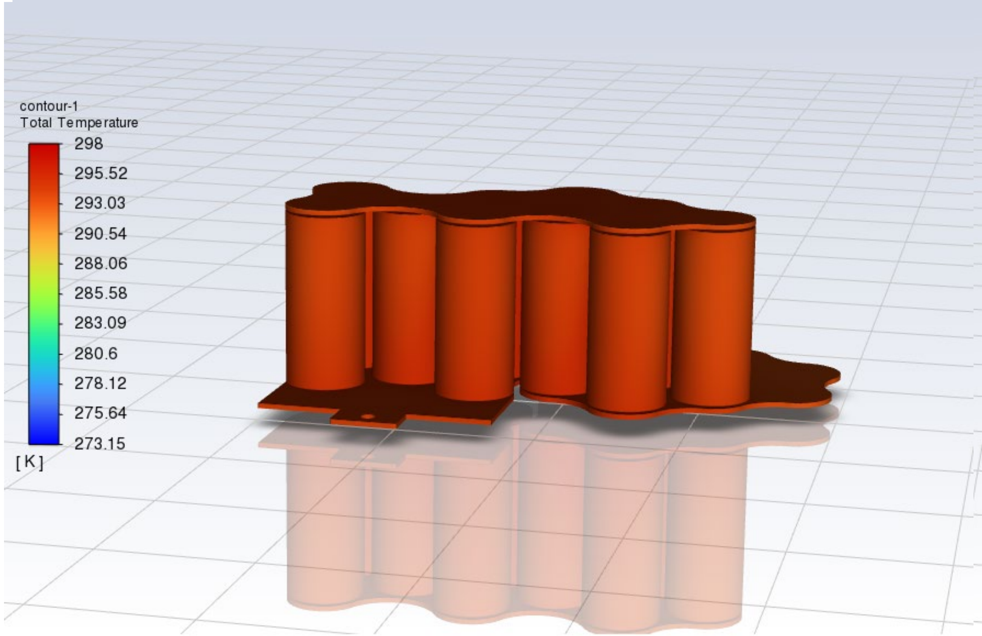


with natural convection

- Temperature increases from 273.15 K to 294.5 K during the 90 percent discharge.

➢ Ongoing and future work

- The small module results need more anlysis to ensure that the model works properly.
- The full module will then be considered.
- Validation will be possible with experimental measurements of the full module.



Thank you for your attention

Any questions?