DEVELOPMENT OF AN AUTODESK CFD BASED
3D MODEL OF A HALL-HÉROULT CELL HOODING SYSTEM
HF CAPTURE EFFICIENCY

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Presented by: Marc Dupuis

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Presenter's Bio

GENISIM

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- **Work experience: Mathematical modelling and design of H.H. cells dealing with thermo-electric, thermo-electro-mechanical, CFD and MHD phenomena.**

Plan of the Presentation

- **Introduction**
- **AUTODESK CFD 3D Thermo-Electric Model of the Anode**
- **AUTODESK CFD Full 3D Model of a Section of a Hall-Héroult Anode Panel and Hooding System**
  - Model Geometry
  - Model Mesh
  - Degrees of Freedom Solved in the Model
  - Model Boundary Conditions
  - Model Solution
- **Conclusions**

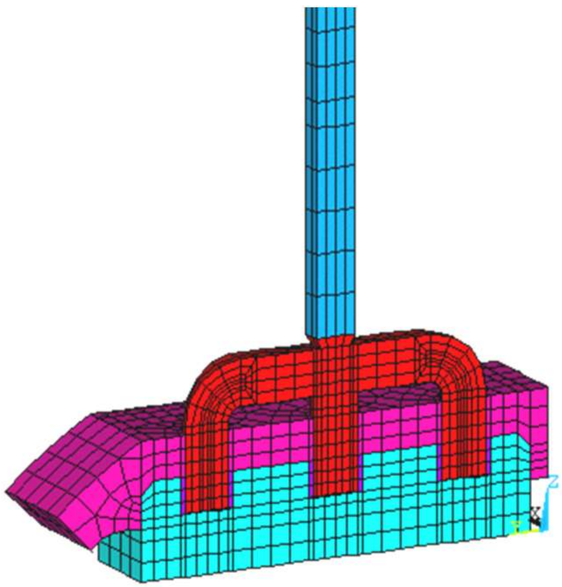
Introduction

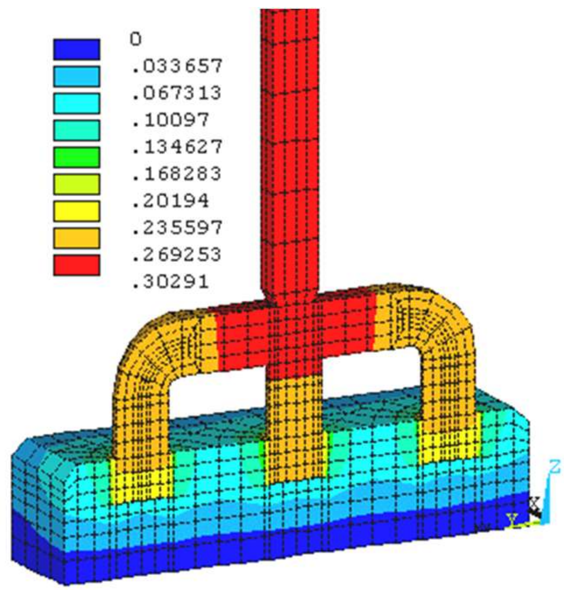
- **The cell hooding design and the HF capture efficiency are important aspects of a cell design.**

- **In order to be able to predict the cell hooding HF capture efficiency and hooding panels operating conditions under a wide range of cell operating conditions like cell amperage, anode cover thickness and especially hooding design and exhaust gas sucking rate, a full 3D model of a section of a Hall-Héroult anode panel and hooding system was developed using the code AUTODESK CFD.**

AUTODESK CFD 3D Thermo-Electric Model of the Anode

- **As a first step, the 3D thermo-electric model of the anode was developed in order to reproduce using AUTODESK CFD the ANSYS based 3D thermo-electric model previously published.**

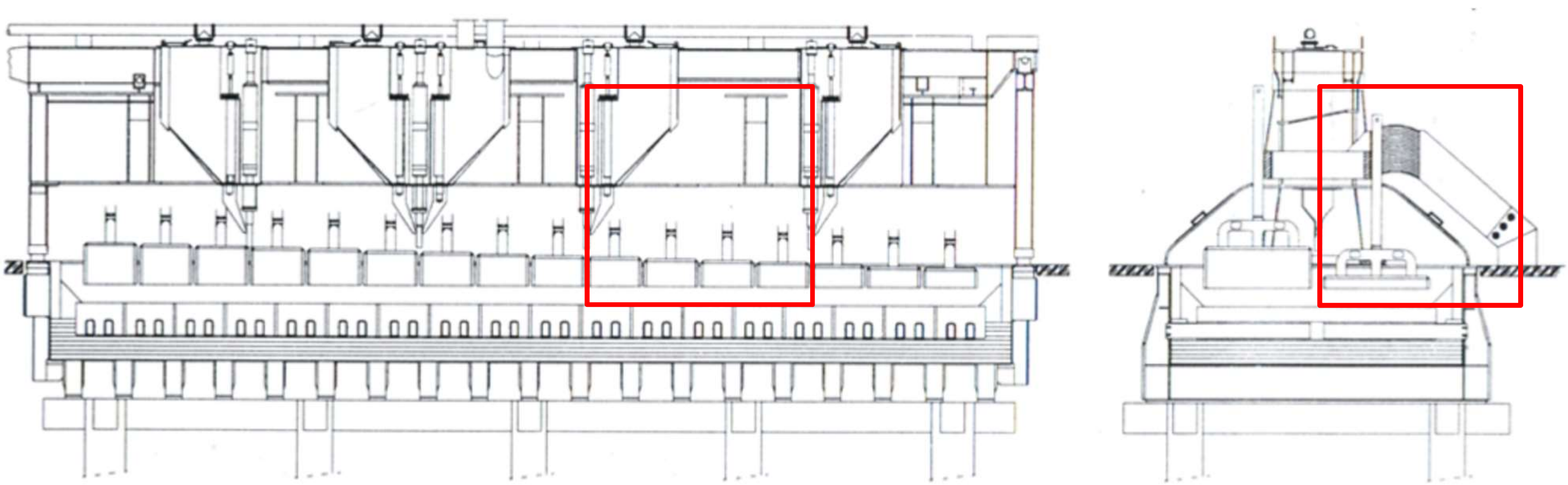




Ref: Marc Dupuis, Computation of aluminum reduction cell energy balance using ANSYS® finite element models, TMS Light Metals 1998, 409-417.

AUTODESK CFD 3D Thermo-Electric Model of the Anode

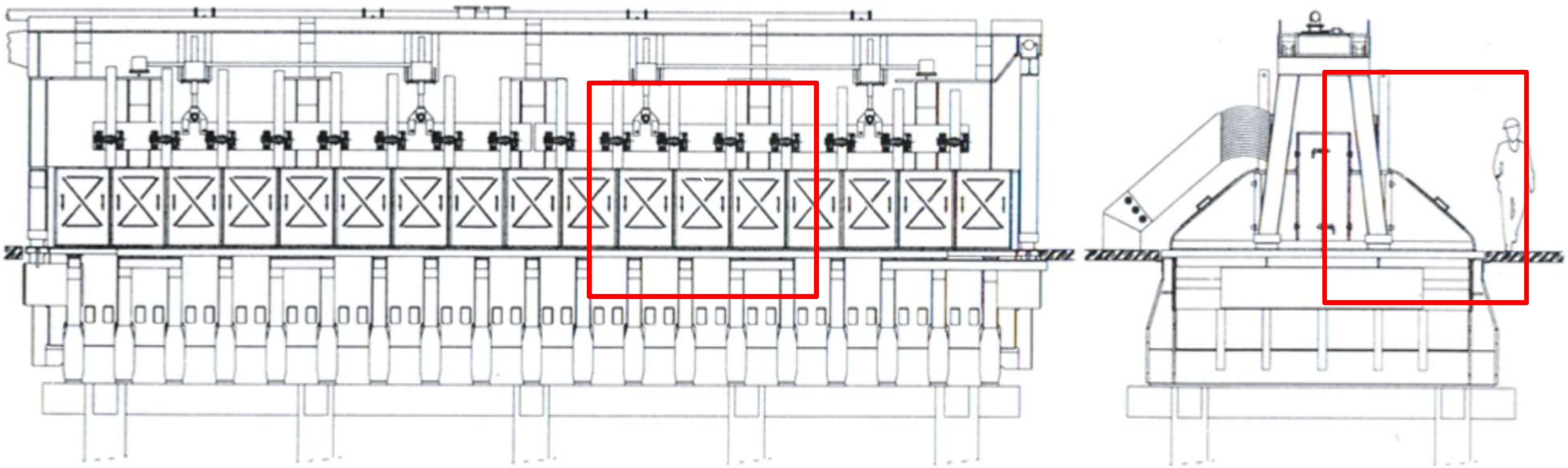
- **The anode geometry is the same geometry as the previously published ANSYS based demonstration 3D thermo-electric model, itself inspired from the VAW 300 cell design published in 1994.**



Ref: Vasili A. Kryukovski, Gennady A. Sirasutdinov, Juergen Klein, and Gerald Peychal-Heiling, International cooperation and high-performance reduction in Siberia, JOM, Vol 46, No. 2, (1994), 23–25.

AUTODESK CFD 3D Thermo-Electric Model of the Anode

- **The VAW 300 cell was operating at 300 kA and was using 32 1.6 m x 0.8 m anodes. Each anode had 3 stubs in line.**



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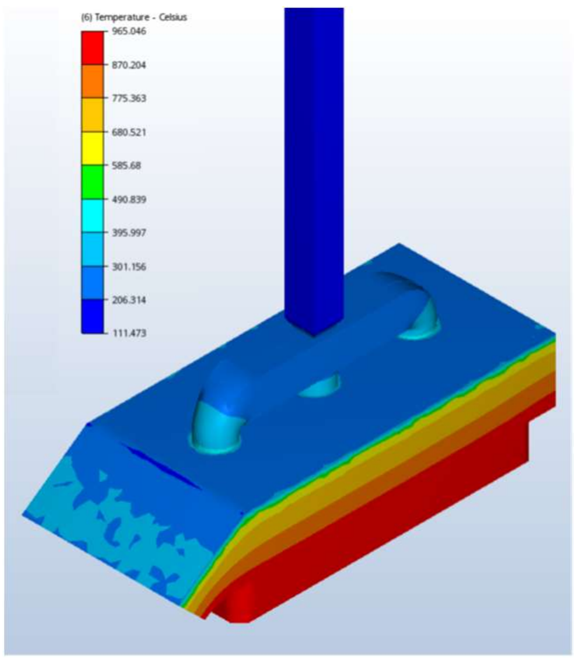
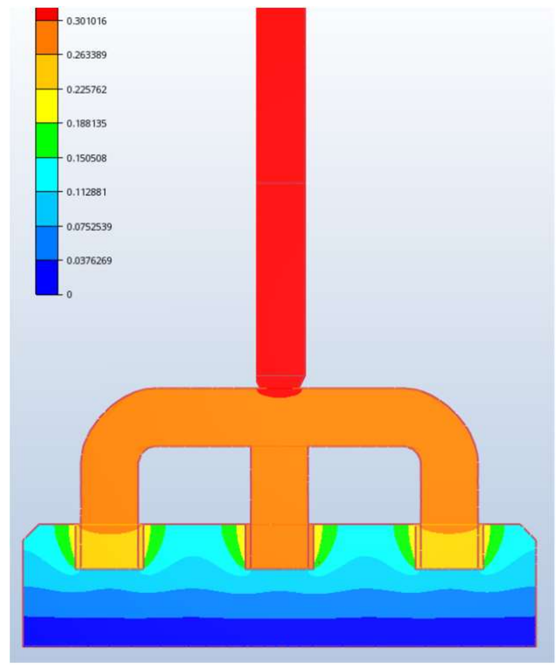
AUTODESK CFD 3D Thermo-Electric Model of the Anode

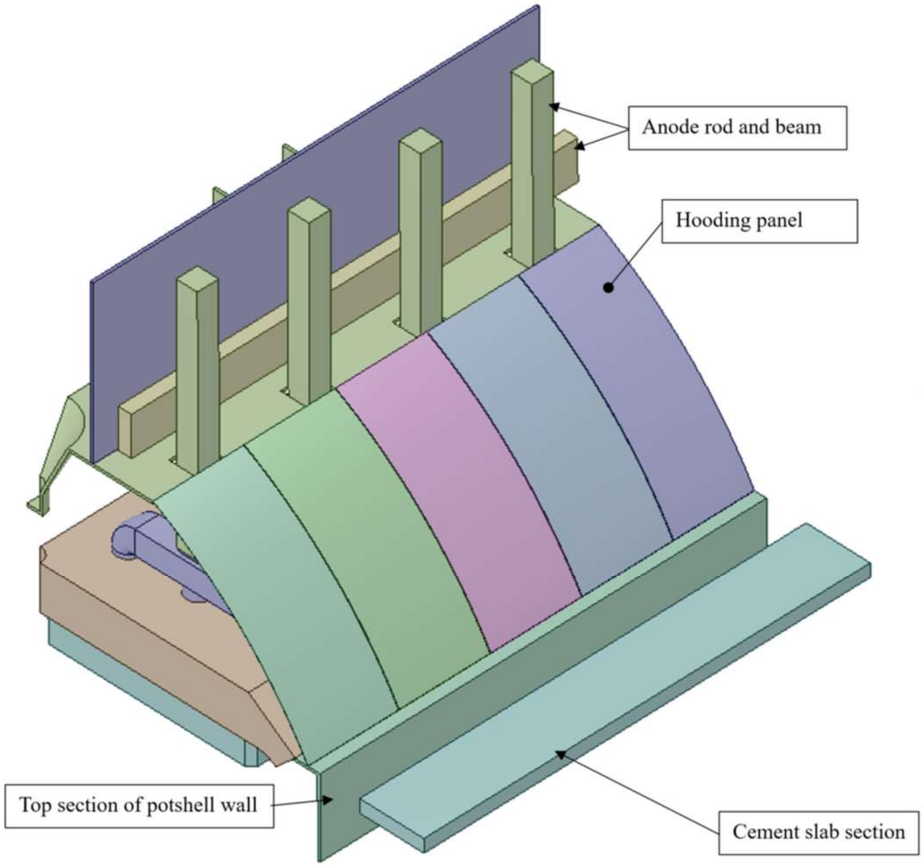
- **Using identical geometry and material properties and very similar combined convection and radiation boundary conditions but a much finer mesh, the AUTODESK CFD model results are very similar to the based ANSYS model.**

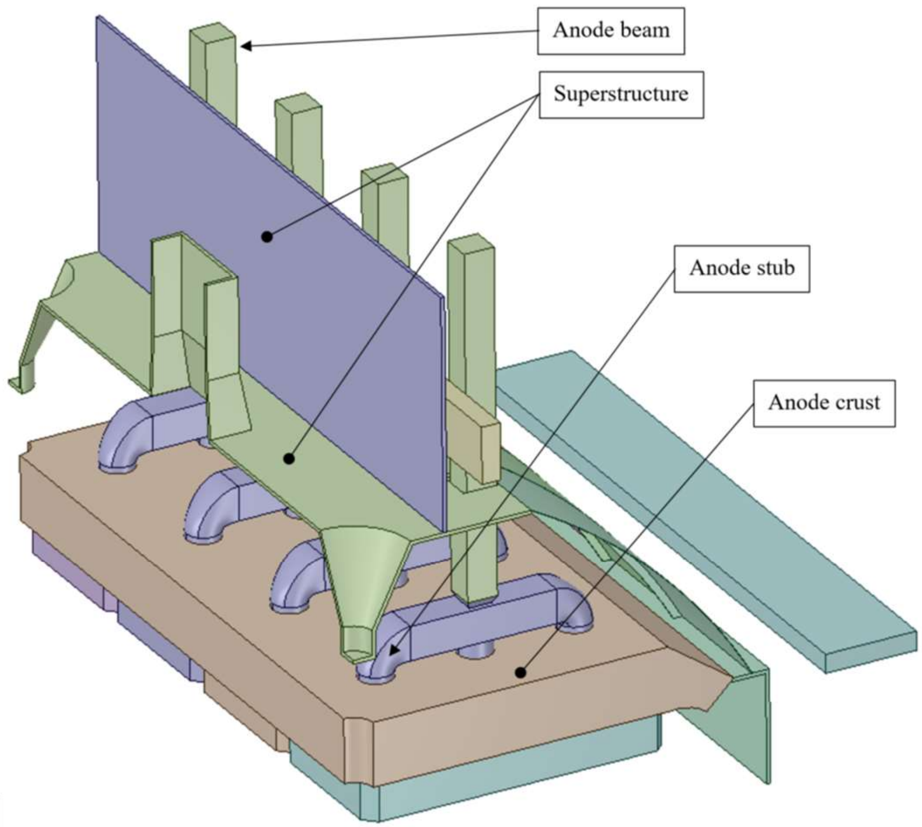




AUTODESK CFD Full 3D Model of a Section of a Hall-Héroult Anode Panel and Hooding System

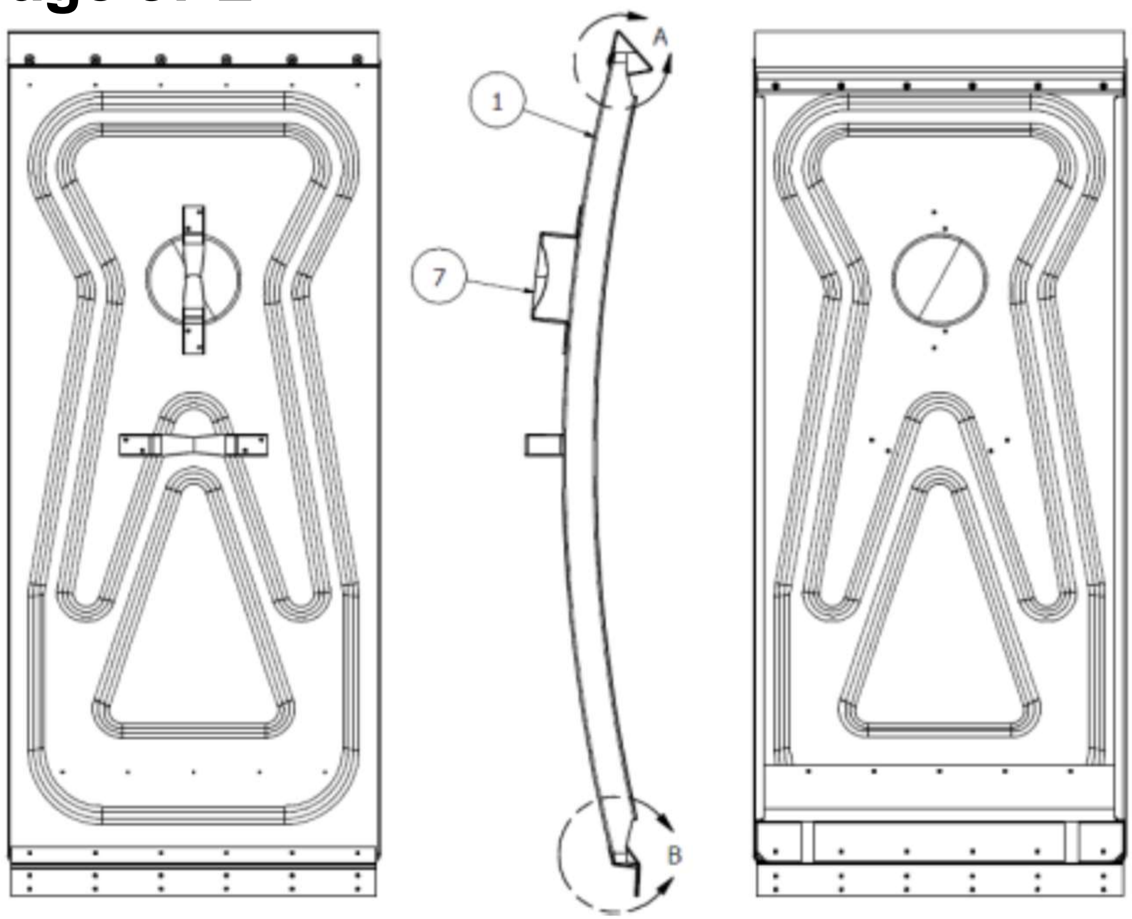
- **Model Geometry**





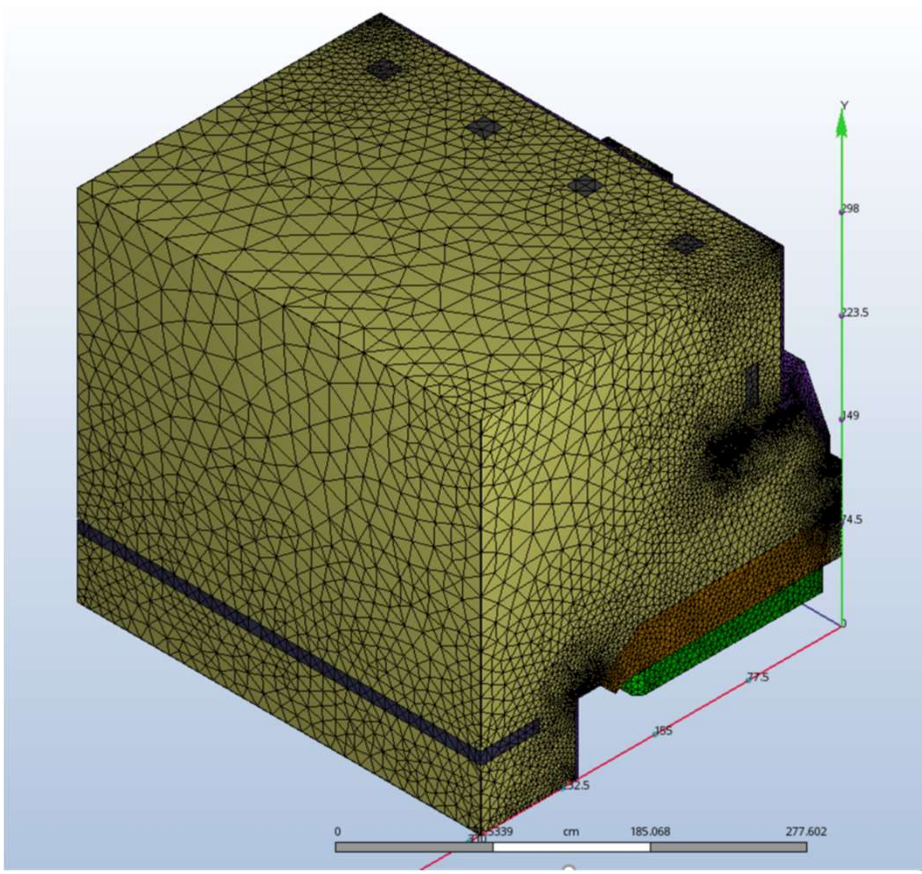
AUTODESK CFD Full 3D Model of a Section of a Hall-Héroult Anode Panel and Hooding System

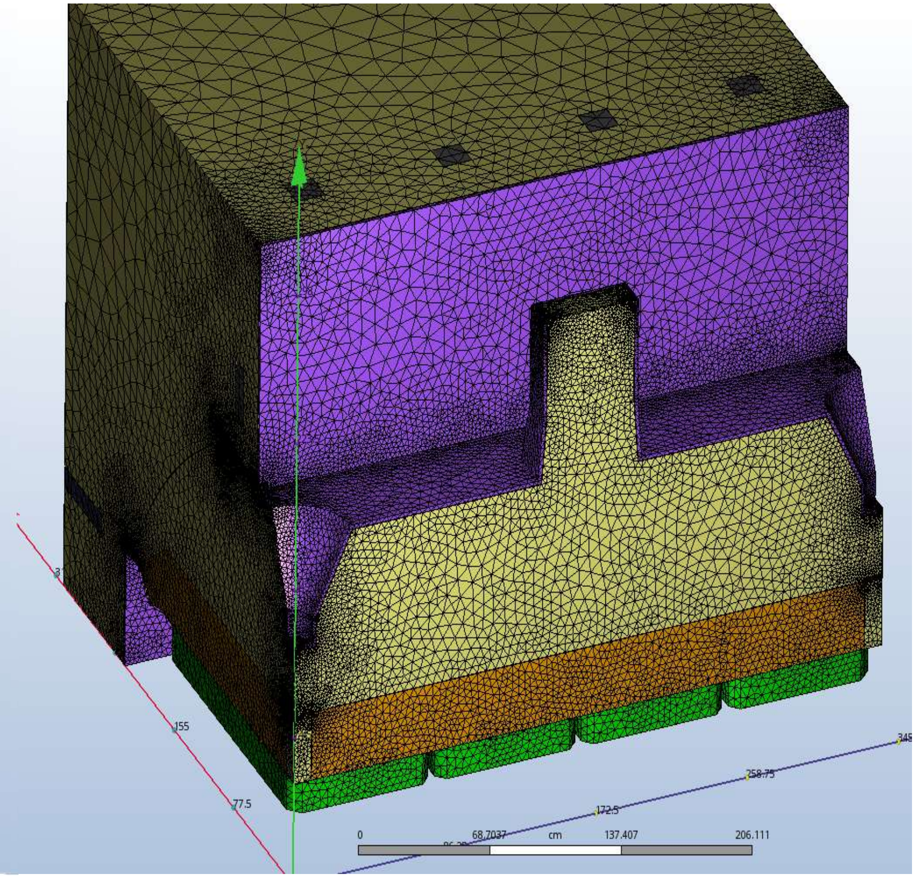
- **The geometry of the hooding panels was provided by Estampage JPL**



AUTODESK CFD Full 3D Model of a Section of a Hall-Héroult Anode Panel and Hooding System

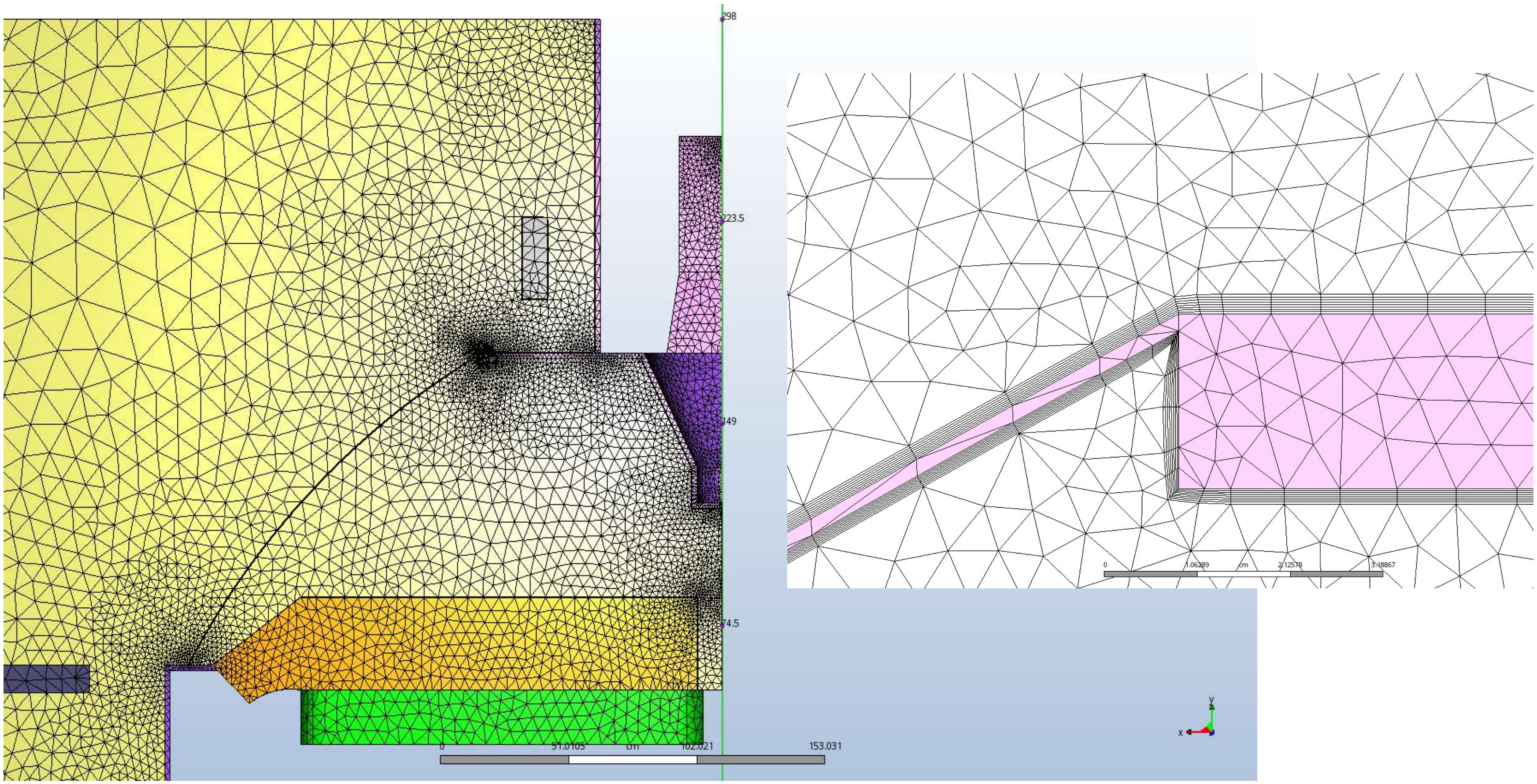
- **Model Mesh: about 7,000,000 fluid elements**





AUTODESK CFD Full 3D Model of a Section of a Hall-Héroult Anode Panel and Hooding System

- **Model Mesh: and about 2,600,000 solid elements**



AUTODESK CFD Full 3D Model of a Section of a Hall-Héroult Anode Panel and Hooding System

- **Degrees of Freedom Solved in the Model**
  - The model was solved for the temperature in the full domain.
  - In addition to the conduction in the solid elements and the convection and conduction in the fluid elements, there is a surface to surface radiation model to calculate the heat exchanged by radiation.
  - The voltage is solved in the thermo-electric solid elements.
  - The Joule heating is added to the temperature equation.
  - For this mixed convection CFD flow problem, the pressure is solved using the low Mach number assumption.
  - The turbulence is represented using the k-ω SST turbulence model.
  - The concentration of the HF in the gas is calculated using a passive scalar equation.

AUTODESK CFD Full 3D Model of a Section of a Hall-Héroult Anode Panel and Hooding System

- **Model Boundary Conditions**
  - The exhaust gas rate at the end of the exhaust duct is imposed. In the study presented here, it was set to 0.3 Nm^3/sec which represents 2.4 Nm^3/sec for the full 300 kA cell.
  - Assuming 95% current efficiency, the cell production of CO and CO_2 have been calculated. It turned out to be 110.835 kg CO_2/hr and 7.839 kg CO/hr. Once the CO is burned into CO_2 this gives 123.15 kg CO_2/hr that corresponds to a gas flow rate of 62.72 Nm^3 CO_2/hr for the cell or 7.84 Nm^3 CO_2/hr for the model equally split between the two quarter feeder crust holes.
  - The burning of the CO is producing 22 kW for the full cell corresponding to 2.75 kW again equally split between the two quarter feeder crust holes.

AUTODESK CFD Full 3D Model of a Section of a Hall-Héroult Anode Panel and Hooding System

- **Model Boundary Conditions**
  - For the HF production, assuming an evolution of 26.5 kg F/t Al, the cell is producing 2.535 kg F/hr or 2.67 kg HF/hr. That HF is not all emitted in its gaseous form but for the present study, it was assumed that all the HF evolved by the cell is in its gaseous form. This then corresponds to a production of 3.2 Nm^3 HF/hr for the cell.
  - That 3.2 Nm^3 HF/hr is added to the 62.72 Nm^3 CO_2/hr and converted into air as far as the properties of the gas produced are concerned. So, the cell is assumed to produce 65.92 Nm^3/hr of gas at the operating temperature corresponding to an “air” inflow of 4.12 Nm^3/hr in the bottom of the two quarter feeder crust holes.

AUTODESK CFD Full 3D Model of a Section of a Hall-Héroult Anode Panel and Hooding System

- **Model Boundary Conditions**
  - The concentration of HF is computed in the model using a passive scalar. The only source of that scalar is the two quarter feeding holes. The concentration of HF in those two inlets is calculated to be 2.67/ 65.92 = 0.0405 kg HF/Nm^3.
  - Assuming 100% HF capture efficiency, based on the dilution ratio, the average HF concentration in the exhaust gas should be reduced to:

$$65.93 / (2.4 \times 3600) \times 0.0405 = 0.000309 \text{ kg HF/Nm}^3$$

  - The reference 0 pressure is fixed at the top surface of the model in the potroom.
  - A very small uniform air inflow is imposed in the bottom face of the model in the basement.

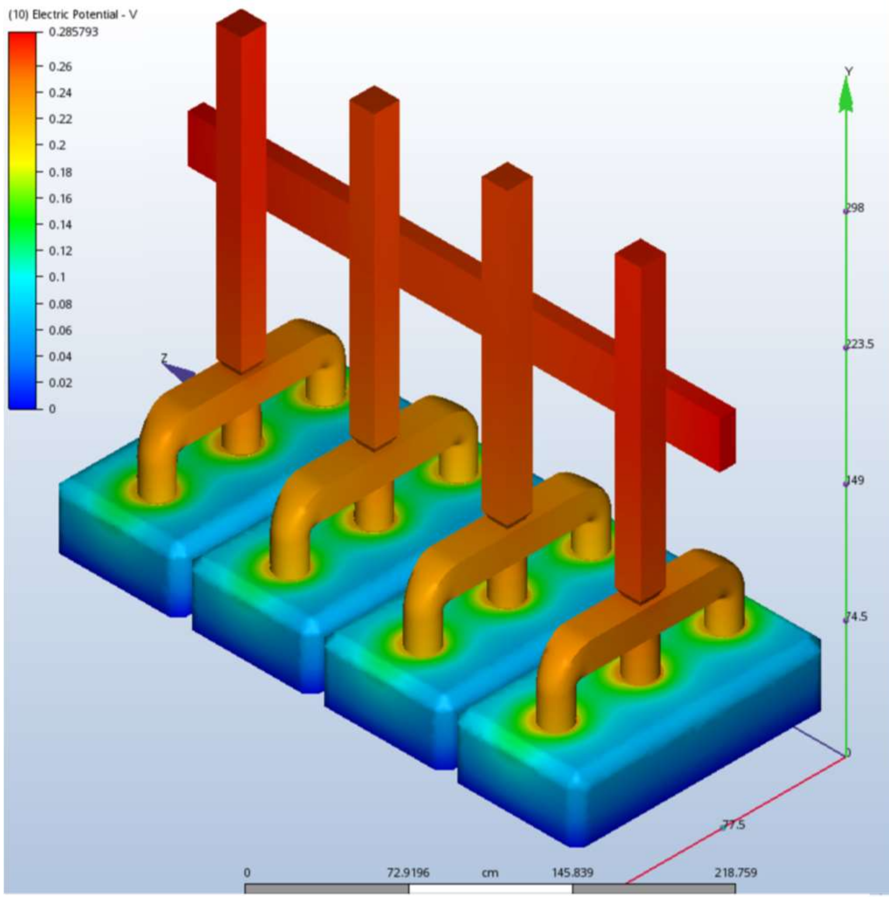
AUTODESK CFD Full 3D Model of a Section of a Hall-Héroult Anode Panel and Hooding System

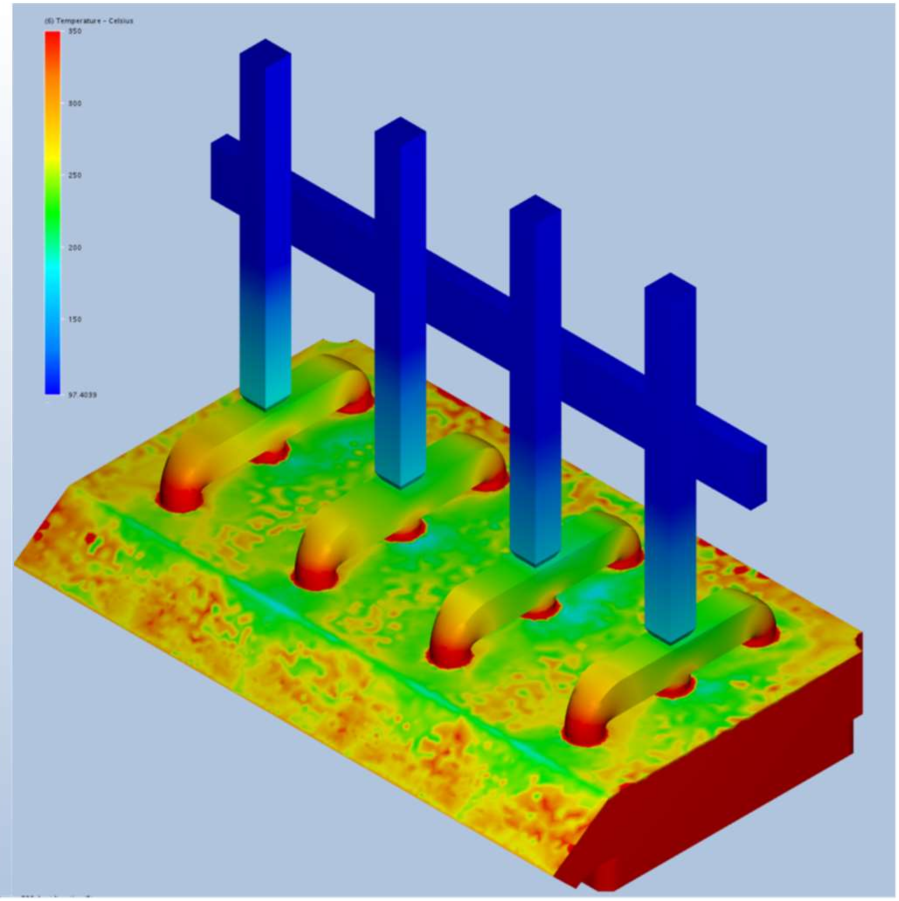
- **Model Solution**

  - The model is solved first in steady state mode using the ADV 5 (Modified Petrov-Galerkin) convergence scheme available in AUTODESK CFD. In the current study, 300 iterations have been used to converge the steady state conditions. Computing that solution required 18h20 CPU using 6 Intel Xeon E2630 v2 processors operating at 2.6GHz on a computer having 64 GB of RAM.
  - It was decided to continue computing the flow evolution using the transient mode starting from that "steady state" initial condition. The flow evolution was computed for a period of 150 seconds using a 0.1 second time step with 3 equilibrium iterations per time step. Computing that transient evolution took 103h33 of additional CPU time.

AUTODESK CFD Full 3D Model of a Section of a Hall-Héroult Anode Panel and Hooding System

- **Model Solution: anodes voltage drop and temperature**





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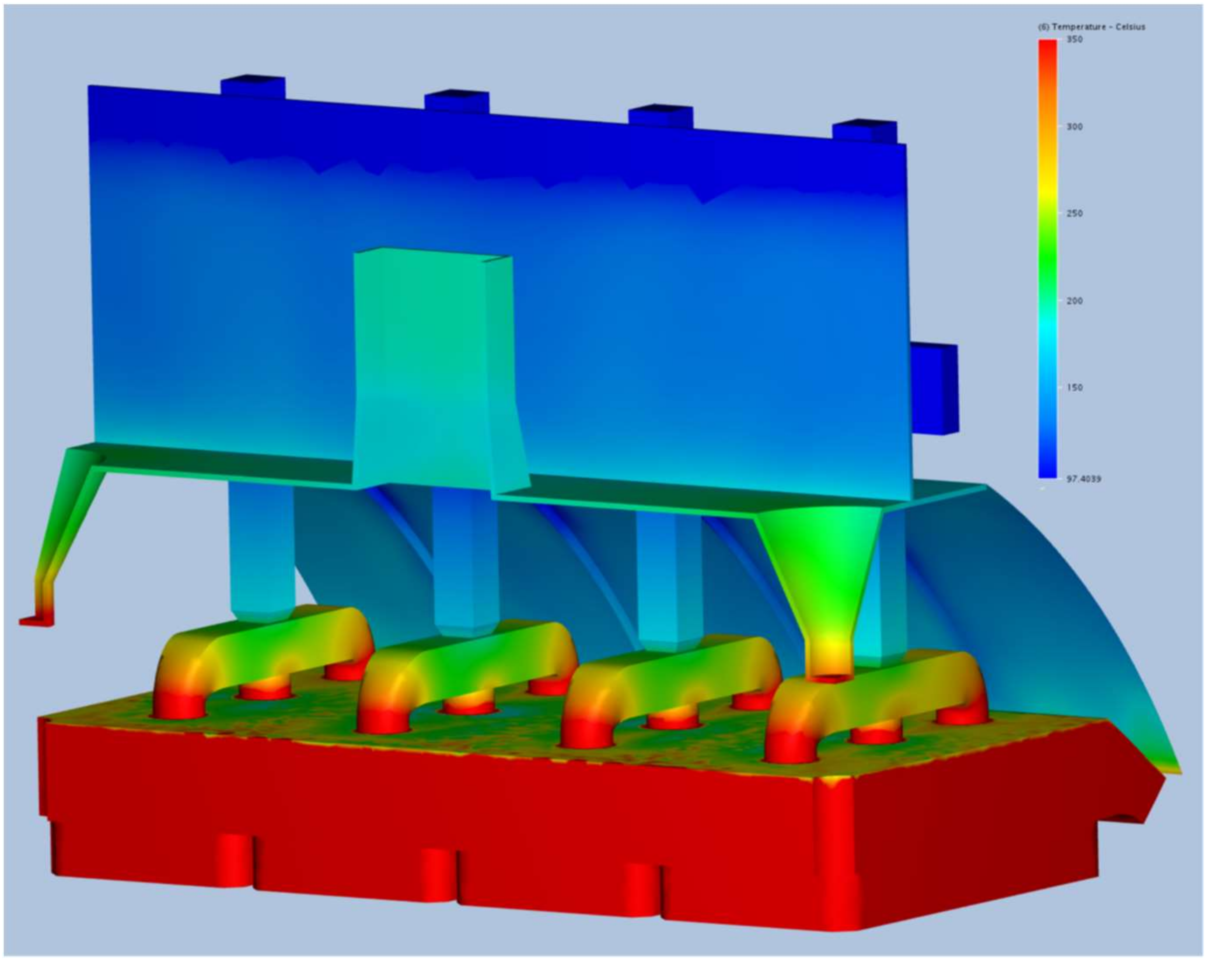
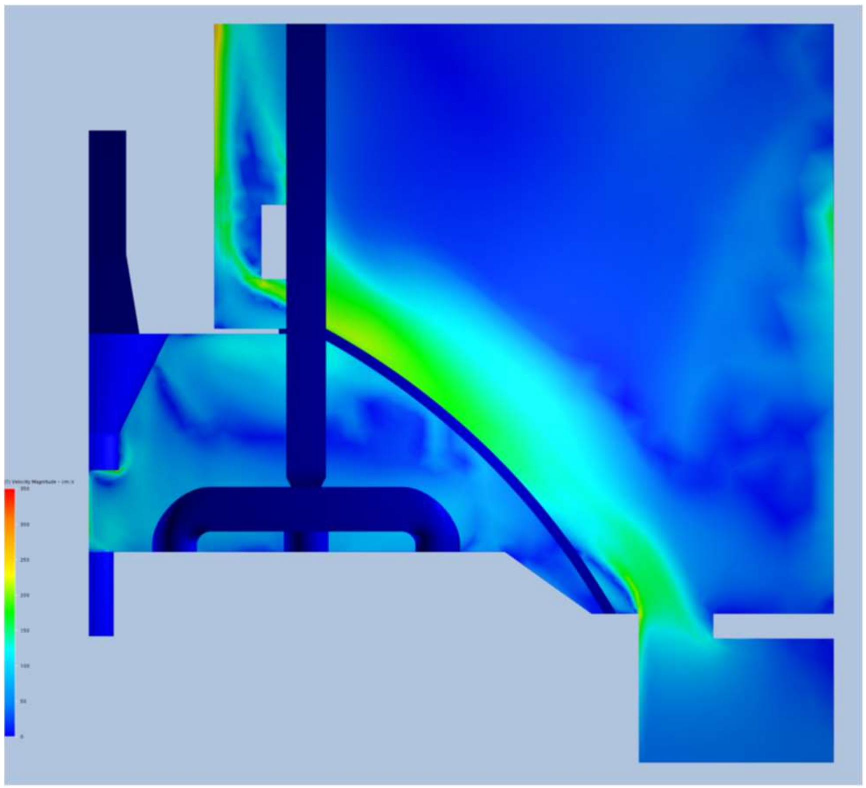
AUTODESK CFD Full 3D Model of a Section of a Hall-Héroult Anode Panel and Hooding System

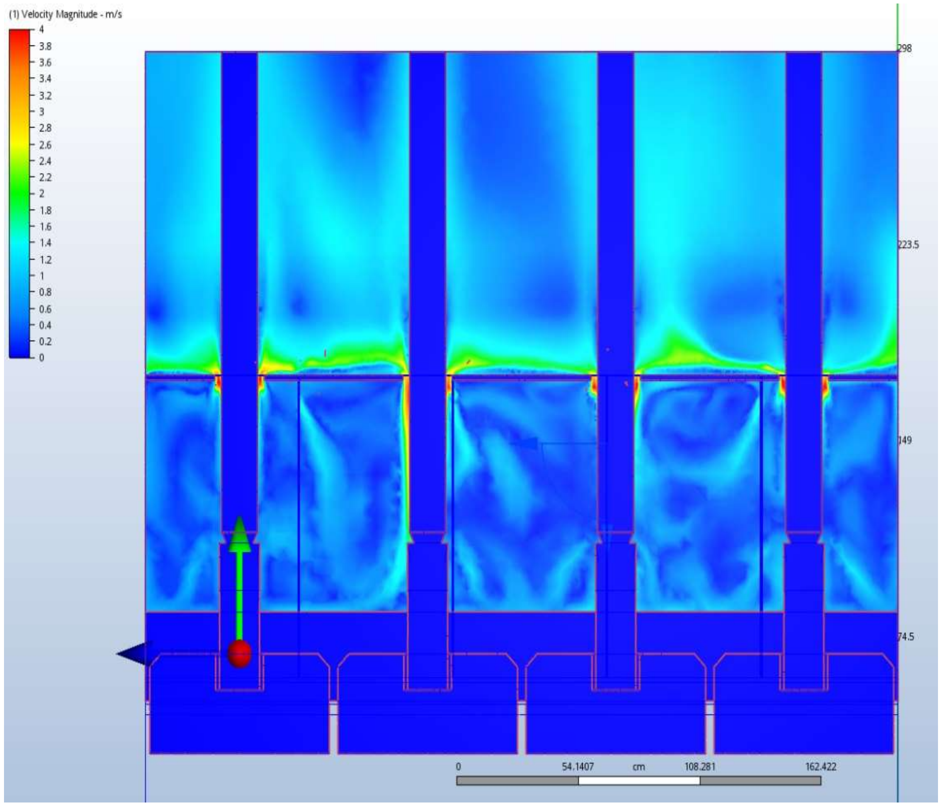
- **Model Solution: temperature of all solids**



AUTODESK CFD Full 3D Model of a Section of a Hall-Héroult Anode Panel and Hooding System

- **Model Solution: air velocity magnitude**





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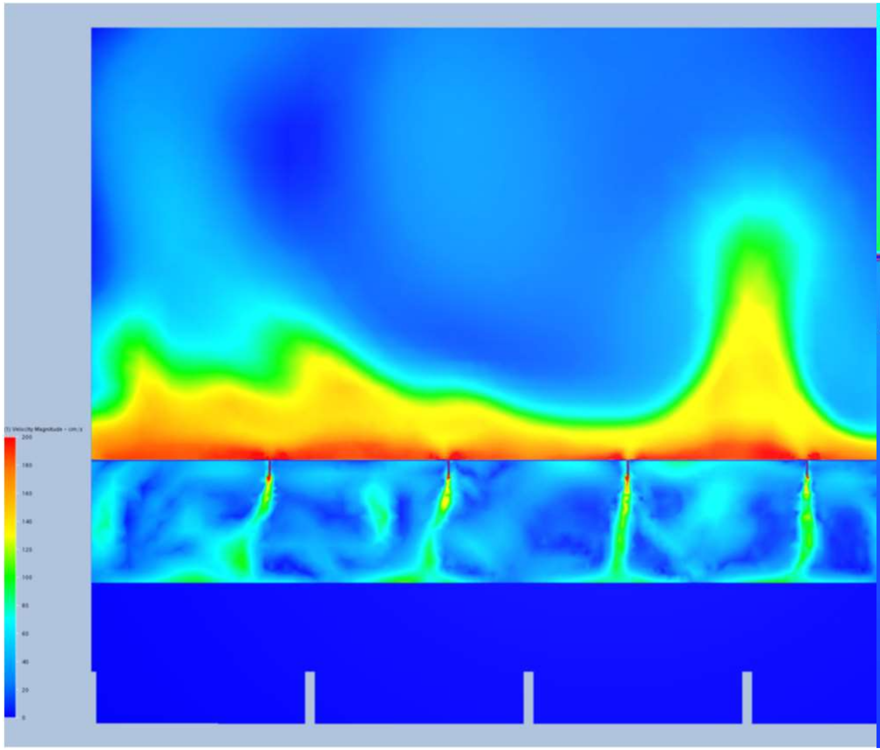
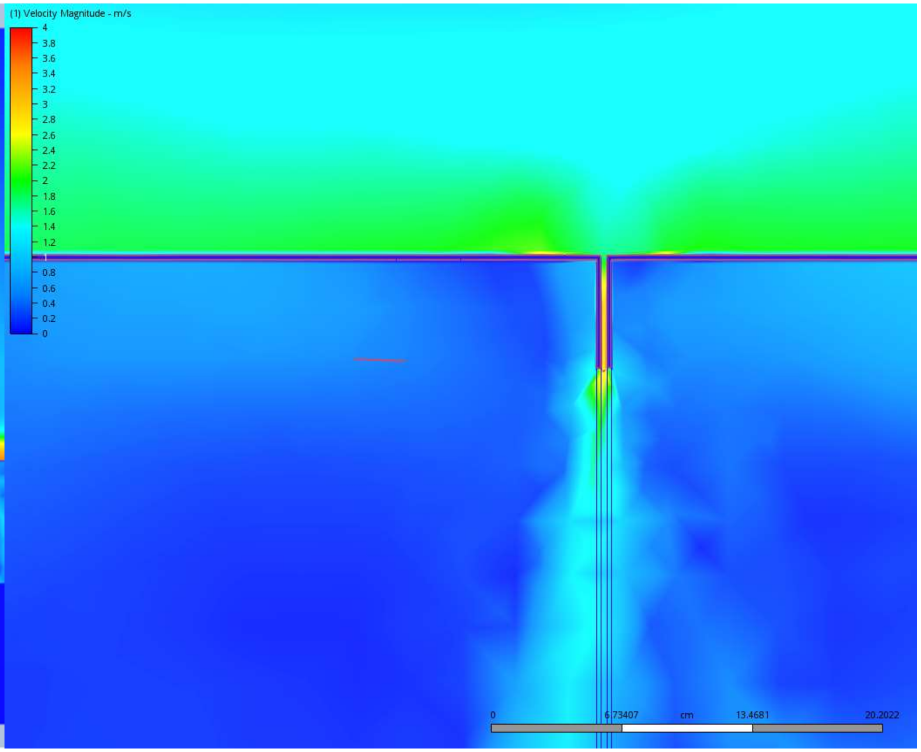
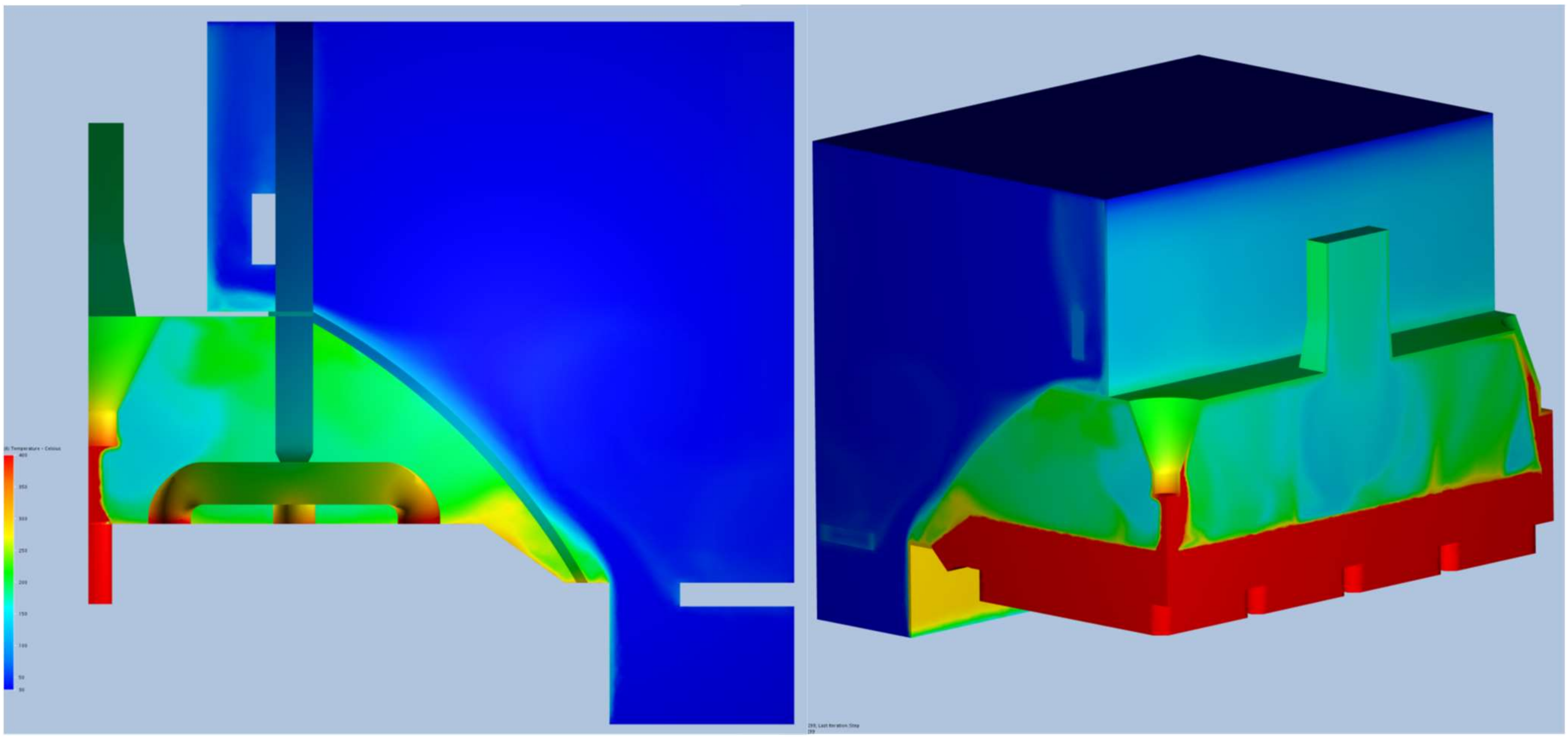




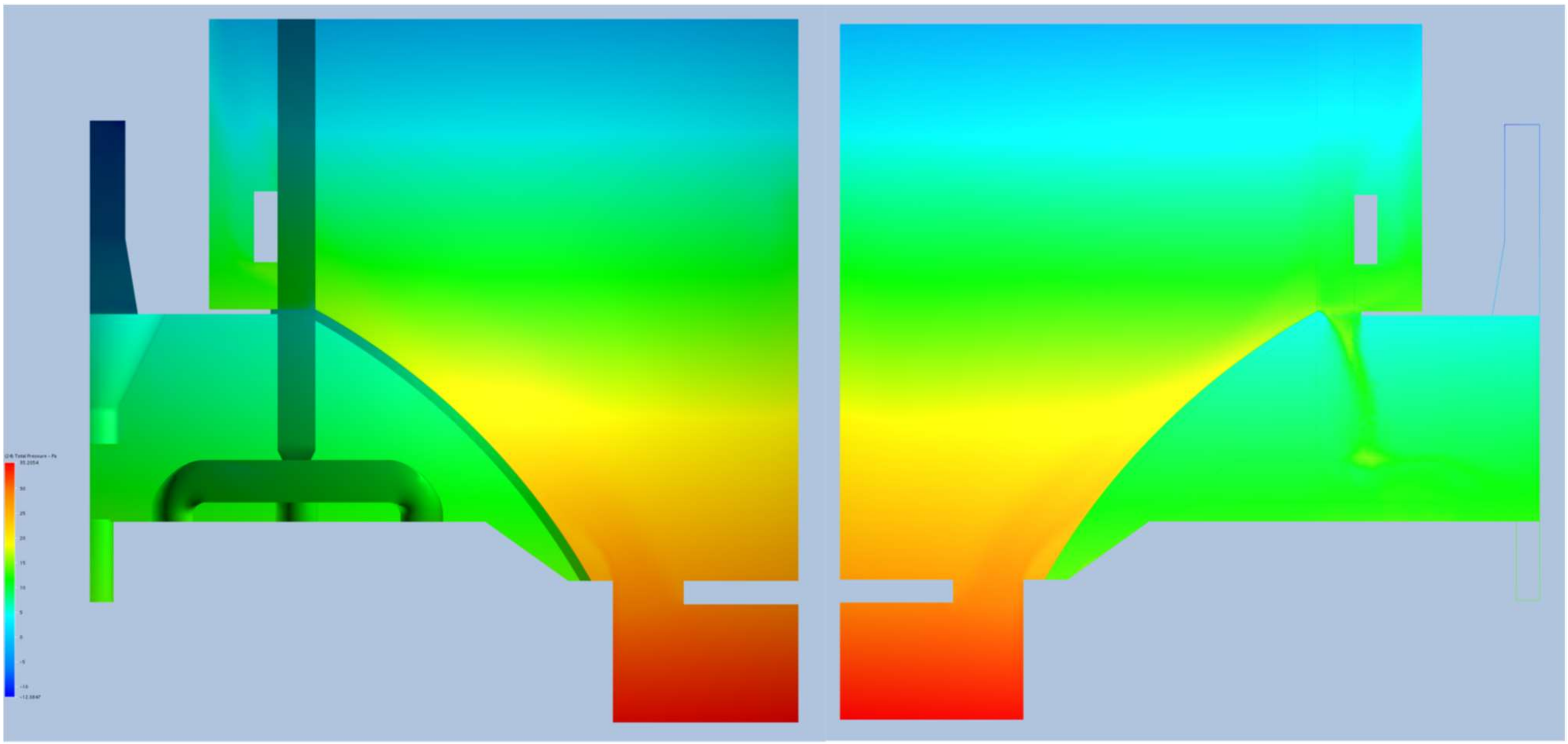
AUTODESK CFD Full 3D Model of a Section of a Hall-Héroult Anode Panel and Hooding System

- **Model Solution: air temperature**



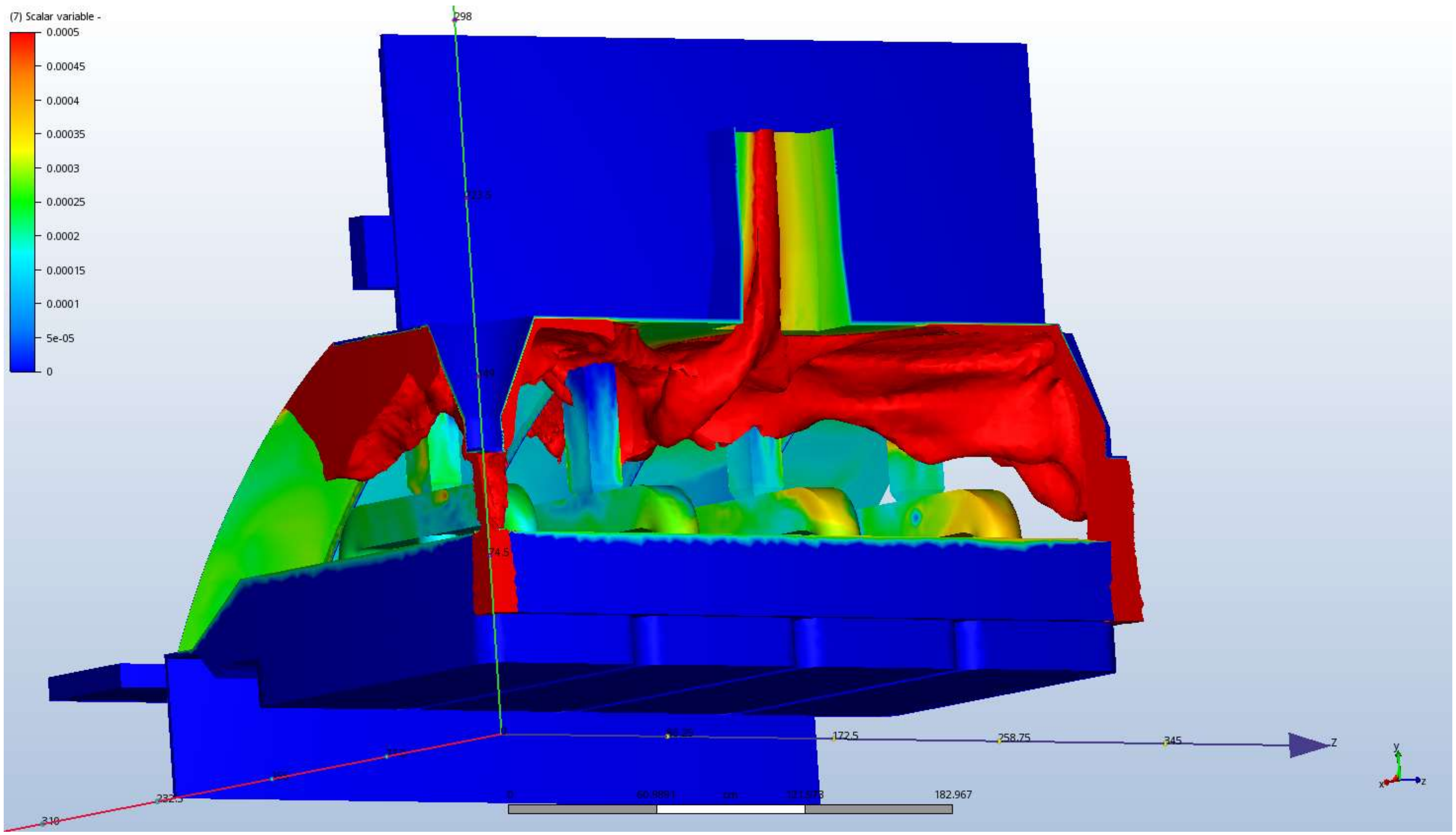
AUTODESK CFD Full 3D Model of a Section of a Hall-Héroult Anode Panel and Hooding System

- **Model Solution: total air pressure**



AUTODESK CFD Full 3D Model of a Section of a Hall-Héroult Anode Panel and Hooding System

- **Model Solution: HF concentration**



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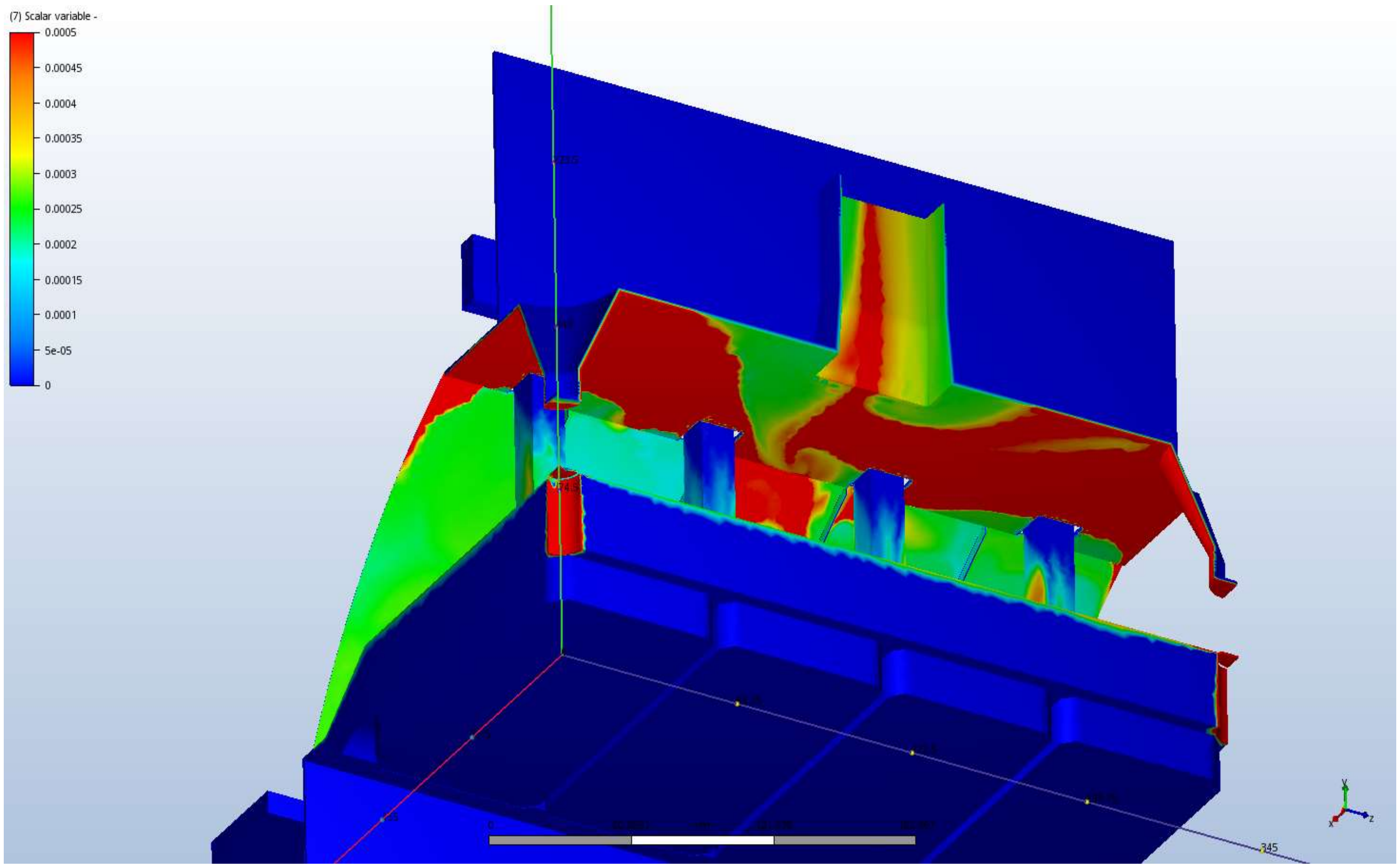

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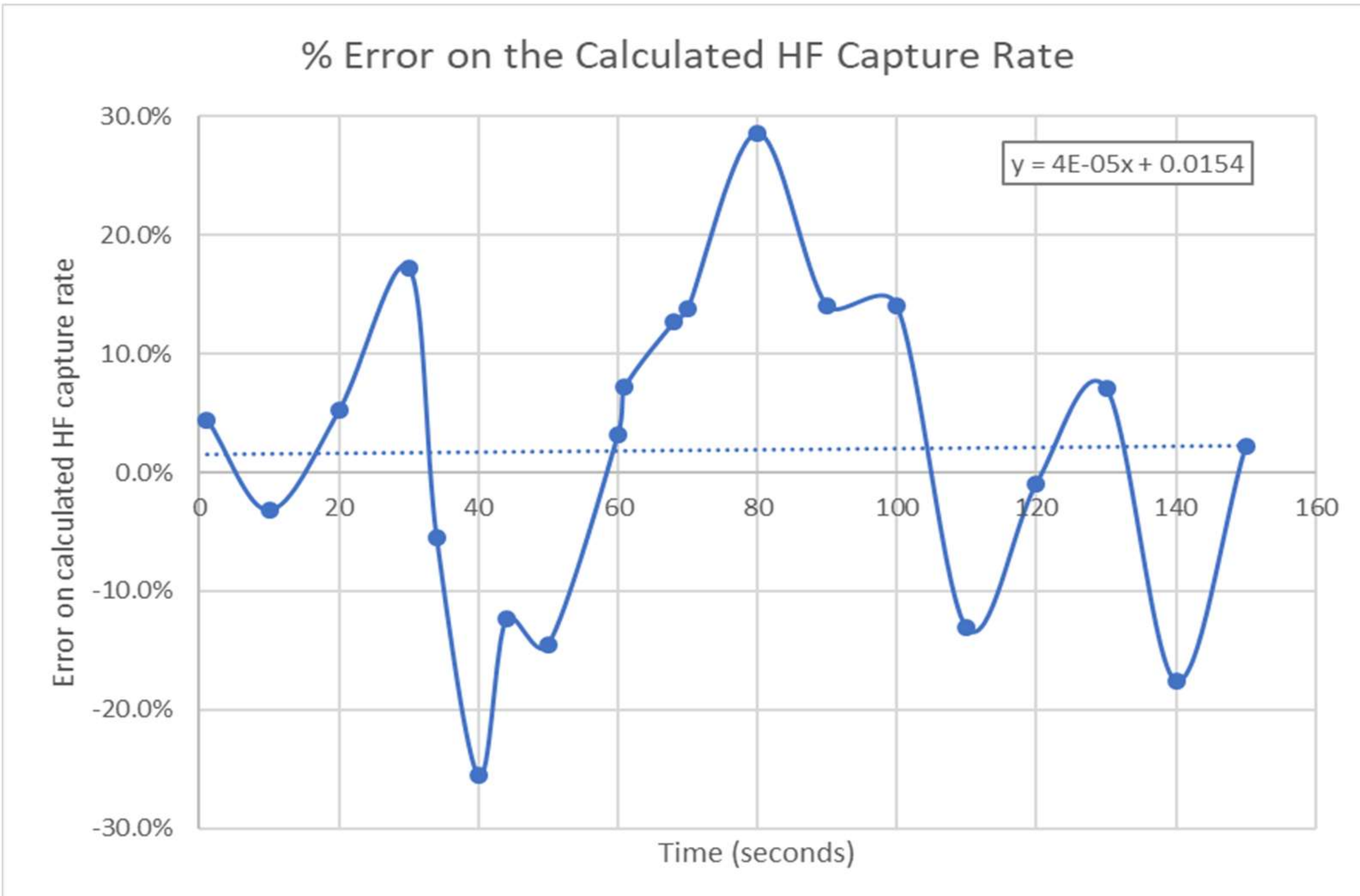
- **Model Solution: HF concentration**



Conclusions

- The aim of the current work was to demonstrate that it is possible to develop a model that reproduces well the complex physics occurring under the hood of a reduction cell. This includes the cell CO_2, CO and HF gas production, the CO burning, the radiation heat transfer between solid surfaces and finally the gas circulation that dictates the convection heat transfer between the solid surfaces and the gas.
- In the present study, the capture rate was 100% since no HF was escaping in the potroom.
- It turned out to be very difficult and expensive to calculate that HF capture rate efficiency based on the concentration of HF in the exhaust gas and the dilution rate as this concentration was not uniform in space nor constant in time.