HOW TO LIMIT THE HEAT LOSS OF ANODE STUBS AND CATHODE COLLECTOR BARS IN ORDER TO REDUCE CELL ENERGY CONSUMPTION

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GENISIM

Plan of the Presentation

- **Introduction: previous work presented in 2018**
  - **TMS 2018:** **500 kA with 100% downstream current exit cell running at 11.2 kWh/kg**
  - **IAJ 2018:** **520 kA with 100% downstream current exit cell running at 10.85 kWh/kg**
  - **12th AASTC:** **Using HHCellVolt to calculate the cell internal heat**
- **Improvement of the model calculated cell heat balance**
- **Revealing the design feature that reduces the stubs and collector bars heat loss**
- **475 kA cell with 100% downstream current exit cell running at 10.44 kWh/kg**
- **Future work**
- **Conclusions**

500 kA with 100% downstream current exit cell running at 11.2 kWh/kg

Amperage	600 kA	500 kA
Nb. of anodes	48	64
Anode size	2.0 m × .665 m	1.95 m × .5 m
Nb. of anode studs	4 per anode	4 per anode
Anode stud diameter	17.5 cm	17.5 cm
Anode cover thickness	10 cm	20 cm
Nb. of cathode blocks	24	24
Cathode block length	4.17 m	4.17 m
Type of cathode block	HC10	HC10
Collector bar size	20 cm × 10 cm	20 cm × 20 cm
Type of side block	SiC	HC3
Side block thickness	7 cm	7 cm
Anode side wall distance: ASD	28 cm	30 cm
Calcium silicate thickness	3.5 cm	6.0 cm
Inside potshell size	17.8 × 4.85 m	17.8 × 4.85 m
Anode cathode distance: ACD	3.5 cm	3.2 cm
Excess AlF_3	12.00 %	12.00 %

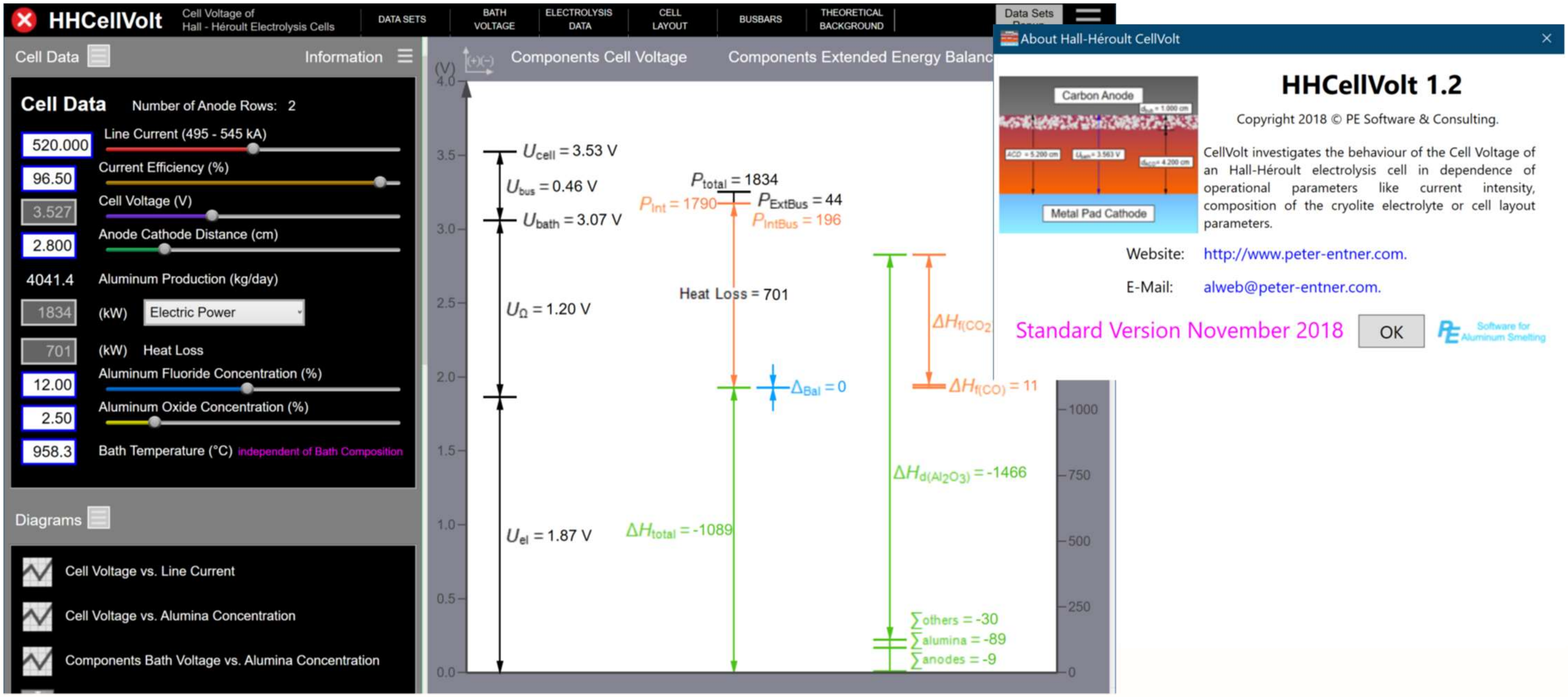
Anode drop (A)	318 mV	238 mV
Cathode drop (A)	104 mV	123 mV
Busbar drop (A)	311 mV	134 mV
Anode panel heat loss (A)	449 kW	292 kW
Cathode total heat loss (A)	692 kW	402 kW
Operating temperature (D/M)	964.8 °C	958.4 °C
Liquidus superheat (D/M)	11.8 °C	5.4 °C
Bath ledge thickness (A)	6.36 cm	11.84 cm
Metal ledge thickness (A)	1.76 cm	3.48 cm
Current efficiency (D/M)	96.40 %	96.30 %
Internal heat (D/M)	1140 kW	699 kW
Energy consumption	13.26 kWh/kg	11.2 kWh/kg

520 kA with 100% downstream current exit cell running at 10.85 kWh/kg

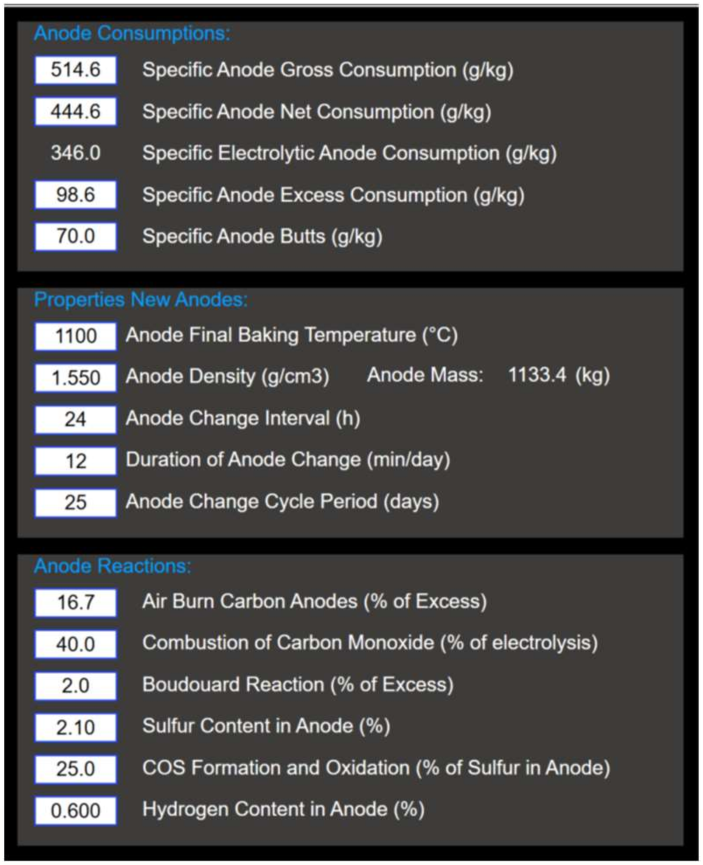
Amperage	600 kA	500 kA	520 kA
Nb. of anodes	48	64	64
Anode size	2.0 x .665 m	1.95 x .5 m	1.95 x .5 m
Nb. of anode studs	4 per anode	4 per anode	4 per anode
Anode stud diameter	17.5 cm	17.5 cm	17.5 cm
Anode cover thickness	10 cm	20 cm	20 cm
Nb. of cathode blocks	24	24	24
Cathode block length	4.17 m	4.17 m	4.17 m
Type of cathode block	HC 10	HC 10	HC 10
Collector bar size	20 x 10 cm	20 x 20 cm	20 x 20 cm
Type of side block	SiC	HC3	HC3
Side block thickness	7 cm	7 cm	7 cm
ASD	28 cm	30 cm	30 cm
Calcium silicate thickness	3.5 cm	6.0 cm	6.0 cm
Inside potshell size	17.8 x 4.85 m	17.8 x 4.85 m	17.8 x 4.85 m
ACD	3.5 cm	3.2 cm	2.8 cm
Excess AlF_3	12%	12%	12%

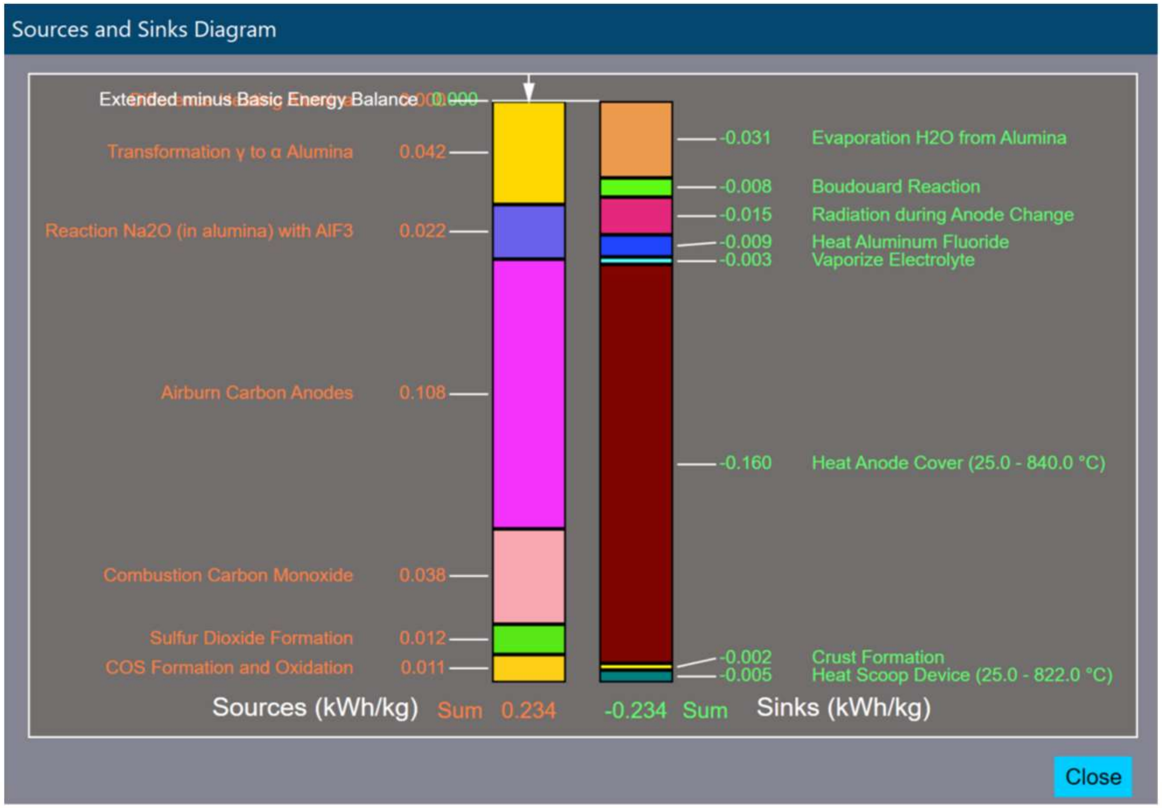
Anode drop (A)	318 mV	238 mV	248 mV
Cathode drop (A)	104 mV	123 mV	128 mV
Busbar drop (A)	311 mV	134 mV	85 mV
Anode panel heat loss (A)	449 kW	292 kW	295 kW
Cathode total lieat loss (A)	692 kW	402 kW	404 kW
Operating temperatur (D/M)	964.8 °C	958.4 °C	958.3 °C
Liquidus superheat (D/M)	11.8 °C	5.4 °C	5.3 °C
Bath ledge thickness (A)	6.36 cm	11.84 cm	11.83 cm
Metal ledge thickness (A)	1.76 cm	3.48 cm	3.46 cm
Current efficiency (D/M)	96.4%	96.3%	96.5%
Intenial heat (D/M)	1140 kW	699 kW	701 kW
Energy consumption	13.26 kWh/kg	11.2 kWh/kg	10.85 kWh/kg

Using HHCellVolt
to calculate the cell internal heat



Using HHCellVolt
to calculate the cell internal heat

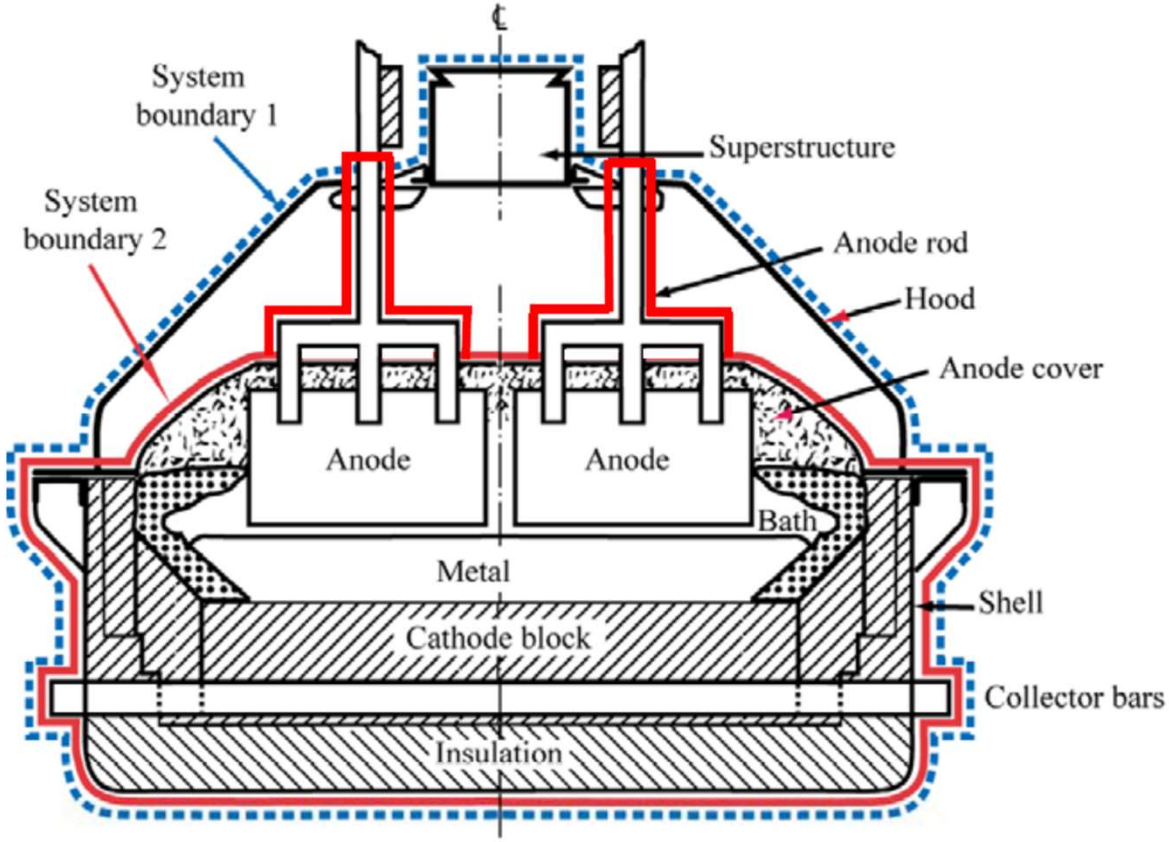




Improvement of the model calculated cell heat balance

The heat balance calculation of any system is based on the establishment of the boundary of that system.

This figure presents two of those possible boundaries.

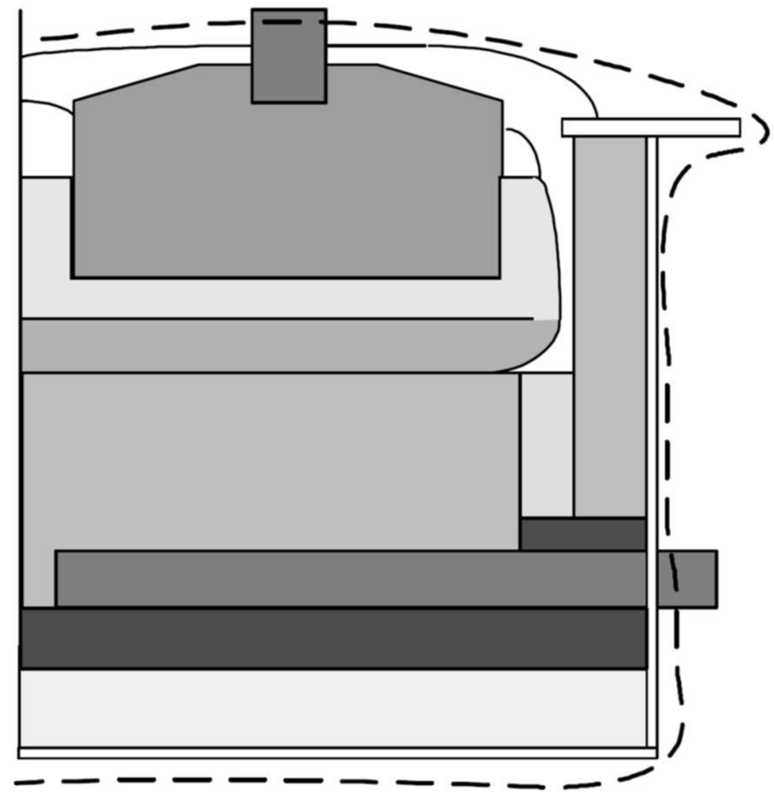


A. Al Zarouni and al., "Energy and Mass Balance in DX+ cells during Amperage Increase", *31st International Conference of ICSOBA, 19th Conference, Aluminium Siberia, Krasnoyarsk, Russia,* September 4 – 6, 2013, 494-498.

Improvement of the model calculated cell heat balance

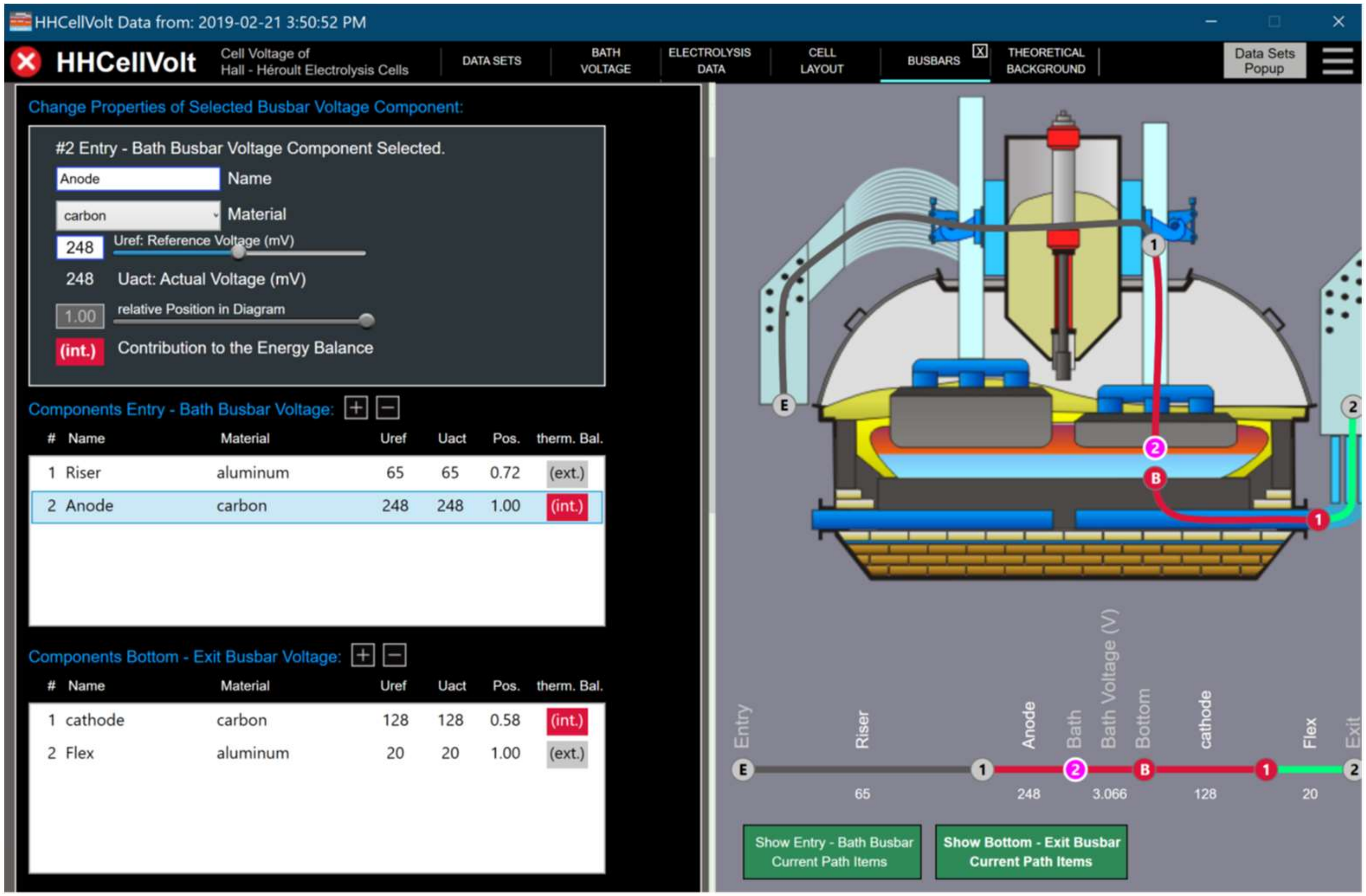
The solid red line boundary in the figure of the previous slide is very convenient as it exactly incorporates the domain of the full anode and cathode.

Yet, the cell boundary that really matters, as far as the cell internal conditions are concerned, is the boundary presented in this figure.

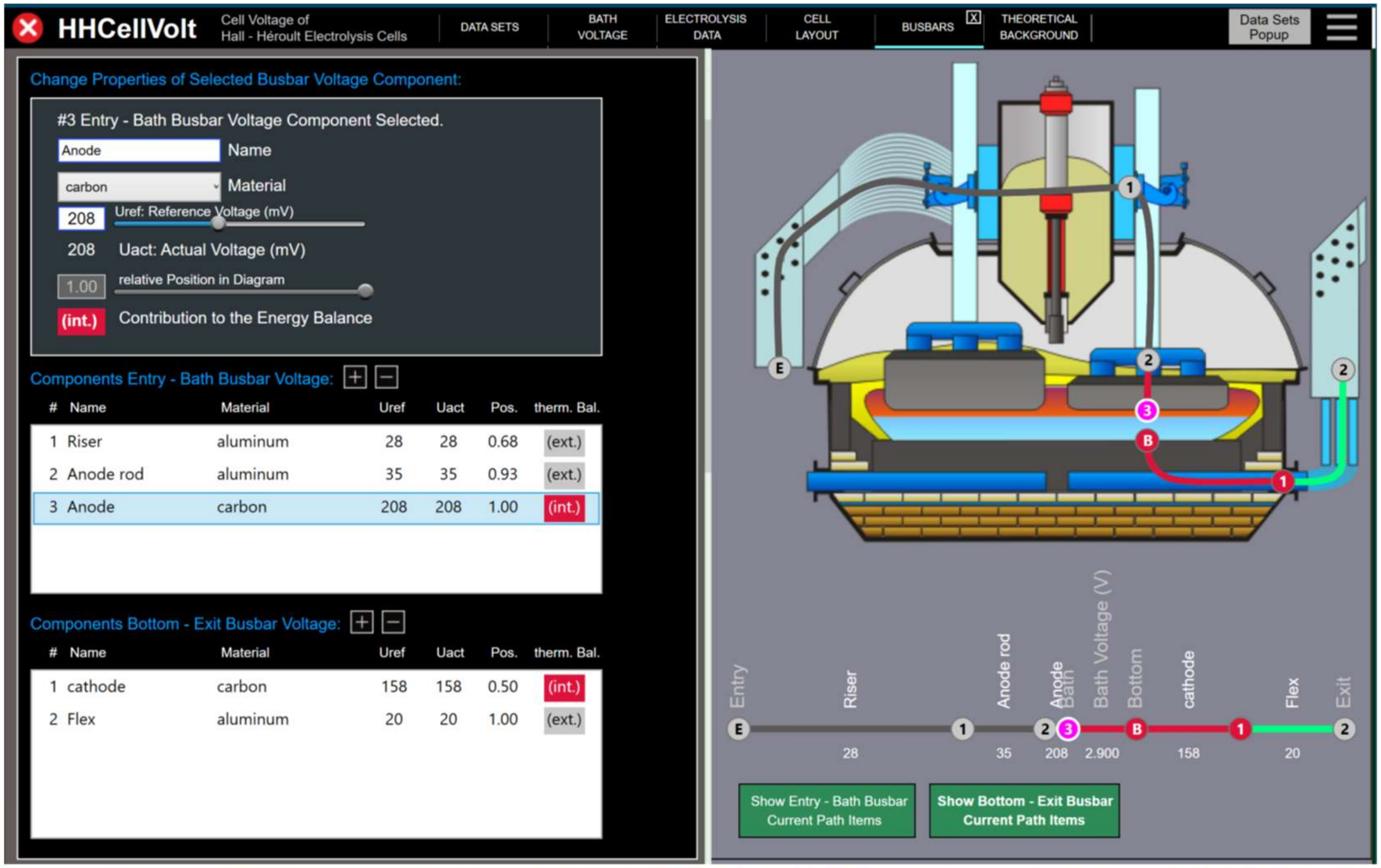


J. N. Bruggeman, "Pot Heat Balance Fundamentals", *Proc. 6th Aust. Al Smelting Workshop*, 1998, 167-189.

Improvement of the model calculated cell heat balance



Improvement of the model calculated cell heat balance

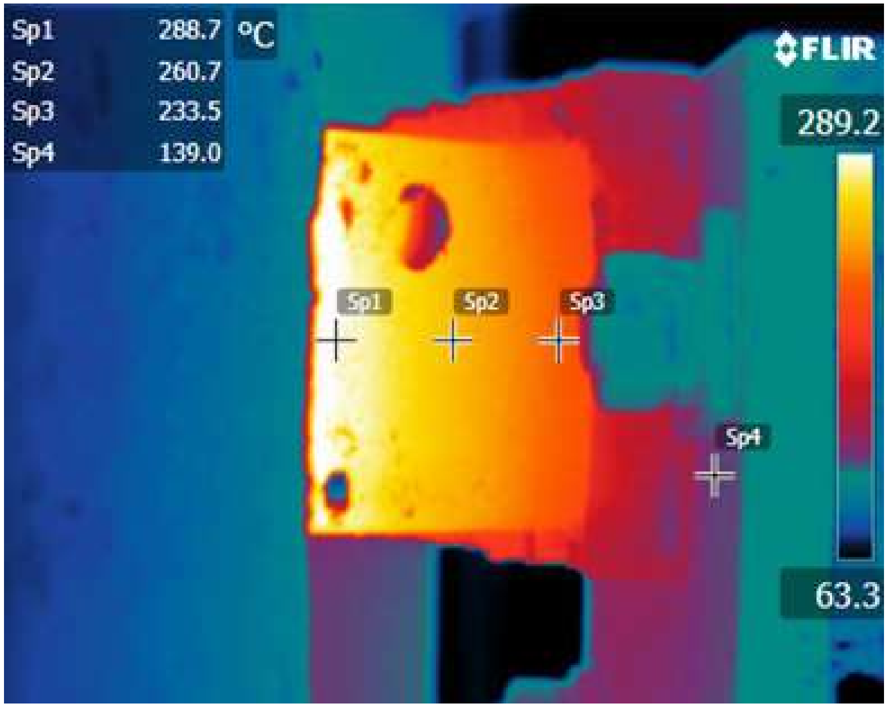


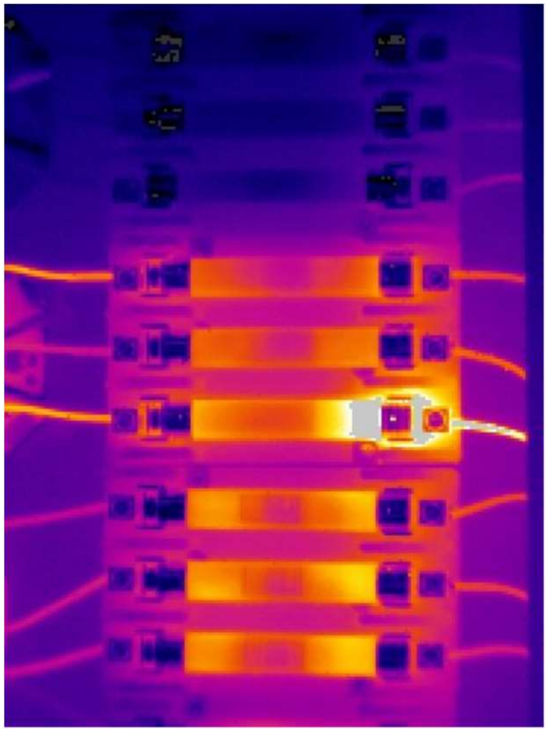
Improvement of the model calculated cell heat balance

Amperage	520 kA	520 kA
Nb. of anodes	64	64
Anode size	1.95 m X .5 m	1.95m X .5m
Nb. of anode stubs	4 per anode	4 per anode
Anode stub diameter	17.5 cm	17.5 cm
Anode cover thickness	20 cm	20 cm
Nb. of cathode blocks	24	24
Cathode block length	4.17 m	4.17 m
Type of cathode block	HC10	HC10
Collector bar size	20 cm X 20 cm	20 cm X 20 cm
Type of side block	HC3	HC3
Side block thickness	7 cm	7 cm
ASD	30 cm	30 cm
Calcium silicate thickness	6.0 cm	6.0 cm
Inside potshell size	17.8 mX4.85 m	17.8 mX4.85 m
ACD	2.8 cm	2.8 cm
Excess AlF_3	12.00%	12.00%

Anode drop (A)	248 mV	210 mV
Cathode drop (A)	128 mV	124 mV
Busbar drop (A)	85 mV	127 mV
Anode panel heat loss (A)	295 kW	286 kW
Cathode total heat loss (A)	404 kW	381 kW
Operating temperature (D/M)	958.3 °C	957.7 °C
Liquidus superheat (D/M)	5.3 °C	4.7 °C
Bath ledge thickness (D/M)	20.0 cm	22.8 cm
Metal ledge thickness (D/M)	15.3 cm	18.1 cm
Current efficiency (D/M)	96.5%	96.5%
Internal heat (D/M)	701 kW	679 kW
Energy consumption	10.85 kWh/kg	10.85 kWh/kg

Revealing the design feature that reduces the stubs and collector bars heat loss

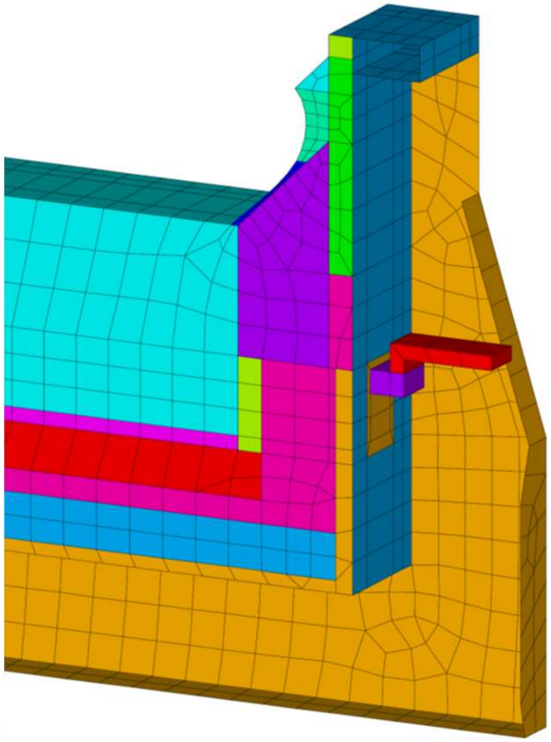


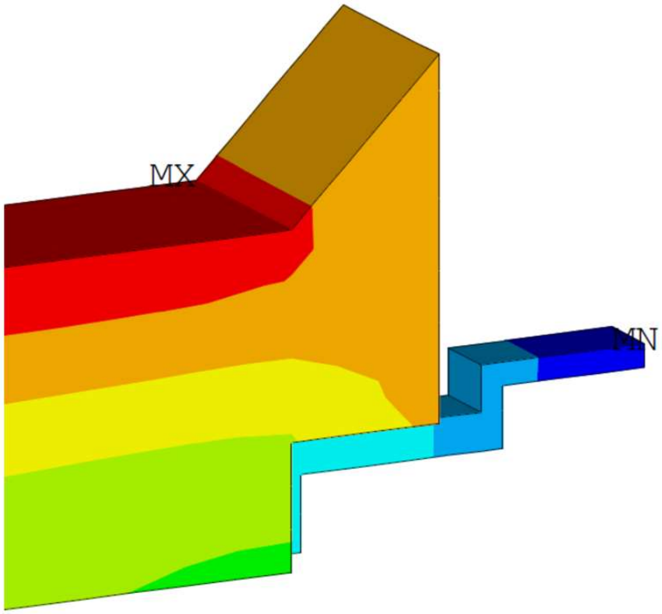


In-Depth Analysis of Lining Designs for Several 420 kA Electrolytic Cells
February 2015TMS Light Metals

Revealing the design feature that reduces the stubs and collector bars heat loss

Since the introduction of a massive copper collector bar in its 600 kA "retrofit" design in 2011, the author has been using a design feature that prevents that massive copper bars to dissipate an excessive amount of heat. That design feature is a quite significant reduction of the copper collector bar section just before going out of the potshell.

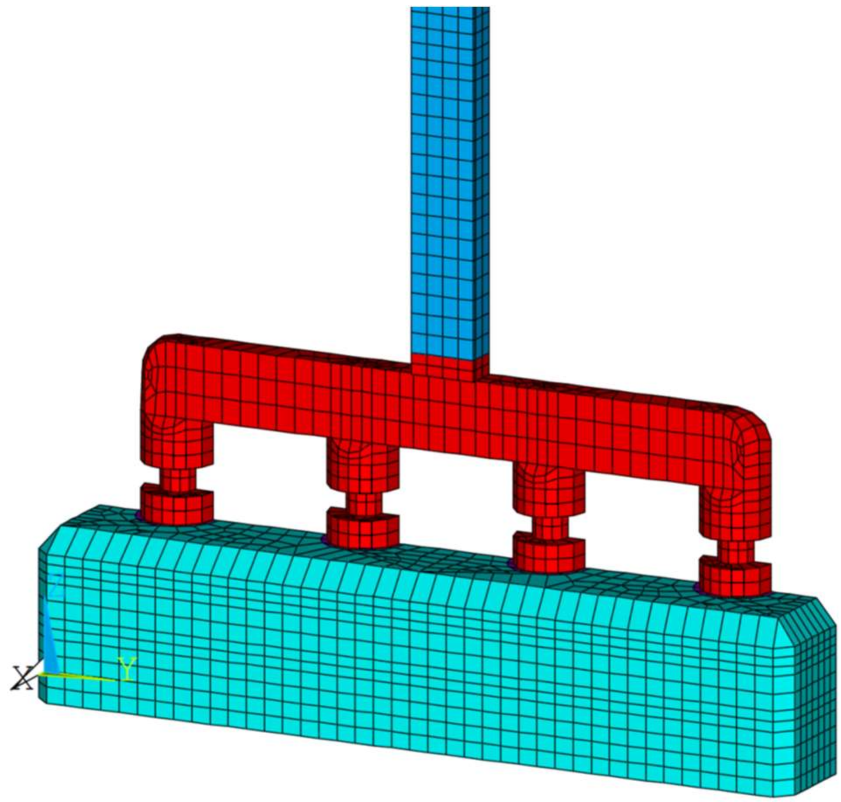




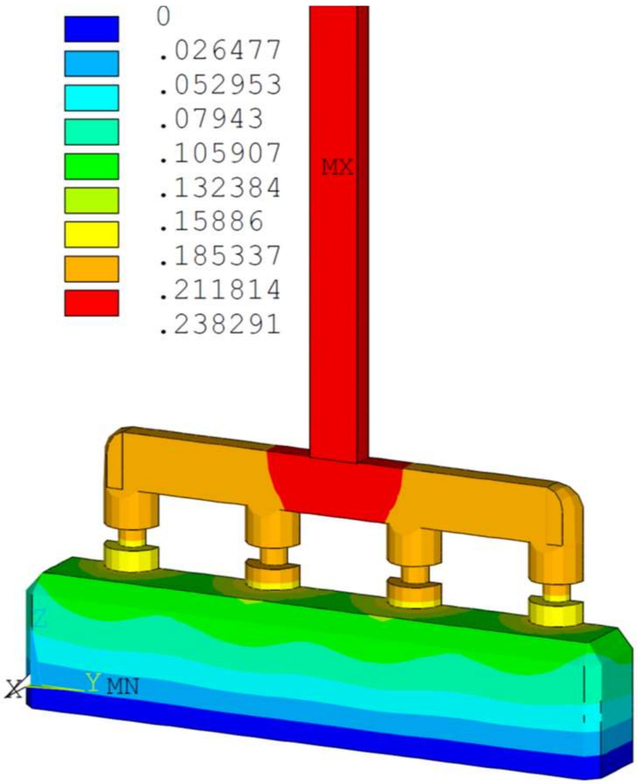
Revealing the design feature that reduces the stubs and collector bars heat loss

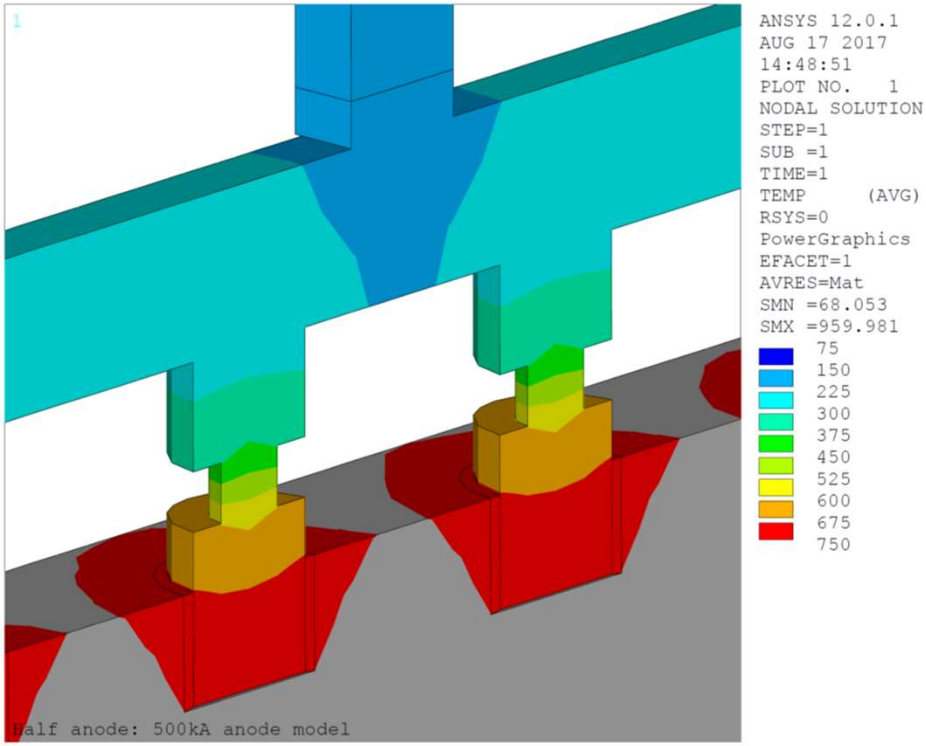
The same design feature can also be used to limit the anode stubs heat loss. Per example, the anode design of the 500 kA 11.2 kWh/kg cell uses that design feature.

This figure presents the geometry of the 500 kA half anode model without the cover material revealing that temporary stub diameter reduction design feature used to decrease the stubs heat loss.

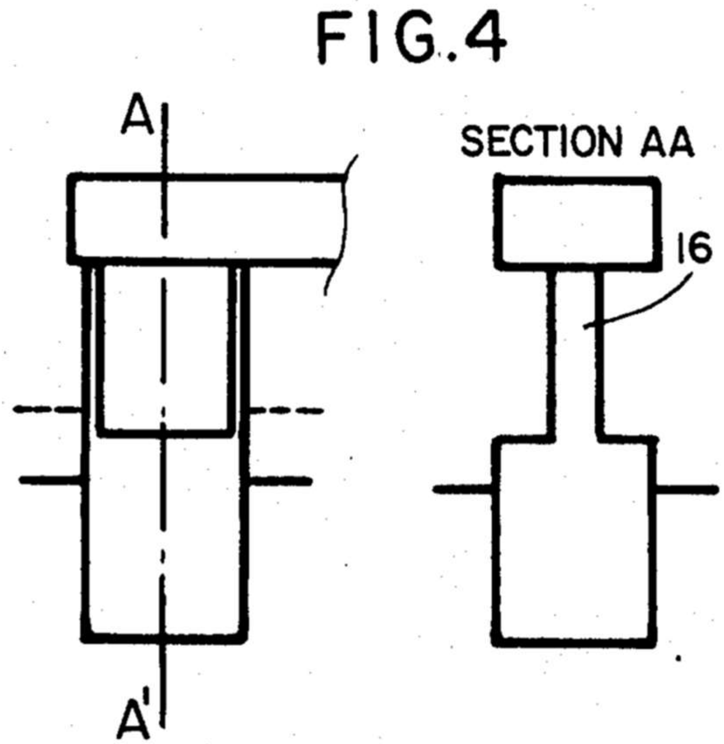


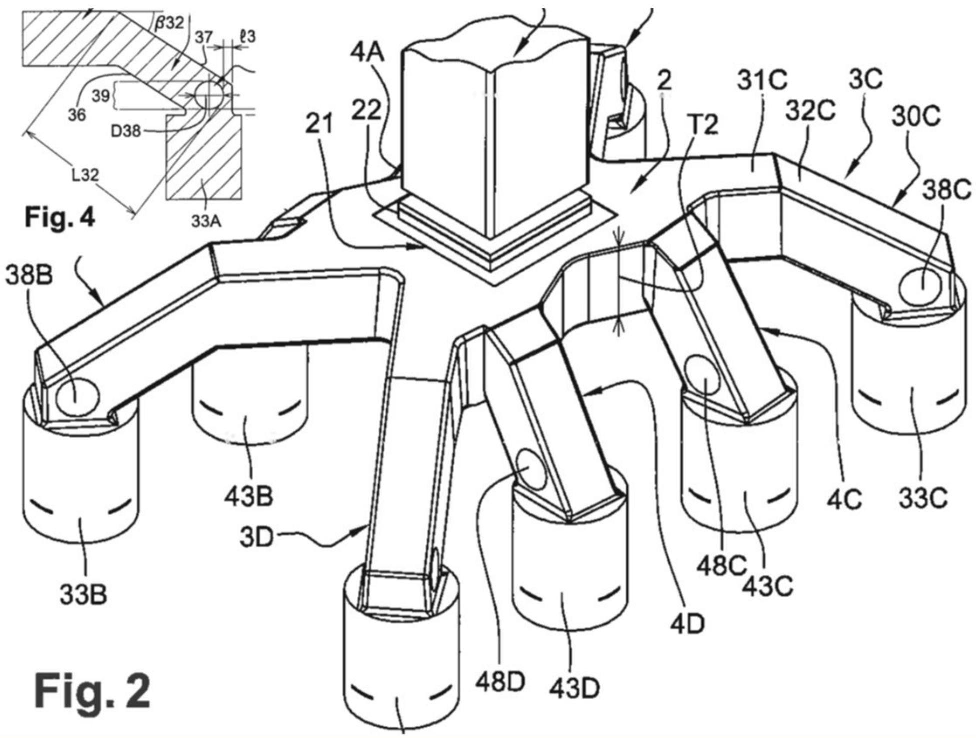
Revealing the design feature that reduces the stubs and collector bars heat loss





Partial Review of the Intellectual Property related to this “special” but not “new” design feature





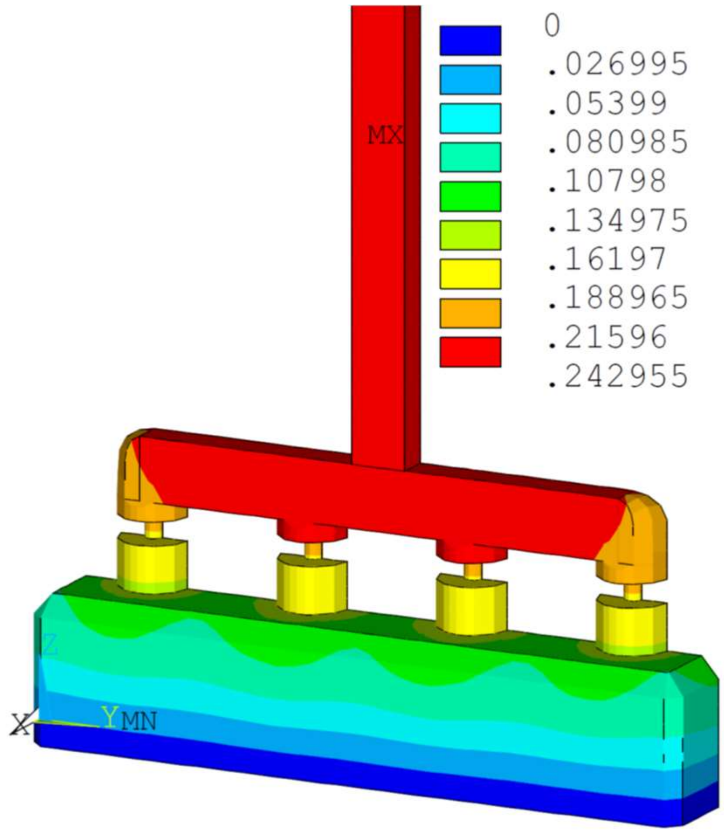
B. Langon, “Carbonaceous Anode with Partially Constricted Round Bars Intended for Cells for the Production of Aluminium by Electrolysis”, US Patent US4612105A, 1986.

L. Mishra and al., “Anode Yoke, Anode Hanger and Anode Assembly for a Hall-Héroult Cell”, Patent Application Number 1721141.8, 2017.

475 kA cell with 100% downstream current exit cell running at 10.44 kWh/kg

**** HEAT BALANCE TABLE ****
**** Half Anode Model : 475 kA ****

ANODE PANEL HEAT LOST	kW	W/m^2	%
Crust to air	121.69	1495.75	51.08
Stubs in to stubs out	116.56		48.92
Total Anode Panel Heat Lost	238.25		100.00



475 kA cell with 100% downstream current exit cell running at 10.44 kWh/kg

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****          HEAT BALANCE TABLE          ****
****      Side Slice Model : 475 kA       ****
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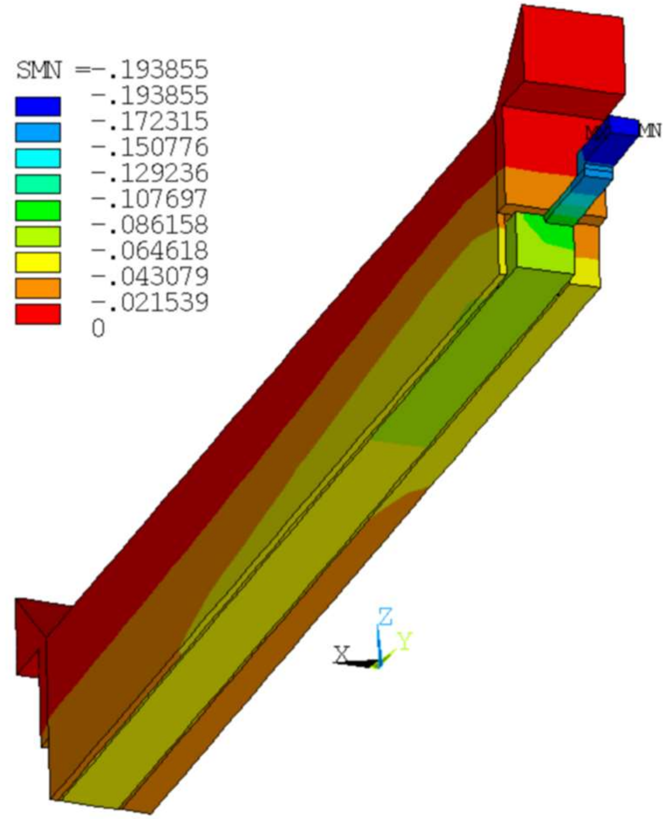
CATHODE HEAT LOST	kW	W/m^2	%
Shell wall above bath level	45.39	781.41	13.67
Shell wall opposite to bath	33.93	3634.74	10.22
Shell wall opposite to metal	21.85	5150.46	6.58
Shell wall opposite to block	57.58	2376.71	17.34
Shell wall below block	7.72	417.04	2.32
Shell floor	31.20	382.96	9.40
Cradle above bath level	1.97	939.32	0.59
Cradle opposite to bath	9.26	1408.30	2.79
Cradle opposite to metal	3.64	1622.32	1.09
Cradle opposite to block	17.25	390.02	5.19
Cradle opposite to brick	3.32	78.24	1.00
Cradle below floor level	36.38	99.59	10.95
Bar in to bar out	80.78		24.32
Cathode bottom estimate	196.81		59.26
Total Cathode Heat Lost	332.08		100.00



475 kA cell with 100% downstream current exit cell running at 10.44 kWh/kg

Amperage	520 kA	475 kA
Nb. of anodes	64	64
Anode size	1.95 m X .5 m	1.95 m X .5 m
Nb. of anode stubs	4 per anode	4 per anode
Anode stub diameter	17.5 cm	20.0 cm
Anode cover thickness	20 cm	20 cm
Nb. of cathode blocks	24	24
Cathode block length	4.17 m	4.17 m
Type of cathode block	HC10	HC10
Collector bar size	20 cm X 20 cm	20 cm X 20 cm
Type of side block	HC3	HC3
Side block thickness	7 cm	7 cm
ASD	30 cm	30 cm
Calcium silicate thickness	6.0 cm	6.0 cm
Inside potshell size	17.8 mX4.85 m	17.8 mX4.85 m
ACD	2.8 cm	2.8 cm
Excess AlF_3	12.00%	12.00%

Anode internal drop (A)	210 mV	208 mV
Cathode internal drop (A)	124 mV	158 mV
External drop (A)	127 mV	90 mV
Anode panel heat loss (A)	286 kW	238 kW
Cathode total heat loss (A)	381 kW	332 kW
Operating temperature (D/M)	957.7 °C	958.1 °C
Liquidus superheat (D/M)	4.7 °C	5.1 °C
Bath ledge thickness (D/M)	22.8 cm	20.6 cm
Metal ledge thickness (D/M)	18.1 cm	15.9 cm
Current efficiency (D/M)	96.5%	96.2%
Internal heat (D/M)	679 kW	576 kW
Energy consumption	10.85 kWh/kg	10.44 kWh/kg

Future work

- As the previous results indicate, the reduction of the ohmic resistance of the cell has reached its limit, the reduction of the cell voltage could only be achieved by further decreasing the anode current density.
- In order to reach 10 kWh/kg Al, further reduction of the anode current density will be required, below 0.7 A/cm^2 most probably. At that very low current anode current density, is it possible to operate the cell below 5.0 °C of cell superheat? If so, part of the remaining reduction of the cell heat loss will come from a further reduction of the cell superheat but not much should be expected to come for that.
- The author is hoping that the next opportunity will come from the design of new cathode lining insulating material that would remain good insulating material under cell operating conditions at high temperature for the entire life of the cell.

Conclusions

- **It turned out it is possible to reduce enough the heat dissipation of a cell to be able to operate that cell in thermal balance at the very low energy consumption level of 10.44 kWh/kg Al.**
- **Electrically, at 0.76 A/cm^2 of anode current density, this requires operating at the lowest achievable ACD, which is around 2.8 cm (EGA reported operation at 2.5 cm ACD in December). It also requires a total ohmic resistance of the anode, cathode and busbar corresponding to a total voltage drop of about 450 mV.**

Conclusions

- Thermally, this requires operating at close to if not the lowest possible cell superheat of around 5.0 ° C, a very high anode cover thickness, very high pier height, and using the “special” but not “new” design feature presented in this work to reduce the stubs and collector bars heat losses.
- Electrically, it is easy to continue to decrease the cell internal heat production by decreasing the anode current density below 0.7 A/cm^2. Clearly the challenge of designing a cell operating at 10.0 kWh/kg Al lies in achieving a cell design having the proper thermal insulation to dissipate so little heat or by recycling part of the cell heat losses.

FIRST ATTEMPT TO BREAK THE 10 KWH/KG BARRIER USING A WIDE CELL DESIGN

Marc Dupuis

GENISIM

Plan of the Presentation

- Introduction: previous work presented in 2018
  - TMS 2018: 650 kA wide cell design running at 11.3 kWh/kg
  - IAJ 2018: 650 kA wide cell design running at 11.0 kWh/kg
- 570 kA wide cell design running at 10.6 kWh/kg
- 530 kA wide cell design running at 10.2 kWh/kg
- Future work
- Conclusions

650 kA wide cell design running at 11.3 kWh/kg

Amperage	762.5 kA	650 kA
Nb. of anodes	48	48
Anode size	2.6 m × .65 m	2.6 m × .65 m
Nb. of anode studs	4 per anode	4 per anode
Anode stud diameter	21.0 cm	24.0 cm
Anode cover thickness	15 cm	24 cm
Nb. of cathode blocks	24	24
Cathode block length	5.37 m	5.37 m
Type of cathode block	HC10	HC10
Collector bar size	20 cm × 12 cm	20 cm × 15 cm
Type of side block	HC3	HC3
Side block thickness	7 cm	7 cm
Anode side wall distance: ASD	25 cm	25 cm
Calcium silicate thickness	3.5 cm	6.0 cm
Inside potshell size	17.02 × 5.88 m	17.02 × 5.88 m
Anode cathode distance: ACD	3.0 cm	2.8 cm
Excess AlF_3	11.50 %	11.50 %

Anode drop (A)	347 mV	296 mV
Cathode drop (A)	118 mV	109 mV
Busbar drop (A)	300 mV	220 mV
Anode panel heat loss (A)	553 kW	327 kW
Cathode total heat loss (A)	715 kW	499 kW
Operating temperature (D/M)	968.9 °C	967.0 °C
Liquidus superheat (D/M)	10.0 °C	8.1 °C
Bath ledge thickness (A)	6.82 cm	11.86 cm
Metal ledge thickness (A)	1.85 cm	3.38 cm
Current efficiency (D/M)	95.14 %	94.80 %
Internal heat (D/M)	1328 kW	832 kW
Energy consumption	12.85 kWh/kg	11.3 kWh/kg

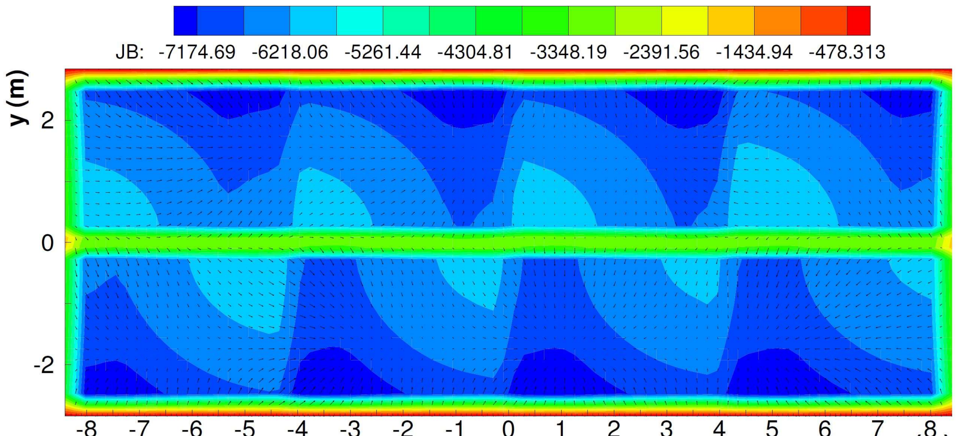
Design of a 650 kA wide cell running at 11.0 kWh/kg

Amperage	762.5 kA	650 kA	650 kA
Nb. of anodes	48	48	36
Anode size	2.6 x .65 m	2.6 x .65 m	2.6 x .86 m
Nb. of anode studs	4 per anode	4 per anode	12 per anode
Anode stud diameter	21.0 cm	24.0 cm	16.0 cm
Anode cover thickness	15 cm	24 cm	25 cm
Nb. of cathode blocks	24	24	24
Cathode block length	5.37 m	5.37 m	5.37 m
Type of cathode block	HC 10	HC 10	HC 10
Collector bar size	20 x 12 cm	20 x 15 cm	20 x 15 cm
Type of side block	HC3	HC3	HC3
Side block thickness	7 cm	7 cm	7 cm
ASD	25 cm	25 cm	25 cm
Calcium silicate thickness	3.5 cm	6.0 cm	6.0 cm
Inside potshell size	17.02 x 5.88m	17.02 x 5.88m	17.02 x 5.88m
ACD	3.0 cm	2.8 cm	2.8 cm
Excess AlF_3	11.50%	11.50%	11.50%

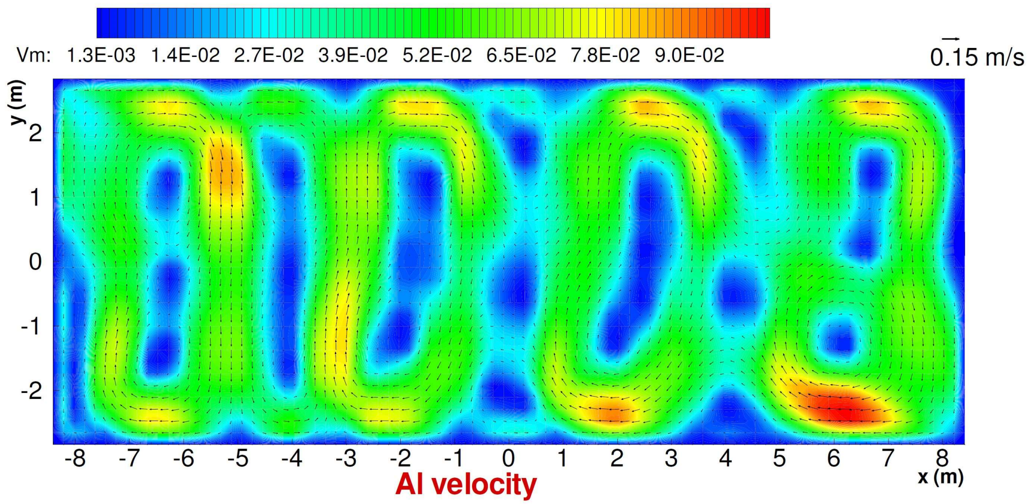
Anode drop (A)	347 mV	296 mV	252 mV
Cathode drop (A)	118 mV	109 mV	109 mV
Busbar drop (A)	300 mV	220 mV	170 mV
Anode panel heat loss (A)	553 kW	327 kW	339 kW
Cathode total lieat loss (A)	715 kW	499 kW	482 kW
Operating temperatur (D/M)	968.9 °C	967.0 °C	966.5 °C
Liquidus superheat (D/M)	10.0 °C	8.1 °C	7.6 °C
Bath ledge thickness (A)	6.82 cm	11.86 cm	14.25 cm
Metal ledge thickness (A)	1.85 cm	3.38 cm	4.58 cm
Current efficiency (D/M)	95.14%	94.80%	94.90%
Intenial heat (D/M)	1328 kW	832 kW	804 kW
Energy consumption	12.85 kWh/kg	11.3 kWh/kg	11.0 kWh/kg

Design of a 570 kA wide cell running at 10.6 kWh/kg

Reducing metal pad thickness from 20 to 10 cm



Electric current density at the cell bottom



Al velocity

MHD cell stability study at reduced metal pad thickness

Design of a 570 kA wide cell running at 10.6 kWh/kg

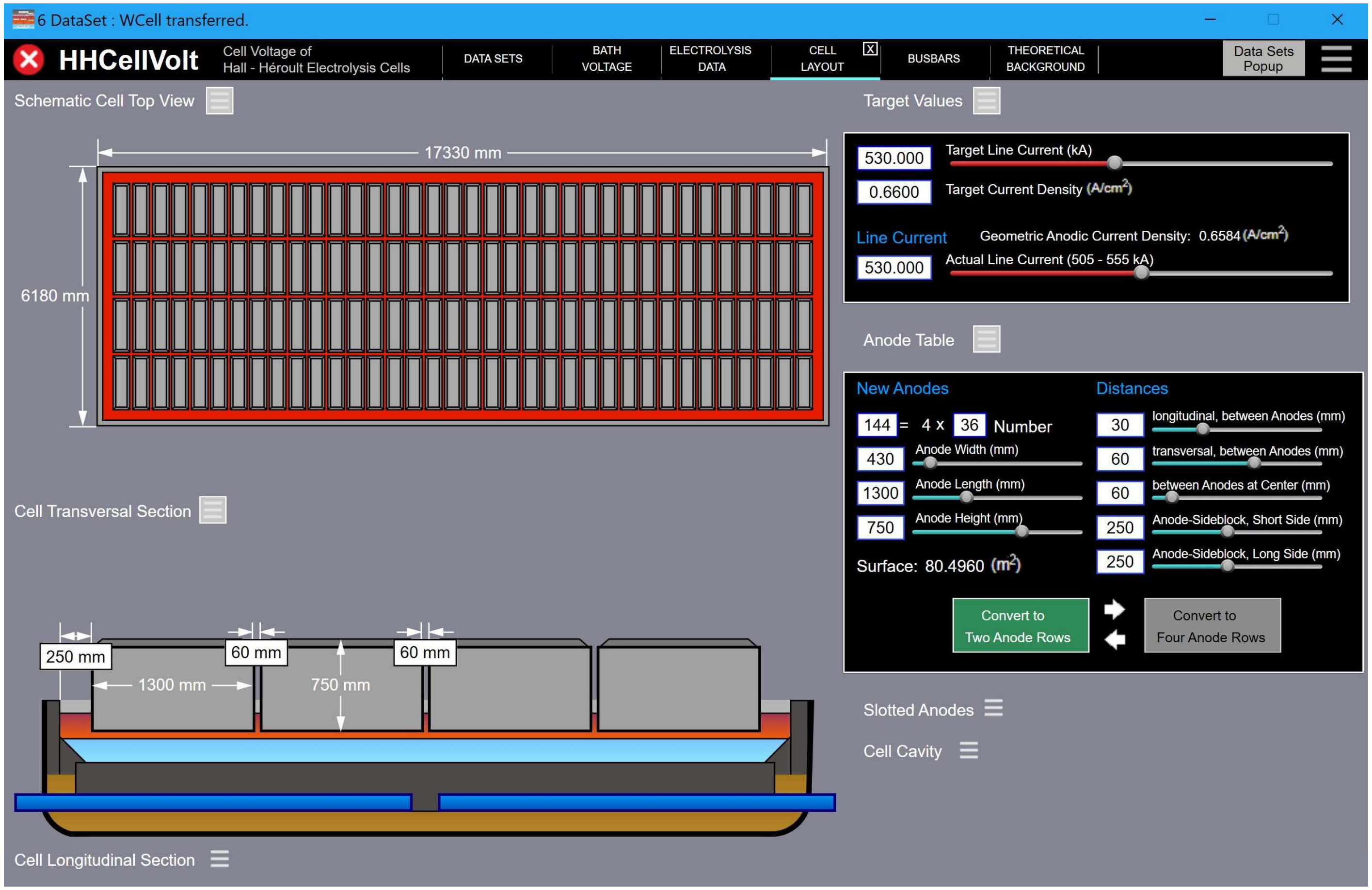
Dyna/Marc was used to calculate the steady-state cell conditions at 570 kA and 2.8 cm ACD. Table 1 presents the Dyna/Marc results summary where the cell voltage is predicted to be 3.36 V, the cell internal heat using Haupin's equation to calculate the equivalent voltage to make the metal is 613 kW at the calculated current efficiency of 94.4% and the cell superheat is predicted to be 7.5 °C. Finally, the cell power consumption is calculated to be 10.61 kWh/kg.

Table 1

Steady State Solution	
Cell amperage	570.0 [kA]
Anode to cathode distance	2.80000 [cm]
Operating temperature	964.064 [C]
Ledge thickness, bath level	8.90003 [cm]
Ledge thickness, metal level	3.19020 [cm]
Bath chemistry:	
Cryolite ratio	2.20470 [mole/mole]
Bath ratio	1.10235 [kg/kg]
Conc. of excess aluminum fluoride	11.50000 [%]
Conc. of dissolved alumina	2.80000 [%]
Conc. of calcium fluoride	6.00000 [%]
Heat balance:	
Superheat	7.5402 [C]
Cell energy consumption	10.6072 [kWhr/kg]
Total heat loss	612.992 [kW]
Electrical characteristics:	
Current efficiency	94.3733 [%]
Anode current density	0.708110 [A/cm*cm]
Bath resistivity	0.454942 [ohm-cm]
Cell pseudo-resistance	2.99735 [micro-ohm]
Bath voltage	0.94007 [V]
Electrolysis voltage	1.87543 [V]
Cell voltage	3.35849 [V]
Voltage to make the metal	2.03522 [V]

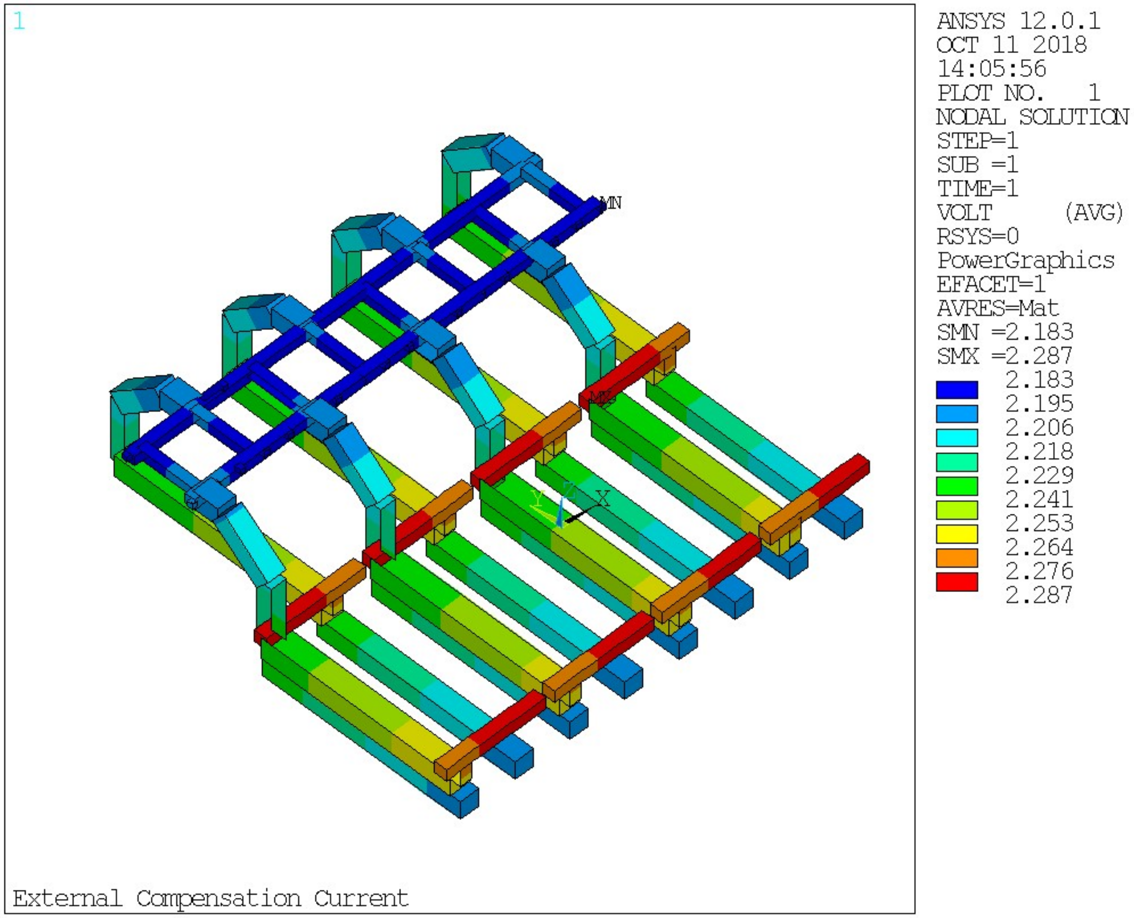
Design of a 530 kA wide cell running at 10.2 kWh/kg

HHCellVolt's cell layout showing the 4 rows of anode blocks



Design of a 530 kA wide cell running at 10.2 kWh/kg

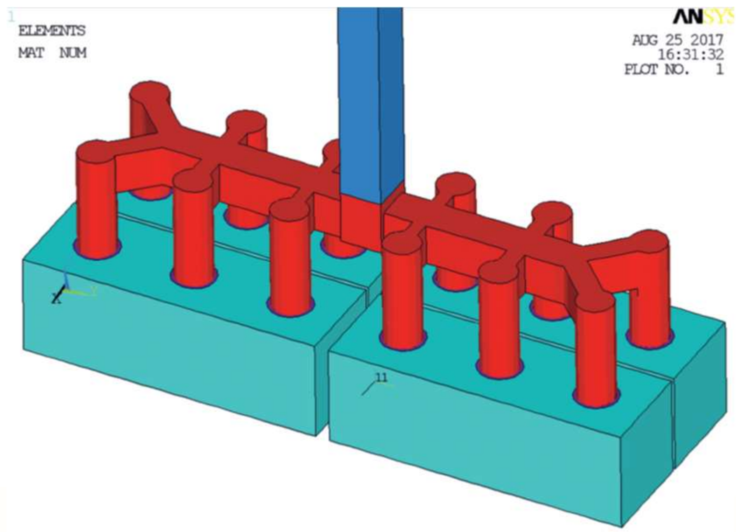
This figure is presenting the obtained busbar drop at 530 kA and it is calculated to be 104 mV.

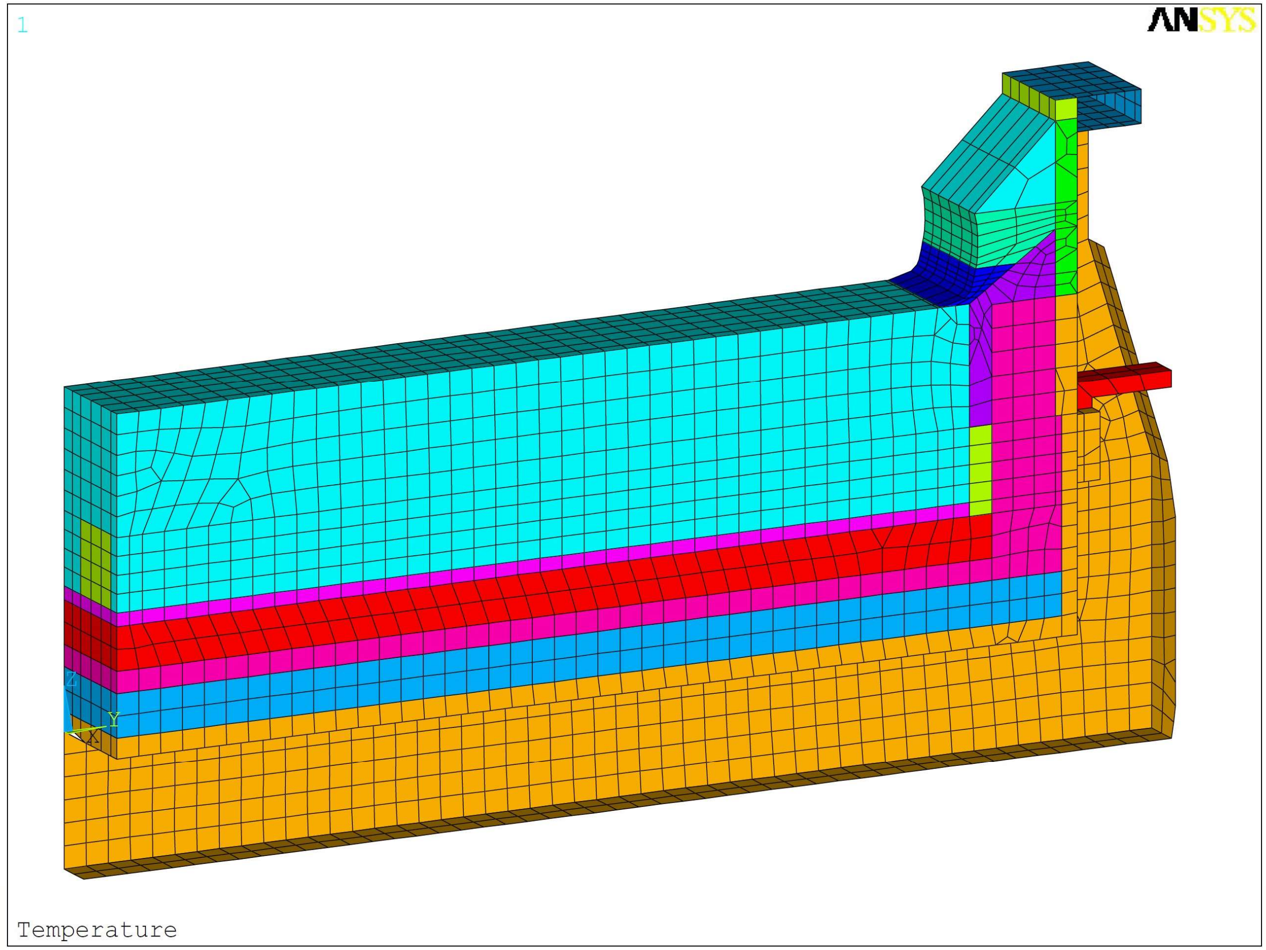


Design of a 530 kA wide cell running at 10.2 kWh/kg

Mesh of the cathode model with reduced metal pad and ramming paste slope height.

Same anode design than in the previous study.

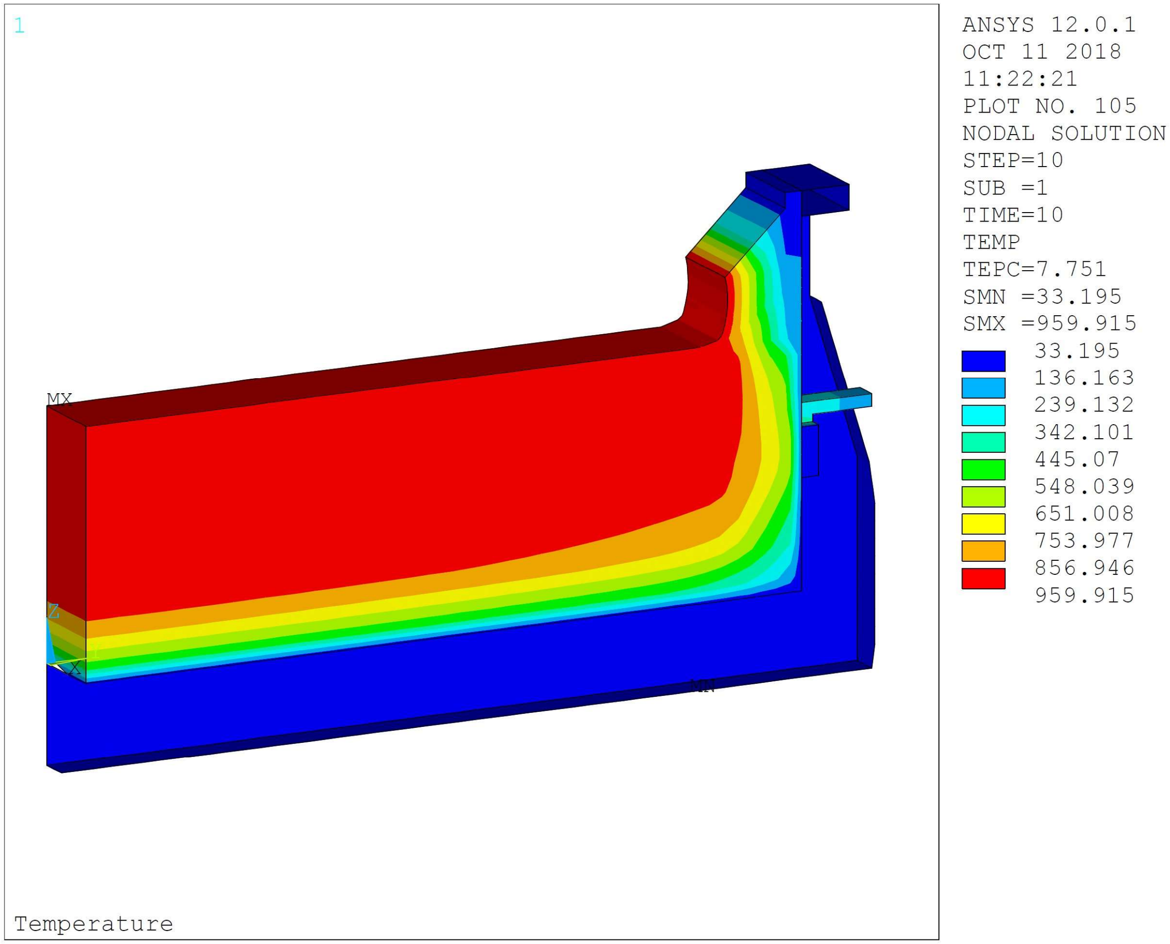




Design of a 530 kA wide cell running at 10.2 kWh/kg

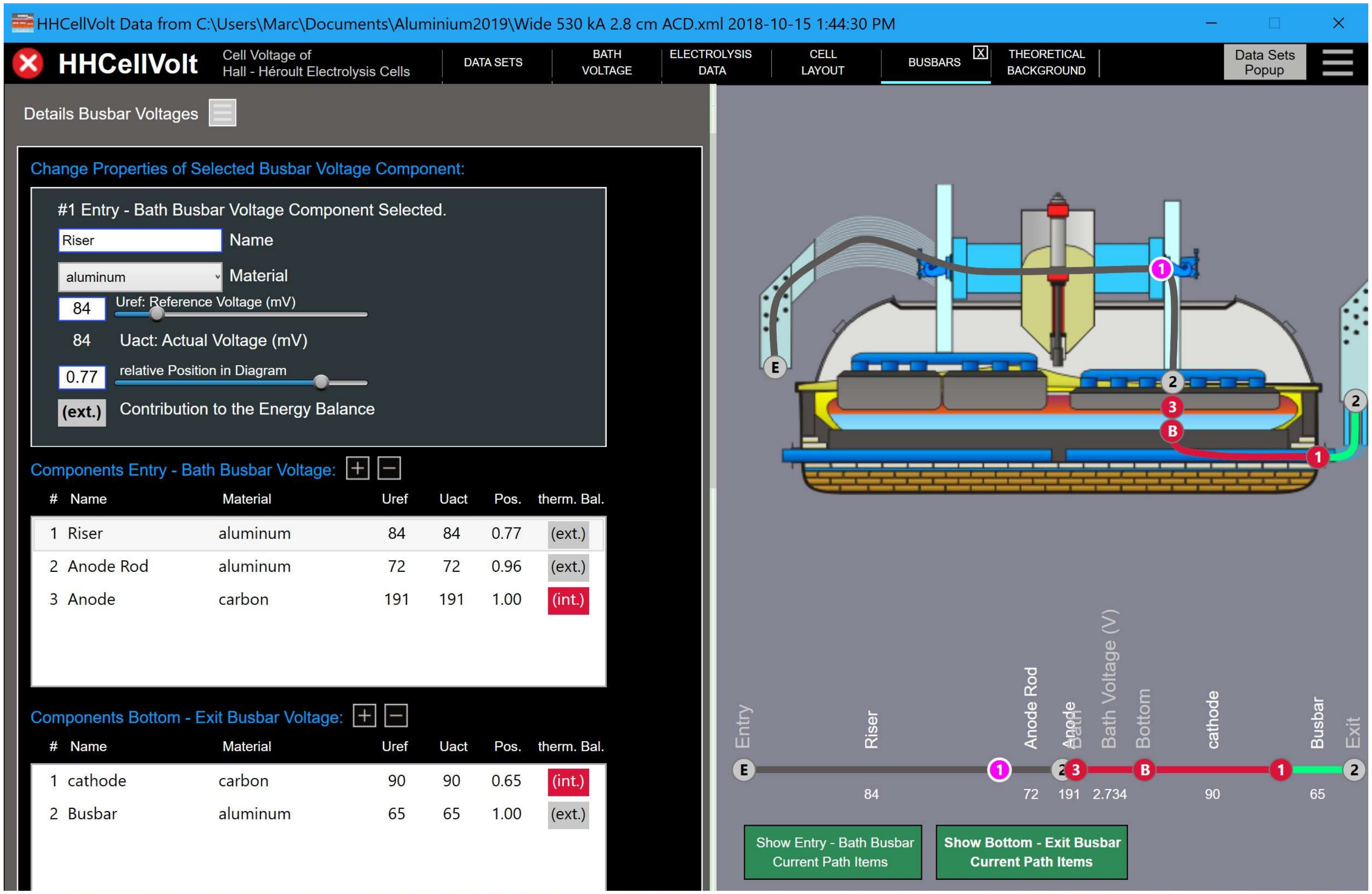
At 530 kA, the internal anode drop is predicted to be 191 mV and the external anode drop (studs outside the crust, the yoke and the rod) is predicted to be 72 mV. The internal anode heat loss is 218 kW.

The figure is showing the cathode temperature solution. The model is predicting an internal cathode drop of 90 mV and an external cathode drop of 45 mV. The heat loss of the internal part of the cathode at 5 °C of cell superheat is 311 kW.



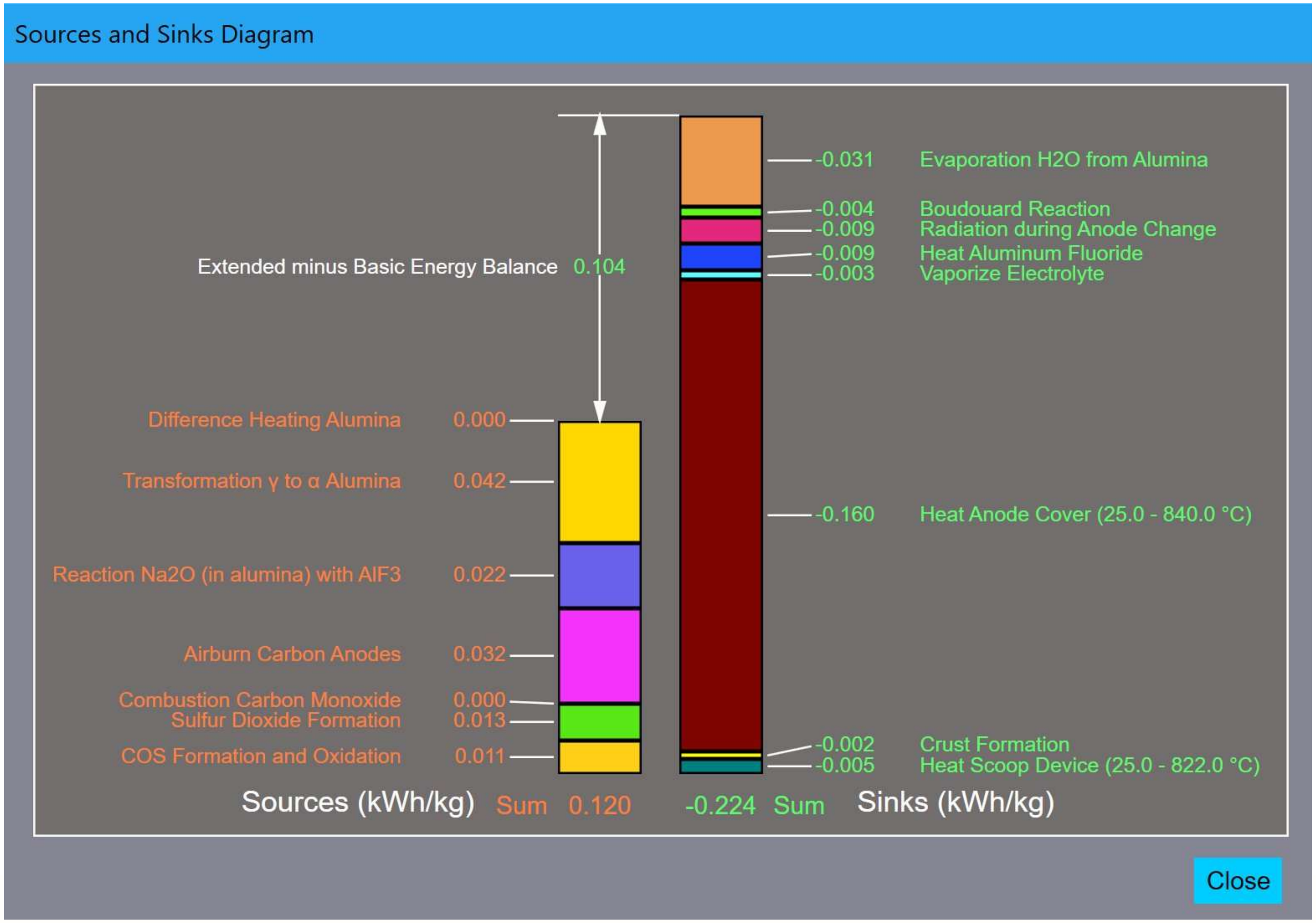
Design of a 530 kA wide cell running at 10.2 kWh/kg

Those ANSYS based electrical results can be entered in HHCellVolt's busbars tab.



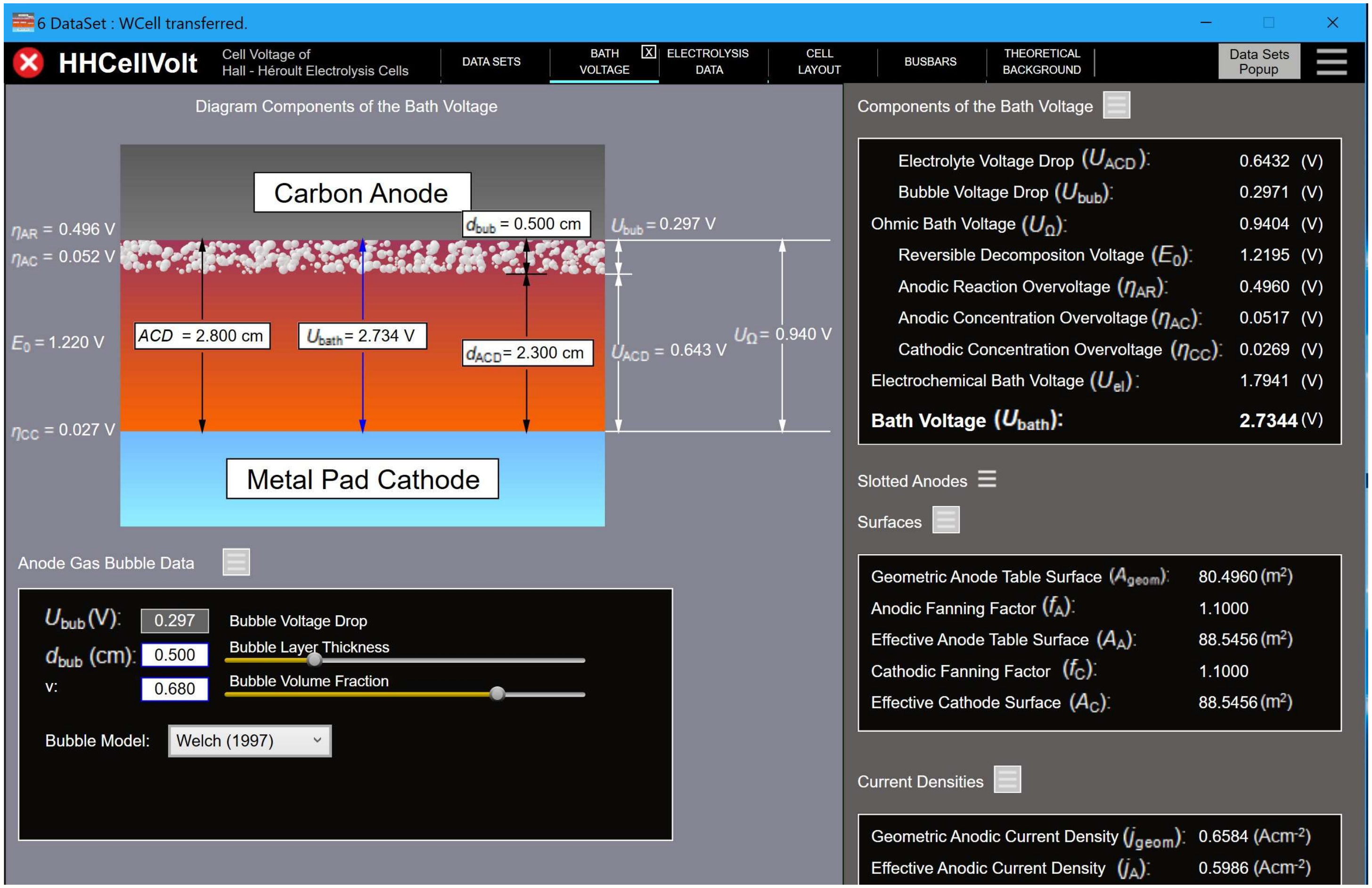
Design of a 530 kA wide cell running at 10.2 kWh/kg

The extended reactions in HHCellVolt can be adjusted to add 0.1 kWh/kg Al extra energy requirement to make the metal in HHCellVolt's electrolysis data tab.



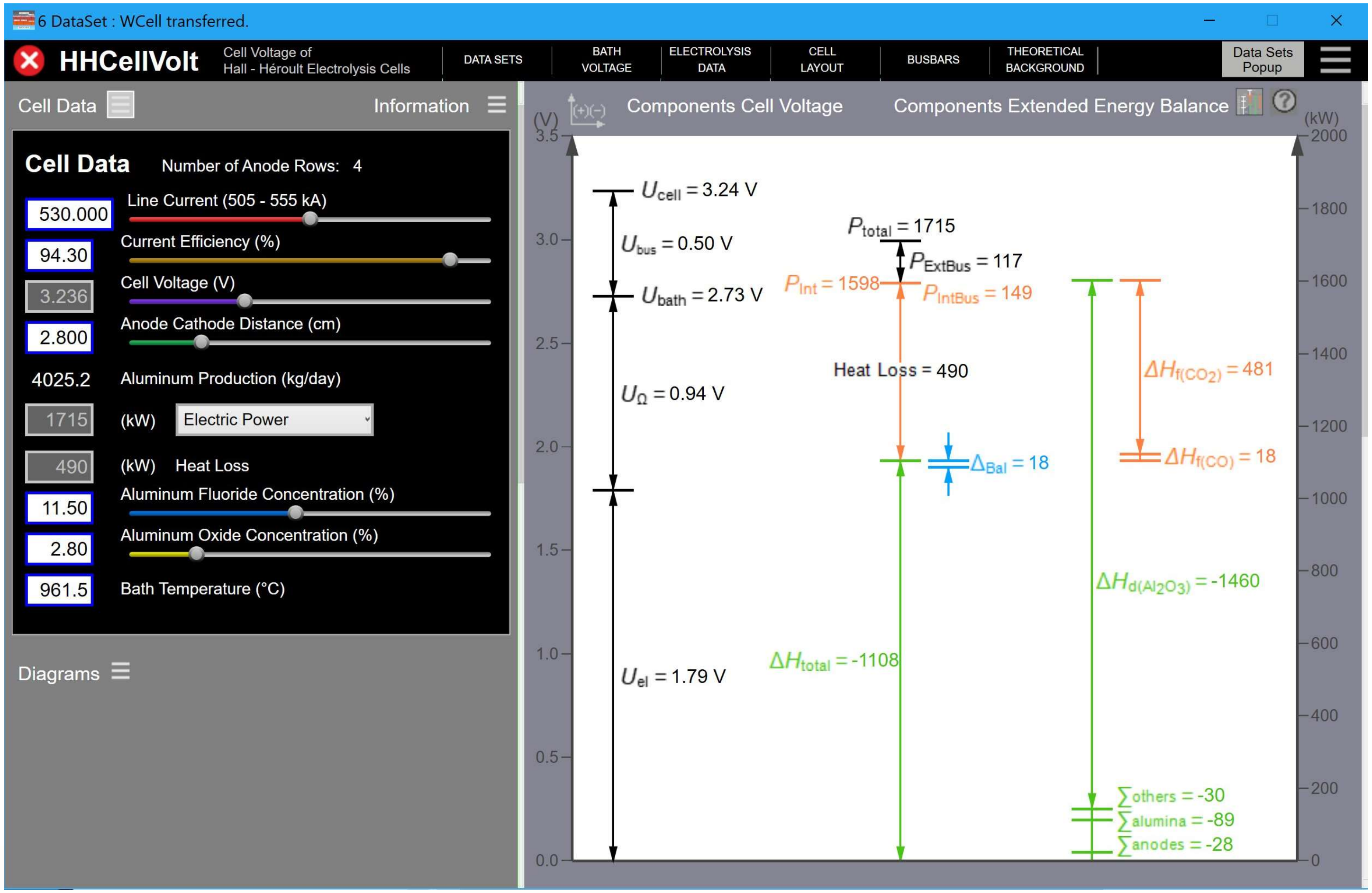
Design of a 530 kA wide cell running at 10.2 kWh/kg

The bubble model is selected and calibrated in the bath voltage tab.



Design of a 530 kA wide cell running at 10.2 kWh/kg

As a final results, HHCellVolt calculates the total cell voltage and cell internal heat using user specified cell operating temperature and current efficiency.



Design of a 530 kA wide cell running at 10.2 kWh/kg

Dyna/Marc is used to calculate the steady-state cell conditions at 530 kA and 2.8 cm ACD. Table II presents the Dyna/Marc results summary where the cell voltage is predicted to be 3.24 V, the cell internal heat using Haupin's equation to calculate the equivalent voltage to make the metal is 516 kW at the calculated current efficiency of 94.3% and the cell superheat is predicted to be 5.0 °C. Finally, the cell power consumption is calculated to be 10.23 kWh/kg.

Table 2

Steady State Solution		
Cell amperage	530.0	[kA]
Anode to cathode distance	2.80000	[cm]
Operating temperature	961.560	[C]
Ledge thickness, bath level	15.79983	[cm]
Ledge thickness, metal level	9.99283	[cm]
Bath chemistry:		
Cryolite ratio	2.20470	[mole/mole]
Bath ratio	1.10235	[kg/kg]
Conc. of excess aluminum fluoride	11.50000	[%]
Conc. of dissolved alumina	2.80000	[%]
Conc. of calcium fluoride	6.00000	[%]
Heat balance:		
Superheat	5.0367	[C]
Cell energy consumption	10.2313	[kWhr/kg]
Total heat loss	516.203	[kW]
Electrical characteristics:		
Current efficiency	94.3031	[%]
Anode current density	0.658418	[A/cm*cm]
Bath resistivity	0.456250	[ohm-cm]
Cell pseudo-resistance	2.99443	[micro-ohm]
Bath voltage	0.87661	[V]
Electrolysis voltage	1.85844	[V]
Cell voltage	3.23705	[V]
Voltage to make the metal	2.03346	[V]

Design of a 530 kA wide cell running at 10.2 kWh/kg

Amperage	762.5 kA	650 kA	570 kA	530 kA
Nb. of anodes	48	36	36	36
Anode size	2.6m X .65m	2.6m X .86m	2.6m X .86m	2.6m X .86m
Nb. of anode studs	4 per anode	12 per anode	12 per anode	12 per anode
Anode stud diameter	21.0 cm	16.0 cm	18.0 cm	18.0 cm
Anode cover thickness	15 cm	25 cm	25 cm	25 cm
Nb. of cathode blocks	24	24	24	24
Cathode block length	5.37 m	5.37 m	5.37 m	5.37 m
Type of cathode block	HC10	HC10	HC10	HC10
Collector bar size	20 cm X 12 cm	20 cm X 15 cm	20 cm X 15 cm	20 cm X 15 cm
Type of side block	HC3	HC3	HC3	HC3
Side block thickness	7 cm	7 cm	7 cm	7 cm
ASD	25 cm	25 cm	25 cm	25 cm
Calcium silicate thickness	3.5 cm	6.0 cm	6.0 cm	6.0 cm
Inside potshell size	17.02 X 5.88 m	17.02 X 5.88 m	17.02 X 5.88 m	17.02 X 5.88 m
ACD	3.0 cm	2.8 cm	2.8 cm	2.8 cm
Anode current density	0.93 A/cm^2	0.81 A/cm^2	0.71 A/cm^2	0.66 A/cm^2
Metal level	20 cm	20 cm	10 cm	10 cm
Excess AlF_3	11.50%	11.50%	11.50%	11.50%

Design of a 530 kA wide cell running at 10.2 kWh/kg

Anode drop (A)	347 mV (T)	252 mV (T)	207 mV (I)	191 mV (I)
Cathode drop (A)	118 mV (T)	109 mV (T)	91 mV (I)	90 mV (I)
Busbar/External drop (A)	300 mV (B)	170 mV (B)	227 mV (E)	221 mV (E)
Anode panel heat loss (A)	553 kW (T)	339 kW (T)	221 kW (I)	218 kW (I)
Cathode total heat loss (A)	715 kW (T)	482 kW (T)	417 kW (I)	311 kW (I)
Operating temperature (D/M)	968.9 °C	966.5 °C	964.1 °C	961.6 °C
Liquidus superheat (D/M)	10.0 °C	7.6 °C	7.5 °C	5.0 °C
Bath ledge thickness (A)	6.82 cm	14.25 cm	18.36 cm	21.38 cm
Metal ledge thickness (A)	1.85 cm	4.58 cm	6.88 cm	7.60 cm
Current efficiency (D/M)	95.1%	94.9%	94.4%	94.3%
Internal heat (D/M)	1328 kW	804 kW	613 kW	516 kW
Energy consumption	12.85 kWh/kg	11.0 kWh/kg	10.6 kWh/kg	10.2 kWh/kg

A = ANSYS; D/M = Dyna/Marc; T = Total; B = Busbar; I = Internal; E = External

Future work

- The previous table summarizes the results of the four wide cell designs presented so far all using the same wide potshell platform. The cell operating at 530 kA, 0.66 A/cm^2 and 10.23 kWh/kg dissipates only 39% of the heat dissipated by the cell operating at 762.5 kA, 0.94 A/cm^2 and 12.85 kWh/kg.
- Both HHCellVolt and Dyna/Marc can easily be used to quickly investigate what would be the cell amperage required to operate at 10.0 kWh/kg assuming no other changes, the answer is 505 kA, 0.63 A/cm^2 and 436 kW of cell internal heat. 436 kW represents 33% of the heat dissipated by the cell operating at 762.5 kA and 12.85 kWh/kg and 84% of the heat dissipated by the cell operating at 530 kA and 10.23 kWh/kg.

Future work

- This 15% extra reduction of the cell heat loss must be achieved without further reducing the cell superheat. It is also fair to assume that it would not be safe to further reduce the metal pad thickness. Yet, after the reduction of that metal pad thickness, there is now plenty of spare cell cavity. This is providing the opportunity to increase the thickness of the cell lining below the cathode block. New semi-insulating lining material that resists sodium vapor have also become available, this combination may provide an opportunity to design a more insulating cathode lining and hence reduce the cathode heat loss at constant cell superheat without risking to have that cathode lining degraded by exposing it to high temperature and sodium vapor.

Conclusions

- Two extra steps toward the design of a cell operating at 10.0 kWh/kg have been presented here. The last step is the design of a wide cell operating at 530 kA, 0.66 A/cm^2 and 10.23 kWh/kg. That cell is operating at the assumed lowest ACD of 2.8 cm (EGA reported operation at 2.5 cm ACD in December), the lowest assumed metal pad thickness of 10 cm and the lowest assumed cell superheat of 5 °C.
- That cell is also operating at 25 cm of anode cover thickness; that may not be the highest value possible but must be quite close to it. Despite that, and the usage of refined design features to limit the studs and collector bars heat loss reported in the TMS 2019 paper, it was not possible to design a cell operating at 10.0 kWh/kg in the current study.