

EXTENDED ENERGY BALANCE FOR HALL-HÉROULT ELECTROLYSIS CELLS

Peter M. Entner



Marc Dupuis

GENISIM

Presented by: Marc Dupuis

12th

AUSTRALASIAN ALUMINIUM SMELTING TECHNOLOGY
CONFERENCE

2-7 Dec 2018
Queenstown
New Zealand

Plan of the Presentation

- **Introduction to Cell Voltage Calculation Software**
- **Introduction to HHCeIVolt**
- **HHCeIVolt on the Microsoft Store**
- **Haupin Diagram and Basic Energy Balance**
- **Extended Energy Balance**
- **Electrolysis Cells with Four Anode Rows**
- **Example of the Calculation of Impact of the Extended Reactions on the Cell Operating Conditions**
- **Conclusions**

Introduction to Cell Voltage Calculation Software

- **The classical Hall-Héroult process produces aluminum by electrolysis using carbon block anodes and a liquid aluminum cathode.**
- **For several years, MS Windows PC programs (ElysePrg [1], AlPrg [2]), were used to investigate the essential parameters to operate such an electrolysis cell like the cell voltage, cell layout, operational factors and electrolyte properties.**
- **HHCellVolt is an enhanced version of this software that contains new features. This publication describes these extensions and improvements.**

Introduction to Cell Voltage Calculation Software

- The energy balance of an electrolysis cell considers as primary reaction the electrolytic decomposition of alumina and the heating of alumina and carbon anodes to the reaction temperature.
- The extended energy balance takes also secondary reaction into account like the air burn of the anodes, the conversion of γ to α alumina, the reactions of the impurities of alumina as well as of the carbon anodes and heating of the scoop device, etc.
- HHCeIVolt investigates this extended energy balance in a transparent and didactic way: it shows the theoretical background of the applied relations, the origin of the thermodynamic data and represents finally the results in a graphical way.

Introduction to HHCeIVolt

Cell Data Number of Anode Rows: 4

- 762.500 Line Current (738 - 788 kA)
- 95.00 Current Efficiency (%)
- 4.110 Cell Voltage (V)
- 3.000 Anode Cathode Distance (cm)
- 5833.9 Aluminum Production (kg/day)
- 3134 (kW) Electric Power
- 1307 (kW) Heat Loss
- 11.50 Aluminum Fluoride Concentration (%)
- 3.10 Aluminum Oxide Concentration (%)
- 958.8 Bath Temperature (°C)

What can you do with the HHCeIVolt Program?

With the program **HHCeIVolt** you investigate the influence of the cell layout and cell parameter on the cell voltage. Some of these parameter are: current intensity, dimensions of the anode table (especially two or four anode rows), anode cathode distance, composition as well as temperature of the electrolyte and gas bubbles on the anode. You may also change the cell voltage and observe the influence on the heat balance of the electrolysis cell. The essential information interesting for cell operation you find on the corresponding diagrams, for instance cell voltage vs. current intensity or cell voltage vs. alumina concentration.

Standard Version August 2018

Website: <http://www.peter-entner.com>
E-Mail: alweb@peter-entner.com

PE Software for Aluminum Smelting

12th

AUSTRALASIAN ALUMINIUM SMELTING TECHNOLOGY
CONFERENCE

2-7 Dec 2018
Queenstown
New Zealand

Introduction to HHCeIVolt

HHCeIVolt Cell Voltage of Hall - Héroult Electrolysis Cells

DATA SETS BATH VOLTAGE ELECTROLYSIS DATA **CELL LAYOUT** BUSBARS THEORETICAL BACKGROUND Data Sets Popup

Cell Layout Number of Anode Rows: 2 **Show/Hide Dimensions**

Schematic Cell Top View

4880 mm 17730 mm

Target Values

475.000 Target Line Current (kA)

0.7610 Target Current Density (A/cm^2)

Line Current Geometric Anodic Current Density: $0.7612 (A/cm^2)$

475.000 Actual Line Current (450 - 500 kA)

Anode Table

New Anodes Distances

64 = 2 x 32 Number

500 Anode Width (mm)

1950 Anode Length (mm)

750 Anode Height (mm)

30 longitudinal, between Anodes (mm)

180 between Anodes at Center (mm)

250 Anode-Sideblock, Short Side (mm)

250 Anode-Sideblock, Long Side (mm)

Surface: $62.4000 (m^2)$

Convert to Two Anode Rows Convert to Four Anode Rows

Slotted Anodes

Cell Cavity

Cell Transversal Section

250 mm 180 mm 1950 mm 750 mm

12th

AUSTRALASIAN ALUMINIUM SMELTING TECHNOLOGY
CONFERENCE

2-7 Dec 2018
Queenstown
New Zealand

Introduction to HHCeIVolt

HHCeIVolt Cell Voltage of Hall - Héroult Electrolysis Cells
DATA SETS
BATH VOLTAGE
ELECTROLYSIS DATA
CELL LAYOUT
BUSBARS
THEORETICAL BACKGROUND
Data Sets Popout

0.449	Sum Ref. Busbar Voltages (V)	0.449	Act. Sum Busbar Voltages (V)
0.271	Sum Ref. Entry - Bath (V)	0.271	Sum Act. Entry - Bath (V)
0.178	Sum Ref. Bottom - Exit (V)	0.178	Sum Act. Bottom - Exit (V)

Overview Cell Voltage

0.449	Sum Busbar Voltage (V)	0.083	Sum External Voltages (V)
2.900	Bath Voltage (V)	0.366	Sum Internal Voltages (V)
3.349	Cell Voltage Voltage (V)		

External, internal Busbar Voltages:

Details Busbar Voltages

Change Properties of Selected Busbar Voltage Component:

#2 Entry - Bath Busbar Voltage Component Selected.

Anode rod Name
aluminum Material
35 Uref: Reference Voltage (mV)
35 Uact: Actual Voltage (mV)
0.93 relative Position in Diagram
(ext.) Contribution to the Energy Balance

Components Entry - Bath Busbar Voltage: + -

#	Name	Material	Uref	Uact	Pos.	therm. Bal.
1	Riser	aluminum	28	28	0.68	(ext.)
2	Anode rod	aluminum	35	35	0.93	(ext.)
3	Anode	carbon	208	208	1.00	(int.)

The diagram shows a cross-section of an electrolysis cell. A current path is highlighted with colored segments and numbered markers: E (Entry), 1 (Anode rod), 2 (Anode Bath), 3 (Bath Voltage), B (Bottom), 1 (cathode), and 2 (Exit). Below the diagram is a graph of Voltage (V) vs. Current Path Items. The graph shows a step-wise increase in voltage: 28V for the Riser, 35V for the Anode rod, 208V for the Anode Bath, 2.900V for the Bath Voltage, 158V for the cathode, and 20V for the Flex. The total voltage is 3.349V.

Item	Label	Voltage (V)
1	Riser	28
2	Anode rod	35
3	Anode Bath	208
4	Bath Voltage	2.900
5	Bottom	158
6	cathode	158
7	Flex	20
8	Exit	20
Total	Cell Voltage	3.349

Show Entry - Bath Busbar Current Path Items
Show Bottom - Exit Busbar Current Path Items

Introduction to HHCeIVolt

HHCeIVolt Cell Voltage of Hall - Héroult Electrolysis Cells

DATA SETS BATH VOLTAGE **ELECTROLYSIS DATA** CELL LAYOUT BUSBARS THEORETICAL BACKGROUND Data Sets Popup

Electrolyte Composition and Properties Information Sources, Sinks

Electrolyte Composition:

- 11.50 Aluminum Fluoride (%)
- 1.1012 Bath Ratio
- 6.00 Calcium Fluoride (%)
- 3.10 Aluminum Oxide (%)
- 3.00 Aluminum Oxide at Anode Effect (%)
- 0.00 Lithium Fluoride (%)
- 0.00 Magnesium Fluoride (%)
- 0.00 Potassium Fluoride (%)
- 79.40 Cryolite (%)

Electrolyte Temperature:

- 955.8 Bath Temperature (°C)
- 4.0 Superheat (°C)

Electrolyte Properties:

Liquidus Temperatur (T_{liqu}):	951.8 (°C)	Solheim (1995)	☰
Electrical Conductivity (κ):	2.1228 (S/cm)	Hives 1 (1994)	☰
Max. Alumina Solubility ($C_{\text{Al}_2\text{O}_3}^{\text{max}}$):	8.01 (%)	Skybakmoen (1997)	
Total Vapor Pressure (p_{total}):	475.0 (Pa)		

Info about the ELECTROLYSIS DATA Page

This page shows on the left side input panels and on the right side the corresponding detail listings and diagrams. You select one of these items to be shown with the combo box or by clicking on the corresponding display/hide button ☰

Input Panels

You change the values in the input field conventionally with the keyboard, the mouse wheel and if available with a value slider. The page contains the following input panels:

- Alumina Data:** on this panel you change values of alumina consumption, temperatures and concentrations of alumina components and impurities.
- Anode Butts Data:** here you change consumption values, properties of new anodes, parameters of anode reactions and anode butts.
- Electrolysis Process Parameter:** here you change values concerning the environment, aluminum fluoride, the anode cover and the top crust.
- Heights and Ledges:** you define metal pad and electrolyte heights, ledge thicknesses and ledge distances and parameter of bath cleaning (scoop device and frequency).
- Electrolyte Composition and Properties:** you set the electrolyte composition, electrolyte temperature and the relations to calculate the chemical and physical electrolyte properties.
- Fanning Factors:** on this panel you define how the fanning factors are determined.

Listings and Diagrams

For the moment being HHCeIVolt shows on the right side only one detail listings panel:

- Extended Energy Balance:** this panel lists the details of the exothermal (**Sources**) and endothermal (**Sinks**) reactions that contribute to the energy balance. You find also the corresponding mass consumption and production values.

On some items you find a button ⓘ. Clicking on it shows detail information how HHCeIVolt determines the corresponding values.

Sources, Sinks

When you click on this button HHCeIVolt shows a popup diagram displaying the sources and sinks especially concerning the difference to the conventional Haupin thermal balance.

12th

AUSTRALASIAN ALUMINIUM SMELTING TECHNOLOGY
CONFERENCE

2-7 Dec 2018
Queenstown
New Zealand

Introduction to HHCellVolt

Cell Voltage of Hall - Héroult Electrolysis Cells

DATA SETS BATH VOLTAGE ELECTROLYSIS DATA CELL LAYOUT BUSBARS THEORETICAL BACKGROUND Data Sets Popup

Diagram Components of the Bath Voltage

Carbon Anode

Metal Pad Cathode

Anode Gas Bubble Data

U_{bub} (V): 0.281 Bubble Voltage Drop

d_{bub} (cm): 0.500 Bubble Layer Thickness

v : 0.559 Bubble Volume Fraction

Bubble Model: Welch (1997)

Get Data from HHBubbles

Components of the Bath Voltage

Electrolyte Voltage Drop (U_{ACD}):	1.1070 (V)
Bubble Voltage Drop (U_{bub}):	0.2806 (V)
Ohmic Bath Voltage (U_{Ω}):	1.3876 (V)
Reversible Decomposition Voltage (E_0):	1.2176 (V)
Anodic Reaction Overvoltage (η_{AR}):	0.5350 (V)
Anodic Concentration Overvoltage (η_{AC}):	0.1620 (V)
Cathodic Concentration Overvoltage (η_{CC}):	0.0430 (V)
Electrochemical Bath Voltage (U_{el}):	1.9576 (V)
Bath Voltage (U_{bath}):	3.3452 (V)

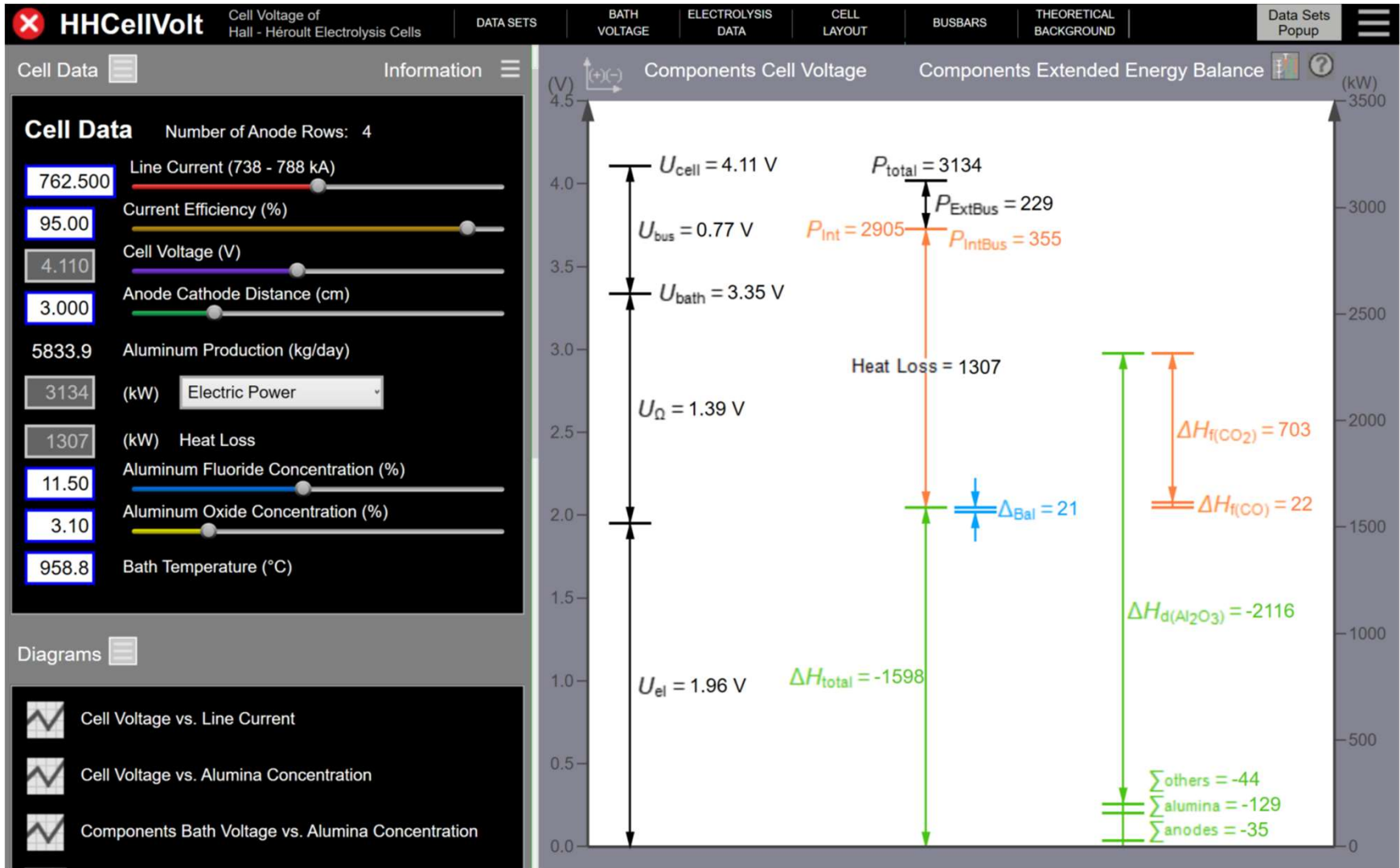
Slotted Anodes

Surfaces

Geometric Anode Table Surface (A_{geom}):	81.1200 (m ²)
Anodic Fanning Factor (f_A):	1.0000
Effective Anode Table Surface (A_A):	81.1200 (m ²)
Cathodic Fanning Factor (f_C):	1.0000
Effective Cathode Surface (A_C):	81.1200 (m ²)

Current Densities


Introduction to HHCeIVolt




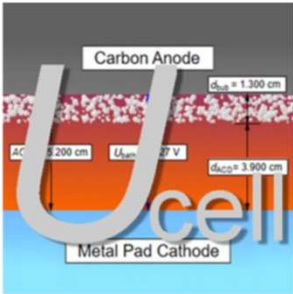
HHCellVolt on the Microsoft Store

Microsoft Store

← Home Apps Games Films & TV

Search  ...

 This product is installed. [Launch](#) ...



HHCellVoltStd


PE Software & Consulting • Education > Study aids

[Share](#)

★★★★★

HHCellVoltStd investigates the behaviour of the Cell Voltage of an Electrolysis Cell for Hall-Héroult Aluminum Smelting. This is done in dependence of operational parameter like current intensity, composition

[More](#)

 **EVERYONE**

Overview System Requirements **Reviews** Related

12th

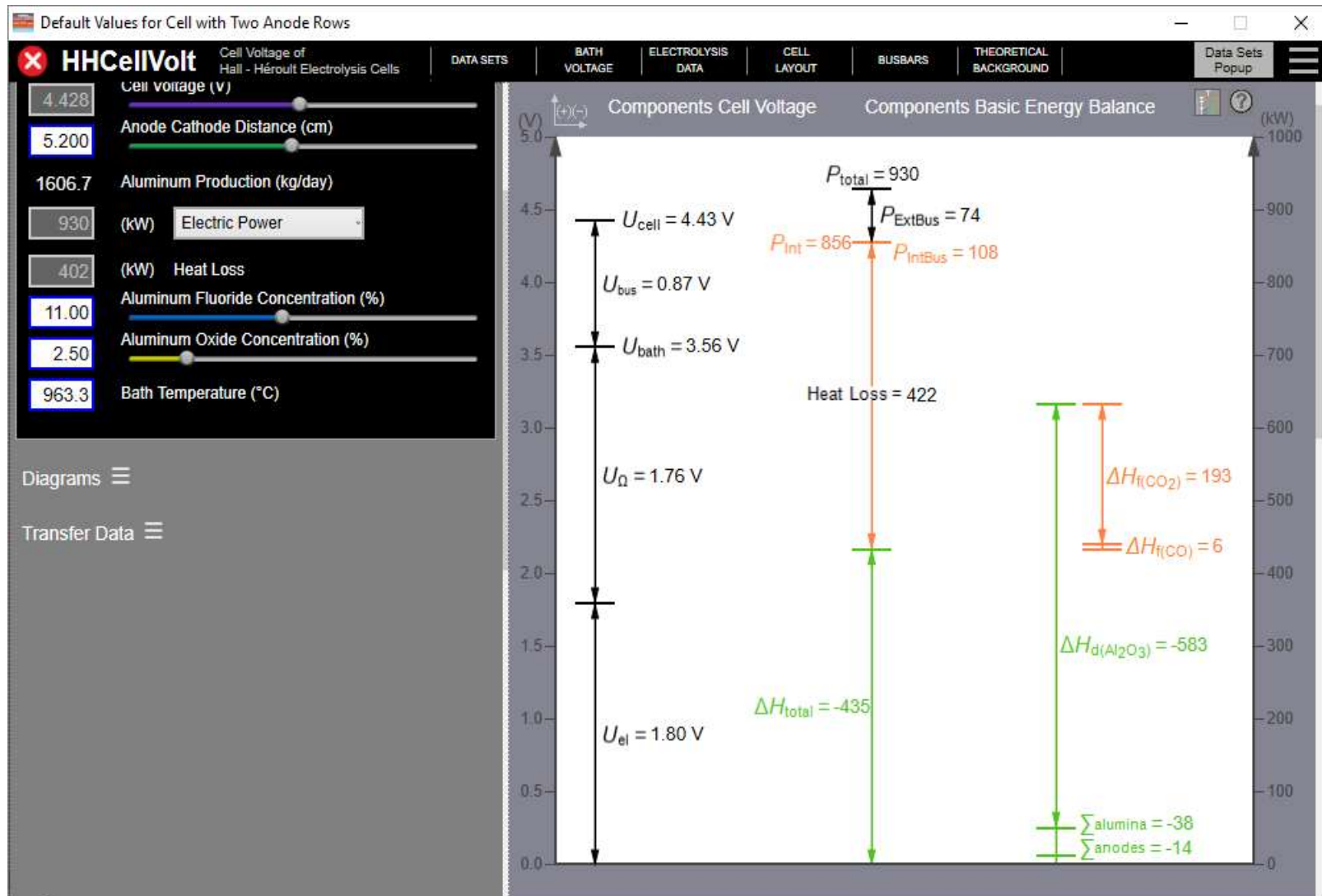
AUSTRALASIAN ALUMINIUM SMELTING TECHNOLOGY
CONFERENCE

2-7 Dec 2018
Queenstown
New Zealand

Haupin Diagram and Basic Energy Balance

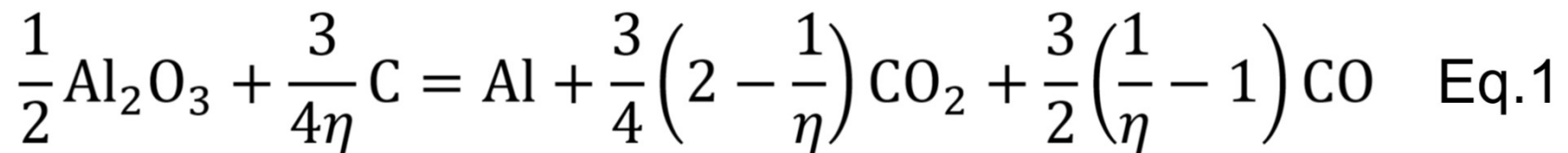
- **Warren Haupin was the first to published diagrams that showed the components of cell voltage and their relation to energy consumption.**
- **HHCellVolt draws similar diagrams. On the left side you see the main panel with input fields and value sliders. You change the value either by conventional keyboard input into the field or by dragging the thumb of the corresponding value slider.**
- **On the right side you see an example of an Haupin Diagram. It shows the components of the cell voltage and of the energy balance. HHCellVolt draws a Haupin diagram showing the components of the cell voltage and of the energy balance.**

Haupin Diagram and Basic Energy Balance



Haupin Diagram and Basic Energy Balance

- The Haupin or Basic Energy Balance considers the electrolysis reactions, heating of alumina as well of the anodes and the heat production of the internal cell conductors.
- This balance considers only the electrolysis reaction (Eq.1, η : fractional current efficiency), the heating of alumina and the heating of the anodes as well as the heat production by Joule heat inside the cell.



Extended Energy Balance

- **The Extended Energy Balance considers in addition to the Basic Energy Balance more events and chemical reaction that happen in the electrolysis cell.**
- **These processes produce either energy (exothermic reactions, heat sources) or consume energy (endothermic reaction, heat sinks).**
- **To make the determination of the Extended Energy Balance transparent as possible HHCeIVolt shows on the THEORETICAL BACKGROUND sliding page the reactions and how it determines the components of the energy balance.**

Extended Energy Balance

HHCellVolt
Cell Voltage of Hall - Héroult Electrolysis Cells

DATA SETS
BATH VOLTAGE
ELECTROLYSIS DATA
CELL LAYOUT
BUSBARS
THEORETICAL BACKGROUND
Data Sets Popup

Contents

Energy Balance

- Introduction
- Alumina
- Carbon Anodes
- Other Reactions
- Relations

Constants and Basic Relations

Relations for the Energy Balance

HHCellVolt applies the data of the [JANAF Thermochemical Tables](#) to determine the thermodynamic values of the energy balance.

Enthalpy of Formation

HHCellVolt uses a linear equation to determine the enthalpy of formation in dependence of temperature:

$$\Delta H_f = b + a \cdot t$$

meaning of the symbols:
 ΔH_f : enthalpy of formation (kJ/mol).
 a, b : coefficients of linear equation determined from the JANAF tables between 1100 K and 1300 K.
 t : temperature (°C).

Enthalpy of Formation Substance: α-Alumina

Values from JANAF Tables	Coefficients
1100 K -1692.437 kJ/mol	a = 0.011235
1300 K -1690.19 kJ/mol	b = -1701.726660

Test Temperature: 962.9 °C
 Test Value: -1690.909 kJ/mol

Shomate Equation

To determine the energy to heat a substance HHCellVolt uses Shomate Equations that calculate the standard enthalpy:

$$H^0 - H_{298.15}^0 = A \cdot t + B \cdot \frac{t^2}{2} + C \cdot \frac{t^3}{3} + D \cdot \frac{t^4}{4} - \frac{E}{t} + F - H$$

meaning of the symbols:
 H^0 : standard enthalpy (kJ/mol).
 A, B, C, D, E, F, H : coefficients from the JANAF tables.
 t : 0.001 · temperature (K).

Shomate Coefficients Substance: α-Alumina (298-2327K)

A: 102.429	Test Temperature: 963.3 °C
B: 38.7498	Test Value: 107.972 kJ/mol
C: -15.9101	
D: 2.628181	
E: -3.007551	
F: -1717.93	
H: -1675.69	

Useful Tables

Conversion of Energy Units

	kJ	kWh	kcal	BTU
kJ	1	2.7778 × 10 ⁻⁴	0.23884	0.947817
kWh	3600	1	859.845	3412.14
kcal	4.1868	1.1630 × 10 ⁻³	1	3.9683

Conversion of Energy Balance Units

Conversion of tension U (V), specific energy E_{spec} (kWh/kg), power P (kW) and enthalpy ΔH (kJ/mol).
 F is the Faraday Constant (96485 C/mol), I the electric current (kA) and M_{Al} the atomic weight of aluminum (26.9815).

	U	E_{spec}	P	ΔH
U	1	$\frac{3600 \cdot E_{\text{spec}} \cdot M_{\text{Al}}}{F}$	$\frac{P}{I}$	$\frac{1000 \cdot \Delta H}{F}$

Extended Energy Balance

Cell Voltage of Hall - Héroult Electrolysis Cells DATA SETS BATH VOLTAGE ELECTROLYSIS DATA CELL LAYOUT BUSBARS THEORETICAL BACKGROUND Data Sets Popup

- Contents
- Energy Balance
 - Introduction
 - Alumina
 - Carbon Anodes
 - Other Reactions
 - Relations
- Constants and Basic Relations

Heat Carbon Anodes

No coefficients of the Shomate relation for carbon were found in the literature. HHCellvolt uses a linear relation determined with the values from the JANAF tables between 1100 and 1300K.

You find the corresponding Shomate coefficients on the Relations for the Energy Balance page.

Airburn Carbon Anodes

Dealing with the reaction of oxygen with carbon the heating of air (i.e. nitrogen) according to AlZharouni ([Web-Lit.Equ. 4, p.5](#)) has to be taken into account.

$$(C + O_2 + 3.8N_2)_{T_a} = (CO_2 + 3.8N_2)_{T_r}$$

T_a : ambient temperature (°C),
 T_r : reaction temperature (°C).

You find the Shomate coefficients for heating of nitrogen on the Relations for the Energy Balance page.

Combustion Carbon Monoxide

HHCellVolt determines the combustion of carbon monoxide as AlZharouni ([Web-Lit.Equ. 5, p.5](#)):

$$(2CO)_{T_r} + (O_2 + 3.8N_2)_{T_a} = (2CO_2 + 3.8N_2)_{T_r}$$

T_a : ambient temperature (°C),
 T_r : reaction temperature (°C).

Enthalpy of formation of carbon dioxide minus enthalpy of Formation of carbon monoxide minus heating of nitrogen.

Boudouard Reaction

$$CO_2 + C = 2CO$$

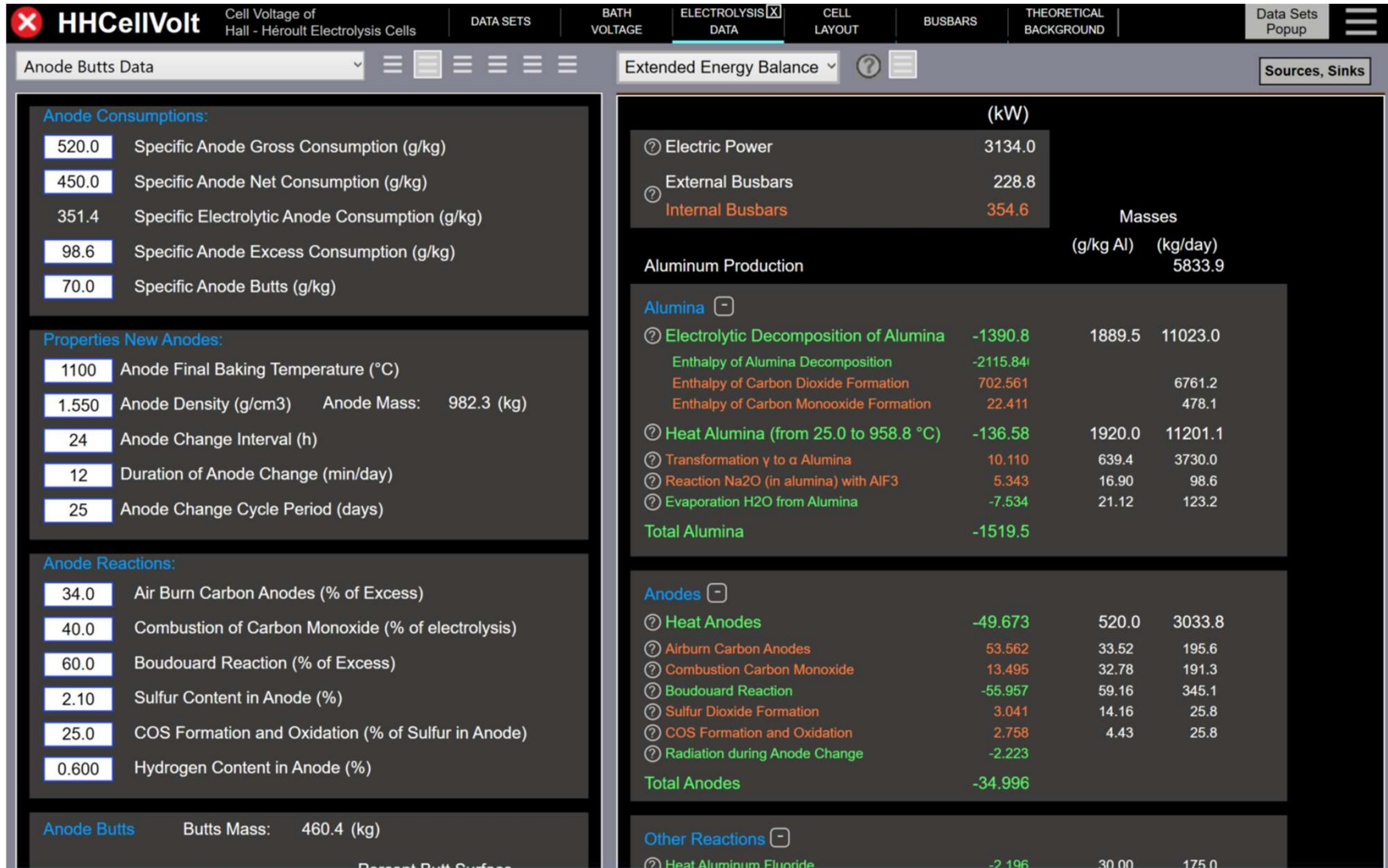
HHCellVolt calculates the enthalpy of reaction for the Boudouard reaction with: enthalpy of formation of carbon dioxide minus twice the enthalpy of formation of carbon monoxide.

Formation of Sulfur Dioxide

The coefficients of the relation for the enthalpy of reaction of:

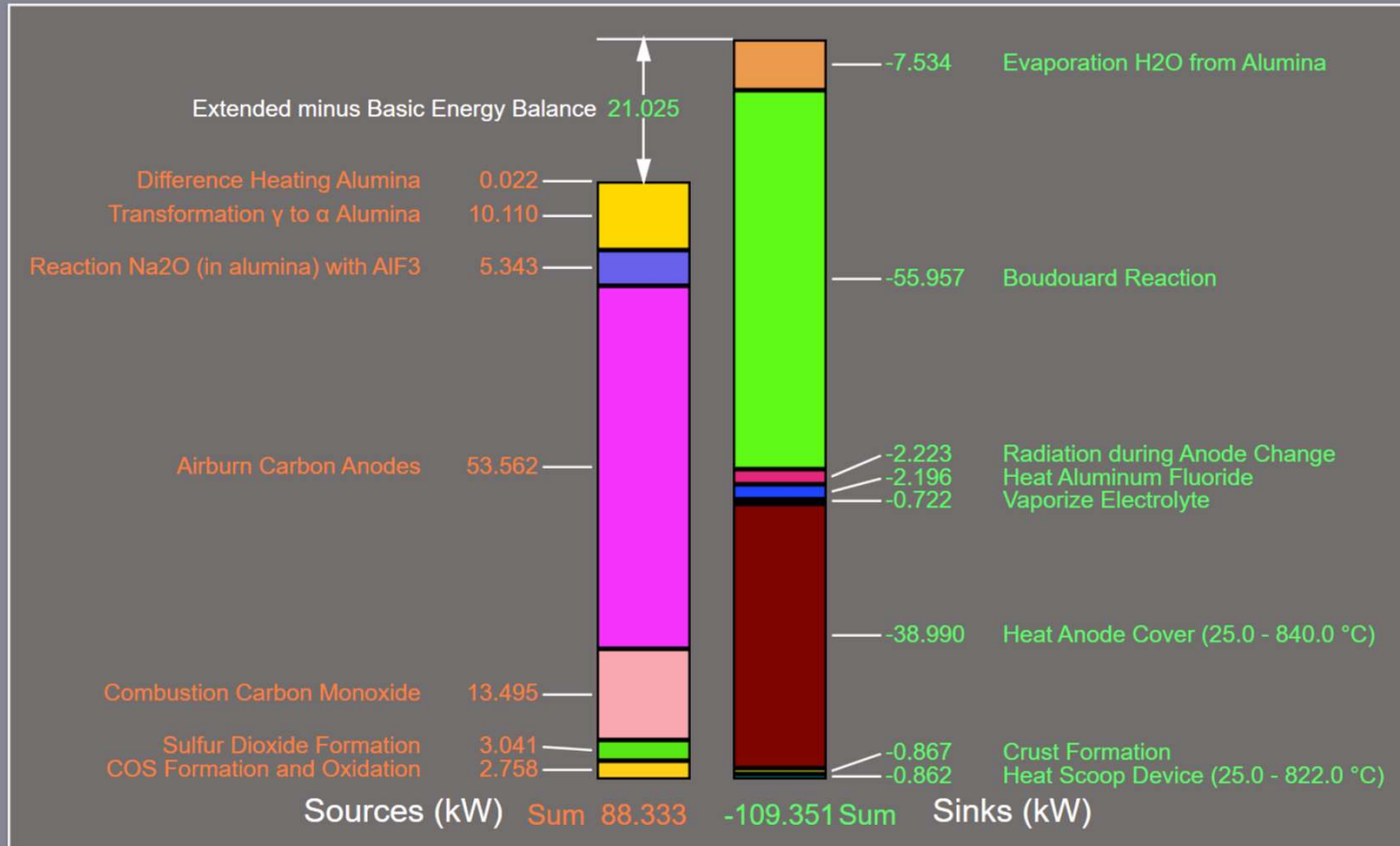
$$S + 2CO_2 = SO_2 + 2CO$$

Extended Energy Balance



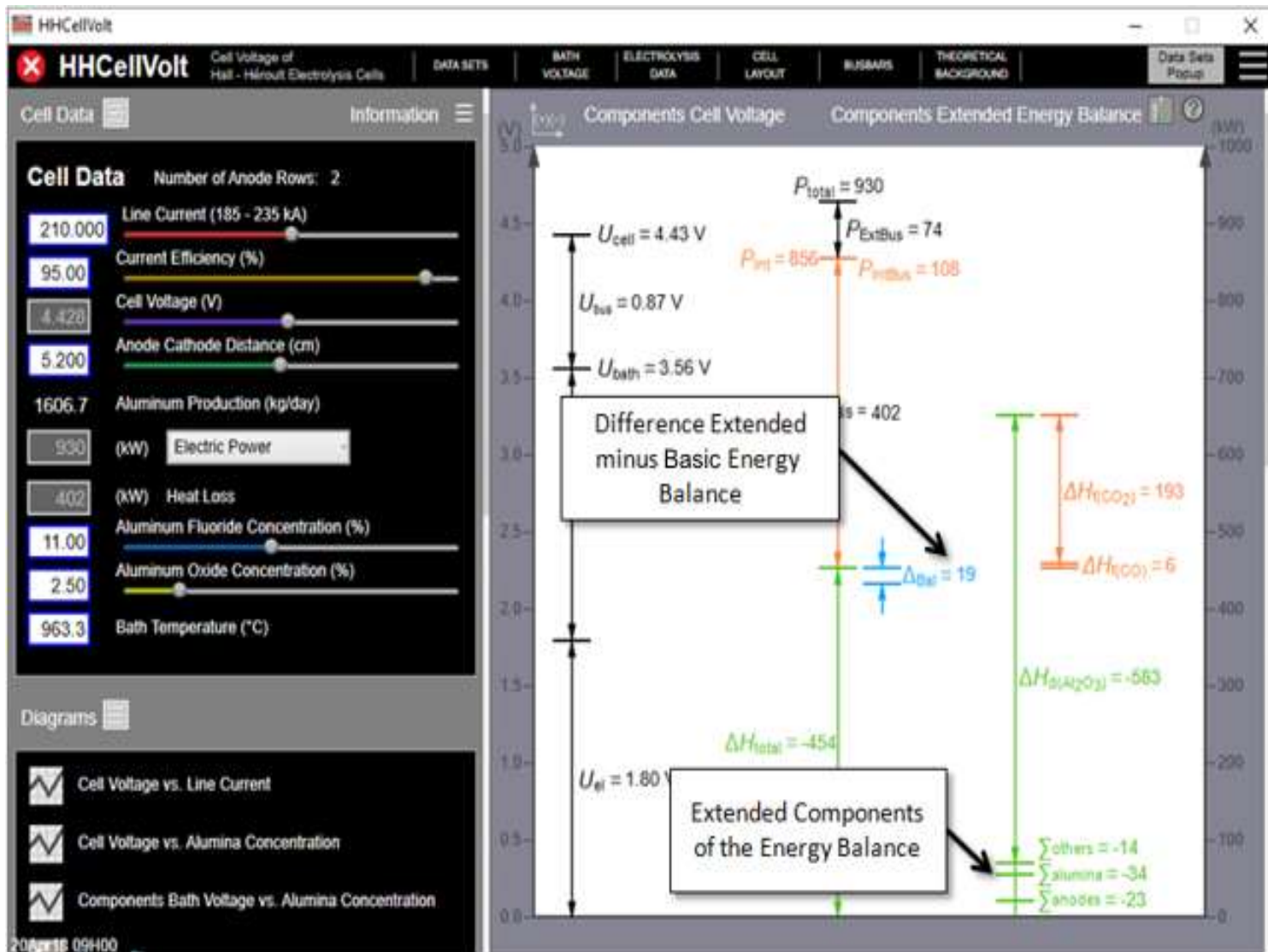
Extended Energy Balance

Sources and Sinks Diagram



Close

Extended Energy Balance



Electrolysis Cells with Four Anode Rows

- A recent publication [13] considers the idea to construct electrolysis cells with four anode rows (see also [14]). With HHCeIVolt you may investigate the design options and corresponding cell voltage of such an electrolysis cell.
- HHCeIVolt contains adapted panels and diagrams to handle this extended anode table layout. Also the algorithms, calculating the anodic fanning factors or bubble voltage, for instance, are adapted to this new anode panel layout.

Electrolysis Cells with Four Anode Rows

HHCellVolt Cell Voltage of Hall - Héroult Electrolysis Cells

DATA SETS BATH VOLTAGE ELECTROLYSIS DATA **CELL LAYOUT** BUSBARS THEORETICAL BACKGROUND Data Sets Popup

Cell Layout Number of Anode Rows: 4 **Show/Hide Dimensions**

Schematic Cell Top View

17320 mm
6180 mm

Target Values

760.000 Target Line Current (kA)
0.9400 Target Current Density (A/cm²)

Line Current Geometric Anodic Current Density: 0.9400 (A/cm²)
762.500 Actual Line Current (738 - 788 kA)

Anode Table

New Anodes Distances

96 = 4 x 24 Number
650 Anode Width (mm)
1300 Anode Length (mm)
750 Anode Height (mm)

40 longitudinal, between Anodes (mm)
60 transversal, between Anodes (mm)
60 between Anodes at Center (mm)
250 Anode-Sideblock, Short Side (mm)
250 Anode-Sideblock, Long Side (mm)

Surface: 81.1200 (m²)

Convert to Two Anode Rows
Convert to Four Anode Rows

Slotted Anodes
Cell Cavity

Cell Transversal Section

250 mm
60 mm
1300 mm
750 mm
60 mm

12th

AUSTRALASIAN ALUMINIUM SMELTING TECHNOLOGY
CONFERENCE

2-7 Dec 2018
Queenstown
New Zealand

Electrolysis Cells with Four Anode Rows

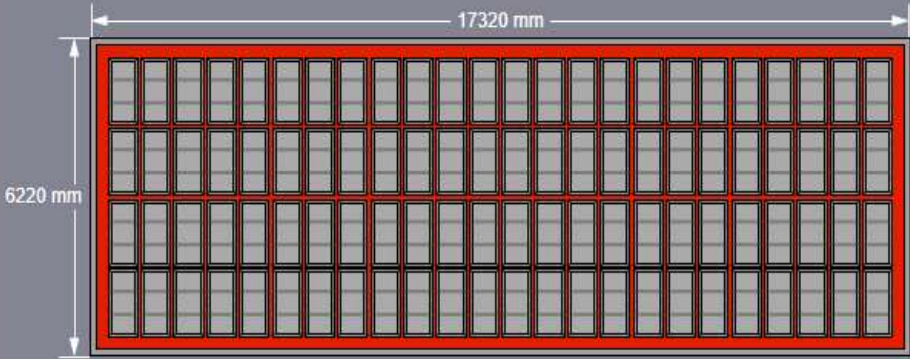
Default Values for Cell with Four Anode Rows

HHCellVolt Cell Voltage of Hall - Héroult Electrolysis Cells

DATA SETS BATH VOLTAGE ELECTROLYSIS DATA **CELL LAYOUT** BUSBARS THEORETICAL BACKGROUND Data Sets Popup

Cell Layout Number of Anode Rows: 4 **Show/Hide Dimensions**

Schematic Cell Top View



17320 mm
6220 mm

Target Values

760.000 Target Line Current (kA)

0.9200 Target Current Density (A/cm²)

Line Current Geometric Anodic Current Density: 0.9158 (A/cm²)

760.000 Actual Line Current (735 - 785 kA)

Anode Table

Slotted Anodes

Slotted Anodes

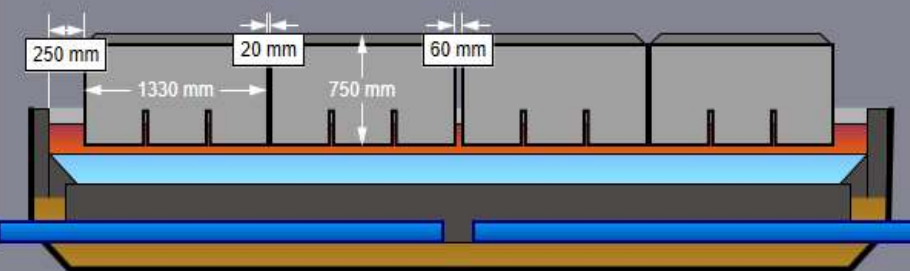
Slot Type: No Slots Longitudinal Transverse

2 Number of Slots

225 Slot Height (mm) 30.0 Slot Height (% of anode height)

30 Slot Width (mm)

Cell Transversal Section



250 mm 1330 mm 20 mm 750 mm 60 mm

Cell Cavity

Cell Longitudinal Section

Electrolysis Cells with Four Anode Rows

HHCellVolt Cell Voltage of Hall - Héroult Electrolysis Cells
DATA SETS
BATH VOLTAGE
ELECTROLYSIS DATA
CELL LAYOUT
BUSBARS
THEORETICAL BACKGROUND
Data Sets PopUp

Overview Busbar Voltages

Reference Values:		Actual Values:	
762.500	Ref. Line Current (kA)	762.500	Act. Line Current (kA)
0.765	Sum Ref. Busbar Voltages (V)	0.765	Act. Sum Busbar Voltages (V)
0.485	Sum Ref. Entry - Bath (V)	0.485	Sum Act. Entry - Bath (V)
0.280	Sum Ref. Bottom - Exit (V)	0.280	Sum Act. Bottom - Exit (V)

Overview Cell Voltage

0.765	Sum Busbar Voltage (V)	0.300	Sum External Voltages (V)
3.345	Bath Voltage (V)	0.465	Sum Internal Voltages (V)
4.110	Cell Voltage Voltage (V)		

Details Busbar Voltages

Change Properties of Selected Busbar Voltage Component:

#1 Bottom - Exit Busbar Voltage Component Selected.

Name
 Material
 Uref: Reference Voltage (mV)
 Uact: Actual Voltage (mV)
 relative Position in Diagram
 Contribution to the Energy Balance

Components Entry - Bath Busbar Voltage: + -

#	Name	Material	Uref	Uact	Pos.	therm. Bal.

Entry 120 Riser 20 Clamp 345 Anode Bath 3.345 Bath Voltage (V) Bottom 120 cathode 160 Busbar Exit 160

Show Entry - Bath Busbar Current Path Items

Show Bottom - Exit Busbar Current Path Items

Example of the Calculation of Impact of the Extended Reactions on the Cell Operating

- In [13] a wide cell using four anode rows operating at 762.5 kA were presented. As proposed by Barry Welch, one of the co-author, the equivalent energy to make metal was specified to be 6.6 kWh/kg instead of Haupin's suggested value of 6.34 kWh/kg.
- For an operation at 95% of current efficiency, this corresponds to an equivalent voltage to make the metal of 2.104 V instead of 2.021 V.
- In turn, for an operation at 762.5 kA that represents 1604.3 kW instead of 1541.0 kW of power requirement to continually produce the metal and carry on the extended reactions.

Example of the Calculation of Impact of the Extended Reactions on the Cell Operating

- For an assumed cell operation at 4.1 V and an external busbar drop of 300 mV, this represents a calculated cell internal heat of 1293.2 kW instead of 1356.5 kW.
- So, for a cell operation at 762.5 kA and 95% current efficient, this 0.26 kWh/kg extra energy requirement to carry-on the extended reactions represent 63.2 kW less of heat dissipation.
- HHCeIVolt will calculate that for us, but it will not tell us what the impact of that difference of cell heat loss on the cell operating conditions will be.

Example of the Calculation of Impact of the Extended Reactions on the Cell Operating

- For that, we have to use another mathematical model, in the present case, Dyna/Marc 14 [15] was used.
- Table II presents the comparison of the cell operating conditions prediction using on the left Haupin recommended 6.34 kWh/kg energy requirement to produce the metal and on the right using Welch recommended 6.6 kWh/kg energy requirement to carry-on both the metal production and the extended reactions.

Example of the Calculation of Impact of the Extended Reactions on the Cell Operating

Table I: Description of the Cell Design and Operating Conditions

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

Example of the Calculation of Impact of the Extended Reactions on the Cell Operating

Table II: Comparison of predicted operational data

Anode drop (A)	347 mV	347 mV
Cathode drop (A)	118 mV	118 mV
Busbar drop (A)	300 mV	383 mV
Operating temperature (D/M)	968.9 °C	967.5 °C
Liquidus superheat (D/M)	10.0 °C	8.6 °C
Bath ledge thickness (D/M)	4.51 cm	6.04 cm
Metal ledge thickness (D/M)	0.54 cm	2.08 cm
Current efficiency (D/M)	95.00%	95.00%
Cell Voltage (D/M)	4.10 V	4.10 V
Internal heat (D/M)	1330 kW	1267 kW
Energy consumption	12.87 kWh/kg	12.87 kWh/kg

Example of the Calculation of Impact of the Extended Reactions on the Cell Operating

- As it can be seen in Table II, even is the extra 63 kW required only represents about 4% of the 1450 kW required to carry-on the metal production, it represents about 5% of the about 1300 kW cell internal heat for a cell operating at 12.9 kWh/kg.**
- That percentage of the cell internal heat will increase further for very low energy consumption cells.**
- Furthermore, since the cell only accommodate the difference by adjusting its cell superheat, that extra 63 kW of energy requirement reduced the cell superheat by about 1.4 °C or 14%.**

Conclusions

- **In recent years, work has been done to refine the calculation of the energy required to carry-on all the reactions taking place in an aluminium reduction cell ([7] - [9]).**
- **This kind of cumbersome enthalpy calculation has been streamlined in a very powerful and user-friendly MS Windows PC program called HHCellVolt.**
- **This make HHCellVolt the prefect tool to make preliminary cell design studies on the impact of the choice of anode current density, ACD, bath chemistry, anode, cathode and busbar voltage drop etc. on the resulting cell voltage and hence cell power consumption.**

Conclusions

- **The importance of considering the impact of the energy required to carry-on the extended reactions taking place in a cell has been demonstrated on the example of a wide cell operating at 762.5 kA published recently [13].**
- **Clearly, this kind of thermal impact need to be considered when designing high amperage and/or low energy consumption cells.**