

THERMO-ELECTRIC DESIGN OF A 500 kA CELL

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Introduction

It is important to well understand the physic of the heat dissipation inside the lining of an aluminum reduction cell to be able to do the thermo-electric design of a new cell.

The key feature to take into consideration is the 2 zones heat loss mechanism [1,2]. In one zone, the driving force is the global thermal gradient between the cell operating temperature and the cell ambient temperature. While in the other zone, the driving force is the cell superheat!

These days, no one would attempt to design a cell without the support of mathematical modeling tools. The simplest possible model that is representative of the two zones heat dissipation mechanism of the cell is the lump parameters+ model [3,4]. That model is so simple, that you can get answer to “what if” design questions in a fraction of second. Nevertheless, as demonstrated in [5,6], the accuracy of the lump parameters+ model predictions are surprisingly accurate considering its simplicity.

As described in [7], the lump parameters+ model has been recently upgraded by adding to it four new sub-models that computed the anode panel heat loss, the cathode bottom heat loss, the anode drop and the cathode drop. With the addition of these new sub-models, the lump parameters+ model also called Dyna/Marc 1.7 cell simulator [8] can be use stand-alone to do per example the thermo-electric design of a 500 kA cell starting from an existing design at 300 kA. Figure 1 and 2 respectively present Dyna/Marc 1.7 “What if” panel and the results of a trend analysis.

From 300 to 400 kA

The initial steps going from 300 to 400 kA have already been presented twice so far. In reference [5,7], the step-by-step retrofit study of a 300 kA cell into a 350 kA cell is first presented. In total 9 changes were required to be able to push the amperage up to 350 kA, they are:

- 1) Decreasing the ACD from 5 to 4 cm
- 2) Increasing the anode length from 1.6 to 1.7 m
- 3) Increasing the excess AlF_3 from 10.9 to 13.5 %
- 4) Substituting the cathode block grade from HC3 to HC10
- 5) Increasing the cathode length from 3.47 to 3.67 m
- 6) Substituting the side block material from HC3 carbon to silicon carbide
- 7) Decreasing the side block thickness from 15 to 10 cm
- 8) Decreasing the anode cover thickness from 16 to 10 cm
- 9) Increasing the stud diameter from 18 to 19 cm

The retrofitted 350 kA cell design is then extended into a 400 kA cell by increasing the cell length by 1.7 m, going from 14.4 to 16.1 m, to be able to add four new anodes and two new cathode blocks. The summary of the results obtained is presented in table I.

From 400 to 500 kA

Now for the first time, a step-by-step study of the extension of this 400 kA cell into a 500 kA cell is presented. In total four changes were required to be able to push the amperage up to 500 kA, they are:

- 1) Increasing the cell length by 1.7 m, going from 16.1 to 17.8m, adding four new anodes and two new cathode blocks
- 2) Increasing the cell width by 0.5 m, going from 4.35 to 4.85 m in order to be able to increase the anode length by 0.25m going from 1.7 to 1.95 m
- 3) Increasing the number of studs per anode going from three 19 cm diameter studs to four 17.5 cm diameter ones
- 4) Increasing the number of cathode blocks from 22 to 24 by decreasing their width, effectively decreasing the current density in the collector bars.

The summary of the results obtained is presented in table II. Obviously, this is only one possible way to get there; the MHD stability study could dictate that other choices for the length to width ratio of the cell are preferable.

Conclusions

It was demonstrated that with enough experience and a good modeling tool, it is fairly simple to do the thermo-electric design of a 500 kA cell. Apart from its quite impressive size, there is really nothing special about the design because as far as the thermo-electric aspect of the cell design is concerned, there is no specific challenges preventing the design of even bigger cell.

References

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Figure 1: Dyna/Marc 1.7 "What if" panel

DYNA/MARC 1.7 - [VAWm16]

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Demo example of a prebaked PBF cell inspired from VAW's JOM paper
 liquidus superheat, 4 cm ACD, 1.95m anode length, 13.5% AlF₃, 500 kA
 HClO 4.17m cathode block, top 10cm bottom 16.5 cm SiC side block
 10 cm cover over anodes, 17.5 cm stud diameter, 4 studs per anode
 40 anodes, 24 cathode blocks, 17.8 m X 4.85 m inside potshell

Date Created : 8/2/1999 Last Modified : 9/15/2002

Steady State Solution

Cell amperage	500.0 [kA]
Anode to cathode distance	4.00000 [cm]
Operating temperature	963.366 [C]
Ledge thickness, bath level	4.44079 [cm]
Ledge thickness, metal level	0.16550 [cm]
Anode beam position	0.0000 [cm]
Mass of metal	33763.7 [kg]
Mass of bath	11020.16 [kg]
Mass of dissolved alumina	275.504 [kg]
Mass of dispersed alumina	79.390 [kg]
Mass of alumina sludge	2.5966 [kg]
Mass of dissolved aluminum fluoride	1487.722 [kg]
Mass of dispersed aluminum fluoride	1.015 [kg]
Mass of aluminum fluoride sludge	0.0003 [kg]
Mass of calcium fluoride	330.605 [kg]
Mass of lithium fluoride	0.000 [kg]
Mass of magnesium fluoride	0.000 [kg]
Alumina feeding rate	310.010 [kg/hr]
Aluminum fluoride feeding rate	3.07019 [kg/hr]
Target cell resistance	5.31686 [micro-ohm]

Steady State derived Variables

Rate of change of:	
ACD	-0.02224 [cm/hr]
Operating temperature	0.0000 [C/hr]
Ledge thickness, bath level	0.000 [cm/hr]
Ledge thickness, metal level	0.000 [cm/hr]
Mass of dispersed Al ₂ O ₃	0.000 [kg/hr]

DYNA/MARC: What If

List of Design Variables

	Design Value		Set as Target
Anode to Cathode Distance	4	cm	<input type="radio"/>
Cell Amperage	500	kA	<input type="radio"/>
Conc. of Excess Aluminum Fluoride	13.5	%	<input type="radio"/>
Concentration of Dissolved Alumina	2.5	%	<input type="radio"/>
Concentration of Calcium Fluoride	3	%	<input type="radio"/>
Concentration of Lithium Fluoride	0	%	<input type="radio"/>
Conc. of Magnesium Fluoride	0	%	<input type="radio"/>
Bath Level	20	cm	<input type="radio"/>
Bath Ledge Heat Transfer Coef.	1425	W/m ² °C	<input type="radio"/>
Metal Ledge Heat Transfer Coef.	2052	W/m ² °C	<input type="radio"/>
Metal Level	20	cm	<input type="radio"/>
Anode Length	1.95	m	<input type="radio"/>
Cavity Length	17.48	m	<input type="radio"/>
Anode Panel Heat Loss	393.971849	kW	<input type="button" value="Advanced"/>
Cathode Bottom Heat Loss	237.657447	kW	<input type="button" value="Advanced"/>
Cell Operating Temperature	963.365699	°C	<input checked="" type="radio"/>
Anode Voltage Drop	319.513746	mV	<input type="button" value="Advanced"/>
Cathode Voltage Drop	311.865904	mV	<input type="button" value="Advanced"/>
Anode Width	0.8	m	<input type="radio"/>
Cavity Width	4.55	m	<input type="radio"/>

Press F1 for Help Demo example of a prebaked PBF cell inspired from VAW's JOM paper 10/3/2002 2:08 PM CAPS NUM INSERT

Figure 2: Dyna/Marc 1.7 Trend Analysis Results

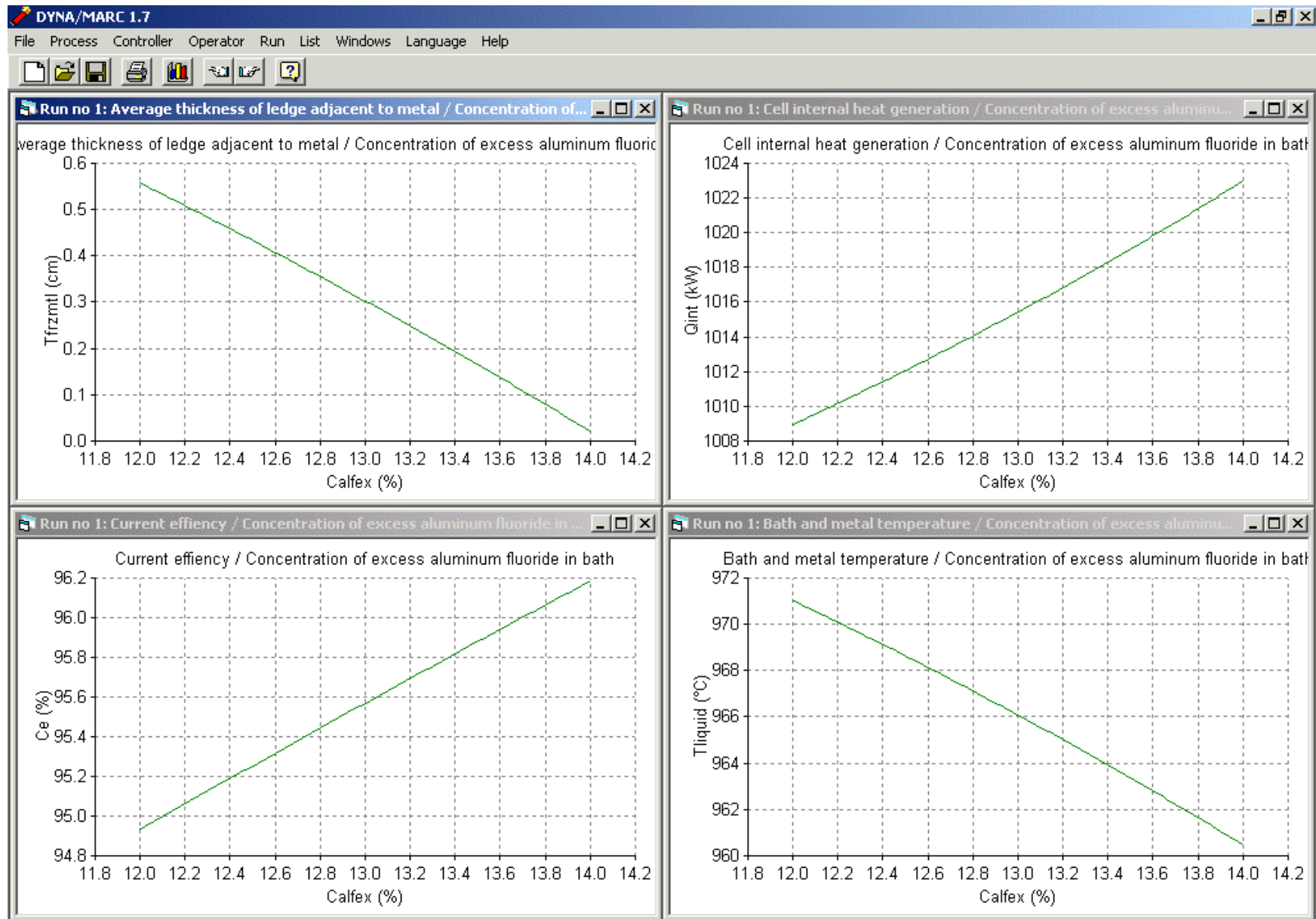


Table I : Going from 300 to 400 kA

	Base case	Step 1	Step 2	Step 3	Step 4-5	Step 6-7	Step 8	Step 9	Step 10
Modeling tool	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7
Amperage	300 kA	322 kA	330 kA	330 kA	330 kA	330 kA	335 kA	350 kA	400 kA
Nb. of anodes	32	32	32	32	32	32	32	32	36
Anode size	1.6 m X 0.8 m	1.6 m X 0.8 m	1.7 m X 0.8 m	1.7 m X 0.8 m	1.7 m X 0.8 m	1.7 m X 0.8 m	1.7 m X 0.8 m	1.7 m X 0.8 m	1.7 m X 0.8 m
Nb. of anode studs	3 per anode	3 per anode	3 per anode	3 per anode	3 per anode	3 per anode	3 per anode	3 per anode	3 per anode
Anode stud diameter	18 cm	18 cm	18 cm	18 cm	18 cm	18 cm	18 cm	19 cm	19 cm
Anode cover thickness	16 cm	16 cm	16 cm	16 cm	16 cm	16 cm	10 cm	10 cm	10 cm
Nb. of cathode blocks	18	18	18	18	18	18	18	18	20
Cathode block length	3.47 m	3.47 m	3.47 m	3.47 m	3.67 m	3.67 m	3.67 m	3.67 m	3.67 m
Type of cathode block	HC3	HC3	HC3	HC3	HC10	HC10	HC10	HC10	HC10
Type of side block	HC3	HC3	HC3	HC3	HC3	SiC	SiC	SiC	SiC
Side block thickness	15 cm +	15 cm +	15 cm +	15 cm +	15 cm +	10 cm +	10 cm +	10 cm +	10 cm +
ASD	35 cm	35 cm	25 cm	25 cm	25 cm	30 cm	30 cm	30 cm	30 cm
Inside potshell size	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m	14.4 X 4.35 m	16.1 X 4.35 m
ACD	5 cm	4 cm	4 cm	4 cm	4 cm	4 cm	4 cm	4 cm	4 cm
Excess AlF ₃	10.9 %	10.9 %	10.9 %	13.5 %	13.5 %	13.5 %	13.5 %	13.5 %	13.5 %
Anode drop	306 mV	325 mV	328 mV	328 mV	328 mV	328 mV	331 mV	330 mV	335 mV
Cathode drop	290 mV	311 mV	319 mV	319 mV	277 mV	277 mV	281 mV	293 mV	301 mV
Anode panel heat loss	239 kW	244 kW	247 kW	247 kW	247 kW	250 kW	275 kW	284 kW	311 kW
Cathode bottom heat loss	166 kW	167 kW	168 kW	168 kW	171 kW	171 kW	172 kW	173 kW	193 kW
Operating temperature	973.3 °C	973.3 °C	973.3 °C	960.8 °C	960.3 °C	960.2 °C	960.0 °C	961.5 °C	962.7 °C
Liquidus superheat	6.8 °C	6.8 °C	6.8 °C	7.2 °C	6.6 °C	6.5 °C	6.3 °C	7.8 °C	9.0 °C
Bath ledge thickness	7.61 cm	7.75 cm	7.71 cm	6.85 cm	7.81 cm	9.02 cm	9.34 cm	6.69 cm	5.11 cm
Metal ledge thickness	2.79 cm	2.93 cm	2.88 cm	2.03 cm	2.98 cm	4.75 cm	5.07 cm	2.42 cm	0.83 cm
Current efficiency	94.0 %	94.4 %	94.2 %	95.9 %	95.9 %	95.9 %	96.0 %	96.0 %	96.0 %
Internal heat	628 kW	633 kW	637 kW	647 kW	633 kW	633 kW	652 kW	712 kW	825 kW
Energy consumption	13.75 kWh/kg	13.32 kWh/kg	13.20 kWh/kg	13.14 kWh/kg	13.01 kWh/kg	13.00 kWh/kg	13.10 kWh/kg	13.37 kWh/kg	13.49 kWh/kg

Table II : Going from 400 to 500 kA

	Base case	Step 1	Step 2	Step 3	Step 4
Modeling tool	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7	Dyna/Marc 1.7
Amperage	400 kA	440 kA	480 kA	490 kA	500 kA
Nb. of anodes	36	40	40	40	40
Anode size	1.7 m X 0.8 m	1.7 m X 0.8 m	1.95 m X 0.8 m	1.95 m X 0.8 m	1.95 m X 0.8 m
Nb. of anode studs	3 per anode	3 per anode	3 per anode	4 per anode	4 per anode
Anode stud diameter	19 cm	19 cm	19 cm	17.5 cm	17.5 cm
Anode cover thickness	10 cm	10 cm	10 cm	10 cm	10 cm
Nb. of cathode blocks	20	22	22	22	24
Cathode block length	3.67 m	3.67 m	4.17 m	4.17 m	4.17 m
Type of cathode block	HC10	HC10	HC10	HC10	HC10
Type of side block	SiC	SiC	SiC	SiC	SiC
Side block thickness	10 cm +	10 cm +	10 cm +	10 cm +	10 cm +
ASD	30 cm	30 cm	30 cm	30 cm	30 cm
Inside potshell size	16.1 X 4.35 m	17.8 X 4.35 m	17.8 X 4.85 m	17.8 X 4.85 m	17.8 X 4.85 m
ACD	4 cm	4 cm	4 cm	4 cm	4 cm
Excess AlF ₃	13.5 %	13.5 %	13.5 %	13.5 %	13.5 %
Anode drop	335 mV	332 mV	347 mV	314 mV	320 mV
Cathode drop	301 mV	331 mV	324 mV	331 mV	312 mV
Anode panel heat loss	311 kW	335 kW	367 kW	391 kW	394 kW
Cathode bottom heat loss	193 kW	202 kW	231 kW	231 kW	238 kW
Operating temperature	962.7 °C	963.4 °C	962.8 °C	962.8 °C	963.4 °C
Liquidus superheat	9.0 °C	9.7 °C	9.1 °C	9.1 °C	9.7 °C
Bath ledge thickness	5.11 cm	4.43 cm	4.97 cm	4.99 cm	4.44 cm
Metal ledge thickness	0.83 cm	0.15 cm	0.70 cm	0.71 cm	0.17 cm
Current efficiency	96.0 %	95.9 %	95.8 %	95.9 %	95.9 %
Internal heat	825 kW	916 kW	964 kW	988 kW	1019 kW
Energy consumption	13.49 kWh/kg	13.53 kWh/kg	13.31 kWh/kg	13.33 kWh/kg	13.39 kWh/kg