

Amperage Increase in DX+ Ultra Demonstration Cells at EGA's Jebel Ali Smelter

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Abstract

DX+ Ultra is EGA's low specific energy consumption, low CAPEX cell technology that was started up in March 2014 using five demonstration cells at 450 kA in Potline 5 Eagle Section in Jebel Ali smelter. After successful demonstration of the technology performance at amperages up to 460 kA, ALBA chose the DX+ Ultra technology for its Potline 6 smelter expansion in 2016. EGA then decided to stop the five demonstration cells and build three cells with the modified cathode design to be used at Alba, but also restart the two remaining cells. The three Alba design cells and the other two cells restarted at 460 kA in the period May to June 2017. After one year of successful operation the amperage was increased to 470 kA to increase cell productivity. This was achieved on 30 July 2018 where it stayed for 8 months. The next stage of development was to raise the amperage further to 480 kA. This was achieved on 22 April 2019. Operating the cells at 480 kA for almost 2 years resulted in an outstanding performance before the cells were finally stopped on 26 March 2021. A new, even higher productivity and lower specific energy consumption DX+ Ultra technology is in the making during the writing of this paper. Continuous development of cell control and monitoring as well as establishing the amperage increase strategy are valuable assets for the support of DX+ Ultra technology clients. In this paper, cell performance, challenges and solutions at various stages of amperage increase will be presented.

Keywords: DX+ Ultra Technology, Amperage increase, Cell performance.

1. Introduction

EGA is the largest industrial company in the UAE outside oil and gas and the world's biggest 'premium aluminium' producer. EGA operates aluminium smelters at Jebel Ali in Dubai and at Al Taweelah in Abu Dhabi, with a combined production capacity of 2.51 million tonnes of cast metal in 2020. The smelter in Jebel Ali has seven potlines operating six home-grown cell technologies: D18+, CD20, D20, D20+, DX and DX+ Ultra. The smelter in Al Taweelah has three potlines operating three technologies: DX in potlines 1 and 2, DX+ in Potline 3 and DX+ Ultra in the most recent extension of Potline 3 [1].

In the Jebel Ali smelter Potline 5 holds a test section named the Eagle Section where EGA can demonstrate new technology in a group of five cells. For example, the original DX technology was demonstrated in this section from 2005 to 2010 and then implemented in Potlines 1 and 2 in Al Taweelah between 2010 and 2011. The DX+ technology was tested from 2010 to 2014 followed by implementation in Al Taweelah Potline 3. The latest development was DX+ Ultra technology that was tested from 2014 to 2021. After successful demonstration of DX+ Ultra technology from 2014 to 2016, Aluminium Bahrain (Alba) selected the DX+ Ultra technology

for its Potline 6 expansion project that commenced 2016. The five DX+ Ultra demonstration cells were stopped on 18 March 2017 and had achieved cell ages from 1050 to 1102 days. Two cells (no. 273 and 274) were rebuilt as industrial (Alba) design with asymmetric busbars and some modifications to the cathode lining. One cell (no. 277) had only the Alba cathode design and no changes made to the busbar. The two remaining cells (no. 275 and 276) were restarted without any changes. These cells started up from 18 May to 18 June 2017 at 460 kA [2]. The restarted cell no. 276 was cut out on 18 July 2019, rebuilt and bathed-up again with Alba cathode design on 24 August 2019. The restarted cell no. 275 was cut out on 4 January 2020 at the age of 2007 days, rebuilt and bathed-up with Alba cathode design on 26 January 2020. All cells were ultimately stopped on 26 March 2021 while operating at 480 kA. They are presently being rebuilt with a more advanced cathode design with the intention to operate them at 500 kA.

In this paper the performance of DX+ Ultra Eagle cells will be reviewed and analysed at amperages of 460 kA, 470 kA and 480 kA.

2. Amperage Increase Strategy

The DX+ Ultra cells started up at 450 kA between March and May of 2014. An amperage of 455 kA was reached shortly after that on 18 July 2014. Thereafter, various amperages up to 469 kA were tested, but then the amperage was taken down again to 455 kA during the period starting 14 February 2015 until 6 September 2016. Following that, the amperage started to be increased again and reached 460 kA on 19 September 2016. It stayed at 460 kA until 3 July 2018. An amperage of 470 kA was reached on 30 July 2018 where it was kept until 4 April 2019. After a period of increases, an amperage of 480 kA was reached on 22 April 2019. It was held at this level until 26 March 2021 when all pots were cut out. Figure 1 shows the amperage evolution and the associated cell voltages.

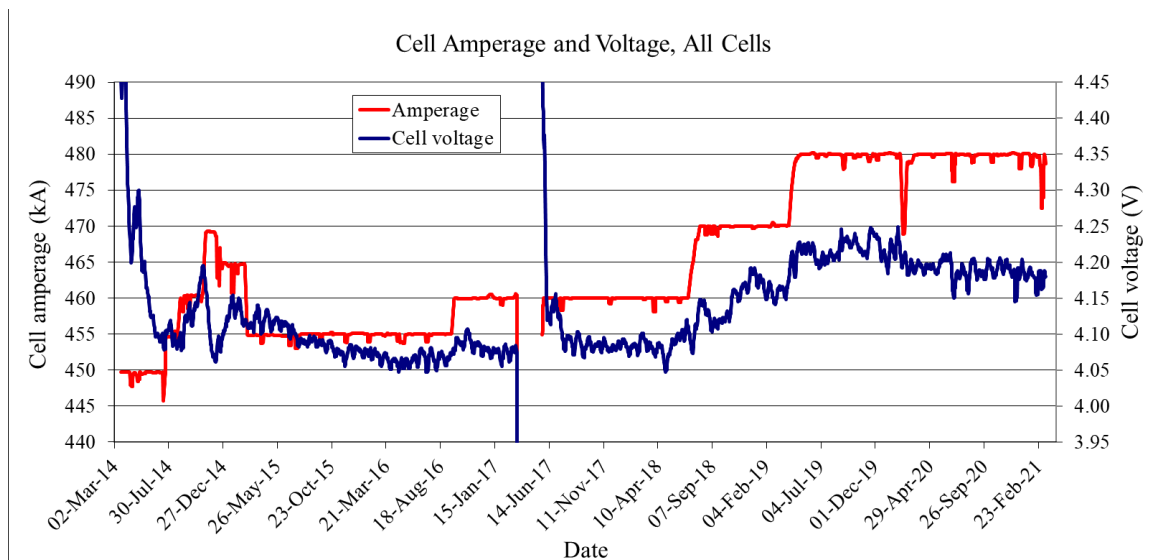


Figure 1. Cell amperage and average voltage of all five DX+ Ultra cells from the original start-up in 2014 to 26 March 2021. High voltages are at the original start-up and at the start-up of the industrial cells.

The cell performance at 455 kA has previously been reported by Alzarooni et. al. for the period of 1 June 2015 to 31 August 2016 (15 months) [3]. The performance was excellent with 95 % current efficiency, specific energy consumption of 12.8 kWh/kg Al and net carbon consumption of 402 kg C/ kg Al. In the present paper, the performance at 460 kA, 470 kA and 480 kA will be

discussed. The transition period to higher amperage level is included in the data of the lower level. This way, no data is omitted.

EGA’s strategy for amperage increases is to use mathematical models for key cell parameter calculations. EGA has full mathematical modelling capability for cell design and for amperage increase studies [4-5]. With these models, the planned amperage increase is evaluated beforehand so that there is a greater certainty when actual cells are tested. In the DX+ Ultra demonstration cells the cell parameter adjustments were linked to three strategies: constant anode cathode distance (ACD), constant voltage and constant internal heat.

2.1 Base Resistance Set Point

The main cell energy control parameter is the Base Resistance Set Point (BRSP) as shown in Figure 2. Cell resistance is added for early life, anode changing, instabilities, bath temperature adjustments, etc. The net cell voltage is $V_{cell} = V_{base} + V_{adders}$. Where $V_{base} = \text{BRSP} (\mu\Omega) \times \text{Amperage (kA)}/1000 + 1.65 \text{ V}$. The contribution of all voltage adders to the cell voltage was approximately 60 mV. In Figure 2 we can see that the BRSP varied by a small amount, being between 5.15 $\mu\Omega$ and 5.24 $\mu\Omega$, thus keeping the base voltage constant within 35-45 mV.

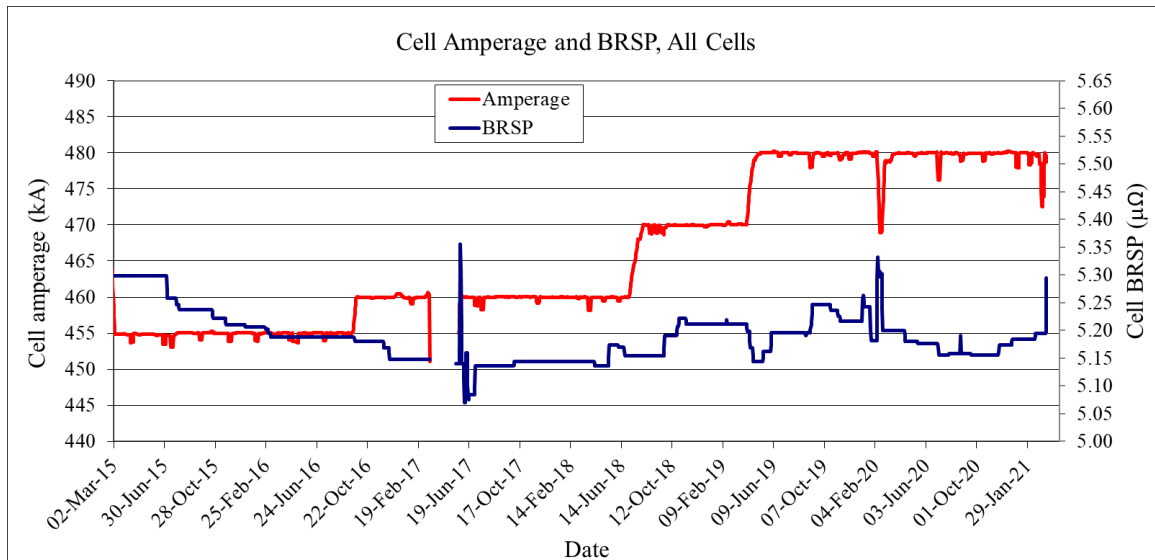


Figure 2. Cell amperage and BRSP.

2.2 Heat Balance and ACD

EGA’s cell energy balance analysis is based on the concept of the cell’s internal heat generation, which is the net heat within the pre-determined boundaries of the cell, i.e., the heat that is generated minus the heat that is absorbed as shown in Equation 1. The boundaries are defined by the surface of the cathode shell and the top of anode cover [4]. Cathode collector bars to the end outside the shell and anode rods to the top below the anode beam are included within these boundaries. The balance requires that all the internal heat is lost across the cell boundaries as defined above. Within these boundaries heat is generated by electrical current and voltage drop within the boundaries, but also by aluminium re-oxidation (current efficiency loss) and by air burn of anode carbon and carbon monoxide. Heat is absorbed by the electrochemical reaction to make aluminium and by some auxiliary processes, such as anode changing, anode butt removal, net bath tapping, fluoride feeding, reactions with alumina impurities, and by evaporation of water.

The main generator of electrical heat is the bath in the interpolar space, determined by ACD.

$$Q_{int} = [V_{cell} - V_{external} - (V_{Al} + V_{aux}) + xV_{C burn} + yV_{CO burn}] I \quad (1)$$

where:

- Q_{int} Cell internal heat, kW
- V_{cell} Cell voltage, V
- $V_{external}$ External voltage drop (the one outside the System Boundary 2), V
- V_{Al} Voltage equivalent of enthalpy to make aluminium, V
- V_{aux} Voltage equivalent of heat removed from the cell by auxiliary processes, such as anode butt removal, cavity scoop, aluminium fluoride and impurity additions, etc., V
- $xV_{C burn}$ Fraction x of voltage equivalent of enthalpy of excess carbon burn (air and CO₂), V
- $yV_{CO burn}$ Fraction y of voltage equivalent of CO burn within the chosen heat loss boundary, V
- I Cell current, kA.

Table 1 gives the internal heat and ACD in different amperage increase stages. The ACD is calculated according to Haupin [6].

We can see that the ACD decreased slightly by 1.5 mm from 455 kA to 460 kA and then remained fairly constant within 0.7 mm. Figure 1 shows that the cell voltage was nearly constant for a long stretch at 455 kA and 460 kA, but then it had to be increased to avoid squeezing the ACD too much. Internal heat generation increased at every stage of amperage increase.

Table 1. Internal heat and ACD.

Target Amperage	kA	455	460	470	480
Amperage in period	kA	454.83	460.39	470.27	479.43
Cell voltage	V	4.076	4.086	4.153	4.199
ACD	mm	29.7	28.7	29.0	28.5
Current density	A/cm ²	0.946	0.944	0.965	0.985
Internal heat	kW	786	793	839	877

The question is how to get rid of this internal heat increase of 91 kW at 480 kA? The DX+ Ultra cell is a low energy, high productivity and low CAPEX technology. Even though it operates at low voltage, it generates a lot of heat in comparison with the heat loss surfaces, and this is because it is designed for high current density as shown in Table 1. An initiative was created to lower current density by increasing anode length from 1850 mm to 1880 mm at 460 kA.

In the operation of cells, two key methods were used to dissipate heat. These were a) decreasing anode cover thickness and b) increasing the metal height.

Figure 3 shows the evolution of anode cover height from 14 cm down to 6 cm while the amperage increased from 455 kA to 480 kA. Figure 4 shows heat loss from the top of the anodes and anode voltage drop. The anode voltage drop was calculated as the average from the top of the anode rod to the bottom surface of the anode as explained in [7]. The anode voltage drop decreases with decreasing anode cover height because of lower temperature in the stubs, yokes and rods. With the decrease of anode cover height from 14 cm to 6 cm the top of the pot under the hood lost 69 kW more heat, which was picked up mostly by the exhaust gases.

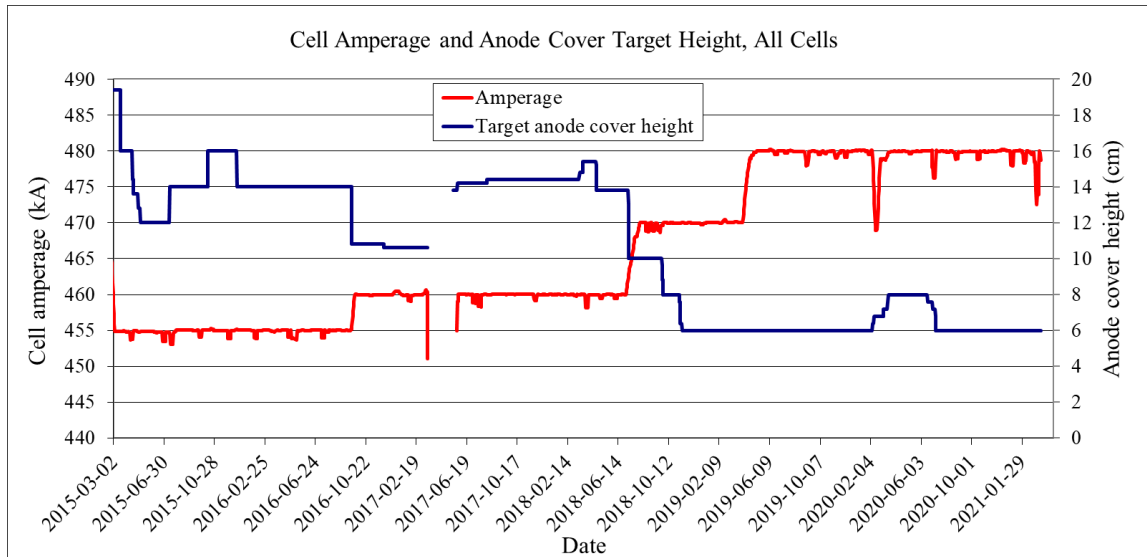


Figure 3. Cell amperage (7-day moving average) and target anode cover height (daily data).

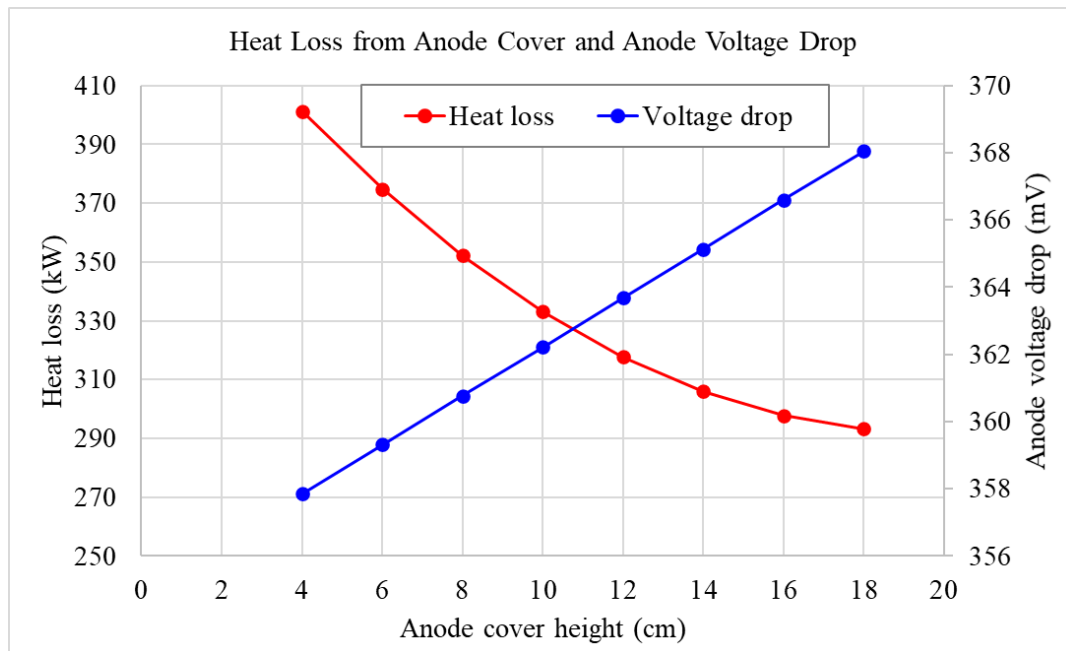


Figure 4. Heat loss from the top of anode cover, anode yokes and rods at 465 kA.

Figure 5 shows the increase of metal height as a function of cell amperage. It is estimated by modelling that the heat loss increases at a rate of 3.5 kW per cm increase of the metal height. With the increase of metal height from 20 to 25 cm, the heat loss thus increased by 17.5 kW.

The remainder of the internal heat, 4.5 kW, was dissipated through the cathode sidewalls by making the freeze somewhat thinner and the shell temperatures higher. Freeze thickness was measured several times at each amperage and no problems were detected. This was confirmed after the cells were cut out on the 26 March 2021 where there was no damage observed on the sidewalls that could be associated with the lack of freeze protection. Figure 6 shows the freeze profile at 480 kA. Shell temperatures were also periodically measured and attention was paid to temperatures especially above 500 °C, which would indicate the loss of freeze in that area. Seeing

red hot potshells would indicate the same. Cooling with compressed air was applied if any hot spots were observed.

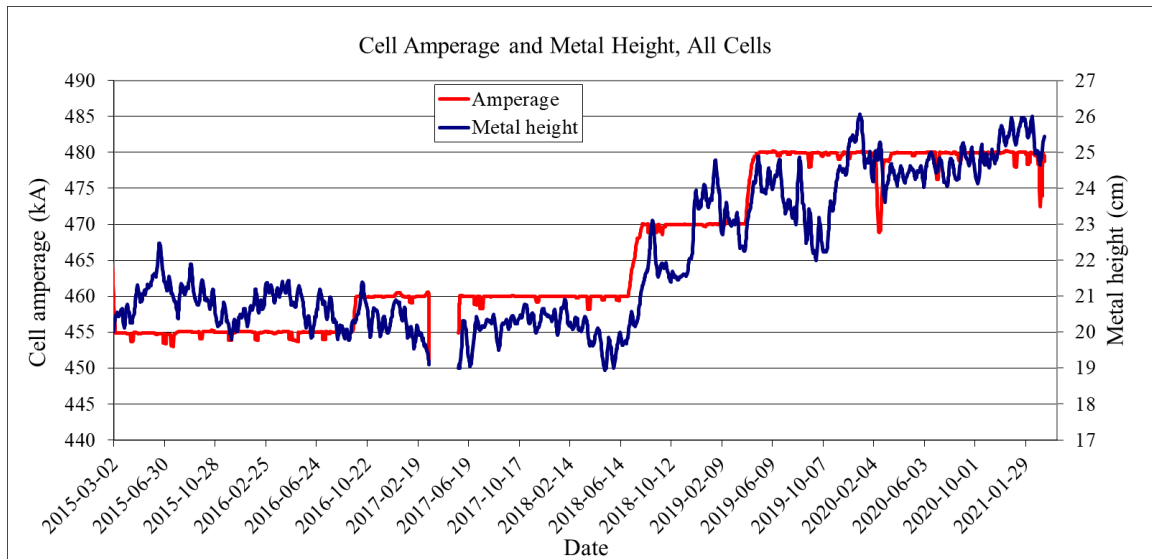


Figure 5. Cell amperage and metal height (7-day moving average).

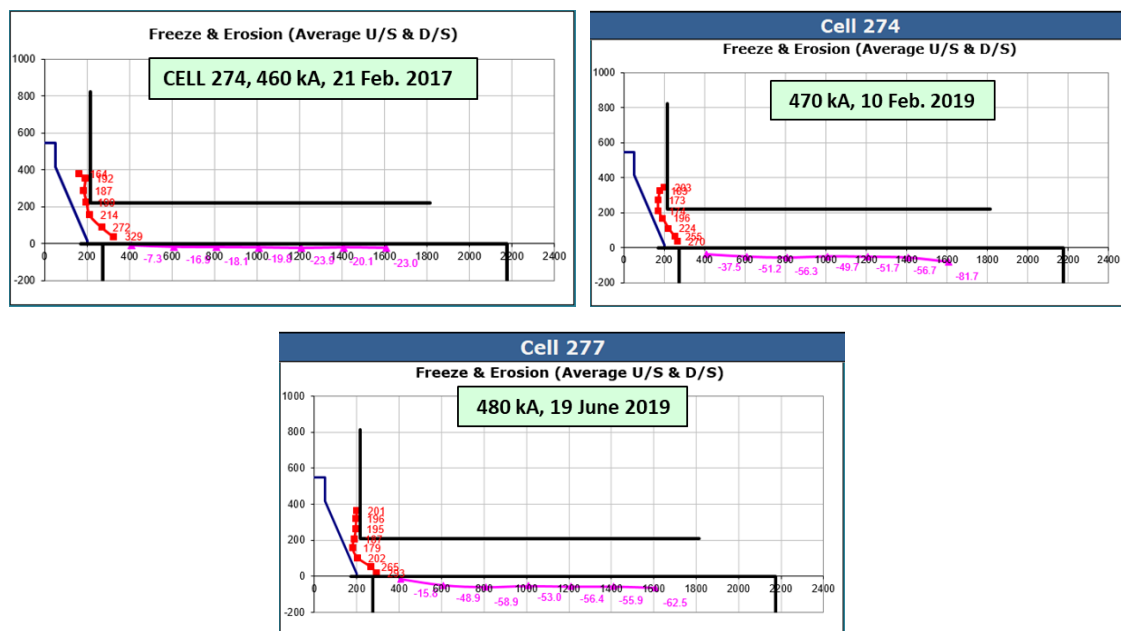


Figure 6. Freeze profiles at 460 kA, 470 kA and 480 kA.

2.3 Anodes

In order to decrease the current density in the anodes and in the bath, the anode length was increased from 1850 mm to 1880 mm in December 2016. This decreased the voltage by 17 mV at 460 kA [2] and facilitated a further amperage increase. Higher anode slots were introduced and gave an estimated gain of 15 mV. Anode height was increased by 15 mm and anode shift life decreased from 76 to 72 shifts at the passage from 470 kA to 480 kA. This was necessary to keep butt thickness around 16-17 cm as shown in Figure 7 for individual cells. The average butt thickness at 460 kA was 17.1 cm, at 470 kA it was 16.3 cm and at 480 it was 16.8 cm.

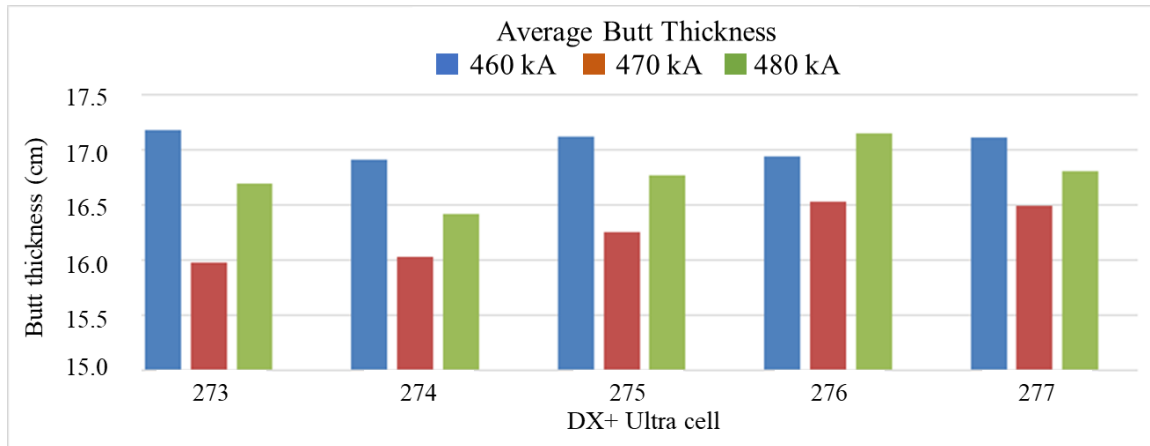


Figure 7. Butt thickness at different amperages and adjusted anode life.

3. Cathode Voltage Drop

The DX+ demonstration cells in Eagle and the first generation of DX+ cells in Al Taweelah Potline 3 had steel collector bars. As energy saving initiative, DX+ Ultra Eagle cells were equipped with copper inserts, both in the original and the industrial design cells whereby the copper inserts were made somewhat longer in the industrial design cells [2]. This reduces the cathode voltage drop (CVD) and can be reflected into lower cell voltage and lower specific energy consumption. Figure 8 shows the CVD evolution with cell age of individual DX+ Ultra cells in comparison with the average of 5 DX+ Eagle cells and the first generation of DX+ cells in Al Taweelah Potline 3 with steel collector bars from 1 January 2014 to 31 December 2017. Later some copper insert cells were entering the Potline 3 and the CVD started to decline.

We can see that the CVD decrease in copper insert cells is substantial, estimated to be about 60 mV over the lifetime of the cells.

The CVD initially increases but after about 2 years it stabilises. At the start-up of the three industrial design cells, the cells no. 275 and 276 were restarted with original DX+ Ultra design. After the restart, the CVD increased by about 40-60 mV but then it decreased gradually to normal CVDs for a pot without restart. Prior to the cut-out and restart, the CVD of these two cells was increasing very slowly, which was also the case with the other three cells of the original design until they were cut out.

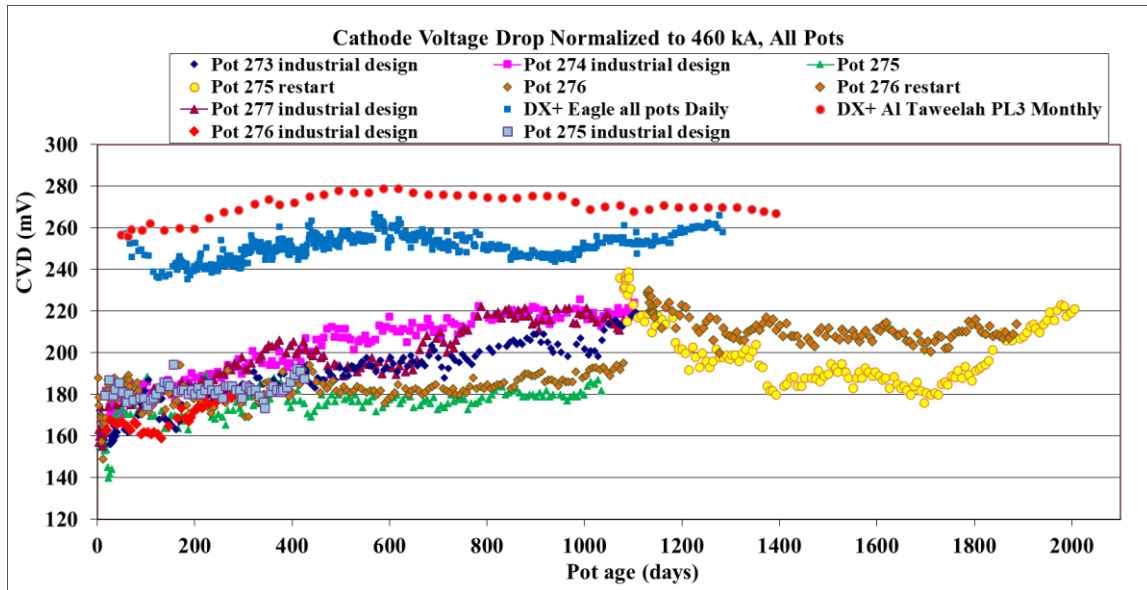


Figure 8. Cathode voltage drop evolution with cell age, normalized to 460 kA.

4. Cell Control

DX+ Ultra Eagle demonstration cells use EGA's advanced Pot Control System (PCS) based on standard programmable logic controller (PLC) hardware architecture, which gives increased human machine interface (HMI) capabilities and assures easy maintenance and future upgrades [8] because the PCS is under continuous development. The DX+ Ultra demonstration cells offer a unique opportunity to test the new developments. One new feature relates to alumina feeding where various crust breaker and alumina feeding configurations are tested and optimised [9]. A specific feature added to DX+ Ultra Eagle cells is to use information from continuous individual anode current measurements installed on the anode beam in these cells. These measurements are also very useful for the analysis of anode current pickup after the anode changes. Another important feature of the EGA's PCS added some years ago is increased automatic protection against potline open circuit due to tapping errors based on patented software development [10].

The EGA's PCS automatically adjusts the cell control parameters to amperage increase when the new control targets are given.

5. Cell Performance

Table 2 gives cell key performance indicators (KPIs) for 460 kA, 470 kA and 480 kA. For 455 kA the performance was previously reported by Alzarouni et.al [3]. The analysis period starts on 1 September 2017 when all DX+ Ultra cells were established, having ages > 56 days. Despite an amperage increase by 20 kA, the KPIs remained quite constant.

Table 2. Performance of DX+ Ultra demonstration cells.

Parameter	Unit	1 Sept 2017 - 29 Jul 2018	30 Jul 2018 - 21 Apr 2019	22 Apr 2019 - 25 March 2021	1 Sept 2017 - 23 March 2021
Target amperage	kA	460	470	480	N/A
Actual amperage	kA	460.39	470.27	479.43	472.52
Current efficiency- tapped	%	93.65	93.31	93.47	93.48
Current efficiency - corrected for metal height change	%	93.65	93.69	93.54	93.60
Metal production (calculated with corrected CE)	kg/cell-day	3472	3548	3611	3561
Net cell voltage	V	4.09	4.15	4.20	4.16
BRSP	$\mu\Omega$	5.15	5.20	5.19	5.18
Net specific energy (DC)	kWh/kg Al	13.0	13.3	13.4	13.27
Net carbon consumption	kg C/t Al	405	407	413	410
Gross carbon consumption	kg C/t Al	530	528	547	539
Excess AlF ₃	%	9.4	9.4	9.9	9.6
Bath temperature	°C	966	965	962	964
Metal height before tap	cm	20.2	22.7	24.5	23.0
Fe	%	0.036	0.040	0.042	0.041
Si	%	0.023	0.024	0.038	0.034
Anode effect frequency	AE/pot-day	0.046	0.031	0.052	0.046
Anode effect duration	s	13.2	11.2	12.1	12.8
PFC emissions, CO ₂ equiv.*	CO ₂ kg/t Al	10.9	6.2	11.5	10.7
Cathode voltage drop	mV	194	203	212	206

*CO₂ equivalent is calculated as in Reference [11], using the Tier 2 method and SAR (Second Assessment Report).

6. Conclusions

EGA has successfully increased amperages in DX+ Ultra demonstration cells from 450 kA to 480 kA. During amperage increases from 460 kA to 480 kA the metal production in industrial cells increased by 139 kg/cell-day. Current efficiency and specific energy consumption remained practically constant during the amperage increase. Metal purity was excellent and, CO₂ equivalent of PFC emissions was world benchmark.

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