

Amperage Increase from 340 kA to 425 kA in EGA DX Technology

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Abstract

Emirates Global Aluminium (EGA) has developed in-house DX Technology which is installed at EGA, Jebel Ali (44 demonstration cells in Potline 8) and Al Taweelah smelters (756 cells in Potlines 1 and 2). Jebel Ali Potline 8 was started in 2008 at 340 kA and reached 425 kA in February 2018. Al Taweelah Potlines 1 and 2 were started in 2010 to 2011 at 350 kA and are now operating at 422 kA. The AT Potlines 1 and 2 amperage increase to 388 kA and of Jebel Ali Potline 8 to 402 kA was already presented at ICSOBA 2015. This paper discusses further amperage increase to beyond 425 kA in DX Technology and different cell operation strategies, control system software improvements and cell design changes applied to minimize the thermal disturbances in the cells and optimize cell performance.

Keywords: DX Technology, EGA Al Taweelah smelter, amperage increase strategies, cell energy balance.

1. Introduction

EGA, Al Taweelah Potlines 1 and 2 (378 pots per potline) were started at 350 kA from December 2009 to January 2011 using DX Technology [1, 2]. Line amperage started to increase in May 2011 and reached 380 kA in October 2012 and stayed at this amperage until August 2014 in order to prove long term performance at this amperage (Figure 1) [3]. It was also considered that further amperage increase required a modification of the potshell to generation 2 (G2) design, which had been already installed and successfully demonstrated in the relined cells in Jebel Ali smelter, Potline 8 that was operating already at 400 kA at that time [4]. Potline 2 started the scheduled cell change-out process in April 2014 [5]. Accordingly, the new cells in both the DX potlines of EGA, Al Taweelah were installed with the newly equipped G2 design. Amperage was increased further to reach 388 kA in March 2015. By that time Jebel Ali DX Potline 8 had reached 402 kA.

By April 2016, EGA, Al Taweelah Potline 2 reached the operating amperage of 400 kA, while Potline 1 reached the same in July 2016. At that time Jebel Ali Potline 8 was already at 420 kA. Al Taweelah Potlines 1 and 2 reached another mile stone of 420 kA in December 2017. Currently both potlines are operating at 422 kA which was achieved in March 2018 whereas the demonstration Potline 8 in Jebel Ali smelter is operating at 425 kA, achieved in February 2018.

Figure 1 shows the different stages of amperage increase from start-up to end of September 2018 in Al Taweelah Potline 1 and 2 whereas Figure 2 shows the same for Jebel Ali Potline 8.

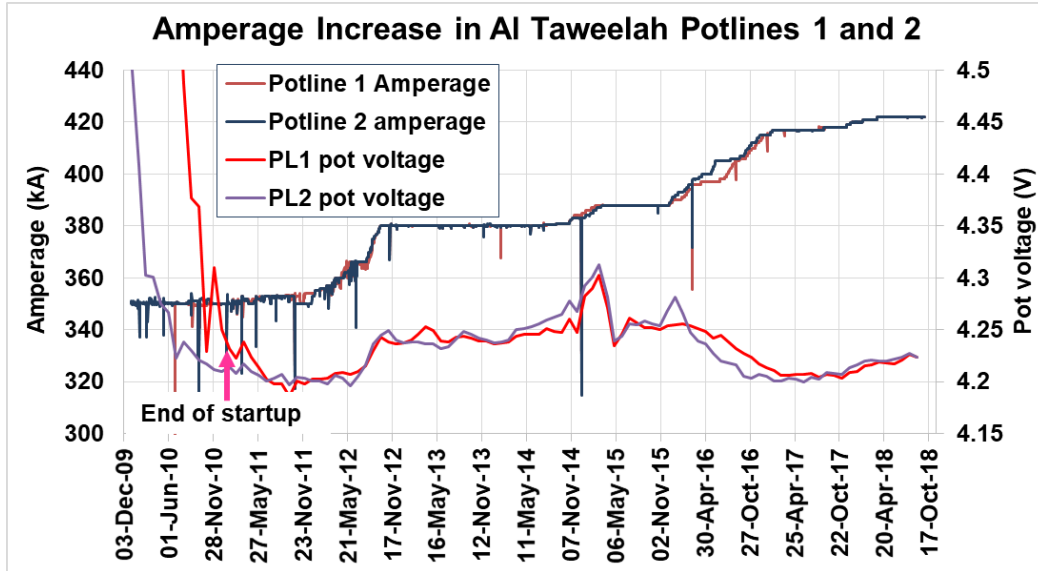


Figure 1. Amperage increase and cell net voltage in Al Taweelah Potlines 1 and 2 from 350 kA at startup to 422 kA at the end of September 2018.

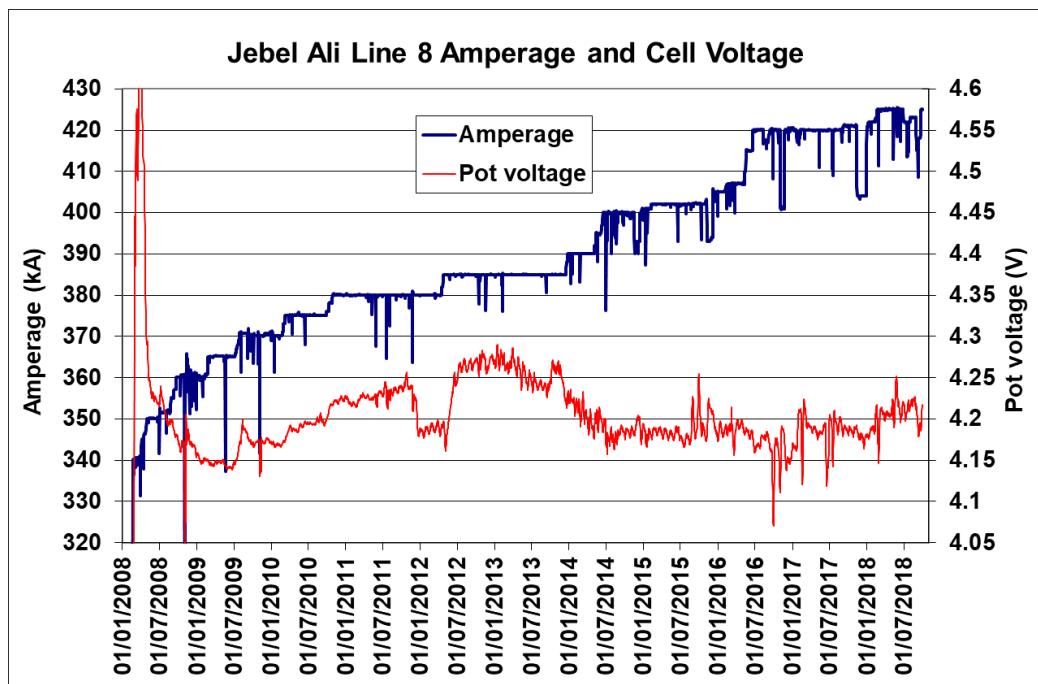


Figure 2. Amperage increase and cell voltage in Jebel Ali Potline 8 from start-up in March 2008 to 30 September 2018. Amperage data are daily, voltage data are 7-day running average from daily data.

2. Summary of Amperage Increase Milestones:

EGA, Jebel Ali Potline 8:

- March 2008: Potline started at 340 kA
- September 2008: Amperage reached 360 kA
- October 2010: Amperage reached 380 kA
- December 2013: Amperage reached 390 kA
- June 2014: Achieved a major milestone reaching 400 kA
- June 2016: Achieved another major milestone reaching 420 kA
- September 2017: Amperage increased to 421 kA
- February 2018: Achieved highest operating amperage for DX Technology at 425 kA.

EGA, Al Taweelah Potlines 1 and 2:

December 2009 to January 2011: Potlines started at 350 kA

October 2012: Amperage reached 380 kA in both potlines

April (Potline 2), July (Potline 1), 2016: Amperage reached 400 kA

October 2016: Amperage reached 410 kA in both potlines

August 2017: Amperage reached 418 kA in both potlines

December 2017: Amperage reached 420 kA in both potlines

March 2018: Amperage increased to 422 kA in both potlines.

Both potlines are operating at 422 kA now (30 September 2018). On the basis of the results achieved in the demonstration Potline 8 in Jebel Ali, further amperage increase to 425 kA is being evaluated.

The discussion in this paper is focused on amperage increase strategies and cell design changes in Jebel Ali Potline 8 and Al Taweelah Potlines 1 and 2 which were required for the amperage increase. Earlier published paper [2] had discussed the amperage ramp up for DX cells from 350 kA to 388 kA.

3. Major Modifications for Further Improvement and Amperage Increase of DX Technology

Simultaneous to cell change-out in Jebel Ali Potline 8 and in Al Taweelah Potlines 1 and 2, the following major modifications and improvements in cell design were undertaken for amperage increase. These design changes were all based on 3D cell modelling by EGA modelling group, who have developed full scope of thermos-electric, MHD and mechanical models [6].

3.1. Potshell Design Modifications

In order to dissipate more heat at increased line current, several modifications were made to the potshells:

- The I-beam cradle (Figure 3 left) was made a T-beam at the metal and bath level by cutting off the inner wing of the I-beam. The cradle was then welded to the shell and to the deckplate in the modified part. The rest of the cradle remained as in the generation 1 (G1) potshell.
- The deckplate was made narrower than in G1 potshell; the space it occupied was replaced with the floor grill for better air circulation.
- The two short cooling fins were replaced by five 620 mm long fins (Figure 3 right); this was specifically beneficial for lowering the potshell temperature.



Figure 3. Potshell modification for more heat loss.

Figure 4 shows the temperatures of the side shells for the different types of side shell configurations at 420 kA. In G1 modified shell, the only modification was to replace 2 short fins with 5 longer fins.

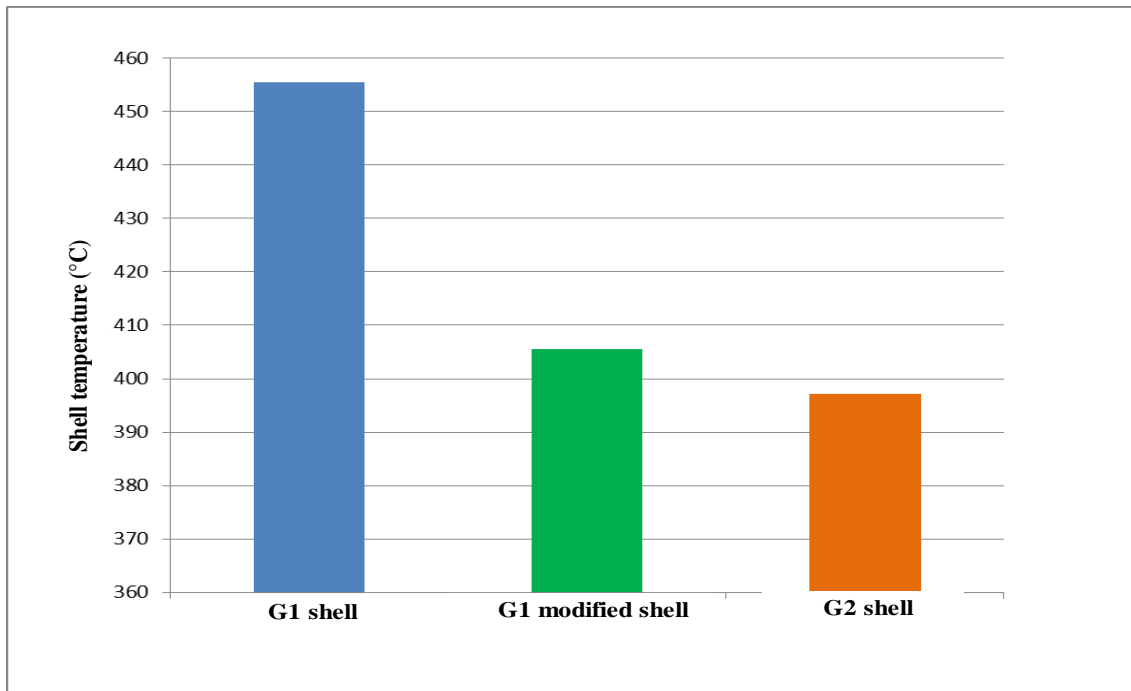


Figure 4. Average side shell temperatures for the different shell types (from [4]).

3.2. Potlining Modifications

Some fundamental changes were done to the potlining for the amperage increase:

- The thickness of sidewall and endwall SiC block was reduced by 16 mm in order to accommodate longer anodes.
- In Jebel Ali Potline 8 the original round collector bars were changed for rectangular. In Al Taweelah, the collector bars of generation 1 (G1) lining were already rectangular, but the cross-section in generation 2 (G2) was increased.
- Some pots Jebel Ali and Al Taweelah potlines are being installed with copper inserts in collector bars. These pots have also higher sidewall insulation.
- Collector bars, split at the centre were introduced from previously continuous.

3.3. Anode Size and Slot Height Modifications

Anode length was increased from 1580 mm to 1690 mm and the slot height was increased by approximately 100 %. The increase in slot height increased average age of anodes with slots at any given time, which reduced the bubble voltage drop by an estimated 15 mV. It also reduced anode noise as shown in Figure 5. The benefit of anode length increase is in lowering the anode current density and bath voltage drop. Moreover, the top profile of the anode was modified as shown in the Figure 6 to decrease gross carbon consumption.

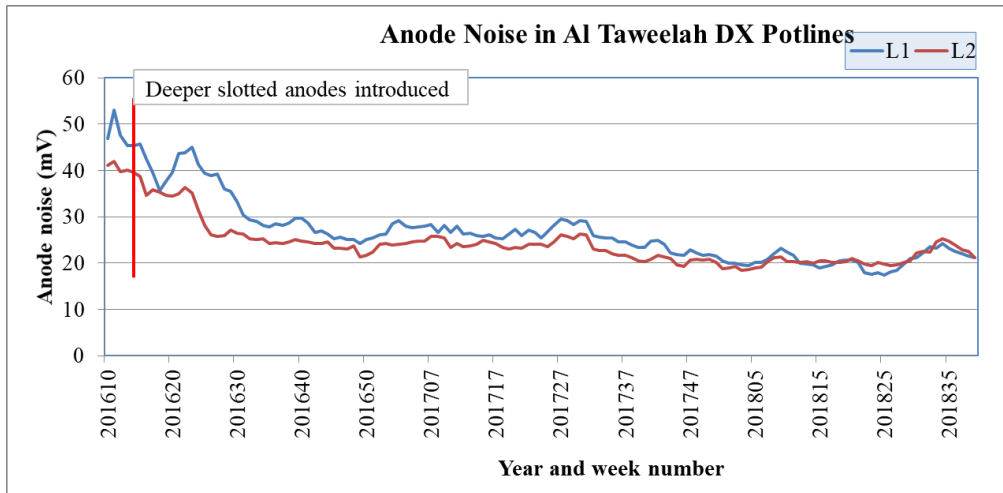


Figure 5. Decrease in the anode noise with the introduction of deeper slotted anodes.

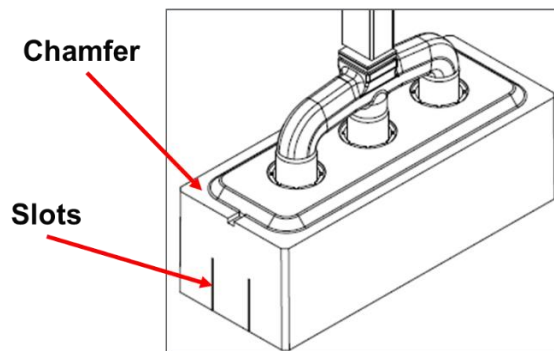


Figure 6. Anode top profile and anode slot modification in DX pots.

4. Amperage Increase from 350 kA to 425 kA

4.1. Strategy of Amperage Increase

EGA strategy for amperage increase is to use mathematical models for key cell parameter calculations. EGA has full mathematical modelling capability for cell design and for amperage increase studies [6]. With these models, the planned amperage increase was evaluated beforehand. EGA has developed an interactive tool for all EGA technologies which can be used to calculate cell operation parameters and plan the amperage increase [7]. Basically, it is a simple mathematical model on an Excel sheet which receives inputs like the line amperage, anode dimensions, bath chemistry, bath temperature target, measured cell voltage components, etc., to calculate the expected internal heat (net heat within the cell boundaries) and the expected anode-cathode distance. This model was extensively used for the amperage increase program and was accurate in its prediction of net cell voltage and internal heat. Additionally, full 3D modelling was done by EGA modelling group to evaluate the heat loss and voltage drops at each stage of amperage increase. This gave an estimated anode cover height to be used for each amperage level. The heat balance and voltage drop predictions were validated through the measurement of cell voltage components, side freeze profile and side shell temperatures which are discussed later in the paper.

One of the following three strategies for amperage increase, or a combination thereof, were used at different amperage levels:

1. Constant anode-cathode distance (ACD); this implies higher cell voltage and higher heat generation.
2. Constant voltage; this implies lower ACD and higher heat generation.
3. Constant internal heat (net heat in the cells); this implies lower voltage and lower ACD.

The decision for the different approaches was based on the freeze thickness of the different lining designs and potshell designs. Jebel Ali Potline 8 has always been ahead of Al Taweelah in amperage increase in order to tune the cell operation parameters on a smaller scale of 44 pots before application to two long potlines of 756 pots.

The rate of amperage increase consisted of fast and slow periods (Figures 1 – 2). The fastest rates in Al Taweelah Potlines 1 and 2 were: 0.6 kA/week from 354 kA to 366 kA, 2 kA/week from 366 kA to 380 kA, 0.35 kA from 30 kA to 388 kA and 0.5 kA/week from 388 kA to 417 kA. The fastest rates in Jebel Ali Potline 8 were: 0.82 kA/week from 390 kA to 400 kA and 2.5 kA/week from 407 kA to 420 kA.

As for the energy balance strategy, Jebel Ali Potline 8 used nearly constant ACD for amperage increase up to 380 kA and Al Taweelah Potlines 1 and 2, up to 388 kA. The AC was decreased by about 2 mm only. This led to increased cell voltage and internal heat of the cells. Process inputs such as anode top cover thickness and metal height were adjusted to dissipate the increased internal heat. Only in the transition period of very fast amperage increase of 2 kA/week from 366 to 380 kA in Al Taweelah, the thermal state of some pots was out of balance and some red potshells were observed [3]; this is because the internal heat increased by 35 kW and was not compensated quickly enough by the decrease of anode cover height. The situation improved after stabilisation of the amperage at 380 kA for a longer time. In the next step in Al Taweelah to 388 kA, at constant ACD, the cell voltage increased to 4.30 V (see Figure 1) and the internal heat by 35 kW again. This could not be compensated with other parameters but decreasing ACD; this was the end of constant ACD strategy.

From 385 kA to 400 kA in Jebel Ali Potline 8 and from 388 kA to 410 kA in Al Taweelah constant internal heat strategy was used. The ACD was decreased by 3 – 5 mm and cell voltage was decreased by about 90 mV. To help, anode length was increased to 1675 mm at first and then to 1690 mm at 401 kA at Al Taweelah. Also higher anode slots were introduced.

From 400 kA to 420 kA in Jebel Ali and 410 kA to 418 kA in Al Taweelah constant voltage strategy was used, the ACD was further reduced and internal heat was increased. Further on mixed approach of marginal reduction in ACD and some internal heat increase was used which led to marginal increase of net cell voltage by 10 – 20 mV.

Metal height and bath chemistry target were reviewed and changed to encounter the increased internal heat and reduced ACD.

Some other parameters were also changed to help amperage increase. Metal height target was increased from 18 cm to 21 cm gradually; this helped the pots to lose some more heat. Excess AlF_3 target was lowered to 9.0 % but in practice, 9.2 % was the average in Al Taweelah and 9.5 % in Jebel Ali from January to September 2018 (see Tables 1 and 2). Bath target temperature was increased from 962 °C to 964 °C but in practice, 965 °C was the average in Al Taweelah and 968 °C in Jebel Ali from January to September 2018 (see Tables 1 and 2). As already said, the anode top cover thickness at Al Taweelah was decreased from 14 cm at 350 kA to 6 cm at 422 kA (Figures 7 and 8). Cell gas exhaust rate was increased from 8500 Nm^3/h to 9500 Nm^3/h .

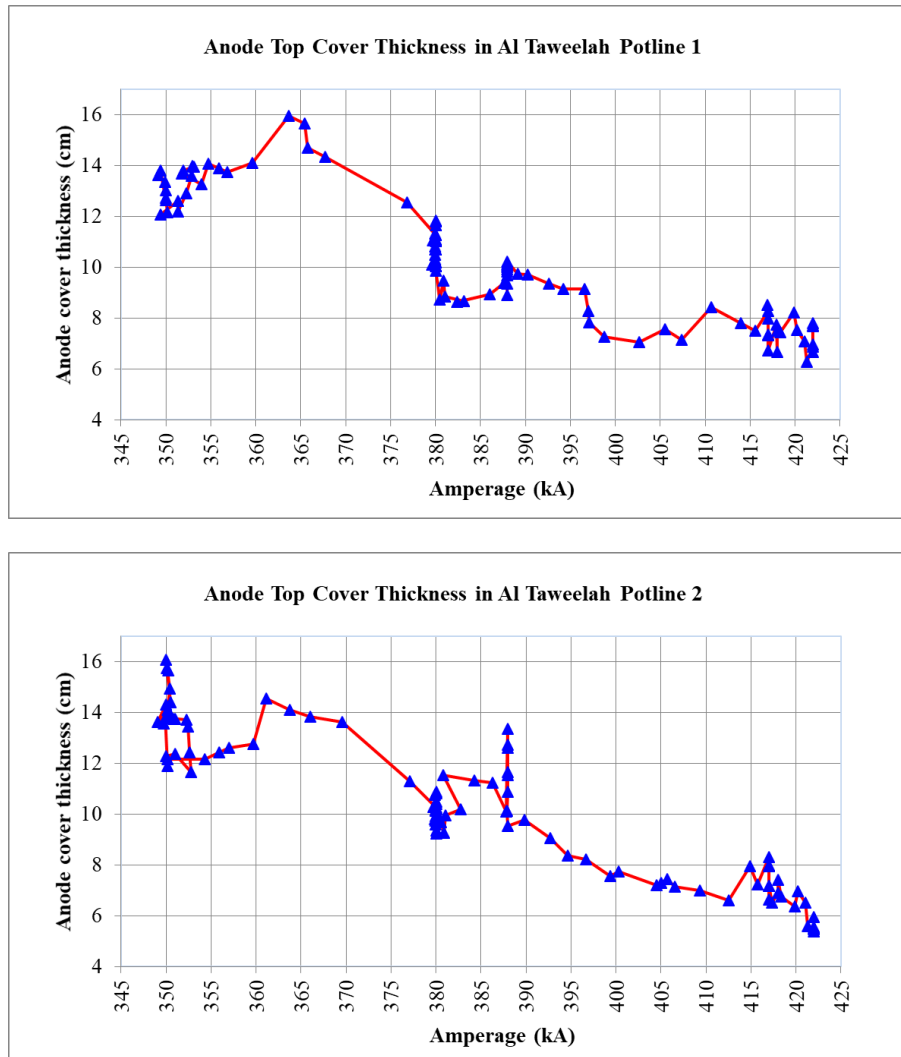


Figure 7. Progressive reduction of anode cover thickness with increasing amperage in Al Taweelah Potline 1 (top) and Potline 2 (bottom) - monthly average data.

4.2. Other Parameters at Various Stages of Amperage Increase at Al Taweelah

4.2.1. Side Shell Temperature

The average side shell temperatures measured at various stages of the line amperage from 350 to 422 kA are given in Figure 8. We can see very low shell temperatures at 350 kA; it is evident that this was due to very low amperage for the cell design and thick freeze on the sidewalls. The cell samples from G1 were included up to approximately 400 kA. The side shell temperature for G1 cell was approximately 60 °C higher than the G2 pots (Figure 4). It is evident that there was a gradual increase in side temperatures for both the line for G2 pots with respect to increasing line amperage. Approximately 25 °C increase in side shell temperature is observed at 422 kA as compared to 400 kA.

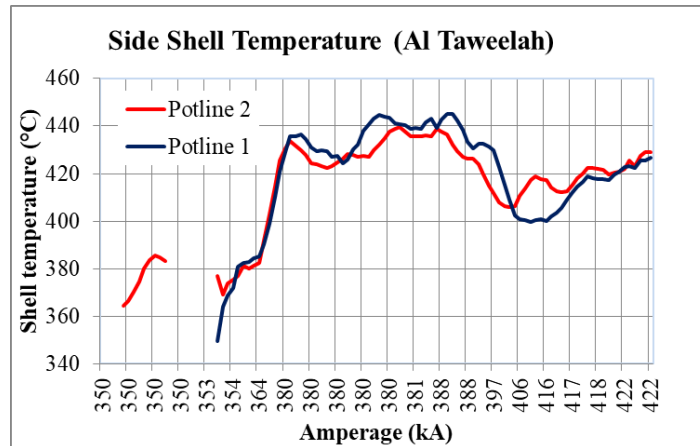


Figure 8. Side shell temperature variation at the different line amperages for DX Potlines 1 and 2. Samples of G1 pots are included in the range of 388 – 400 kA.

The ‘Side Shell Surveys’, usually made weekly in the night shift on all pots, were used in decision making of next step of amperage increase. Compressed air cooling was provided to the pots with red shells to help building freeze at such locations.

4.2.2. Side Freeze Profile

Three G2 cells 2A011, 2A016 and 2A018 were selected for the measurement of side freeze profile at two stages of operating line amperage. The selection was based on the age of the cells and such that the measurement represents the major population of cathodes used in cell construction. Freeze profile was measured while the line was operating at 388 kA in April 2015 for first stage and again measured at 422 kA in July 2018. The objective of the measurement was to determine the condition and the change of the shape of the freeze and erosion of the cathode with the age and increased line current. Figure 9 shows typical profile which was similar at both amperages. The maximum and minimum are variations in the cell and from cell to cell. The horizontal lines in Figure 9 indicate cathode block erosion.

Cell autopsy also shows how well the sidewall had been protected by freeze during the life. Figure 10 shows the upstream (US) sidewall and the surface of cathode blocks near the upstream of the first stopped DX pot in Al Taweelah at the age of 1560 days and the amperage of 380 kA. The most important observations witnessing the good thermal balance of the cell are:

- The minimum freeze thickness at the time of cut-out, at the bath-metal interface, was 5 – 50 mm and uniform all along the cell; no bare wall was observed.
- The SiC wall was in perfect condition everywhere with no erosion.
- The erosion of the cathode blocks had two levels of erosion. The primary erosion was going on during all the life and marks the position of the ledge which was fairly far from the sidewall on the cathode blocks, undoubtedly in earlier life when the amperage was 350 kA. The secondary erosion started during amperage increase, where the freeze toe receded towards the sidewall, exposing the end of the cathode blocks to electrical current flow and erosion; it was estimated that this erosion was there for about 2 years before the cell cut-out.

Measurement of cathode erosion at freeze measurement time is an EGA routine to detect any major abnormality, such as a crack or pothole in the cathode. It is quite approximate and is not used for cell life prediction. An exact erosion profile for cell life prediction can be obtained at cell autopsy, such as the one shown in Figure 10.

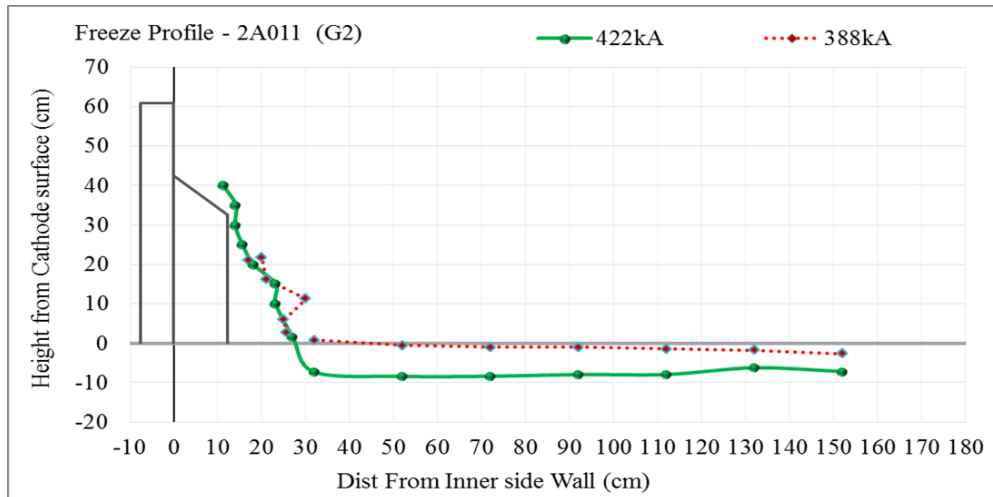


Figure 9. Typical freeze profile and cathode erosion at 388 kA and 422 kA in AT Potline 2. The horizontal lines indicate cathode block erosion.



Figure 10. Sidewall of Al Taweelah Pot 2B002 autopsy, showing elements of good thermal equilibrium during lifetime.

4.2.3. Bath Superheat Trends

Stable measured superheat trend for sample pots is a satisfying indicator of the healthy thermal balance and side freeze thickness. Al Taweelah Potlines 1 and 2 are operating in range of 8 – 12 °C of superheat as shown in Figure 11.

4.2.4. Bath Temperature and Excess AlF_3

As mentioned earlier, the target excess AlF_3 was decreased to 9 % in AT and that of bath temperature was increased to 964 °C to maintain good thermal; balance and to avoid anode spikes. Figure 11 below the variation of the line-average excess AlF_3 and bath temperature. No abnormal period of high temperature occurred at any stage.

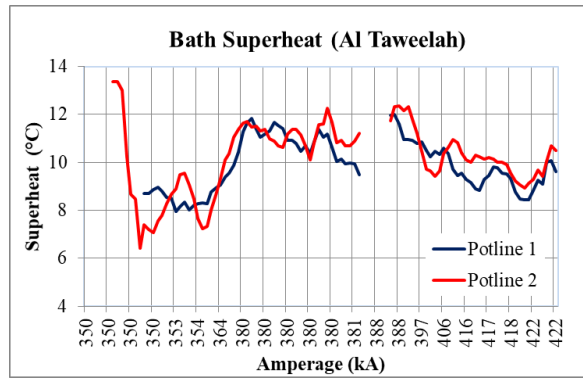


Figure 10. Measured bath superheat at the various amperages in DX cells at Al Taweelah.

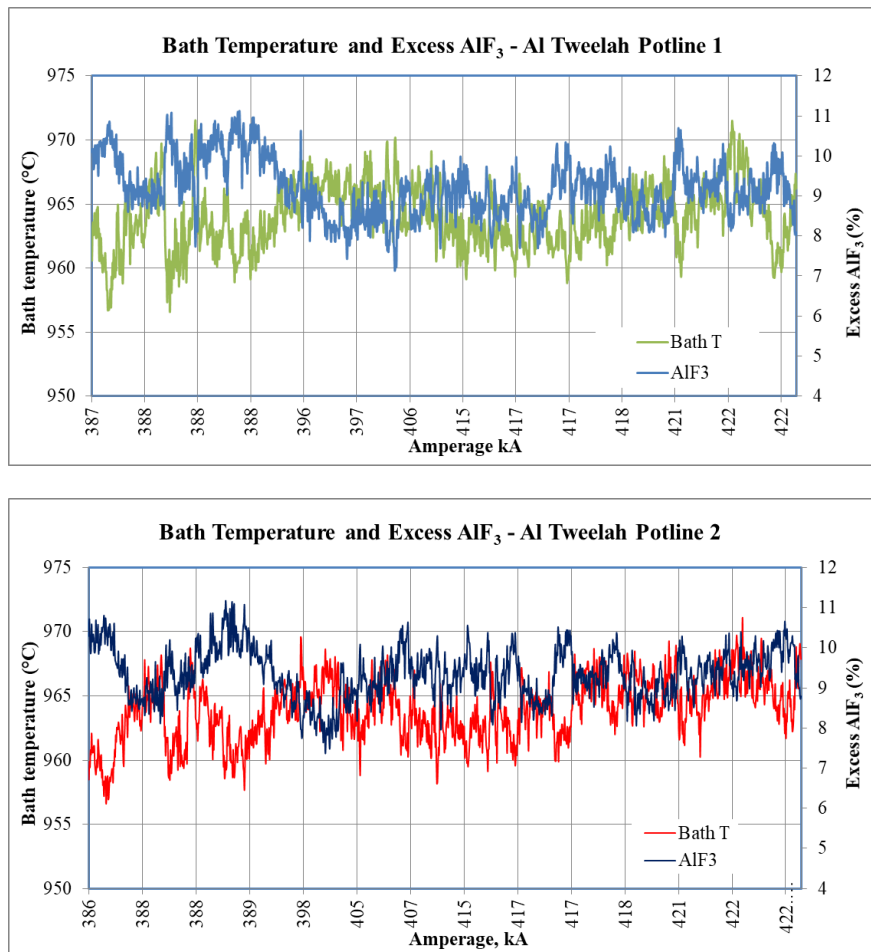


Figure 11. Bath temperature and AlF3 variation for Al Taweelah DX potlines. For data up to 388 kA, see [3].

4.2.5. Cathode Voltage Drop

Figure 12 shows the evolution of the measured cathode voltage drop (CVD) in Al Taweelah potlines during the amperage increase. Excluding the impact from G1 cell measurements as highlighted, there has been a steady increase in cathode voltage drops (mV) with amperage increase, but most of this increase is just proportional to the amperage increase. Normalized to the same amperage, there is only 20 mV increase of CVD in potline 2 from 400 to 422 kA, i.e., in two and a half years. In potline 1 the normalized voltage increased by 9 mV from 417 kA to 422 kA, i.e., in 1.7 years. Note that the amperage on the axis is not stretched the same way as time. The age and cathode type distribution are the main factors in a somewhat higher CVD in Potline 2 than in Potline 1.

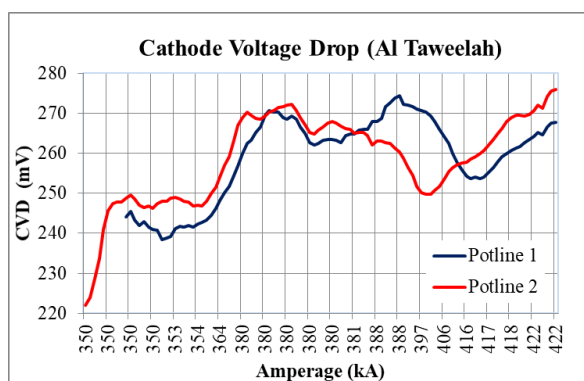


Figure 12. Evolution of cathode voltage drop with amperage increase. The range from 388 kA to 415 kA shows the transition to second generation of potlining.

5. Performance of DX Technology:

Tables 1 and 2 below, summarize the performance of the DX Technology in Al Taweelah Potlines 1 and 2 and Jebel Ali Line 8, respectively. The DX Technology has proven to be consistently good on specific energy consumption and achieved progressively extremely low PFC emissions due to the reduced anode effect frequencies and durations. Current efficiency has decreased with amperage increase, but metal production per cell is much higher now than at 350 kA.

6. Conclusions and Way Forward

EGA DX Technology has proven to be highly productive and low energy consumption technology. Low PFC emissions have set a new benchmark in the industry. EGA DX Technology has successfully increased the amperage to 425 kA while keeping excellent pot performance:

Table 1. Historical performance of Al Taweelah Potlines 1 and 2.

Parameter	Unit	2011	2012	2013	2014	2015	2016	2017	2018 (Jan-Sep)
Amperage	kA	351.4	367.1	380.0	380.6	387.8	402.1	417.5	421.6
Current efficiency	%	96.0	95.4	94.4	94.3	93.4	94.0	93.6	93.5
Metal production	kg/pot-d	2717	2821	2888	2891	2917	3043	3146	3176
Pot voltage	V	4.21	4.22	4.24	4.25	4.27	4.24	4.21	4.22
DC net specific energy consumption	kg/t Al	13.06	13.17	13.39	13.43	13.61	13.43	13.39	13.44
Net carbon cons.	kg/t Al	416	416	419	415	419	417	415	416
Gross carbon cons.	kg/t Al	545	543	541	546	561	559	528	522
Fe	%	0.045	0.046	0.038	0.045	0.074	0.052	0.047	0.048
Si	%	0.032	0.030	0.024	0.029	0.030	0.027	0.026	0.028
Bath temperature	°C	955	958	960	961	962	965	963	965
Excess AlF ₃	%	9.9	9.9	9.6	10.1	10.0	9.1	9.2	9.3
AE frequency	AE/pot-d	0.17	0.14	0.07	0.05	0.08	0.08	0.04	0.04
AE duration	s	38	11	12	24	74	60	8	7
PFC emissions, CO ₂ equivalent*	CO ₂ eq. kg/t Al	117	28	15	22	107	87	6	5

*CO₂ equivalent is calculated as in Reference [8], using the Tier 2 method and SAR (Second Assessment Report).

- Metal output has increased by 17 % in comparison to operation at 350 kA.
- Specific energy consumption remained constant in Jebel Ali Potline 8, but increased slightly in Al Taweelah Potlines 1 and 2.
- Net specific carbon consumption remained constant at about 416 kg C/t Al in Al Taweelah PL 1 and 2 and 423 kg C/t Al in Jebel Ali Potline 8.

Table 2. Historical performance of Jebel Ali Potline 8.

Parameter	Unit	2011	2012	2013	2014	2015	2016	2017	2018 (Jan-Sep)
Amperage	kA	379.8	383.4	385.1	395.2	401.3	413.1	417.9	423.0
Current efficiency	%	95.1	94.4	94.8	94.9	94.4	93.6	94.0	92.9
Metal production	kg/pot-d	2909	2916	2940	3021	3051	3113	3164	3164
Pot voltage	V	4.226	4.231	4.247	4.190	4.183	4.174	4.185	4.197
DC net specific energy consumption	kg/t Al	13.24	13.35	13.32	13.16	13.19	13.29	13.26	13.42
Net carbon cons.	kg/t Al	421	424	432	413	419	427	428	421
Gross carbon cons.	kg/t Al	540	527	556	532	511	525	530	538
Fe	%	0.043	0.052	0.063	0.051	0.039	0.048	0.056	0.061
Si	%	0.029	0.028	0.027	0.025	0.025	0.026	0.025	0.030
Bath temperature	°C	959	961	963	963	965	966	965	968
Excess AlF ₃	%	10.5	10.5	10.8	10.2	10.1	9.6	10.1	9.5
AE frequency	AE/pot-d	0.06	0.04	0.08	0.09	0.11	0.14	0.06	0.09
AE duration	s	16	14	29	14	19	22	19	19
PFC emissions, CO ₂ equivalent*	CO ₂ eq. kg/t Al	17	10	42	23	38	56	21	31

*CO₂ equivalent is calculated as in Reference [8], using the Tier 2 method and SAR (Second Assessment Report).

The use of copper inserts in collector bars, which is being applied on relining basis, will further bolster the capability of the DX Technology and will be used either for lowering specific energy consumption or improving current efficiency or further amperage increase.

7. Acknowledgement

We wish to thank Dr. Vinko Potocnik for his thorough review of this paper.

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