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THE SUCCESSFUL IMPLEMENTATION OF DUBAL DX TECHNOLOGY AT EMAL

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Abstract

Between 2 December 2009 and 2 January 2011, all 756 DUBAL DX technology cells in Phase I of the EMAL smelter in Abu Dhabi were successfully commissioned. This represented the culmination of DUBAL DX technology fast-track development from prototyping to large scale industrialization. The process began with the design and engineering phase in 2004, followed by commissioning of five prototype pots in 2005, a demonstration line of 40 pots in 2008 and finally the commissioning of the giant smelter at EMAL Phase I in 2009/2010. The commissioning and normalization of the pots at EMAL Phase I were very smooth, without a single lining incident. This was achieved through excellent team work and coordination between the various teams at all stages (pot preparation, preheat, start-up and normalization). The rapid and stable commissioning also demonstrated the robustness of DX technology. Both potlines at EMAL Phase I are now operating at 353 kA and are achieving excellent performances: 96.0% current efficiency and 13.0 kWh/kgAl for more than 18 months since start-up.

Introduction

In 1990 and 1998 respectively, DUBAL and Comalco jointly developed two magnetically compensated reduction cell technologies: CD20 (with an operational design capability of 200 kA) and CD26 (with an operational design capability of 260 kA). Both featured side positive anodic risers and point breakers-feeders. Subsequently, DUBAL independently designed and engineered the DX reduction cell entirely in-house in 2004. From 2005 to 2010, DUBAL proprietary DX technology progressed successfully from initial prototyping through to large scale industrialization. Five DX prototype cells were installed in a dedicated development potroom at DUBAL, known as the Eagle Section, and energized at 325 kA between September and December 2005 [1]. The successful and stable performance of these prototype DX Eagle cells led to the strategic decision to invest in the construction of a demonstration potline of 40 cells, known as Potline 8, which was commissioned in 2008 at 340 kA [2].

EMAL, a joint venture between Mubadala Development Company and DUBAL, is located at Al Taweelah in Abu Dhabi [3] [4]. The project, which is the largest greenfield smelter development to date, marked the next significant step in the industrial deployment of DX technology. EMAL Phase I comprises two potlines of 378 DX cells each, operating initially at 350 kA with a nominal production capacity of 740 000 tonnes per year.

Milestones in the development of DX technology

DX Eagle Prototype Cells: The design and engineering of the DX technology cells were carried out during 2004. This was followed by the construction of five DX cells in DUBAL's Eagle Section, which were completed and ready for start-up in September 2005. The DX Eagle cells received main line amperage from Potline 5 and from dedicated booster rectifiers.

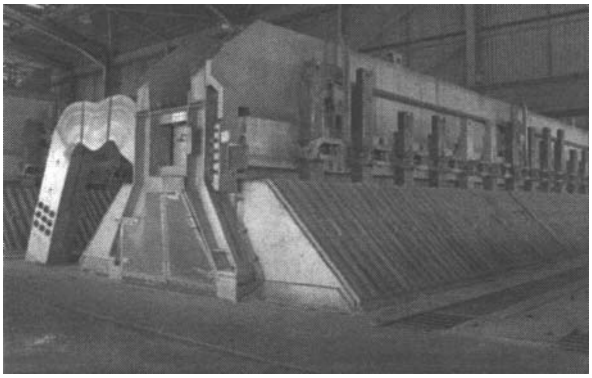

Figure 1. DX Eagle Cells (2005 to 2010).

Tables I and II show the average performance of the five DX Eagle cells during four years of operation. The cells were stopped on 2 November 2008 due to the shutdown of Potline 5, caused by a power problem. The cells were restarted in February 2009 after cleaning, inspection, and observation of the good condition of the cathode surface.

Table I. Performance of the Five DX Eagle Cells.
(January 2006 to December 2007)

Parameters	Stage 325 kA	Stage 330 kA	Stage 340 kA
Date	28 Jan'06 to 24 Feb'06	25 Feb'06 to 09 Feb'07	10 Feb'07 to 31 Dec'07
Amperage (kA)	327.4	333.2	340.0
Bath Temp. (^{o}C)	962	964	964
Excess AlF3 (%)	9.5	10.5	10.6
Current Efficiency (%)	95.7	95.5	96.6
Energy (kWh/kg Al)	13.86	13.62	13.26
Cell Voltage (volts)	4.45	4.36	4.33
Metal Purity (% Al)	99.90	99.93	99.92

Table II. Performance of the Five DX Eagle Cells.
(January 2008 to December 2009)

Parameters	Stage 345 kA	Stage 350 kA	Stage 350 kA
Date	1 Jan'08 to 18 Jul'08	19 Jul'08 to 17 Oct'08	28 Feb'09 to 05 Dec'09
Amperage (kA)	344.6	350.7	349.7
Bath Temp. (° C)	964.5	963.8	959.8
Excess AlF3 (%)	10.9	11.1	10.4
Current Efficiency (%)	96.0	95.1	94.9
Energy (kWh/kgAl)	13.21	13.15	13.11
Cell Voltage (volts)	4.25	4.20	4.16
Metal Purity (% Al)	99.91	99.89	99.90

DX Eagle Cell Autopsy: The five DX Eagle prototype cells were shut down on 10 and 11 December 2009 in order to prepare the section for conversion to the new higher amperage DX+ design. Detailed autopsy was carried out on two cells. Surface autopsy and some observations during the de-lining were carried out in the remaining three cells.

Figure 2 shows the cross-section of the lining in a DX Eagle cell. The lining was intact and in good condition, with no damage to the insulating layers. The blocks had practically no heaving. There was no bath accumulation below the cathode blocks. This good condition of the lining was observed in all slices.

Figure 2. Bottom lining (insulating materials not attacked).

The cathode surface had a W-shaped erosion pattern along the length of the blocks, typical for graphitized blocks, with regions of higher wear towards the end of the blocks. Figure 3 shows the cathode block erosion data for one DX Eagle cell.

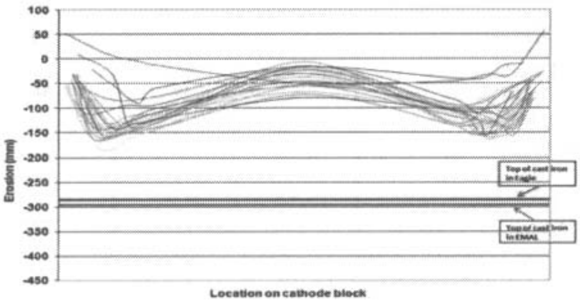

Figure 3. Erosion data for all cathode blocks in one cell.

The cathode erosion rate was calculated to predict the life expectancy. As shown in Table III, average cathode erosion rate at the location of maximum erosion was 4.6 cm/year and the maximum erosion rate was 5.0 cm/year.

Table III. Erosion data and cell life expectancy prediction

Eagle Cell no.	Age at cut out		Erosion rate
	days	years	cm/yr
DX-1	1358	3.72	4.1
DX-2	1382	3.79	4.7
DX-3	1432	3.92	4.4
DX-4	1387	3.80	4.8
DX-5	1346	3.69	5.0
		Average	4.6

The following was concluded from the autopsy:

- Cell life expectancy is between 1 800 and 2 300 days with most probable life expectancy of 2050 days.
- DX EMAL cell life expectancy should be approx. 80 days more (EMAL cells have 10 mm more carbon above the cast iron).
- In spite of the first cut-out of 2 November 2008, the cathodes remained in very good state, proving the robustness of the design.
- The collector bars and cast iron were in very good condition. The contact between the cast iron and carbon was generally good.
- The insulating materials on the bottom were in exceptionally good shape and on the side walls, too.
- Freeze on the side- and end walls provided good protection from erosion. The sidewalls will not be the limiting factor in cell life expectancy.
- The potshells were in excellent shape: no corrosion of the shell walls or deck plate was observed. No repair will be needed for relining the second generation DX cells.

DX Demonstration Potline (Potline 8): The decision to build a DX Demonstration Potline in DUBAL was taken in 2006 after just one year of successful operation of the DX Eagle Prototype Cells. The Demonstration Potline, commissioned in 2008, has since been used to demonstrate the capability limits and robustness of the technology for the implementation of amperage increases at large industrial scale. It has also provided a platform for training EMAL personnel and to evaluate control and work practice improvements.

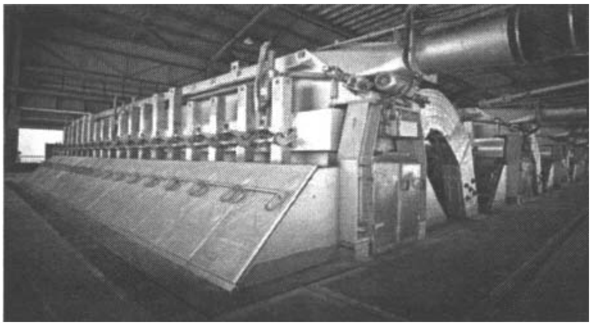

Figure 4. DUBAL Potline 8.

Table IV. DUBAL Potline 8 performance at increasing amperage. (June 2008 to July 2009)

DUBAL Potline 8 (DX Technology)	Unit	Jun'08 to Sep'08	Oct'08 to Feb'09	Mar'09 to Jul'09
Amperage	kA	352.8	360.3	365.2
Current Eff.	%	96.6	95.8	95.1
DC Specific Energy consumption	kWh/ kg Al	12.97	12.94	13.01
Volts per Cell	V	4.20	4.16	4.15
Metal Purity	%Al	99.91	99.93	99.93
AE Frequency	AE/pd	0.037	0.020	0.015
AE Duration	s	30	62	47
Total Fluorides (roof + stack)	kg/t Al	0.34	0.36	0.23
PFC Emissions* CO_2 (Computed)	CO_2t/ t Al	0.020	0.022	0.013

Table V. DUBAL Potline 8 performance at increasing amperage. (August 2009 to June 2011)

DUBAL Potline 8 (DX Technology)	Unit	Aug'09 to Feb'10	Mar'10 to Oct'10	Nov'10 to Aug'11
Amperage	kA	370.0	375.4	379.9
Current Efficiency	%	95.2	94.7	95.2
DC Specific Energy consumption	kWh/ kg Al	13.05	13.20	13.21
Volts per Cell	V	4.17	4.19	4.22
Metal Purity	%Al	99.94	99.93	99.93
AE Frequency	AE/pd	0.018	0.015	0.064
AE Duration	s	36	29	11
Total Fluorides (roof+ stack)	kg/t Al	0.21	0.19	0.19
PFC Emissions CO_2 equivalent*	CO_2t/t Al	0.012	0.008	0.008

*PFC measurements in Potline 8 in December 2010 show emission levels of 0.015 CO_2 equivalent t/t Al. CO_2 equivalent is calculated as in Reference [5], using the Tier 2 method for all periods, except from November 2010 to August 2011, for which the Tier 3 method was used since measurements were available.

EMAL Industrial DX Potlines: The EMAL Phase I project was launched before the start-up of the DX Demonstration Potline (Potline 8) at DUBAL. The EPCM Company was selected in May 2007 with the Notice to Proceed (NTP) issued in December 2007. The first structural steel in the potline buildings was erected in October 2008, and the start-up of the first cell took place at the beginning of December 2009, 23 months after the NTP. All 756 cells were energized by the end of December 2010, just 36 months after the NTP and 13 months after the first cell start-up.

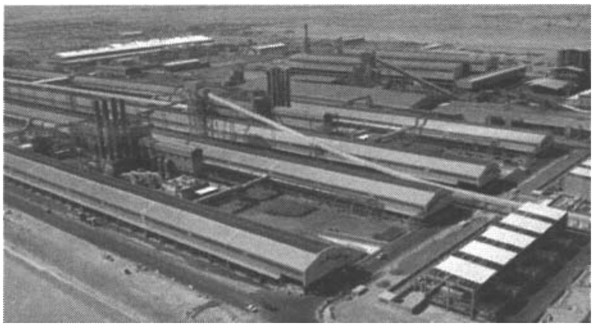

Figure 5. EMAL Phase I.

DUBAL supported EMAL strongly during the Engineering, Construction, Commissioning and Operation phases through:

1. The release of a DX Reduction Technology Package, comprising more than 550 engineering drawings and more than 150 specifications and/or procedures.
2. The supply of more than 8 000 hours of assistance on site during the construction phase and more than 14 000 hours during the start-up and early operation phase.
3. The delivery of more than 7 600 training days at DUBAL on DX technology.
4. The permanent transfer of 205 DUBAL employees to EMAL.
5. The sealing of 5 000 cathode blocks at DUBAL.
6. The rodding of 10 000 anode assemblies at DUBAL.
7. The delivery of more than 900 000 tonnes of alumina, coke and pitch from DUBAL Docks in 2010.

The EMAL potlines were started at 350 kA. Based upon the excellent performance of DUBAL DX Demonstration Potline at 380 kA, EMAL has since decided to install one additional rectifier transformer to each potline substation, so as to boost the amperage of both potlines in 2012.

Figure 6. EMAL Phase I DX Potline.

Table VI. EMAL Potline 1 & 2 performance (stabilized cells) since start-up.

KPI's	Unit	2010		Jan'11 to Aug'11	
		PL 1	PL2	PL 1	PL2
Amperage	kA	349.7	350.2	351.3	351.0
Current Efficiency	%	96.7	96.1	96.4	96.3
DC Net Specific Energy consumption	kWh/kg Al	12.98	13.07	13.04	13.02
Net Volts per Cell	V	4.22	4.22	4.22	4.21
Aluminium Purity	%	99.87	99.88	99.89	99.89
Anode Effect Frequency	ae/pd	0.10	0.13	0.17	0.12
Cells in Operation at Period End	No	373	378	378	378

Key differences between DX Prototype Eagle, DX Demonstration Potline and EMAL Phase I DX Cells

Table VII. Characteristics and differences between Prototype, Demonstration and Industrial DX cells.

Item	DX Eagle	DX Potline 8	DX EMAL
Range of Operating Amperage (kA)	325-350	340-380	350 (planned to be increased in 2012)
No. of Cells	5	40	756
Operating Period	Sep'05 to Dec'09*	From Feb. 2008	From Dec. 2009
No. of Anodes	30	36	36
Stub/Yoke configuration	4 stubs, spider	3 stubs in line	3 stubs in line
Working Schedule (h)	24	32	32
Busbar section	-	+20% of prototype	+20% of prototype
Collector bar section	-	+13% of prototype	+13% of prototype
Cathode block height	-	+20 mm of prototype	+20 mm of prototype

*The five prototype DX Eagle cells were deliberately stopped, so as to be replaced by a higher amperage cell called DX+.

EMAL Phase I Performance Test: As specified in the Technology Licence Agreement, a Performance Test of the reduction technology provided by DUBAL was carried out on a group of 30 adjacent typical reduction cells (2A055 to 2A084) over a period of 28 days starting on 31 January 2011. During the test, amperage was stable at 350 kA except for two load reductions to 251 kA and 236 kA of approximately one hour each.

Average excess AlF_3 content in the bath, analysed every four days, was 10.1% and the corresponding standard deviation 1.2%. Average CaF_2 content was 7.0%. Average bath temperature, measured every two days on each cell, was 952.5°C and the corresponding standard deviation 6.4°C. Metal height and bath height, measured every 32 hours, had a respective standard deviation of 0.6 and 1.7 cm.

The performances of the test cells were monitored throughout the 28-day test period. DUBAL advisors were present (shift coverage) to monitor the test cells, evidencing excellent collaboration with and support of the EMAL operation team.

Metal tapping operation took place every 32 hours for each of the test cells, without any delay or backlog. The daily average liquid metal tapped from the test cell, of 2 716 kg, was identical to the full potline average metal tapped per cell during the same period, and more than 4% above the guaranteed performance criteria. This equated to a current efficiency of 96.3%.

The metal reserve was measured for each of the test cells before and after the test period, using the copper dilution method. A net average increase in metal reserve of more than 1 tonne per cell was measured, corresponding to an additional 42 kg of metal production per cell per day. Solid metal from skimming material and crucible cleaning was also monitored, and accounted for an additional 3 kg per cell per day.

Specific energy consumption, the other contractual criterion, was calculated using the average cell voltage as recorded by the cell controllers. Average net cell voltage for the period was 4.21 V and line amperage was recorded at 350.2 kA.

The net specific DC energy consumption does not include the share of linkage busbar voltage drops. The average total potline voltage over the test period was reported to be 1 603.0 V for 378 operating cells, including linkage busbars. Therefore, the gross cell voltage was computed to be 4.24 V.

Gross specific DC energy consumption during the test period was therefore 13.1 kWh/kg, if only liquid metal sent to the casthouse is considered and 12.9 kWh/kg, if variation of metal reserve and solid metal from skimming and crucible cleaning is included.

Non-contractual process data monitored during the test period:

1. Net carbon consumption (NCC): In the month proceeding the performance test period, the weight of all baked anodes (30 000 anodes) was recorded and their average weight reported. During the test period, the spent anodes coming from the test cells were tracked through the rodding shop and weighed after the butt shot blasting operation. NCC of 406 kg/t Al was achieved during the test period.
2. Metal purity: During the test period, metal was sampled in the cells every 96 hours and analysed. The averaged iron content was 0.047% and silicon content was 0.022%. These values were similar to the potline averages, indicating very good control of bath height.
3. Fluoride emissions: The performance test group was selected in a section of Potline 2 that is equipped with fluoride monitoring equipment:

- Each half potroom within the EMAL Potlines is equipped with an online Boreal laser HF continuous monitoring system to measure instantaneous HF gas emissions.
- One quarter of each potroom within the EMAL Potlines is equipped with a cassette fluoride continuous sampling system to measure average particulates and gas fluoride content using the US EPA method 14A. The performance test group was equipped with the cassettes system.
- Total fluoride emissions through the potroom roof were found to be less than 0.3 kg/t Al during the test period.

Graphs of EMAL Phase I Performance Test (February 2011)

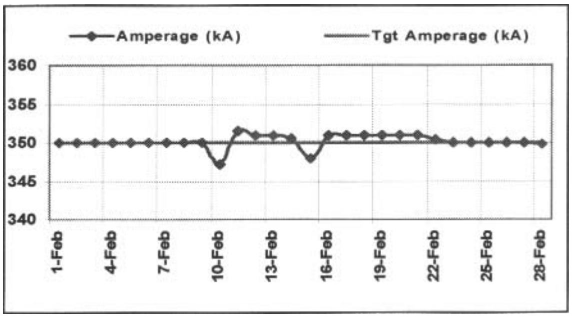

Figure 7. Amperage.

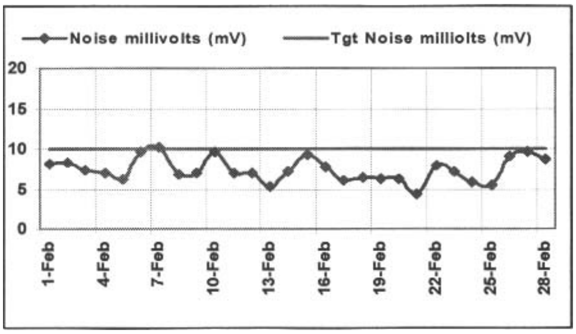

Figure 8. Noise.

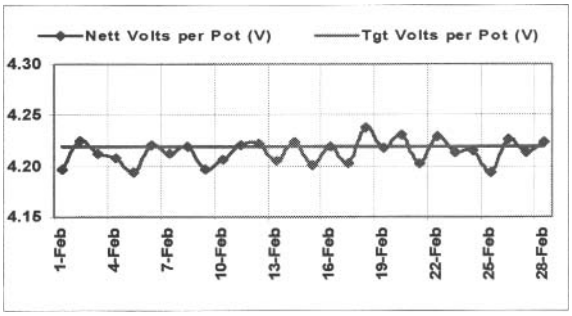

Figure 9. Cell voltage.

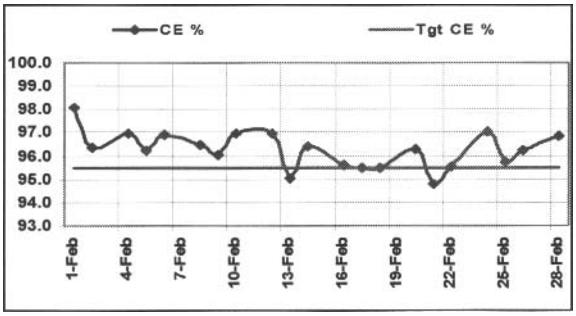

Figure 10. Current efficiency.

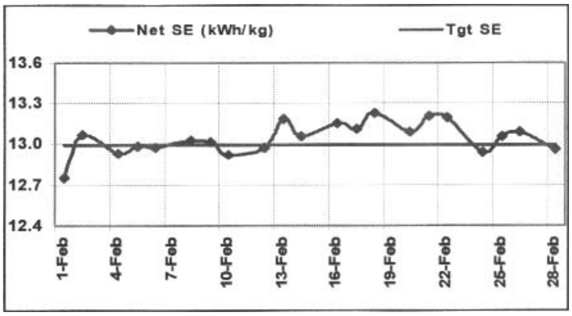

Figure 11. Specific energy consumption.

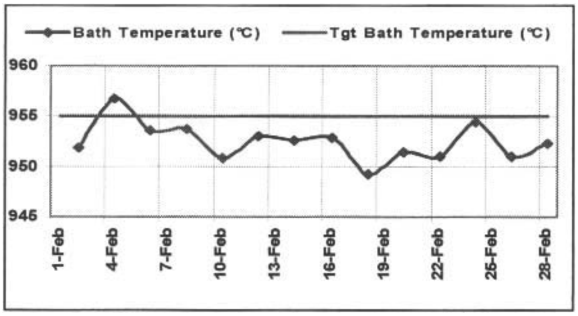

Figure 12. Bath temperature.

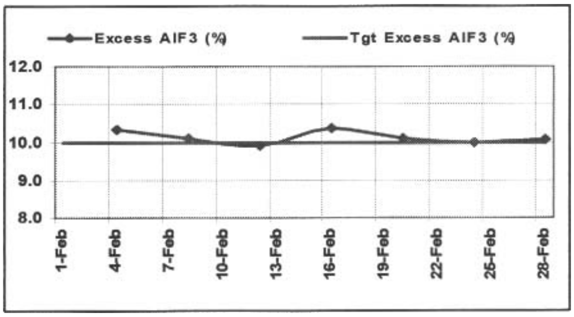

Figure 13. Excess AlF_3.

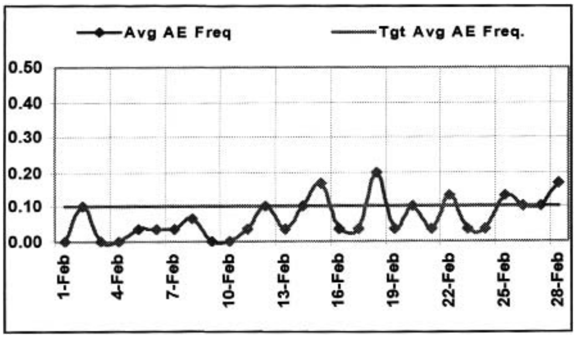

Figure 14. Anode effect frequency.

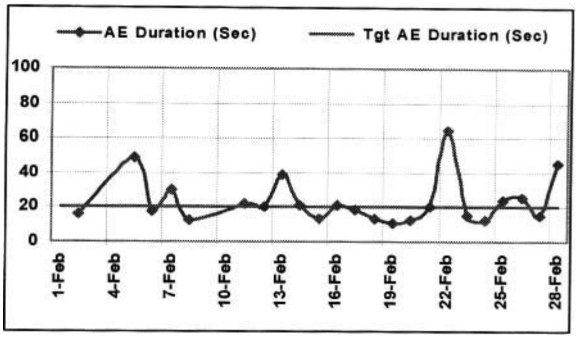

Figure 15. Anode effect duration.

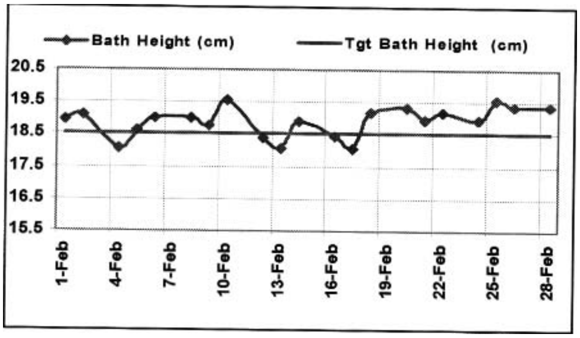

Figure 16. Bath height.

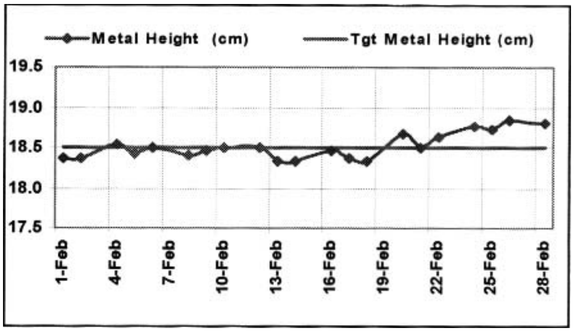

Figure 17. Metal height.

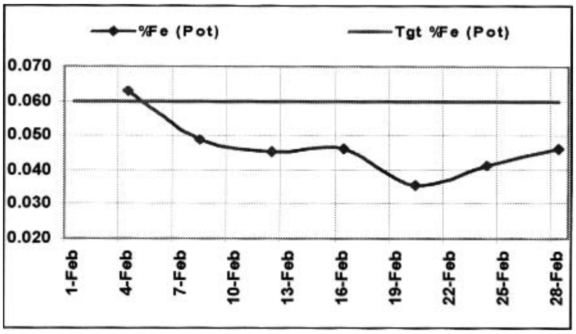

Figure 18. Fe percentage.

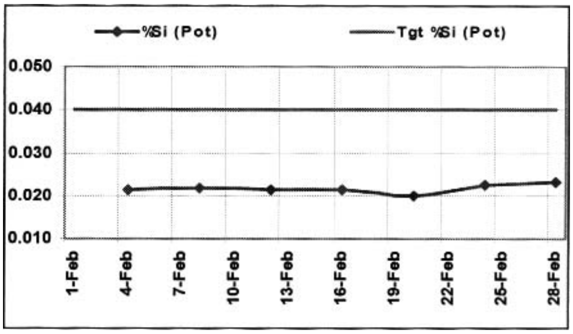

Figure 19. Si percentage.

Conclusion

DUBAL DX technology has progressed from the conception and modeling phases through to industrial implementation in a very short period of time. Following considerable analysis and optimization, DX technology consistently achieves world-class operational performance standards. DX technology also offers additional advantages as it requires neither forced potshell cooling nor external magnetic compensation. Overall the performance of DX cells is among the very best technical performance levels ever achieved by large scale industrial aluminium reduction technologies.

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