Light Metals 2013 *Edited by: Barry Sadler*
TMS (The Minerals, Metals & Materials Society), 2013

PRODUCTION GROWTH AND FUTURE CHALLENGES IN ALUMINIUM BAHRAIN (ALBA)

Isa Al-Ansari[1], Abdulla Habib[1], Mittal A.C.[1], Nabeel Al-Jallabi[1]
[1] Aluminium Bahrain (Alba)

Keywords: Production, expansion, current creep, current efficiency, pot life.

Abstract

Aluminium Bahrain B.S.C. (Alba) consistently ranks as one of the largest and most modern Aluminium smelters in the world. Known for its technological strength and innovative policies, Alba enforces strict environmental guidelines, and is widely regarded as one of the top ten performers on a global scale. Commissioned in 1971 with a capacity of 120,000 tons per year, Aluminium Bahrain has steadily progressed and today is one of the world's top performing and largest Aluminium producers worldwide. Production output has increased stepwise since start-up through numerous technology improvement projects and several major expansions using latest available technology in the market. The current plant capacity is close to 890,000 tons per year. The main strategy adopted by Aluminium Bahrain since the early days has been to sweat the assets by maximizing the production of the electrolytic cells using latest technology, upgrade of technology, expansions with sustaining cost effectiveness position through different programs, maintaining lowest impact on the environment, developing nationals along the way aiming to zero harm as a core principle of the business. This paper describes the strategy adopted by Aluminium Bahrain highlighting the challenges encountered to achieve the key milestones along with the future plans.

Introduction

With the objective to diversify the economy of Kingdom of Bahrain from oil based along with utilizing natural gas as source of energy and creating employment opportunities for Nationals, Aluminium Bahrain (Alba) was commissioned in 1971. Aluminium Bahrain (Alba) started as a joined venture of Bahrain Government, Saudi Government and Briton at a rated capacity of 120.000 tons per year. Alba started its metal production with commissioning two reduction lines namely Reduction Lines 1&2 using side break un-hooded, end to end Montecatini technology at line amperage of 100 kA. The two reduction lines contained a total of 456 pots distributed on four reduction rooms. Alba's first expansion was in 1982 when Reduction Line 3 was built followed by another expansion in Reduction Line 3 in 1989. The giant step was taken in 1992 when Reduction Line 4 was constructed and finally Reduction Line 5 was built in 2005. Since the beginning, Alba had its own carbon plant where carbon anodes are produced and its own power station to generate the required electrical Power for the reduction lines. On the other hand, Cast House was made to produce different types of finished products starting from standard ingots, T ingots, rolling slabs and extrusion billets. The present Alba production capacity (2012) exceeded 880,000 tons per year.

This paper describes the past, present and future of Aluminium Bahrain in improving the smelters productivity, energy efficiency along with remaining as one of the lowest cost competitive curve.

Major Expansions in Reaching a capacity of 890, 000 TPY

During the years, Alba had always selected the state of art technologies during the expansions as discussed below.

The first expansion was commissioned in 1981 where a new potline-3 was added. The new potline-3 initially had 152 side break end to end pots using the Kaiser which was the latest technology at that time and was compatible and had a lot of synergy with Reduction Lines 1&2. Reduction line 3 pots were initially operated at 115 kA which increased the plant production capacity by 50,000 tons per year. Eight years later, (1989) another 76 pots were added to Reduction line 3. Reduction line 3 was expanded further in 1996 where another 76 pots were added. So presently Reduction Line-3 has total of 304 pots.

In 1992, there was a significant shift in Alba approach toward moving ahead with the expansion and increasing the metal production throughput. Hence, Alba decided to take a giant leap by doubling its production. The newly constructed (Reduction line 4) used the state of art Pechiney (AP30) technology. Reduction line 4 consisted of 288 AP30 pots initially started at 295 kA which aimed to produce 235,000 tons per year

In 2005, reduction line 5 was built using AP30 technology being the longest reduction line at that time with a total of 336 AP30 pots. Reduction line 5 Pots started up in strategic way in the shortest duration of reduction line start up ever that taken only 77 days to bath up all the 336 AP30 Pots. With this expansion, Alba metal production reached new height adding 305,000 ton per year to Alba total metal production to 830,000 ton per year.

Amperage Creep and Improving Reduction Cells Performance

Increasing production through amperage creep and process improvements with objective to increase cells Current Efficiency are considered to be a less costly option as compared with Greenfield expansions. However, this option remains to be more challenging as it involves sweating the present assets and adopting a significant change to the process which might lead to catastrophic failure if the risk is not properly mitigated and precautions not taken. Hence, a systematic approach with extensive planning are required along with a well trained staff to execute the plans.

Reduction Lines 1-3

The side worked end to end pre-baked anode technology cells were progressively installed in Alba pot lines 1-2 and pot line 3 during1971 – 1981`. Pot lines 1-2 and line 3 were initially operating at around 105 kA and 115 kA respectively achieving a current efficiency of around 87%. The performance was gradually improved and by 1991, pot lines 1 & 2 and line 3 were operating at 112 kA and 123 kA respectively, with the current efficiency averaging around 90% in both lines 1-2 and line 3. In the period 1992 -1995, the three pot lines were retrofitted and changed over from side break to point feed cells, which included installation of alumina and aluminium fluoride feeders controlled using individual cell controller, gas collection system and changing anode setting pattern. After retrofitting, the line current was gradually increased to 128 kA (lines 1 &2) and to 142.5 kA (line 3) as shown in figure 1.

As a result of the change over from side break to point fed technology, the current efficiency improved and maintained at around 92.5% till year 2004. Since 2005 significant improvement in current efficiency has been achieved as shown in figure 2.

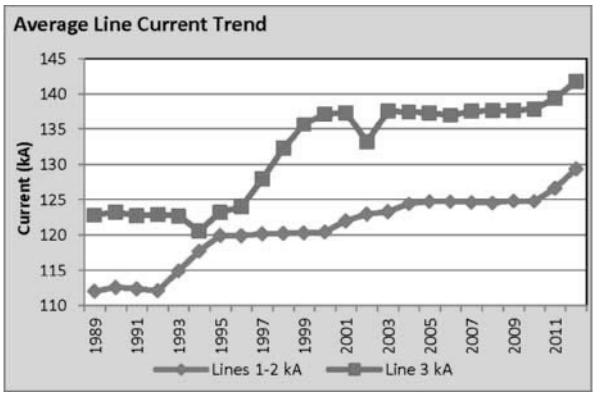

Figure 1: Line Current Trend in Reduction Lines 1-3

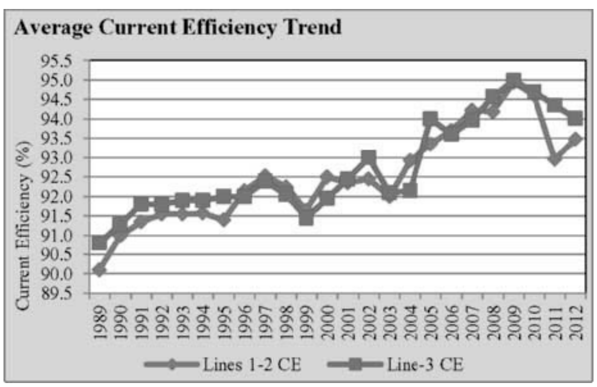

Figure 2; Reduction Lines 1-3Current Efficiency Trend

Improvement in workmanship quality through more dedication, training and sharing the ownership with the employees, along with followings is the major changes factors contributed to the success;

- Introduction of modified Thermal Control Model.
- Introduction of new Alumina Feeding Model
- Pot lining design changes and Voltage review.

<u>Modified Thermal Control Model</u>

In the old thermal control model there was over emphasis on correcting the high bath temperature by excessive Aluminium Fluoride addition and expecting fast response as shown in Figure 3 below. This approach has following errors.

- It does not allow for the operating band that is inherent in the process (the oval of the Figure).
- It assumes constant bath volume.
- It assumes the difference in bath temperature is due solely to aluminium fluoride concentration.

Rarely any of these assumptions are valid and there was a need for major change in the philosophy as follows:

- Allow for the dead band as indicated by the dashed line graph in figure 3. (This illustration is schematic only; the actual algorithm is non-linear but similar.)
- Reduce the maximum and increase the minimum additions of Aluminium Fluoride.
- Reduce the slope of the curves for less aggressive additions of Aluminium Fluoride.
- Introduce limits on the cumulative deviation from the cell's average consumption of Aluminium Fluoride.

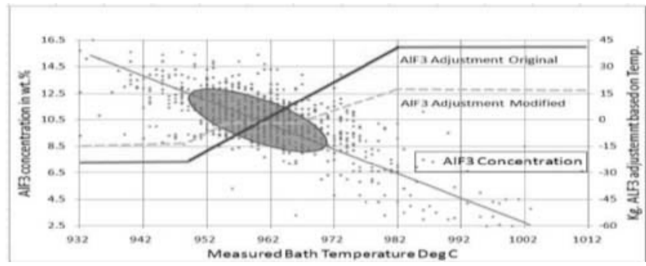

Figure 3: Original and modified AlF3 addition strategy

The aim for these changes was to stabilize the variation in Aluminium Fluoride addition and enable better cell control since deviations outside the control band are usually due to deviations in other operational routines.

<u>Introduction of New Alumina Feeding Model</u>

Alumina feeding was based on an adaptive feeding model. The characteristic nonlinear relation between the alumina concentration and the pot resistance was modelled where the estimated slope of resistance versus alumina concentration (parameter b1) gives information about the concentration of alumina. This information was used to control the alumina supply to the pot.

In the old model, the average overfeed time was in the range of 60 to 90 mins with a maximum limit of 120 mins. This was effectively increasing the alumina concentration in the bath. The ratio of underfeed to overfeed was extremely irregular which was due to the back feeding and sludge formation. The program didn't take in consideration the changes in Alumina dump weights, the mount of Alumina feed due to self feeding and variation in Alumina solubility.

Figure 4 shows considerable variation in under feed times resulting only in 8 feeding cycles in 24 hours.

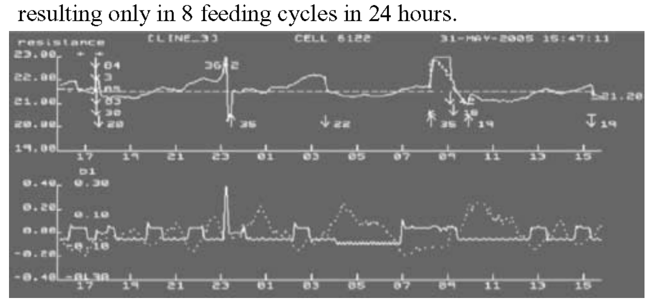

Figure 4: Resistance, Alumina Feeding & Slope Value trend graph

<u>Change Over To Fixed Alumina Overfeed Strategy</u>

An attempt was made in year 2005, to change over from adaptive alumina feeding control to fixed duration over feeding – alumina feeding strategy.

Implementing a new alumina feeding strategy in the existing 20 years old control system hardware, with limitations in the communication system network between the pot controller and the central computer was a challenge. Keeping this in mind a simple fixed over feeding alumina feeding strategy was chosen in

preference to the advanced alumina feeding strategies evolved and adopted in modern Aluminium smelters.
This proved to be very successful in reducing the anode effect frequency by more than 50% and improve the alumina concentration control in the cell as evident from the increase in the feeding cycles (change from underfeed to overfeed) per day from around 6-8 cycles to around 13 cycles

Design Changes & Voltage Review of the Individual Pots
The followings changes in 2004 have resulted in a total voltage saving of more than 100 mV and have contributed towards stable side protection ledge and improved cell voltage stability.

- Increasing the depth of the anode stub hole from 100 to 120 mm
- Introducing single slotted anodes of depth 150 mm.
- Increasing the collector bar cross section by 28%.
- Composite high thermal conductivity SiC/Carbon sidewall

To improve the superheat and to reduce the voltage fluctuation of individual pots over long period, the target resistance was increased by around 0.3 micro ohms (around 40 mV) without significantly affecting the overall voltage of the pots.
The overall performance of the pot line before and after implementing the modified lining design, thermal control and alumina feeding strategy is summarized in Table 1 below;

PARAMETER	UNIT	Reduction Lines 1-2		Reduction Line 3	
		Year 2004	Year 2010 Jan - Oct	Year 2004	Year 2010 Jan - Oct
		Before the change	After the change	Before the change	After the change
Line Current	kA	124.4	124.8	137.5	138
Cell Voltage	V	4.66	4.67	4.66	4.69
Current Efficiency	%	92.8	94.7	92.6	94.7
Specific Energy	kwh/kg Al	14.95	14.70	15.00	14.77
Anode Effect Frequency		0.33	0.19	0.39	0.18
Average Age of failed cells	days	1769	1822	1828	2381

Table 1: Comparison of the overall performance of the Pot line 1-2 and Line 3 before and after modifications

Improvement in Pot life
The cell heat balance comparing the situation at line currents of 112 kA, 120 kA & 128 kA for line 1-2 and 123 kA and 142.5 kA for line 3, as expected, highlighted the increase in the amount of heat for dissipation from the cells, a consequence of various process changes as summarized in Table 2.

	Line 1-2 in kW			Line 3 in kW	
Period	Pre 1992	1995 2000	After 2007	Pre 1992	After 2007
Line Current kA	112	120	125	123	138
Gross cell \energy	513	552	581	558	638
Net Electrical energy input to cell	483	517	544	522	593
Electrical energy used for process	227	248	263	249	290
Electrical energy available for heat dissipation	256	269 (+13)	281 (+25)	273	303 (+30)

Table-2; Impact of Changes on Cells Heat Balance

Not only does this explain why there is a predominance of sidewall failures, but it also highlights the need to improve process efficiency (thus increasing the process energy utilization) and sidewall heat dissipation to increase the thickness of the protective ledge. The need to address the pot life issue has also been highlighted by the fact that the dimensions of the key components of the cell indicate that further increase in line current should be possible.
While significant gains have been made in the current efficiency (reducing the surplus energy by approximately 5.5 kW) the actions taken to achieve this are not the focus of this paper, which is confined to design and heat dissipation issues.

Strategy for Achieving a Cell Life > 2000 Days
The initial focus in 1998 was to extend the cell life to > 2000 days. Short term plan focused on increasing the side ledge thickness through improving operating efficiency, and increasing the heat dissipation through increasing metal level, reducing anode top cover, reducing side and bottom insulation. The trend of Pot life is shown in figure 5 below;

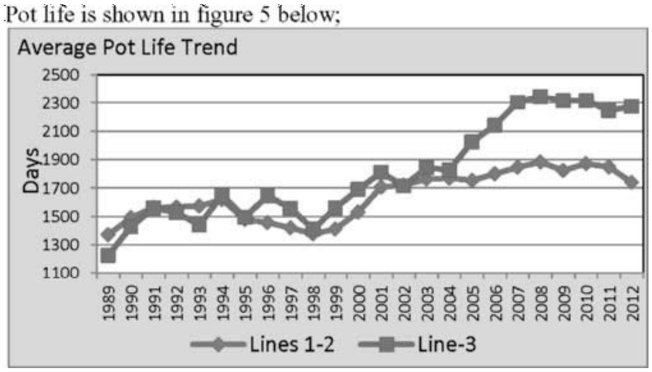

Figure 5, Trend of Pot Life in Reduction Lines 1-3

Details of some of the significant improvements or changes which contributed to this increase in cell life of between 600 to 900 days over a period of 10 years and their impact on heat balance are given below and summarized in Table 3.

	Lines 1-2 cells	Line 3 Cells
Increase in heat loss from the cell		
- Welding cooling fins on the pot shell	≈ - 4 kW	≈ -5 kW
- Increase in metal level by around 2 cm	≈ -2kW	≈ -2 kW
- Reduction in the anode top cover	≈ -6kW	≈ -9 kW
- Reduction in bottom insulation	≈ -3kW	≈ -4 kW
- Reduction in side insulation	≈ - 3kW	≈ -3 kW
Total increase in heat loss from the cell	≈ - 18kW	≈ -23 kW
Mismatch in heat balance with Retrofitting & increase in line current	+25 kW	+30 kW
Improved control & CE %	≈ -5.5kW	≈ -6kW
Cell life (days)	≈ 1900	≈ 2350
Remarks: Further adjustment through bigger collector bar and high thermal conductivity insert taken up in next phase from 2007 onwards.		

Table 3; Impact of Improvement & Changes on Cells Heat Balance

Strategy for Cells Life to > 2500 days Along With Increase in Line Current
As the cells were not operating at their full productivity potential a detailed heat balance study and modelling was conducted in 2005 to enable further line current increase without compromising

on cell life. In the long term plan of improving the cell life further included:

- Increasing the diameter of the anode stub,
- Increasing the cross section of the collector bars
- Using Silicon Carbide sidewall with high thermal conductivity carbon inserts.
- Installing vertical cooling fins outside on shell.

Since 2007, cells are being installed with the required increased cross section of collector bar and composite high thermal conductivity sidewall.

Reduction Line 4

Performance of Reduction Line-4 is considered to be one of the best among AP30 smelters and considered to be a bench mark in term of the highest current efficiency, lowest energy consumption and one of the best metal purity produced. This has been achieved through the years by outstanding workmanship quality along with the followings, modifications which will be discussed in details;

- Amperage Increaser along with changes associated
- Performance and Modification of cells lining through the years
- Modification in Alumina feeding control system

<u>Amperage Increase in Reduction Line-4</u>

Line 4 Current was increased from 295 kA in 1992 to 344 kA in 2012 with maintaining high current efficiency as shown in figure 6 &7 below.

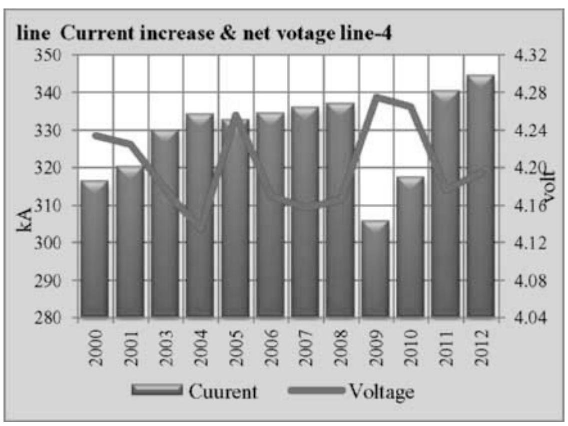

Figure 6: Trend of Line Current Increase vs Net pot voltage

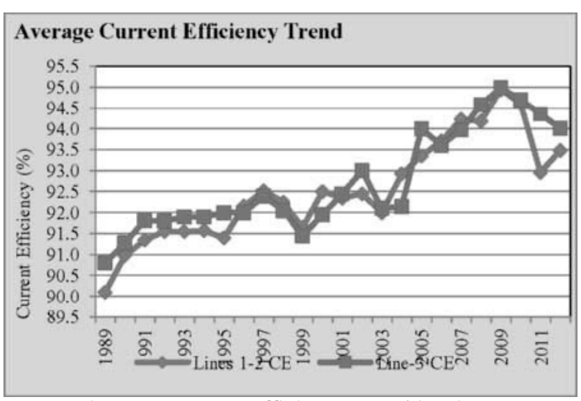

Figure 7: Current Efficiency Trend in Line-4

The followings were carried out to enable the cells to cope with the extra heat inputs and improve the current efficiency in Line-4;

- The major current increase was started on 1996 where second generation cells with graphitised cathode blocks introduced and the cell voltage was reduced by around 30 mvolt due to lower cathode resistance.
- The target bath level of the first generation pots was reduced by 1 cm (from 19 to 18 as first step then to 17 cm) with the objective to reduce the risk of tapout and maintain good pots metal purity.
- The anode height was increased from 600 mm to 618 mm starting from week 48/1996 in order to compensate for the decrease in butt thickness with increase in line current. This is in turn to eliminate the negative impact of the amperage increase on the pots metal purity.
- Anode length increased from 1450 mm to 1500 mm during 2001which gave a saving of 100 mvolt
- Alumina feeding intervals were modified to increase the alumina feeding to the pots as the pots are acquiring alumina due to higher metal productivity
- Double Anode slots of 150 mm per block were introduced in 2003 which gave a saving of around 50 mvolt. Then it was increased to 200 mm in 2009.
- The cells were squeezed more than their original design in order to cope with the current increase. A precise operation has been required to maintain good operation and maintain high efficiency.

<u>Performance and modification of cells lining through the years in Reduction Line-4.</u>

- The start up of the first generation pots in the line commenced on 17-05-1992. The start up of the 288 pots in the line was completed smoothly on 2-12-1992 without any significant abnormalities. The start up & normalisation of the first generation pots was an example of the harmonious blend between Alba experience & the state of art AP30 technology. Despite all difficulties encountered through the years, pot life in Line-4 continued to increase as shown in figure 8 below;

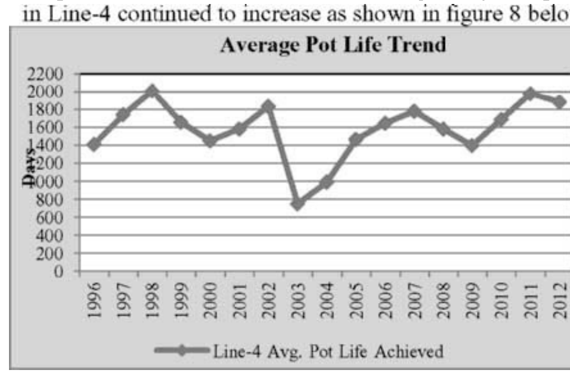

Figure 8, Trend of Pot Life in Reduction Line-4

The upgrade of lining designs to cope with the current increase along with potlife achieved from first generation till now is discussed in table 4 below;

Gen. #	Avg. pot age	Comments
1	1649	Shells lined with semi graphitic cathodes, Carbon side wall and rammed with hot ramming paste. Collector bar window sealing

		only from inside. 126 pots (43%) cut out prematurely due to side wall tap out. Carbon side wall found oxidized due to air ingress from collector bar windows. Pots restarted after replacing sidewalls. stuffing box was fixed and filled with KUB concrete to seal the area/stop air ingres.
2	1646	Initially shells were lined with semi graphitic and graphitic cathode blocks, SiC side walls and hot ramming paste from .Use of stuffing box started to stop air ingress from collector bar windows. In Sept 1996 graphitized cathode blocks using warm ramming paste. In 2nd generation pots ware failed mainly due to high iron caused by cathode erosion
3	1589	About 80% of pots lined with graphitized and improved quality of graphitized cathode blocks. Main reason for achieving lower pot age is that during the year 2005 significantly high numbers of pots (124 pots) in line 4 failed at lower age due to power outages taken to put in service a swing rectiformer between Line 4 and 5 and deficiency in operation control
4	1755	All pots of 4th generation were lined with graphitized or with improved quality of graphitized cathodes. 12 pots had to cut out at average age of 800 days mainly due operational problem after 4 hrs of D.C. power outage in Aug 2010. Test group of cathodes with 490mm ht was installed and achieved avg. pot age of 1929 days. From 2006 onwards composite side wall were introduced in line 4.
5	565 (6% failed)	The following changes were carried out in Second generation cells as preparation for current increase. - Cathode height increased from 450mm to 490 mm - SiC side wall was replaced by composite side wall (SiC + C) Collector bar cross section change from 150 x 100mm to 122 x 122mm

Table 4: Changes in lining design in Reduction Line-4

Modification in Alumina Feeding Control System in Line-4

Due to the higher anode effect frequency in Reduction Line 4 (0.25 A/E/pot/day), a study was conducted to identify the shortcoming the feeding model and come up with necessary corrective actions. The shortcomings in the old alumina feeding program are summarized below;

- End of Phase-1: Sudden increase in the resistance at the end of underfeed phase without the ability of the system to detect such increase earlier. This leads the pot to go on anode effect
- Interruption of Phae-1: During the underfeeding period, the target resistance could change by modifying the components of the target resistance. This leads to disturbance in Phase-1 and lead to lose the time to follow the evolution of the resistance.
- Slope below Critical: Due to unrepresentative of the slope calculated at the end of Phase-1, the slopes resulted from the calculation is lower than critical which allow underfeed phase to continue but with very low alumina concentration leading to anode effect.
- Phase-2; The resistance during phase-2 doesn't become lower than the target in spite of the higher overfeeding rate which ends with increase in resistance during the next underfeed and causing anode effect.

New Alumina Feeding Control System

The followings are the main feature of the new control system;

- Calculation of the slopes and the changes in the resistance is done all the time both in underfeed and overfeed.
- The decision to switch to overfeed depends not only on the slope value but depend on the difference in resistance and also on the average resistance at the end of phase-1. This makes the system response faster before anode effect occur.
- The resistance is filtered in order to determine the actual alumina feeding concentration from just the noise because of the current signal or others.
- The feeding reduces by itself during the underfeed when the resistance stays in under feed for a long period.

Performance of the new Alumina feeding Control System

- It could be seen from the figure 9 below reduction to anode effect frequency about 0.10 AE/pots/day when the new software implemented.

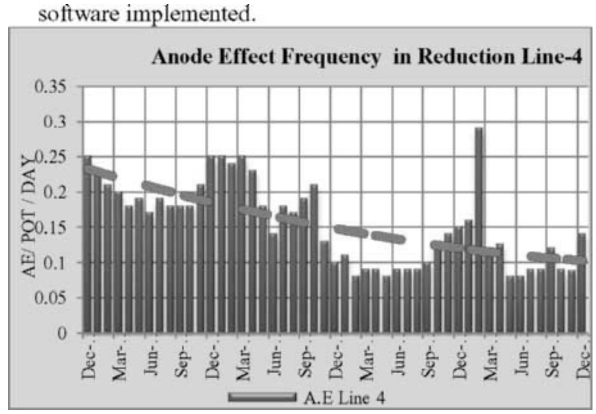

Figure 9; Trend of Anode Effect Frequency in Line-4

Reduction Line 5

The followings are the main features in Reduction Line-5 since the start up till dates;

- Current Increase with minimum major expenditures
- Improvements in Pot life along with upgrade of Lining design

Current Increase in Line-5

Maintaining high current efficiency while increasing the current has been the main challenge in Reduction Line-5. Reduction Lines is considered to be one of the best AP30 plants in term of highest current efficiency and lowest energy consumption as shown in figure 10:

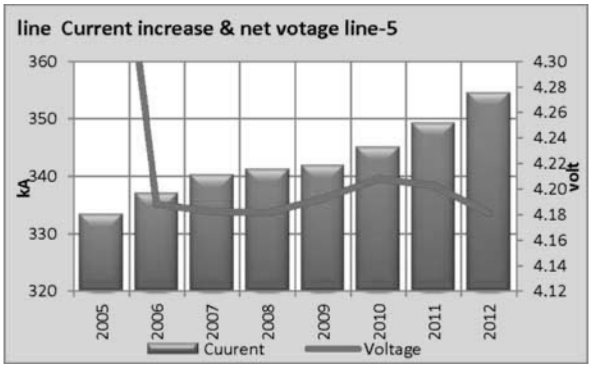

Figure 10: Trend of Line Current vs Net Voltage in Line-5

The following were done to cope with this increase in current;

- Increasing anode length from 1500 to 1530 mm (saving of 35 mvolt) and Increasing anode height from 620 mm to 650 mm in order to maintain high metal purity without decreasing the anode cycle
- Increasing the anode slots from 150 mm to 270 mm (saving of 50 mvolts)
- Reducing the ACD along with putting more control and tight operation to keep cells stable and maintain Current Efficiency.

Performance of Lining in Reduction Line-5

The following Figure-11 shows the performance of the cells lining since the start up. It could be seen that the average of the cut out pots has increased since the start up.

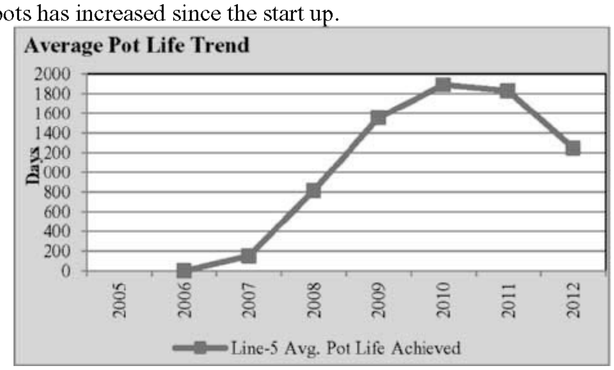

Figure-11: Trend of Pot Life in Reduction Line-5

The main characteristic of first and second generation of pot lining of Reduction Line-5 is shown in the table-5 below;

Gen #	Avg. pot	Comments
1	1827	All pots of 1st generation were lined with graphitized and improved quality (pitch impregnated) of graphitized cathode blocks, SiC sidewalls and warm ramming paste. The average pot life achieved by 1st generation was 1829days
2	763 (2% failed)	The following changes were carried out in Second generation cells as preparation for current increase. - Cathode height increased from 450mm to 490 mm - SiC side wall was replaced by composite side wall (SiC + C) - Collector bar cross section change from 150 x 100mm to 122 x 122mm.

Table 5; Changes in pot lining design in Line-5 till 2012

Conclusion & Future Challenges

Since the commissioning of Reduction Lines 1 & 2 in 1971, Alba adopted the continual improvement and growth strategy. It is obvious that the adopted approach was successfully implemented which had taken Alba production from around 120,000 tpy in 1971 to about 890,000 tons per year in 2012 (as shown in Figure-12 below) and planning ahead to cross 1.2 Millions tones per year in the coming few years.

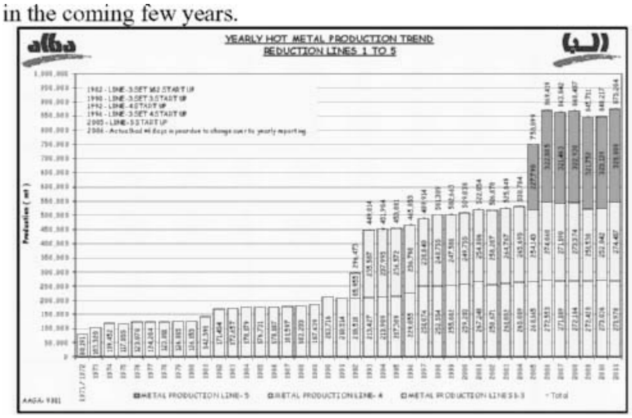

Figure 12: Hot Metal Production Trend in Reduction Lines 1-5

Alba Future is promising further and followings are being planned;

- Operate Lines 1-2 above 140 kA after increasing the anodes length and anodes stub diameter along with modifying anode beam and lining designs
- Operate Line-3 above 155 kA after increasing anode length and anodes subs diameter along with modifying the lining designs. Introduce Alumina feeding to the cells via Hyper Dense Phase System instead of using Alumina point feed vehicles.
- Operate Lines 4&5 above 400 kA after enlarging anode size and modifying lining designs with minimum specific energy requirements
- As both of Level-1 and Level-2 cells control systems are obsolete, a program has been initiated to upgrade and retrofit the existing systems with objective to improve cells performance
- There are many spare capacities within the plant made available for the provision of Line-6 since the start up of Line-5 in 2005. Alba is in the stage of selecting the best and latest technology, which maximizes the plant production beyond 1.2 million tons per year with attractive return of Investment.

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