Improving Current Efficiency of Aged Reduction Lines at Aluminium Bahrain (Alba)

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Abstract

The side worked end-on-end pre-bake anode technologies installed during 1970's at Alba achieved a current efficiency of 90%. During the early nineties, the potlines were retrofitted from side break to point fed cell arrangement, along with an increase of 7% and 10% in line current. The retrofits included anode gas collection system, a changed anode setting pattern, and installation of alumina and aluminium fluoride feeders controlled using individual cell controller, which increased the current efficiency to 92.5%. During the last 6 years, improvements done in the alumina feeding control, thermal control and stability of cell operations has increased the current efficiency to 94.5%. Close monitoring and follow up of quality of work and key parameters on daily basis by the new employees forum introduced at Alba in 2004 called SMART Centres (See My Actions Reflect Targets) has also contributed towards this improvement and maintaining it.

Introduction

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 – 1982`. Pot lines 1-2 and line 3 were initially operating at around 100 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 120 kA (lines 1 &2) and to 138 kA (line 3) as shown in figure 1. The line current in lines 1-2 was further increased gradually from 120 kA to 125 kA during 2001 to 2004 and maintained at 125 kA till now.

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. During 2005 to 2010, significant improvement in current efficiency has been achieved as shown in figure 2. Following changes introduced and improvements done has lead to increase in the current efficiency from around 92.5 to 94.5%, which are discussed in this paper.

- Introduction of modified Thermal Control Model.
- Design changes and Voltage review.
- Introduction of new Alumina Feeding Model.
- Improvement in quality of work
- Introduction of new employee form called SMART Centres.

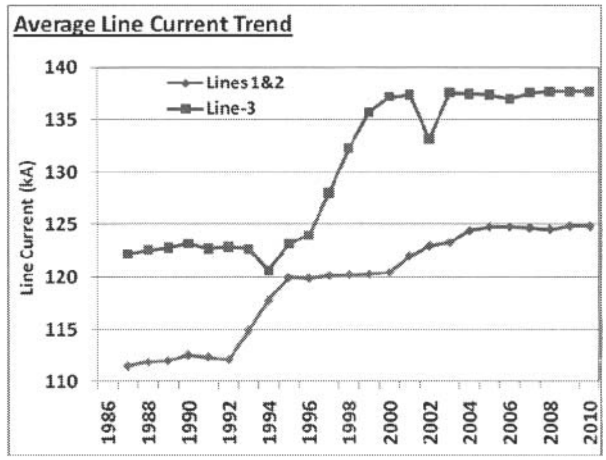


Figure 1: Line Current Trend in Reduction Lines 1-3

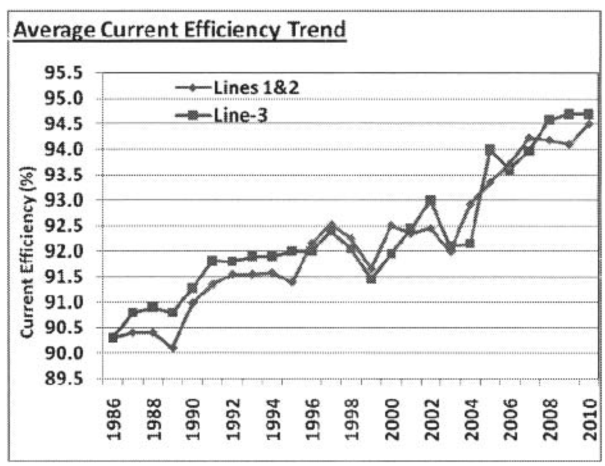


Figure 2; Current Efficiency Trend in Reduction Lines 1-3

Modified Thermal Control Model

Reviewing the trend of bath temperature and bath acidity of the individual pots over a prolonged period (120 days) indicated 2 to 3 swings in bath temperature and bath acidity and such swings were even observed while analysing the average data on potroom basis also. This was mainly due to the wide variation in the daily aluminium fluoride addition from 0 to 60 kg/day/cell compared to average requirement of 17 kg/day/cell. The aluminium fluoride addition control strategy used originally is represented in figure 3 by the solid line graph and at the centre point the base amount of 17 kg/day is added. In this strategy there was over emphasis on correcting the high bath temperature by excessive aluminium fluoride addition and expecting fast response. 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 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.

• Reduce the slope of the curves for less aggressive additions.

• Introduce limits on the cumulative deviation from the cell's average consumption.

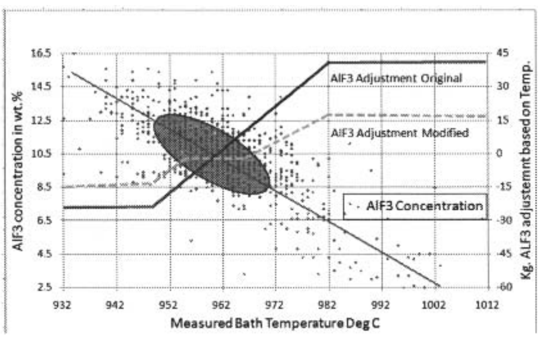


Figure 3: Original and modified AlF3 addition strategy.

The aim for these changes was to stabilize the variation in fluoride addition and enable better cell control since deviations outside the control band are usually due to deviations in other operational routines. Even though it is not expected to give significant direct improvements in cell performance, it is definitely an enabler for better control. It makes it easy to diagnose the causes of deviation from normal behavior in cells. Thus enabling to attack the root cause of the problem of high bath temperature, rather than trying to correct it through aluminium fluoride addition.

Design Changes & Voltage Review of the Individual Pots:

Following design changes (figure 4) gradually introduced since 2004 has resulted in a total voltage saving of more than 100 mV and has contributed towards stable side 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 sidewall

These savings in individual voltage components could not be realized in terms of reduced cell voltage due to heat balance and superheat requirements, which were confirmed by the measurements. However it enabled a beneficial increase in anode-cathode distance.

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.

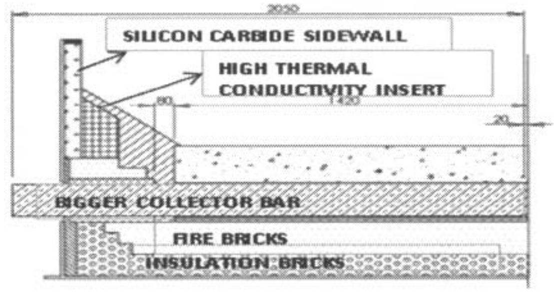


Figure 4: Improved Lining Design

The saving in voltage achieved through the design changes is part of the plan to increase the line current by 5% which will be implemented in 2011.

Original Alumina Feeding Model

Alumina feeding was based on an adaptive feeding model. The characteristic nonlinear relation between the alumina concentration and the pot resistance was modeled by an adaptive linear model 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. For the feeding control to be successful it was necessary to maintain stable pot resistance and the only "variability" in the pot was supposed to be the variation in alumina concentrations, due to the different feeding modes introduced. However, alumina concentration control was exposed to uncertainties because of

- Variation in alumina dump weight (assumed constant alumina dump weight)
- Variation in transfer of alumina from hopper to bath (assumed 100% transfer)
- Solubility of alumina (assumed 100% solubility). Alumina always does not completely dissolve due to higher alumina dump weight of 1.6 kg and high number of rapid alumina dumps at the end of tracking (25 dumps) and after anode effect (60 dumps)
- Feeding from other sources (sludge / crust and anode top cover etc.)

To ensure that sludge build up was prevented, every 24 hours the pots were set on tracking mode.

Analysis of Alumina Feeding Irregularities and Feed Cycles

The total number of feed cycles typically was found to vary from 6 to 8 per day, which was considered low and could not enable good clean periods to occur for good control.

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 by about 1.1%, which was high. Normally it should be targeted to increase by around 0.6% to get to the start of the flattening of the resistance versus alumina curve and avoiding entering the insensitive rising section on the alumina rich side.

Ratio of underfeed to overfeed was extremely irregular which was due to the back feeding and sludge formation.

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

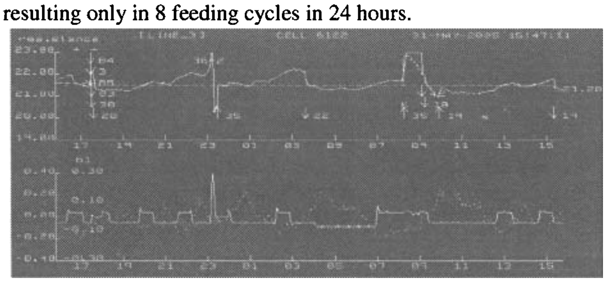


Figure 4 : Resistance, alumina feeding & slope value trend graph

The Figures 5 and 6 presented below shows only 6 feeding cycles and unusual resistance slope curves at certain times.

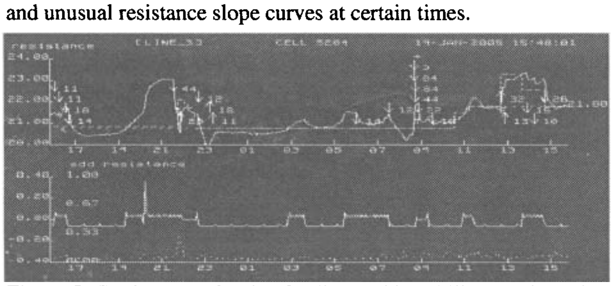


Figure 5 : Resistance, alumina feeding and instability trend graph.

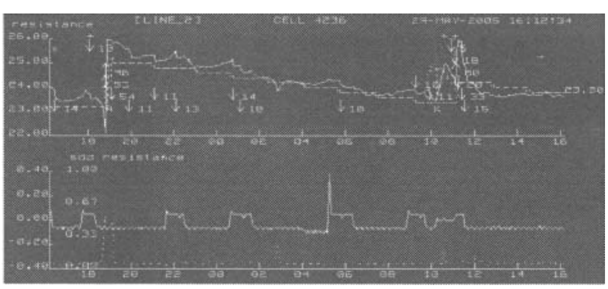


Figure 6 : Resistance, alumina feeding and instability trend graph.

From this detailed review it was clear that the number of feed cycles needed to be increased from 6 – 8 cycles per day to around 12 - 16 cycles per day by reducing the overfeeding duration to less than 60 mins. The sampling time for the alumina feed control logic to be reduced from the original 5 mins to improve the sensitivity of the control system. The optimum value of the sampling time was to be determined taking into account the existing limitations in the hardware of the communication system network between the individual pot controller and the central pot line computer.

The change over to the new fixed overfeed alumina feeding strategy to achieve these above goals are discussed below.

Change Over To Fixed Alumina Overfeed Strategy

An attempt was made in year 2005, to change over from adaptive alumina feeding control with a sampling time of 5 minutes to fixed duration over feeding – alumina feeding strategy with a sampling time of 3 minutes in line 1-2 pots and 4 minutes in line 3 pots.

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. Due to the hardware limitations in the communication system the alumina feeding control sampling time could not be reduced below 3 minutes in line 1-2 pots and below 4 minutes in line 3 pots.

Fixed duration over feeding strategy followed consists of over feed sequence for a definite period, followed by an under feed for a shorter period and subsequently putting the pot on tracking to reach a fixed alumina concentration level in bath before starting a new feeding cycle. This fixed duration over feeding strategy provided easily adjustable parameters to control the alumina concentration in the bath at the desired level and there by reducing the anode effect frequency. Different setting of the fixed duration over feeding strategy were tried and optimised at 45 minutes over feeding at 150% feed rate, followed by an under feed for 20 minutes at 60% feed rate and tracking at a feed rate of 11%. 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 per day from around 6-8 cycles to around 13 cycles as indicated in Figures 7, 8 and 9.

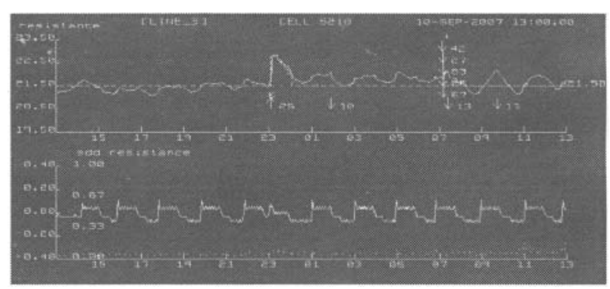


Figure 7 : Resistance, alumina feeding and instability trend graph.

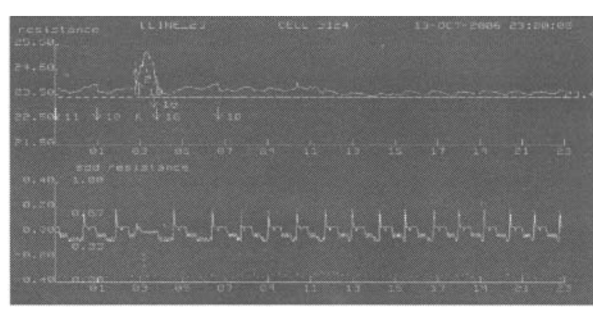


Figure 8 : Resistance, alumina feeding and instability trend graph.

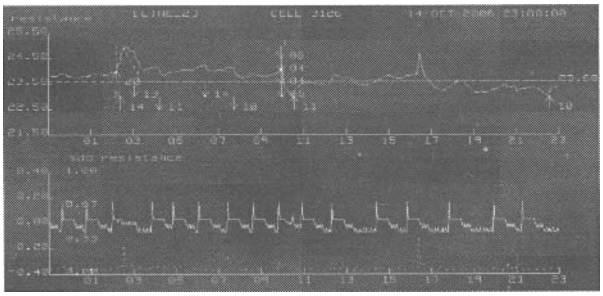


Figure 9 : Resistance, alumina feeding and instability trend graph.

Other Modification to the Original Alumina Feeding Strategy

Anode effect Termination Feeding Logic:

The alumina rapid feeding after anode effect (60 dumps / 90 kgs in 7 mins) was high. This was a greater mass than could possibly dissolve and it was contributing to sludge build up.

The number of alumina shots fed rapidly after anode effect was reduced from 60 to 20 after conducting trials and establishing that there were no repeat anode effects in the short time afterwards which would otherwise indicate insufficient addition of alumina. This also contributed improved general feeding control and reduced the chances of build up of sledge in the pots.

Tracking Termination Feeding Logic:

The alumina rapid feeding at the end of tracking (25 dumps / 35 kgs in 3 mins) was also considered high which was reduced to 15 dumps and subsequently to 7 dumps. Thus reducing the risk of sludge formation.

Anode Change Feeding Logic:

To increase the alumina concentration just before anode change and reduce the risk of anode effect during anode change due to colder bath and higher current density, alumina feeding logic was modified to add 15 shots of alumina at the normal overfed rate prior to the anode setting. This modification reduced the anode effect at the time of anode change from 0.04 to 0.02.

Performance of Modified Alumina Feeding Strategy

Control of Alumina Content in bath:

In order to assess the effectiveness of the fixed overfeed alumina feeding strategy in maintaining the alumina concentration in the desired range of 1.8 to 2.8%, extensive study of alumina content in bath was carried out in a group of pots over a period of 24 hours by actually measuring the alumina content in bath samples taken every 15 mins.

Alumina concentration change was found to be broadly matching with the type of alumina feeding i.e, increase in alumina concentration during overfeeding and decreasing in alumina concentration during under feeding and tracking. In most of the pots the alumina content in bath was being controlled at the desirable range of 1.8 to 2.8 %. However, some times the high self feeding during activities or repeated anode moves, was found to completely mask these correlations and pushed the alumina concentration to high and outside the range values as observed in some pots having alumina content in the range of 3.5 to 5.0 % for few hours. Repeated tracking feature of the new fixed alumina overfeeding strategy ensures that these instances of higher alumina concentrations are brought down to the desired range with in few hours (1 – 2 cycles). Thus the risk of sludge formation and sludge build up was greatly reduced.

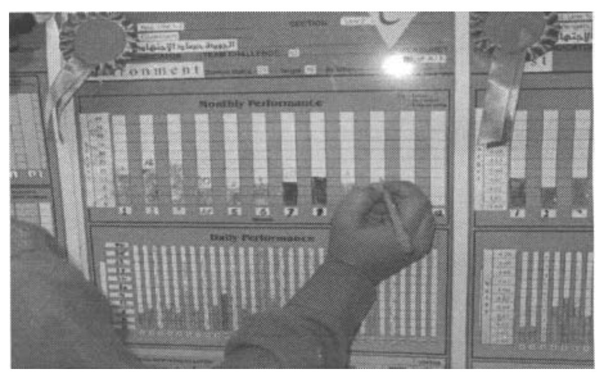
The above observations confirm that the new fixed overfeeding duration alumina feeding programme is working good.

Improvement in quality of Work through SMART Centre

Employees in Alba is working based on the concept of SMART i.e. **S** see **M** my **A** action **R** reflect **T** targets.

The concept of smart centre is to converts strategic and business plans into easily understood and measurable actions on the shop floor to enable and encourage teams to share, participate, innovate, solve problems and effectively plan together.

Smart centers had positively impacted on the people and their commitment, ownership and performance that lead to increased productivity.
The importance of teamwork was practically emphasized through the team building training. There was a need to have a way through which shop floor workers are brought on board and engaged in the decision making process and hence the idea of implementing the concept of the SMART PROCESS was explored.



The teams meet at the start of every shift for a 15 minutes meeting to discuss pertinent issues for the day. During the meeting, they updated and monitor their performance using daily and weekly charts.

Once a week the team meets to discuss their general performance, evaluate their suggestion and resolve problems encountered. They take time to celebrate success and discuss improvement plans. The team was empowered to put solutions to their problems themselves and follow it up even with other teams or sections.

As result of tight relationship built between the management and employees, the gap is closing and links established for common understanding and agreement to resolve issues related to employee's welfares, safety and meet the company corporate targets. Implementation of the changes was helped by the motivation of the smart centre groups.

Performance Improvement with modified design & control logic

The overall performance of the pot line before and after implementing the modified lining design, thermal control and alumina feeding strategy is summarised in Table 1 and Figure 2, 10, 11 & 12.

PARAMETER	UNIT	Reduction Lines 1-2 Year 2004 Before the change	Reduction Lines 1-2 Year 2010 Jan - Oct After the change	Reduction Line 3 Year 2004 Before the change	Reduction Line 3 Year 2010 Jan - Oct 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 implementing the modified lining design, thermal control and alumina feeding strategy.

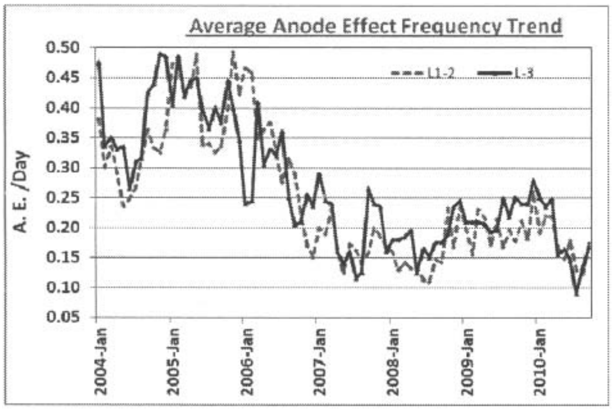


Figure 10 : Trend graph of anode effect frequency

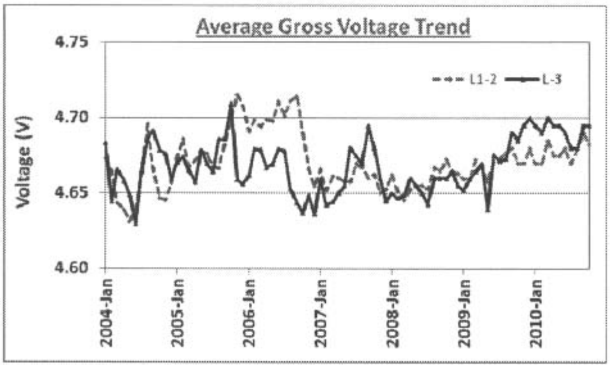


Figure 11 : Trend graph of Cell Voltage.

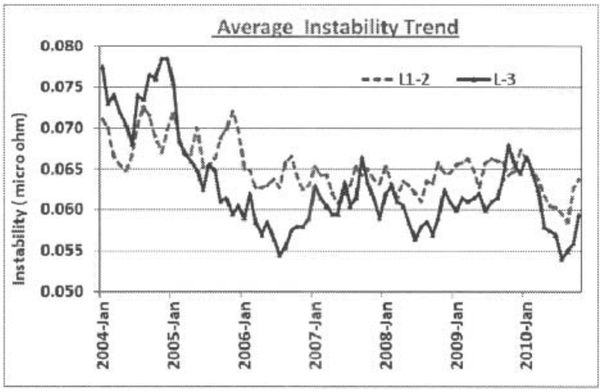


Figure 12 : Trend graph of instability

Conclusions

After implementing the modified alumina feeding strategy, the anode effect frequency across lines 1, 2 and 3 has been reduced from level of around 0.40 to 0.15 and correspondingly reducing the PFC emissions by more than 50%. The collective effect of improvements in alumina concentration control, thermal control, lining design and quality of work is reflected in the improvement in the current efficiency across lines 1-3 of the order of 2.0%. This high level of performance is achieved and being maintained with active participation of employees through SMART Centers.

Acknowledgements

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References

[1] K.S.R.Raghavendra, Reducing anode effect frequency in aged pot lines by changing alumina feeding & control parameters and overhauling of breaker feeder system, Ninth Australasian Aluminium Smelting Technology Conference and Workshop 4-9 November 2007 pp 149-161.

[2] Abdulla Habib, K.S.R. Raghavendra, Barry Welch, Improving heat dissipation and cell life of aged reduction lines at Aluminium Bahrain (ALBA), Light Metal 2010 pp xxx – xxx.

[3] Lynette wilsenach, Customised Integrated Process for ALBA SMART Process combined with Teambuilding Activities may 2004.

[4] Hasanain Hassan Al Ojaimi, EMPLOYEES BEHAVIOUR IN IMPROVING ROOF EMISSION IN REDUCTION POTLINES 1-3, Ninth Australasian Aluminium Smelting Technology Conference November 2007.

[5] Hasanain Hassan Al Ojaimi, 1st Smart Center @ ALBA Annual Review 2009.