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AP40 : the latest of the AP Technology™ solutions

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Abstract

Another significant step in the AP30 development has been successfully demonstrated; one that further enhances productivity. After the AP39 technology validation, an enhanced operating point has allowed cells to operate above 400 kA without decrease in energy efficiency. Since July 2010, these cells, now referred to as AP40, operate at St Jean de Maurienne in the range of 400-405 kA with specific energy consumption below 13150 kWh/t. Achieving this performance required an extensive review of operational aspects including busbar capability, operational quality, and process control. Also essential was the use of an "operating window" approach to determine the optimal operating point. By following a cell development methodology over two years, results have demonstrated a high level of process performance (anode effect frequency, current efficiency and energy consumption). Measurement campaigns have confirmed the excellent level of pot robustness.

Introduction

Initiated in a dedicated boosted section at the St Jean de Maurienne smelter, the development of the AP30 technology has not ceased to push the limits of pot productivity and energy consumption since the beginning of the eighties. The first AP30 potline was built in St Jean de Maurienne with one hundred and twenty pots and was considered at that time to be the most advanced technology in operation (Figure 1). Designed initially to operate at 280 kA, these cells rapidly demonstrated their robustness and capacity for increased productivity, with amperage reaching more than 300 kA by the beginning of 1990 [1].

Fig.1: AP30 in operation in G Line at Saint-Jean-de-Maurienne

In order to enhance and accelerate this very promising development, and aiming at cell designs still more efficient for limited capital cost, a complete R&D program was launched in 1990 based on trials in boosted sections in several plants. A first trial section was installed in the brand new Dunkerque smelter in 1991, followed by another one in St Jean de Maurienne in 1996 and a third one in Alma in 2004. These test sections were then able to contribute in an integrated way to the development of the AP30 technology in line with internal or external customer requests. Combined to support a very aggressive vision of the AP30 technology, this R&D work was the starting point of a development that has pushed the operating point from the initial 300 kA to more than 400 kA today. In parallel, the number of AP30 type pots installed in the world has increased steadily, reaching 4282 cells in 2011, which corresponds to about 9% of the world's annual aluminium production (see Figure 2).

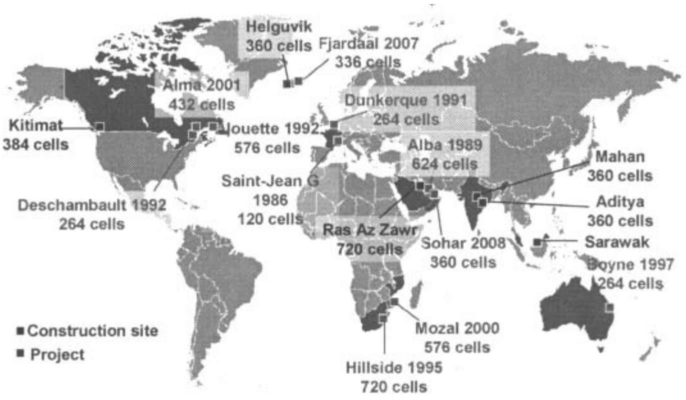

Fig.2: AP30 technology around the world

A first very important milestone was reached in 2002 with the validation of the AP35 technology on the St Jean and Dunkerque test platform. Subject to the limitation of keeping the same shell dimensions and superstructure, the AP35 technology offered a pot operating at 350 kA with a specific energy consumption of 13500 kWh/t [2].

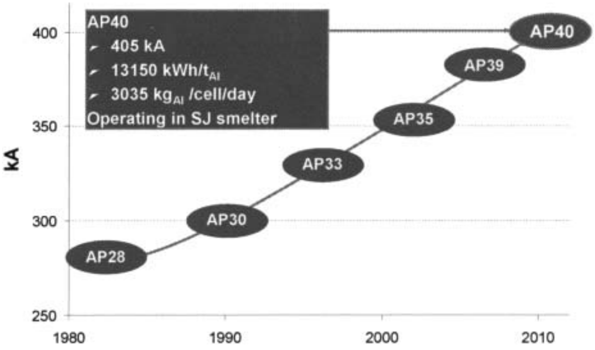

Fig.3: Successive versions of the AP30 technology

This first milestone attained, the AP35 technology was optimized to become first the AP36 and then the AP37, based on combined tests in Alma, St Jean de Maurienne and Dunkerque [3]. In 2006, the development plan for the AP30 technology was thoroughly reviewed, resulting in the decision to launch the AP40 development with the goal of an AP30 cell operating at more than 400 kA [4]. Figure 3 above illustrates the rapid advance from the first AP30 installation to the AP40, which is the latest version.

Table 1 below lists the evolution of the operating points of these technologies since 2005.

Version	Location & period	Goals
AP36	St Jean de Maurienne - Dunkirk 2005-2007	360 kA 13100-13500 kWh/t
AP37	Alma 2006-2008	370 kA 13150-13500 kWh/t
AP39	St-Jean de Maurienne 2007-2010	385 kA 13000-13400 kWh/t
AP40	St-Jean de Maurienne 2010-2011	405 kA 13400 kWh/t

Table 1: Operating points of the latest AP3X – AP40 development

AP40 development plan

After the validation of the AP39 technology in 2009 and based on its features, another cycle of cell development began in which the ultimate target of 400 kA was exceeded with no increase in specific energy consumption.

In our preliminary studies, modelling work was carried out to investigate the cell design for operation at 405 kA as well as some operational aspects (busbar network, process control system and superstructure).

Preliminary study

Based on our experience in the AP39 development pots together with a better understanding of the design criteria obtained from modelling, it appeared that it would be sufficient to adjust the process settings, most importantly the anode-cathode distance, in order to attain the desired current level without major changes to the cell design. This conclusion was possible by using the new concept of the operating window, integrating the different constraints of the design criteria and process parameters in a common approach.

Operating window concept

The operating window is an essential tool used by Rio Tinto Alcan Technology and R&D to define an acceptable zone for cell operation within prescribed design limitations, as shown in Figure 5. The recommended operating region for the cell is represented by the white area in this graph of amperage versus specific energy consumption. Adjusting operating set points like amperage or cell voltage so as to operate in this region ensures acceptable thermal balance and stability margin. Operating close to its boundaries will reduce robustness, i.e., make the cell more sensitive to the various uncontrolled process disturbances that are inevitable in industrial operations.

Several design criteria have been defined, based on the experience gained by R&D teams during cell development as well as on benchmarking studies carried out on operating plants' actual set points. A first set of criteria characterizes the thermal balance of the cells. These criteria are based on studies with the calibrated cell model, and include side ledge thickness at various levels in the cell, and superheat criteria. Other criteria are both operational and quantitative from studies; in particular, the ACD (Anode Cathode Distance) limit is based on smelter trial data but also on magneto-hydrodynamic modelling studies being able to compare different cell designs.

Operating beyond any one of the three boundaries shown in Figure 5 can be linked to a specific behaviour. Running the cell "too hot" above the upper thermal limit presents risks of inadequate side ledge protection and reduced cell life, whereas running "too cold" below the lower thermal limit increases the risk of sludge deposit, poor alumina dissolution and stability, with a loss of cell productivity. The ACD limit is rather operational: the object being to keep it as low as possible, consistent with stable and robust operation. Operating beyond this limit increases cell noise with potentially more anode effects.

For the development of the AP40 technology, the operating window was defined considering the likely need to adjust various process settings, including not only the ACD but also the flow rate of the potshell forced cooling network and the levels of the bath and the metal pad.

Figure 5 shows the operating window for AP40 and the evolution from AP39. The AP40 operating point is positioned well within the thermal window.

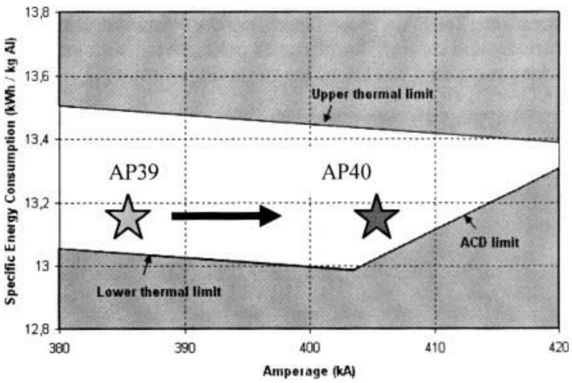

Fig.5: The AP40 operating window

Trial setup

From risk analysis study together with experience on the Alma development platform, the process control system was found to be a key element for maintaining AP40 cell performance. Raising line current from 385 to 405 kA requires dissolving 5% more alumina per day in the cell in a very limited bath volume. This necessitates even more precise alumina feeding control to ensure that alumina shots are released at the appropriate time to avoid anode effects while avoiding non-dissolution, which results in bath sludging with cell instability. Modifications were therefore made to the process control system related to alumina feeding strategy and instability treatment.

The dedicated power supply was upgraded in order to be able to supply more than 400 kA in the St Jean boosted section. The amperage was increased in two steps, first to 395 kA and then to 405 kA, with regular temperature and deformation measurements at critical points in the busbars to confirm that they could withstand operation at these higher line current levels.

Measurement campaigns were also planned to take place after operations had stabilised at these two levels of current, as indicated by the smaller stars in Figure 6, at the end of the first and last quarters of 2010. Figure 7 shows the levels of line current at these times.

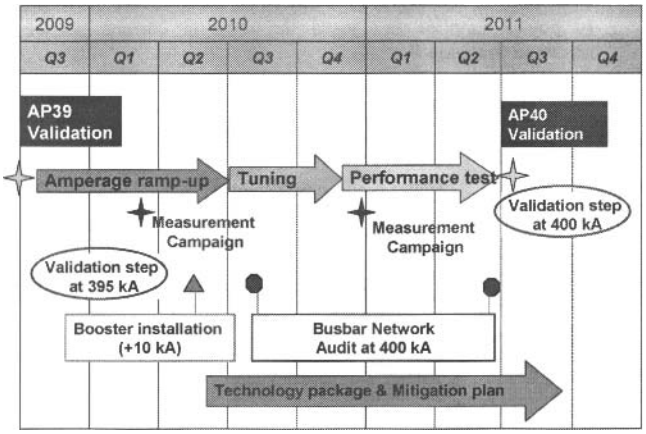

Fig.6: Activities and milestones along the way from 385 above 400 kA

Trial execution and results

The booster section located within the AP30 G-line at Saint-Jean-de-Maurienne consists of eight cells, six of them fitted with AP40 cells, and the two others fitted with modified linings to test the behaviour of transition cells at high amperage. The ages of the cells at the beginning of this cycle of development were between 24 and 50 months.

The AP40 cell results were compared with those of reference cells operating in the same line G. The test was divided in two phases corresponding to the two amperage targets.

The first phase began in October 2009, the test cells current being gradually raised to 395 kA and then held at this level until July 2010. Measurements of voltage drops, temperatures and deformations were carried out on the shell and the busbar network, confirming that no problems were to be expected at current levels above 400 kA.

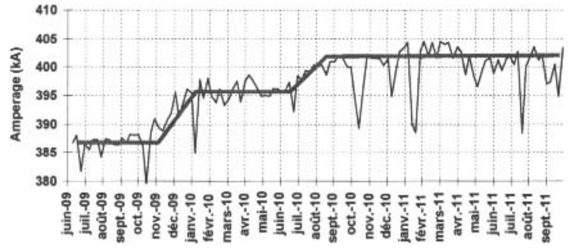

Fig.7: Weekly average test cell current (target current in red)

A preliminary measurement campaign on the AP40 cells was completed during this first phase at 395 kA, demonstrating the good operational behaviour of the cell, with adequate ledge protection for the lining.

Cell efficiency was very good, with current efficiency above 94.5% and specific energy consumption below 13200 kWh/t in the test section, which implies less than 13000 kWh/t for a Greenfield installation.

The automatic cell control system and the new operating procedures confirmed their ability to run the cell with good control under normal industrial operating conditions.

A decision was taken in the second quarter of 2011 to increase the line current to more than 400 kA. An additional booster group was installed and line current exceeded 400 kA for the first time in July 2011.

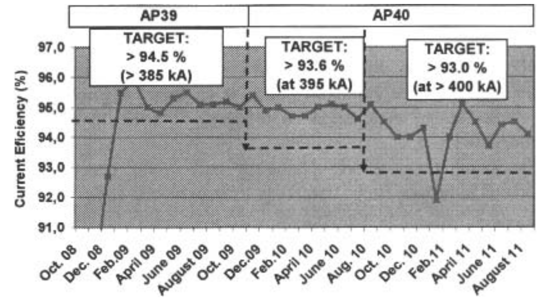

Fig.8: Current efficiency monthly results of AP39 and AP40 test cells

Current efficiency and specific energy consumption

During the second phase of the test, with the line current generally above 400 kA, current efficiency fell slightly, as it usually does when the current is raised with an accompanying reduction in ACD. The average value with the current above 400 kA is significantly above 94%, which is still very good performance.

Figure 8 shows a big drop in current efficiency in January 2011. This was the result of a power interruption of more than three hours' duration followed by a three-day period when the booster groups could not deliver the expected level of current. The cells were severely affected but all of them were kept running, and they all recovered quite rapidly after the current returned to normal, a successful and very harsh test of their robustness.

Cell voltage

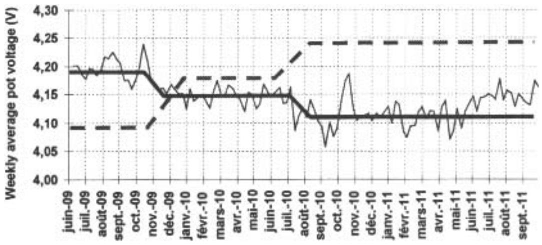

Fig.9: Weekly average cell voltage and test cells amperage

In line with the operating window guidelines, ACD was reduced in order to lower cell voltage and thus maintain good thermal balance and unchanged specific energy consumption as current was increased.

Cell stability

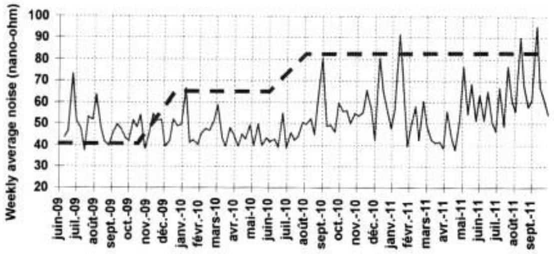

Fig.10: Cell noise and test cells current

Cell stability was maintained suitably below 70 nano-ohms, which is the standard instability limit for AP30 cells at St Jean. As can be seen in Figure 10, the cell noise increased significantly as the current reached 400 kA in September 2010 – though it was still mostly below the instability limit - but adjustments to the instability treatment procedure similar to those applied in Alma and Alouette [6] succeeded in bringing it back to normal by February 2011.
In the same time, anode changing and cover practices were optimized to reduce their disturbing effects on the cells.

These results are quite satisfactory given the difficult conditions at the St Jean de Maurienne smelter, with numerous amperage drops and potline outages due to the energy contract (easily observed in Figure 7).

Anode effect frequency

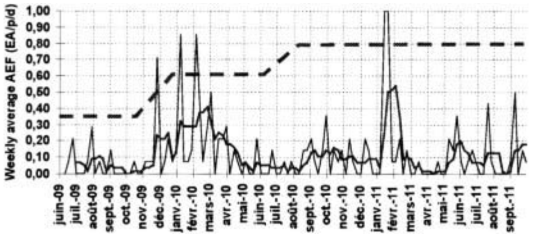

Fig.11: Anode effect frequency and test cell current

Ensuring good alumina dissolution is a key challenge for the AP40 cells because of the reduced amount of bath due to the long anode design. The auto-adaptive feeding algorithm [7] proved very beneficial in improving alumina dissolution by allowing a lean alumina set point, while keeping anode effects under control. Anode effect frequency (Figure 11) was maintained at or below 0.1 AE/cell/day once the feeding algorithm was tuned (May 2010), but significant efforts still had to be made on bath height control. Low bath height values immediately cause the anode effect frequency to go up, and preventive and corrective actions to maintain the bath height level above 14 cm had to be reinforced. The "blip" in January 2011 is due to the same severe interruption to power supplies as caused the drop in current efficiency observed in Figure 8.

Trial measurements

Cell design

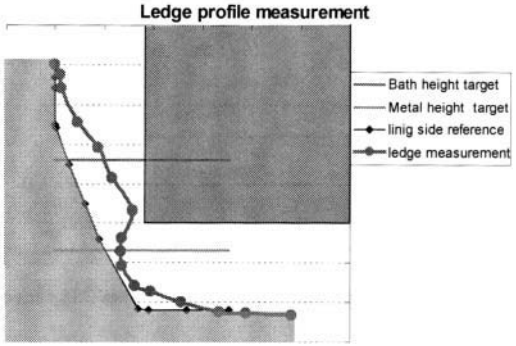

Fig.12: Typical ledge profile for the AP40

At the end of 2010, a measurement campaign was performed in order to confirm the good behaviour of the cell at this level of amperage. Ledge protection was measured along the side of the cell at the bath-metal interface, with typical results as seen in Figure 12. This level of ledge protection limits lining erosion to an acceptable degree.

Table 2: Summary of performance targets and results achieved in the AP40 trials

		AP40 St Jean trial		target	
		Q1 2011*	Q2 2011**	St Jean trial	Greenfield project
Amperage	kA	402,9	400,2	> 400	405
Current Efficiency	%	94,5	94,3	> 93	> 93
Energy Consumption	kWh/tAl	13074	13226	< 13400	< 13150
Energy Consumption @ CE 94,5	kWh/tAl	13078	13202	< 13400	< 13150
Anode Effect	AE/pot/d	0,08	0,13	< 0,1	< 0,1
Stability level	nano-Ohms	46	62	< 70	< 70
Fe Content	ppm	813	1122	< 1000	< 1000

* : February, March, April
** :June, July, August

Potshell maximum temperatures were measured around the shell at the level of the bath-metal interface, showing values ranging from 250°C to 400°C, the pattern following the metal and bath velocity pattern within the cell (see Figure 13).

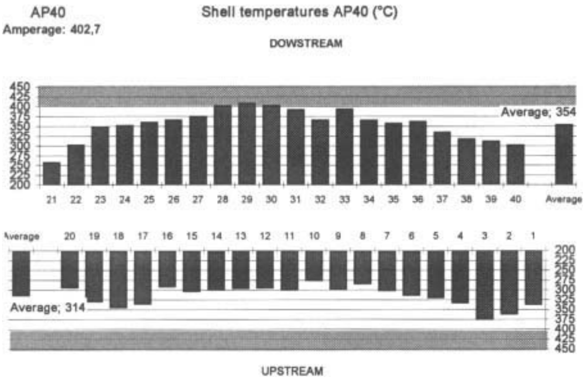

Fig. 13: Cell shell temperatures 403 kA

The temperatures of the collector bars and anode assembly were also measured. The collector bar temperatures do not exceed the safe temperature for the critical connection between collector bar and flexibles. The collector bar current distribution is very uniform, which contributes to maintaining good cell stability.

The anode assembly design is the same as that of the AP39, so the temperatures were thoroughly monitored to ensure that the higher current did not result in unduly high temperatures at the critical points. In particular, the anode clad temperatures showed a significant increase, but they still remained well below the acceptable limit.

AP30 Busbar

One of the main risks identified was that the AP30 busbar network might not be able to handle more than 400 kA in both standard and short-circuit configurations.

For Brownfield projects, the corrective actions implemented for the AP39 testing in St Jean de Maurienne of the first AP30 busbars generation to reach 385-390 kA validated all the modifications and checks to be done to increase amperage above 400 kA. Operation at 405 kA confirmed the adequacy of these arrangements for AP40 cells both in normal industrial operation and in stopped configuration. New equipments were validated after proving their robustness in industrial environment.

For Greenfield project, the AP40 experience confirmed the capability of the last generation of AP30 busbars to operate above 400 kA. The short-circuiting zone and wedges were redesigned and tested and are now part of the up-to-date AP40 package for Greenfield.

Conclusion

Following the intense development of the latest AP30 technology, initiated with the AP39 program, the target of operating regularly at more than 400 kA has been reached for an AP30 based cell with the AP40 technology. This results in a cell producing more than 3000 kg of aluminium per cell per day with reduced capital costs and operating expenses.

Using the same AP39 design but with different operating parameters, AP40 cells proved their robustness in standard industrial operation for an operation at 405 kA, with a specific energy consumption of 13150 kWh/t and an anode effect frequency below 0.1 AE/p/d.

All the associated equipment has also been checked during these trials, and the AP40 technology will be deployed for Greenfield projects or for creeping of AP30 smelters above 400 kA.

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