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AP 50: THE PECHINEY 500 kA CELL

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ABSTRACT

As a result of ten years of extensive tests carried out on three prototypes, Aluminium Pechiney has developed a new generation of reduction cell.

Designed with the help of advanced computer models to achieve magnetic stability and optimize potroom ventilation and temperature, these prototype cells were progressively boosted with improved shell ventilation and modified anode assemblies allowing operation at 500 kA with a current efficiency of 95%.

The AP 50 cell process control features fully integrated automatic measurement of bath temperature and height for enhanced thermal stability. Improved alumina feeding almost totally eliminates anode effects, ensuring a CO_2 equivalent emission level close to the anode consumption CO_2 emission.

The AP 50 technology with a single potline of 336 cells having an annual output of 460 kt will increase productivity per employee by 35% and reduce investment cost by 15% compared to a two-potline AP 30 smelter.

1. INTRODUCTION

Starting in 1975, the Aluminium Pechiney Research Center at Saint Jean de Maurienne (LRF) concentrated its efforts on designing, testing and perfecting the Aluminium Pechiney center point feeding reduction cells.

The story began with the AP 18 pot (180 kA), which was successfully launched in 1978 with the construction of the F line in Saint Jean. Including the most recent Nalco expansion project (India), 3412 AP 18 pots are now in operation, accounting for a total production of 1.8 million tonnes per year.

The AP 30, tested from 1981, was launched in 1986 with the G line, still in Saint Jean, and quickly outperformed its smaller sister, with today 2472 operating pots producing around 2.2 million tonnes per year.

Together, these pots are currently producing 4 million tonnes of aluminum, i.e. 20% of the Western world's overall yearly production.

1989 was the time for the research center to face a new challenge, to push the limits for the size of a reduction cell to further improve the profitability of Greenfield projects.

The design phase ended with the start-up of the first prototype, followed in 1990 with a second pot and finally, in 1993, the third prototype, which was started in the experimental LRF potroom.

The chart of the amperage of the pots (Figure 1) clearly reflects two development stages. During the first stage, the focus was to master the operation of such a large pot at the target amperage of 400 kA. In 1995, the AP 40 technology was ready for industrial usage. However, at this point in time, Aluminium Pechiney had no plans to invest in a new Greenfield smelter.

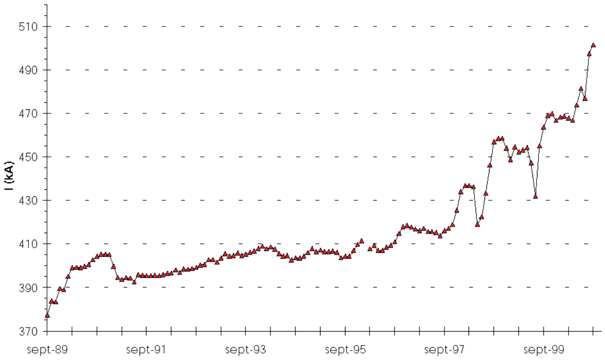

Figure 1: Evolution of prototype amperage.

The consistency and the robustness of the pot operation and the potential of the design encouraged the Aluminium Pechiney research team to undertake a second stage of development aiming at the 500 kA target.

The success in developing the AP 50 technology enabled a significant breakthrough in terms of return on investment of a Greenfield smelter.

2. POT DESIGN

The conceptual design of a new generation of reduction cell today relies on the use of more and more sophisticated mathematical models made available by ever increasing computing resources.

The pillars in the design process are:

- The magnetic and magneto hydrodynamic models to calculate magnetic fields to obtain the optimum stability of the metal pad and to minimize the effect of the horizontal current distribution.
- The thermo-electrical model to evaluate the position of the bath ledge and the optimum location of the isotherms in the lining.
- Electrical models are used to evaluate the overall balance of the busbar as well as mechanical models to compute superstructure and potshell design.
- More advanced routines, like transient thermo-mechanical analysis, are used to study particular points of interest such as the behavior during the start-up phase.

The AP 50 design benefited from the experience developed with the previous AP 18 and AP 30 designs as well as from the parallel work undertaken for the AP 21 and AP 35. The key factor was the ability for the research team to test and check the computed results against a wide range of pots of different size. The overall result is a very robust design integrating all the know-how of the previous generations of the Aluminium Pechiney reduction cells.

However, the AP 50 is not just an upsized version of the AP 30. The design of the new cell includes numerous significant innovations, which have been protected by several patents.

1. An innovative busbar design:

It is well known that the shape of the bath-metal interface and the velocity of the liquids in the pots are dependent on the vertical component of the magnetic field and on the symmetry, or lack of it, of the horizontal components. In the case of high amperage cells, the situation worsens as the sensitivity to the magnetic field increases with the dimension of the metal pad. In order to alleviate such problems, the cell busbar system is designed to partially balance the magnetic field and, in the general case, part of the current outing from the upstream part of one cell is directed to the next cell through passing around cell heads, leading to increased length of the busbar system.

When designing busbars for very high amperage cells, it became obvious that upsizing current design will lead to uneconomical solutions, not only because of the complex shape of the busbar but also because, due to the size of the different bars, the distance between two adjacent pots would have to be widened. This, in turn, would have a significant impact on the length of the potroom building.

Therefore, a new busbar system was designed, which, as illustrated in Figure 2, enables very satisfactory vertical component of the magnetic field and hence metal pad stability.

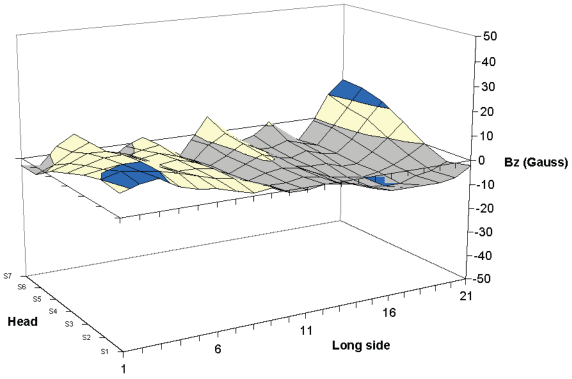

Figure 2: AP 50 vertical magnetic field component.

In comparison with the standard layout, and for amperage of 500 kA, the new AP 50 busbar design allows:

- ➢ Up to 25% decrease in aluminium weight
- ➢ Around 350 mm decrease in pot-to-pot distance
- ➢ Furthermore, the simple design allows high level of prefabrication, for even lower investment cost.

Another benefit of the new busbar system is the possibility of caring easily for the next row compensation.

2. A new superstructure concept:

Another major challenge the research team faced in the development of the AP 50 was the mechanical behavior of an 18 m long superstructure.

A reduction cell superstructure must exhibit sufficient stiffness to ensure:

- Supporting over and above its own weight, the weight of the anode assemblies and the anode beam, the alumina, AlF_3 and bath full hopper, the crustbreakers and feeding devices and the fume ducts.
- Supporting the strain induced by covering bath crust during anodic plane displacement.
- Ensure a consistent ACD all along the pot length for efficient operation of the pot process control system.

The solution was found by using a new superstructure concept, which in addition features new design anode clamps. These new clamps remain on the anode beam during anode change, thus avoiding any safety hazard during this operation. The new anode clamps are designed to ensure proper electrical connection and avoid anode rod slippage even with anode assemblies, which weigh around 50 % more than the AP 30 assemblies.

3. An optimized lining + potshell design:

Several lining designs were tested in order to ensure an extended pot life as well as the best operational stability both during standard operation and start-up phase.

After initial prototypes were started with semigraphitic grade cathode blocks, we selected low electrical resistivity and high thermal conductivity cathode grade; and the industrial version of the pot is equipped with graphitized cathode blocks.

Of particular interest is the layout and choice of material for the side lining: the AP 50 is fitted with the patented improved potshell ventilation device enabling accurate control of the heat flow through the side lining and therefore ensuring the permanent presence of a protective frozen bath ledge with the suitable shape.

Evaluation of different combinations of materials in a range of thermal conductivity, and of heat extraction capability of the potshell ventilation allowed us to find the best fitting for the targeted balance of side heat flow.

Another indirect benefit of this layout is a decrease (80 °C to 100 °C) of the average thermal loading of the potshell and the elimination of hot spots leading to reduced maintenance costs.

4. Anode assemblies optimization :

Increasing the anode surface area, which means looking for the maximum anodic working surface area versus available cathodic area, is an efficient way of increasing amperage as it maximizes the “pot surface” productivity. Furthermore, the resulting decrease in bath resistance contributes to keep the specific energy consumption under control.

The limits of increasing the anode surface are linked to the sizes of the center and side channels. The reduction of the bath volume impacts on the capability of alumina dissolution, the total amount of alumina available and the thermal balance of the side lining.

Pushing the anodic surface to the edge is possible provided an efficient pot process control is available.

Another key parameter to take into consideration is the anode pin dimension, which governs the rate of heat dissipation through the top of the pot.

Final setting of the pin dimension is therefore driven by the targeted heat flow balance of the pot.

3. POT PROCESS CONTROL

The development of the AP 50 technology was also the opportunity for a significant redesign of the Aluminium Pechiney electrolysis information system (ALPSYS).

During their early life, the AP 50 prototypes were fitted with the well-known AP “slope calculation” feeding control system with which most of the AP 18 and AP 30 pots are equipped.

However, with the reduction of the “free” bath volume available in the pot (ref. above paragraph), keeping alumina dissolution under control whilst operating in the “lean” zone and avoiding anode effects became more and more difficult.

At the same time, growing concern about the greenhouse effect was another factor to trigger the need for enhancement of the alumina feeding control system.

A new patented (1) algorithm was developed with the aim of a “lean” operation for high current efficiency with an anode effect rate lower than 0.05 AE/pot/day. Its main feature is a “parabolic slope calculation”, which detects the approach to the AE in a much more accurate way and triggers overfeeding sequence in time to avoid the AE.

The other avenue explored during this period was to reduce the standard deviation on bath temperature and superheat in order to improve the stability of the operations.

The solution was the design of new (2) pot equipment: the semi Continuous & Automatic Measurement Device (CMD). This equipment (Figure 3) performs a dual measurement: bath level determination and bath temperature measurement and is fully integrated in the process control chain, i.e. the pot micro and the potline supervisory systems.

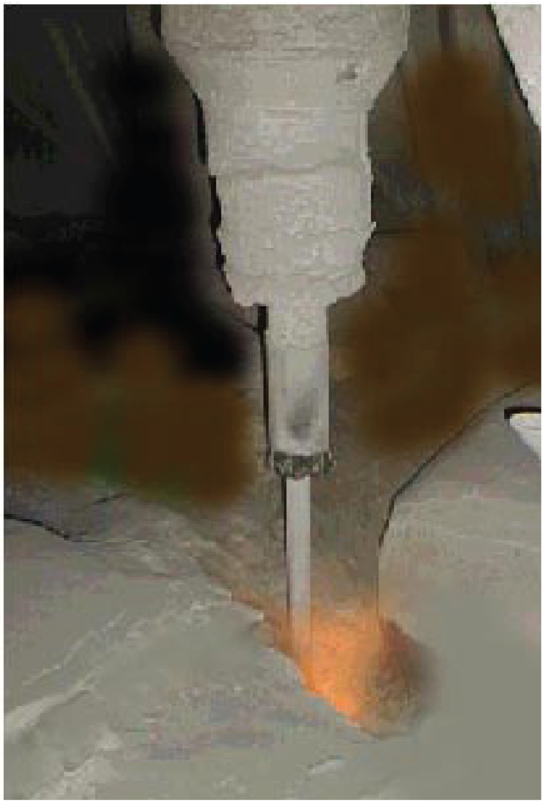

Figure 3: The CMD in operation in the pot.

The AP 50 prototype pots were fitted with CMD early in their life and numerous evaluations of physical location in the pots as well as multiple tests of algorithm were performed during the ten-year period. These developments were described in a previous paper (3).

In 1996, the AP 50 pots were fitted with the new ALPSYS pot micro, which included both the new alumina feeding control algorithm as well as the CMD management and a new algorithm for the bath temperature regulation process (4).

The principle is to calculate the average temperature over the last four shifts in order to eliminate time variations due to normal operations such as tapping and anode change, then to correct the value in order to eliminate spatial variation such as the position of the last changed anode in relation to the position of the CMD measurement hole. The average corrected temperature value is then used by a regulation algorithm, which calculates a corrective additional set point resistance (positive or negative) in order to keep the pot at its set point temperature.

Pots are equipped with a CBFD (Crushed Bath Feeding Device). As in the case of the temperature, the CMD delivers a bath level value for each 8-hour shift. The bath control procedure was modified to make a new calculation of the bath additions every 8- hour shift instead of for every 32-hour operational cycle. A more sensitive bath adjustment table was developed; this had become possible with the additions lasting 8 hours instead of 32 hours. With this new procedure bath level dispersion decreased as did the number of bath tapping operations.

The bath adjustment table requires a bath height value. Another procedure makes it possible to determine the metal level. The bath height is then calculated as the difference between the bath level and the metal level.

4. VENTILATION AND WORKING CONDITIONS

Once the key issues of the pot design and process control are addressed, one must consider the integration of the new pot in the future potroom building.

Of particular interest for the electrolysis process is the potroom ventilation:

- The temperature at the floor level is a key element of the working conditions.
- The flow patterns around the pot shell influence the thermal balance and thus the performance of the pots.

In this area too, computer modeling is the way to forecast the flow pattern around the pots and adjust the potroom building design.

The aim of the model is to predict the:

- Flow rate through the inlets, the gratings along the pots and the roof ventilator
- Temperature distribution at the work floor
- General flow pattern inside the potroom

The model, which has been extensively tested and adjusted on AP 30 potrooms, was used to compute the flow pattern in the LRF's experimental potroom and the temperature profile in-between two pots. The results were in very good agreement, even though the layout of the LRF workshop is vastly different from that of a future industrial building.

Several industrial configurations were studied in order to ensure working conditions equal to or better than the industry benchmark. Figure 4 details an example of computed temperature profile in the centerline between two AP 50 pots for a standardized elevation of 1.4 m above ground.

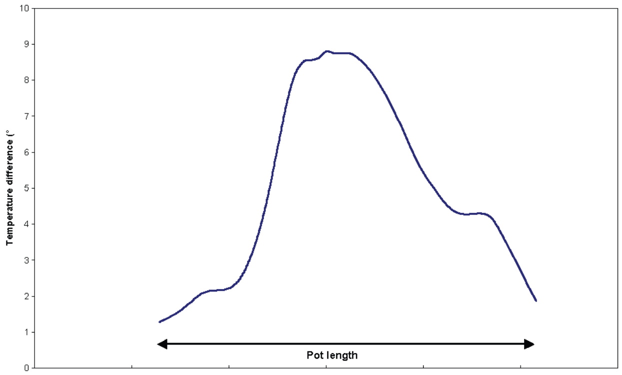

Figure 4. Temperature profiles between two AP 50 pots. X-axis represents the length of the pot whilst Y-axis represents increase from outside temperature.

Fume control efficiency, measured frequently on the prototypes, is excellent and exceeds the regulation limits.

5. AP 50 PROTOTYPE POT PERFORMANCE

The AP 50 prototypes are now stabilized in operation at 500 kA. The three prototypes accumulated ten years of experience in an industrial environment including not only the basic operation but several stoppages and start-ups of new versions with improved design as well as operation at reduced amperage and many outages, some as long as 3 hours, during the several upgrade projects undertaken in the LRF's experimental potroom with the pots in operation. This "real life" experience demonstrates the robustness of the technology.

Key technical results are shown in the following graphs (Figures 5 to 8).

Except during start-up phases, and even with the numerous disturbances of the upgrade projects, the current efficiency matched the industry benchmark of 95%. Such operation enables a production of 3825 kg/pot/day or 5100 kg/pot/tapping on a 32 hour-based organization.

Such a result has been made possible because of the especially low instability level of those pots (typically around 20 nΩ) which, in turn, is the proof of the accuracy of the MHD design.

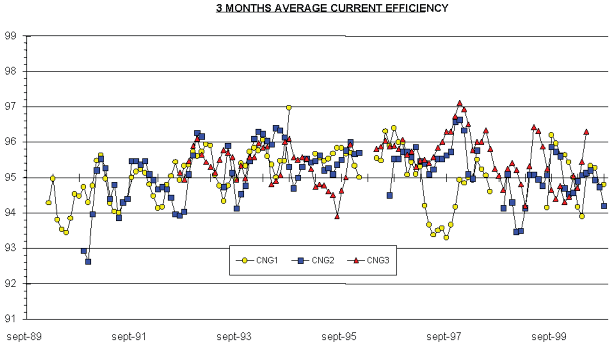

Figure 5: Current efficiency evolution (%).

Another key element of interest is the anode effect frequency. Figure 6 represents the results achieved on prototypes 2 and 3 during 1999.

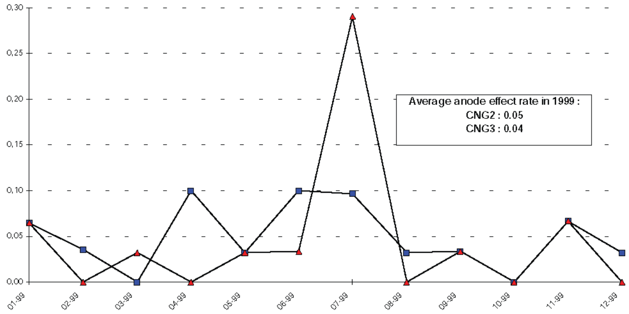

Figure 6: Monthly anode effect frequency on prototypes 2 and 3.

With a yearly average of 0.04 to 0.05 AE/pot/day, the AP 50 pots demonstrate an equivalent CO_2 emission lower than 1.6 t/t Al, i.e. only 0.1t/t Al above the anode consumption CO_2 emission.

In terms of pot life expectation, it is too early to debate statistical results. However, information is already available to assess the potential of the technology in that field.

The side ledge profile shown below (Figure 7) is a representative profile of the AP 50 pots.

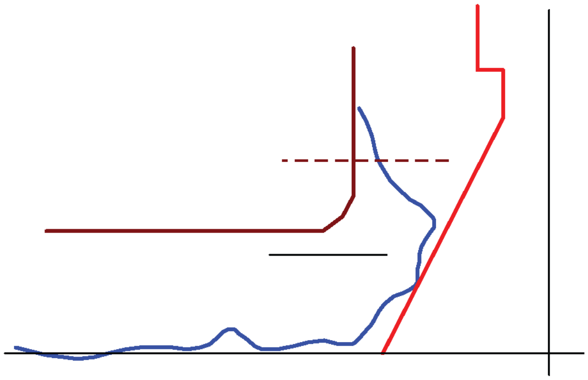

Figure 7: AP 50 side ledge profile.

It is worth noting the lack of heel protruding across the bottom of the cathode and the thickness of the ledge existing at the level of the bath-metal interface. Good protection of the side lining is instrumental for achieving an excellent pot life.

Another encouraging result was achieved when comparing the first results on prototype pots with performance of other smelters using AP technologies. The chart in Figure 8 demonstrates that, for equivalent cathode block quality, the AP 50 compares with industrial results and that no correlation is found between cathode current density and pot life.

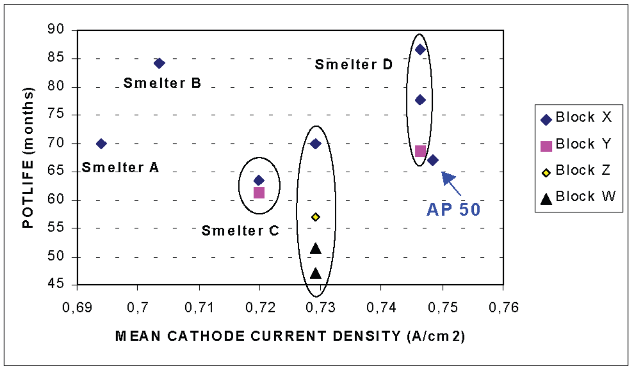

Figure 8: AP 50 first potlife data compared with industrial results.

6. ECONOMICS OF AN AP 50 BASED SMELTER

The economics of a new smelter benefit from an increase of the size of the pot in term of specific investment cost:

- the ratio "building surface area" to "pot surface area" decreases.
- the pot tending and process control equipment required is correlated with the pots regardless of their size.

The operating cost is also decreased due to higher labor productivity.

An AP 50 based smelter will consist of a single potline of 336 pots (this figure being computed from the best combination of pot "working groups", whilst still acceptable regarding the sub-station technology).

The output of this smelter will be 460 kt per year. Such a figure looks well adapted for a joint venture project in an industry undergoing concentration:

- 1990 : AP 30 – 250 kt/y – 1.8% of the world production (14 millions metric tonnes per year)
- 2000 : AP 50 - 460 kt/y – 2.3% of the world production (20 millions metric tonnes per year)

But beyond the pot technology, the AP 50 based smelter will develop new concepts where the smelter is optimized as a whole from the basic engineering, the project and operation organization up to the employee's training package.

This in turn will deliver further savings in terms of investment costs as well as operating cost through reduced project duration and production ramp up.

Table I below details some comparative figures of the different reduction technology generations.

		AP 18	AP 30	AP 50
Number of series / cells		**3 / 720**	**2 / 576**	**1 / 336**
Amperage	**kA**	**190**	**320**	**500**
Capacity	**kt/year**	**380**	**500**	**460**
Productivity	**t/year/ employee**	**350**	**550**	**750**
Investment cost	**US$/t**	**4 500**	**4 000**	**3 400**
Construction time	**month**	**30**	**30**	**24**
Production buildup time	**month**	**18**	**12**	**8**

Table I: Economics of AP 50 key figures.

On the financial viewpoint, these figures correspond to a decrease of respectively 15% and 10 % of investment and operating cost when comparing an installed capacity of 500 kt (2 AP 30 potlines) against 460 kt (a single AP 50 potline) leading to an increase of 4% of the IRR.

7. CONCLUSION

The AP 50 technology is the latest evolution of the AP point feeding cell family. As such, it benefits from the experience of more than 5900 installed reduction cells throughout the world. This new technology, which features significant enhancement both in design and process control, is stabilized at 500 kA with the experience of ten years of operation of three prototypes in an industrial environment and is now ready for industrial implementation.

Beyond the cell technology, the AP50 is the cornerstone of a new approach of highly efficient Greenfield smelters, optimized as a whole from the design phase to the training package.

Reference Journal

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