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RIO TINTO ALCAN AP4X LOW ENERGY CELL DEVELOPMENT

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Abstract

High performance AP4X cell technologies have been developed as part of a complete cell development program based on AP30 platform. The latest development for this technology is AP4XLE, which refers to low energy consumption cell technology at more than 400 kA with a target for energy consumption at 12.4 kWh/kg. This technology aims at maximizing the production and the profitability of smelters having limited energy block size. It could be used either for retrofit of existing AP30 cells or for greenfields. Following the Rio Tinto Alcan cell development methodology and using modeling and low ACD operation knowledge, lining and anode assemblies were designed to support smelters amperage creeping. Both St-Jean-de-Maurienne and Alouette smelters are involved in the development process by operating tests on designated booster sections. Excellent energetic and environment performances have been recorded from these trials. Prototype cell performances and future technology development steps are described in this paper.

AP30 Technology Evolution

The first AP30 technology line was started in 1986 at the Saint-Jean-de-Maurienne Smelter, located in France, at a current intensity of 280 kA and corresponding energy consumption of 13.2 to 13.4 kWh/kg [1]. These cells rapidly demonstrated their robustness and capacity for increased productivity, with amperage reaching more than 300 kA by the beginning of 1990. In order to meet the aluminium industry needs, Rio Tinto Alcan has continuously and successfully developed the AP30 platform towards higher amperage technologies, up to 405 kA with the AP40 validated in 2010 [2]. In 2011, 4282 AP30 cells were in operation worldwide, which corresponded to about 9% of the world aluminium production.

Before 2010, development activities were focused on amperage creep and pot productivity increase up to 3000 kg/pot/d with high current efficiency (94.5%). The specific energy consumption has been kept at approximately 13.0 to 13.4 kWh/kg. To support higher amperage to approximately 370 kA, the AP30 designs have evolved in a way to increase heat dissipation capabilities to disperse the extra heat generated at elevated current intensity. Then, the amperage creep has been supported by an Anode-Cathode Distance (ACD) reduction with a corresponding decrease in specific energy consumption. Nominal performances are listed in Table 1.

Table 1. Nominal Operating Point of the AP3X and AP4X Cells

Cell Technology	Current (kA)	SEC (MWh/t)
AP30	280	13.2
AP36	360	13.3
AP37	370-375	13.15 – 13.55
AP39	385-400	13.0-13.4
AP40	400-405	13.15

Increasing Cost of Power and Low ACD Operation

The world energetic demand is growing and this tendency is expected to persist in the coming years with a corresponding price increase. Therefore, aluminium producers and technology developers are forced to improve the energy efficiency of the aluminium reduction process in order to decrease production costs and improve plant profitability. Moreover, some existing plants operate under fixed energy availability (power contract). For those plants, such as Aluminerie Alouette Inc., optimization of the operation practices and pot regulation improvement to minimize the anode-cathode distance (with a resulting decrease of heat loss and significant decrease in specific energy consumption) were the solutions to maximize the plant production. In some cases, such a power limitation could lead to several pot stoppages as the amperage increases. This approach led to the low ACD operation. Aluminerie Alouette Inc., located in Canada, is leading the AP30 family in terms of low ACD operation and low specific energy consumption [3-4]. It is expected, however, that a limit, in terms of minimum ACD, to ensure cell stability, should be found shortly and, at this time, the ACD reduction will no longer be a lever to decrease the energy consumption.

Before launching design programs for the future cells, Rio Tinto Alcan developed an economical project evaluation model to define the optimal cell design taking into consideration technical and economical data (such as energy and aluminium prices), CAPEX and OPEX. Application of the model to various business case scenarios has demonstrated that low energy cell designs create more value when the energy price is high than high productivity cells. Therefore, low energy cell designs will be a key element to reduce the negative impact of higher energy prices on smelter profitability [5].

Challenge of Low Energy Cell Development

Today, based on different experiments carried out in 2012 in an existing AP30 plant, the minimum ACD for stable pot line operation is believed to be achieved. It is a new challenge to decrease significantly the energy consumption as the amperage increases, all the while maintaining a very low and constant ACD (Figure 1).

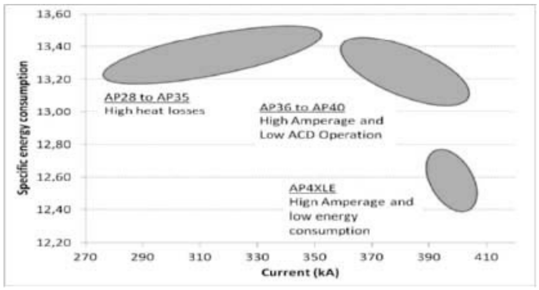

Figure 1. Evolution of the energy consumption of the Rio Tinto Alcan AP3X and AP4X technologies

Using the well-known set of equations, it is possible to describe the relationship between SEC and heat losses.

$$SEC = 2.98\ V_{pot}/CE \text{ (in kWh/kg)} \qquad (1)$$

$$\text{Heat loss} = I \times (V_{pot} - V_{ext} - 1.648CE - 0.48) \text{ (in kW)} \qquad (2)$$

where: V_{pot} : pot voltage;
CE: current efficiency (as a ratio);
I : amperage in kA;
V_{ext}: external voltage drop.

As an example, for a 400 kA operation with constant ACD and constant current efficiency of 93%, and assuming a brownfield situation where it could be too expensive to modify the external conductors, a change in SEC from 13.0 to 12.4 kWh/kg (0.6 kWh/kg decrease) means a reduction of the cell voltage drop of 187 mV with a corresponding change in heat loss of -75 kW.

From those equations, it is obvious that cell voltage and/or external conductor voltage losses must be reduced and, consequently, heat losses dissipated by the cell external surfaces must also be decreased to significantly improve energy consumption. The design solutions could also be different, whether we are looking for a brownfield or a greenfield design, since the options to decrease heat loss and voltage drop may be limited by the existing plant configuration (conductor and busbar cross section, anode size, etc.).

Ways to reduce heat loss are of two kinds:

1. Increase thermal resistance at selected area in the cell.
2. Decrease conductor cross section to reduce heat losses. However, the best compromise lies between heat loss through conductors and voltage drop through them.

The ways to reduce voltage drop:

1. Decreasing the ACD could lead to a significant drop in energy consumption. It is usually the way to manage the ACD with the amperage creep. When the minimum ACD to ensure cell stability has been reached, the ACD reduction is no longer a lever to decrease power consumption. In this particular case, the design challenge is even bigger since all the power reduction lies on the conductor resistance.
2. Increasing the external conductors and busbar cross section while maintaining magnetic stability of the cell and low CAPEX. However, a low energy cell design could be very sensitive to this kind of modification. Once again, the best compromise between heat loss, power consumption and cost has to be established.

In a brownfield situation, the cell is specially designed to meet the customer needs, allow retrofit of the existing AP3X technology and allow a smooth technology implementation. This last statement is very important since the new cell design and the existing one will have to operate at the same current intensity during the implementation period. The current intensity during that period is usually lower than the one targeted for the new cell design. The technical limitations come from the existing plant configuration and the ACD compatible with a full line operation. This last limitation is generally defined by the customers.

AP4XLE Development

AP4X Technology and Cell Development Methodology

In 2010, Rio Tinto Alcan has launched two R&D low energy cell development programs with the ultimate objective to offer low CAPEX and highly productive business solutions to the aluminium industry by extending the AP30 platform towards elevated amperage as well as a low energy consumption for new or retrofit of existing AP30 smelters. The new technology, called AP4XLE, refers to low energy consumption cell technology at more than 400 kA with a 12.4 kWh/kg target for energy consumption and world class overall performance:

- Current intensity: more than 400 kA.
- Specific energy consumption: 12.4 to 12.8 kWh/kg.
- Anode effect frequency: lower than 0.1 AE/pot/d.
- Robustness.
- Low CAPEX with possible retrofitting of existing AP30 plants.

One AP40LE design, compatible with the retrofit of an existing AP30 plant and intended for a nominal 395 kA operation, has been developed and validated with the great help of Aluminerie Alouette Inc. to support amperage creep with limited energy availability. Another design AP4XLE, intended to any new smelter project using the AP30 platform and a current intensity higher than 400 kA, is developed with the help of the Saint-Jean-de-Maurienne Smelter. Several development activities are currently in progress in agreement with the Rio Tinto Alcan Cell Development Cycle (Figure 2) and will lead to the validation of at least two new AP cell designs available for new customers and existing AP30 in 2013.

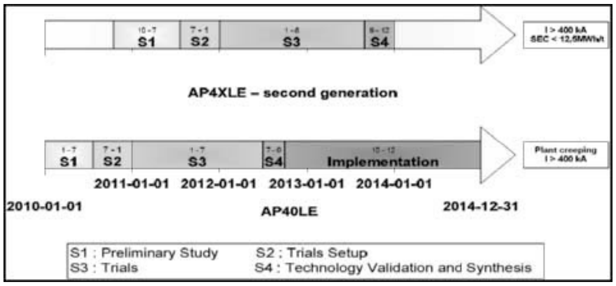

Figure 2. Timelines - Summary of the Rio Tinto Alcan AP40LE and AP4XLE development programs

AP40LE Validation at Aluminerie Alouette Inc.

In 2009, Rio Tinto Alcan and Aluminerie Alouette Inc. have established a « win-win » partnership to develop and validate the AP40LE technology within a two-year period. Rio Tinto Alcan cell design expertise and the Alouette very low ACD operation knowledge were combined to design and test a new AP cell. During the test period, the operating point for the technology validation has been revised with the following targets:

- Nominal current intensity: 395 kA.
- Minimum specific energy consumption: less than 12.75 kWh/kg.
- World class environment performance.
- Increased cell life (more than 2 500 days).
- Similar cathode lining cost.

Four cells were successfully started and operated for a six-month period at 380 kA (expected to be the highest possible current intensity for the cells currently in place for a limited period) and at

395 kA (target for nominal operation) to validate the performance during the implementation period.

To be validated, the technology must comply with the defined targets and specifications in terms of energetic, environment and cell life performances. The trials conducted on the AP40LE technology have led to the validated performances presented in Table 2. The following sections present some detailed results.

Table 2. Validated AP40LE Process Performance at 380 kA and 395 kA

Key Performance Indicator	380 kA	395 kA
Production – t/pot.d	2.83	2.91
SEC (line) – MWh/t	12.78	12.75
AEF – AE/pot.d	< 0.15	< 0.15
Instability – nano-Ohm	76	80

AP40LE Technology Validation at 380 kA

The "Trials" phase of the Cell Development Cycle started in January 2011 with the construction of four AP40LE prototype cells successfully started (with standard anode assembly) and operated until technology validation, in November 2011, at a current intensity of 380 kA, only two years after the beginning of the preliminary study. Thermal and electrical performances were assessed with continuous process performance follow-up and detailed thermo-electrical measurements.

From the first validation step at 380 kA, it has been concluded that it was possible to build and start the AP40LE cell design with standard lining and start-up procedures. The cell could also be operated with standard anode assembly during the implantation period. After six months of stable cell operation, Key Performance Indicators (KPI) were satisfactory and in agreement with the thermo-electrical modeling, considering gaps between the real and the modeled operation parameters (bath and metal levels, postponed anode change).

The AP40LE design has been validated at 380 kA and can be implemented without significant operation issues with satisfactory energetic performances of 12.78 kWh/kg within the design thermal limits.

After validation, efforts were successfully made by Aluminerie Alouette Inc. management and operating team to eliminate the gaps between real operation parameters and those required for the validation at 395 kA.

AP40LE Technology Validation at 395 kA

The amperage of the boosted section was increased from 380 kA to 395 kA in only three weeks, without operation issues despite the magnitude of the operating point change. As shown in Figures 3 and 4, there was a dramatic drop in cell resistance with the corresponding ACD drop. Despite the ACD reduction, the cells did not suffer of an increased instability, which remained normal considering the very low ACD operation.

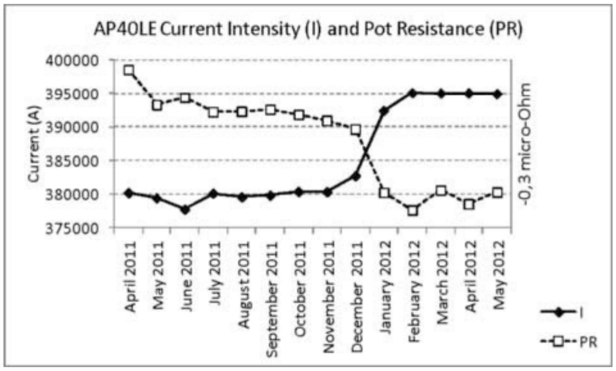

Figure 3. AP40LE current intensity evolution during the validation period

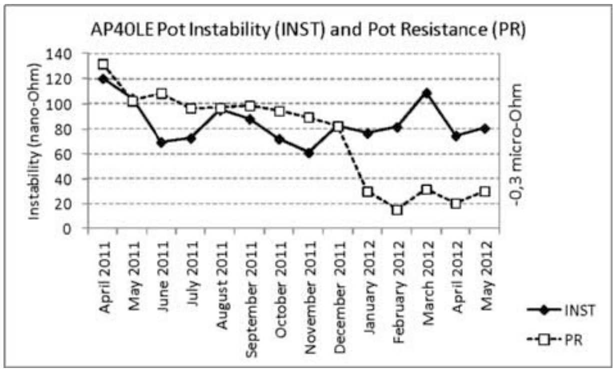

Figure 4. AP40LE cell instabillity evolution during the validation period

In January 2012, three more cells were successfully started at 395 kA to validate the start-up procedure at high amperage with low electrical resistance anode assembly. Only the graphite pad dimensions for electrical preheating were adjusted, taking into account the higher amperage and aiming a 40-hour preheating period.

After the 395 kA amperage had been reached, the cell operating point (cell resistance, liquid level, bath chemistry) was stabilized for a six-month period to reach thermal equilibrium prior to the final validation measurement campaign. Based on the measurements, it was concluded that KPI were on target and as predicted by thermo-electrical models (considering the revised ACD), except for the ledge protection at the bath-metal interface, judged insufficient to ensure long-term robustness. This observation led to a design adjustment recommendation, which is presented in the next section.

Anode effect frequency was recorded over the 16-month testing period and results show that, under controlled bath level (16 to 17 cm) conditions, the AP40LE technology is capable of an anode effect frequency lower than 0.1 EA/pot/d as targeted with very low duration.

Finally, both validated operating points are located in the recommended region with a SEC lower than 12.8 kWh/kg. In Figure 5, the dark dots are the validated operating points.

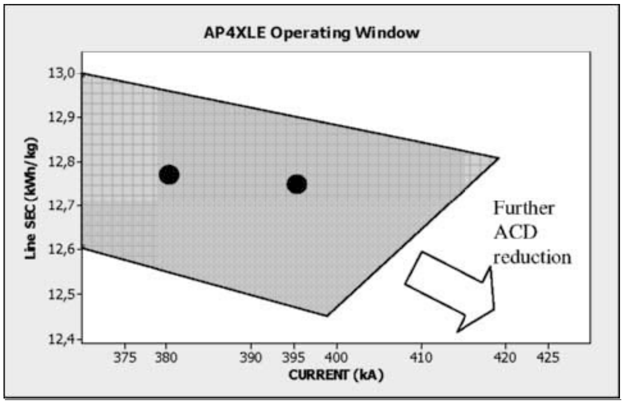

Figure 5. Operation – Potential - AP40LE operating window

Design Adjustment and Cell Life

AP40LE prototype cells are obviously too young to draw any reliable conclusions about the cell life, but the design shows good potential since several features that support elevated cell life were integrated. However, to take advantage of these features, the sidewall must be sufficiently covered with ledge.

During both measurement campaigns conducted during the validation period at 380 kA and 395 kA, ledge profile measurements were done to assess the sidewall protection. Non optimal ledge protection at the bath-metal interface level was measured and, as design improvement, it has been recommended to increase thermal conductivity of the sidewall material to allow the ledge growth below bath-metal interface (Figure 6). This low risk and "implementation ready" design adjustment is effective and has been integrated into the final validated design. From thermo-electrical modeling, recommended change in thermal conductivity of the sidewall allows up to 20 mm protective ledge in front of the sidewall materials.

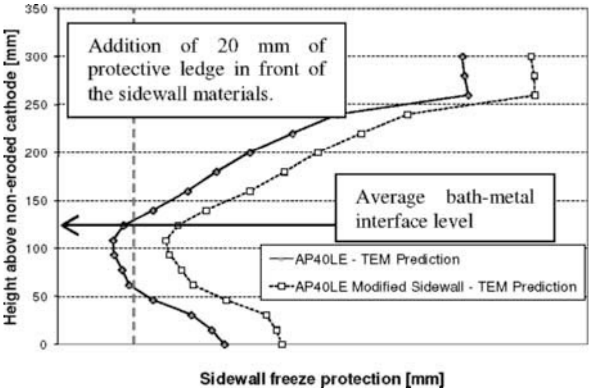

Figure 6. Ledge thickness in front of the sidewall materials

During the "Preliminary Study" phase of the development cycle, design experts and low ACD operation experts combined their respective knowledge and knowhow to define a design with the lowest possible electrical resistance and the lowest heat loss to support a very low heat generation at high amperage and very low energy consumption.

AP4XLE Trial at St-Jean-de-Maurienne

By definition, a greenfield design does not depend so much on plant configuration. However, it has to be tested on existing boosted section and available plant configuration. For practical reasons, the boosted section of the Rio Tinto Alcan St-Jean-de-Maurienne Smelter has been designated as the trial site for the test. This boosted section is not entirely equipped with the optimized features of the new design (available anode design and external conductors configuration). As a result, some of the features must be individually tested or modeled and trial pots must be especially designed to be representative of the thermal equilibrium that the AP4XLE would have under optimized conditions. This condition has been met by designing a test cell with the same thermal and chemical equilibrium and heat loss from the bath to be operated on the available booster configuration.

Several risks and gap analyses were conducted to understand and quantify, with a high level of confidence, the impact of these gaps through various modeling and experimented activities. We can extrapolate the performance of the test pots to that of the optimized AP4XLE, which is expected to reach specific energy consumption as low as 12.4 kWh/kg (Figure 7). The technology validation from the industrial scale trials should be completed by the end of 2013.

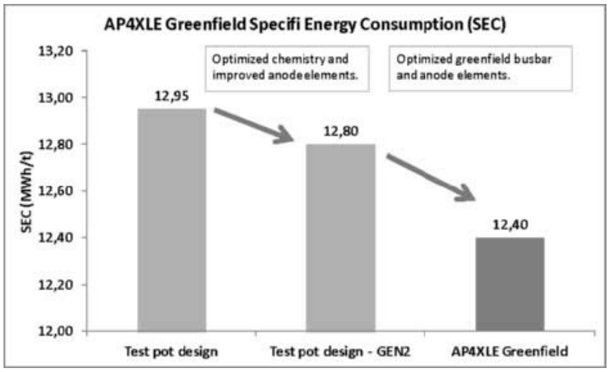

Figure 7. Extrapolation of the test pots performance of the AP4XLE greenfield under optimized conditions

Next Steps

The implementation of the validated AP40LE design will be launched shortly on a replacement basis at Aluminerie Alouette Inc. to prepare the pot lines for the amperage creeping. With this implementation, Aluminerie Alouette Inc. and Rio Tinto Alcan will keep improving the technology performance by optimizing the operating procedures and cell thermal design as well as power regulation.

Other tests to validate the optimized AP4XLE greenfield design are already ongoing. Rio Tinto Alcan plans to validate this design with industrial scale tests by the end of year 2013.

Optimization of the required CAPEX (for maximum profitability) and the technology engineering in order to deliver the technology package will be completed.

As the tests current intensity of the available booster section will gradually move towards higher amperage, Rio Tinto Alcan will develop the AP4XLE design towards higher amperage.

Conclusions

Low energy cell development programs are conducted by Rio Tinto Alcan with the great help of internal and external partners to continuously create value as the price of energy increases.

The AP4XLE keeps pushing the AP30 platform limits beyond 400 kA, with business solutions for either greenfield smelters or the retrofit of existing AP30 smelters.

Within the two-year period, design and test activities led to the validation of a AP40LE design with a specific energy consumption of 12.75 kWh/kg, capable of world class environmental performance in terms of gas emission and cell life.

Based on the promising results from pot trials, Rio Tinto Alcan is on its way to validate a 12.4 kWh/kg AP4XLE technology by the end of 2013.

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