AP12 Low-Energy Technology at ALRO Smelter

Marian Cilianu, Bertrand Allano, Ion Mihaescu, Gheorghe Dobra,
Claude Ritter, Yves Caratini, and André Augé

Abstract

Electricity cost is one of the main determinants of the competitive structure of an aluminium smelter. Over the past few years, ALRO Group, the biggest industrial power consumer in Romania, has completed ambitious projects to reduce specific energy consumption. To reach the next level, in 2018, ALRO mandated Rio Tinto Aluminium Pechiney (RTAP) to supply AP12 Low Energy technology. To guarantee smooth technology transfer and achieve step-change performance the AP Technology™ standard "cell development cycle" approach was used. ALRO and RTAP worked together as a team to execute specific activities such as a measurement campaign, modelling, risk analysis, readiness assessment, on-site and remote support, data analytics, Go/No Go. This article presents this project, which achieved a significant reduction in specific energy consumption, along with some of the supporting activities and tools.

Keywords

Aluminium electrolysis • Cell design • Low energy • Technology transfer and validation

Introduction

ALRO Group is the biggest industrial consumer of electricity in Romania, taking about 9% of the country's total. Increasing energy prices and strong competition leading to low London Metal Exchange (LME) aluminium prices have forced aluminium smelters all over the world to reduce their energy consumption. Electricity direct and associated costs (green and CO_2 certificates, cogeneration tax, injection fee, transportation, distribution, system services, reactive energy) are the most important determinants of the competitive structure of the aluminium industry. Over the past few years, successive cost-cutting plans have reduced the in-house technical resources available to the ALRO smelter. Meanwhile, major firms such as Norsk Hydro, Rio Tinto, and Gami have carried out ambitious projects aimed at progressively reducing the anode–cathode distance (ACD) so as to lower specific energy consumption (SEC). In 2018, ALRO entered into an agreement with Rio Tinto Aluminium Pechiney (RTAP) for the supply of the AP12LE technology. To meet this kind of challenge and to guarantee a smooth and reliable improvement in performance, RTAP has developed a whole suite of benchmark tools, including technical support from a location distant from the smelter concerned. This article presents the project for upgrading ALRO's pots from AP12 to AP12LE, and describes some of those benchmark tools, including the operating window, the low ACD operation assessment and development plan, the transition plan for moving from the present situation to the new one, the go-no go process, and also covers the remote support system.

About ALRO

The ALRO Group covers the whole aluminium production chain. This includes a bauxite mine in Sierra Leone from where 1200 kt/y are transported by sea and barges to the

M. Cilianu (✉) · I. Mihaescu
Alro Primary Division, Vimetco Alro, Romania
e-mail: mcilianu@alro.ro

B. Allano · C. Ritter · Y. Caratini · A. Augé
Aluminium Technology Solutions, Rio Tinto, France

G. Dobra
Vimetco, Romania

L. Perander (ed.), *Light Metals 2021*, The Minerals, Metals & Materials Series,
https://doi.org/10.1007/978-3-030-65396-5_84

alumina refinery in Tulcea. About 400 kt of alumina go to the ALRO smelter from which 260 kt of primary aluminium and 30 kt of aluminium scrap are transformed into value-added products. Wire rod, rolled products, and extruded products are made at Slatina. Continuous improvement principles guide us to invest in assets which update our competitiveness and increase our worker skills. Investing in rectifiers and substations, in energy efficiency and in implementing ISO 50001 show our concern for surviving in one of the highest cost environments in Europe for smelters.

ALRO Slatina has four potlines, out of which three are functioning for a total of 600 pots in operation, together with all the supporting facilities consisting of green anode shops, anode baking furnaces, rodding shop, rectifiers and utilities, cast house, spare parts plant, and gas treatment centres, including all the infrastructure for handling alumina, coke and pitch, and so on.

The AP12 Low Energy Project

In 2017–2018, ALRO entered into discussions with RTAP to study the possibility of reducing SEC even though this smelter is one of the most efficient plants of its generation. Rio Tinto has a solid track record in this field, with almost all of its plants operating at higher amperage than that for which they were first designed. Similarly, in ALRO the AP8 technology which was designed for 80 kA is now operating at 120 kA, based on modifications performed in-house [1].

The project development cycle illustrated in Fig. 1 is used to ensure that the proposed design will be optimal considering the technical and economic constraints of the plant.

Technology Bricks Selection

Each plant has its own improvement strategy, driven by its particular technical and economic constraints. RTAP has developed a full portfolio of technological improvements, referred to as “AP Technology™ bricks”. Examples are a magnetic compensation loop, a low energy lining, and optimised anode slots. Their main targets are either to lower the pot’s energy consumption or to increase its productivity. ALRO used Low-Energy bricks [2], because the AP12LE pot design is based on this approach as developed by RTAP, using new lining materials, new cathodes and busbar assemblies, and slotted anodes (Fig. 2).

Risk Analysis

It is important at the start to have an operational assessment of the capability of the plant to handle a progressive improvement project. In particular, good operating practices need to be assessed. The areas covered are the following:

- anode fabrication, with all the main areas of activity: paste plant, anode handling and storage, anode baking including fume treatment, anode rodding including bath and carbon recycling;
- reduction, including potlines and gas treatment centres, metal transportation, raw material handling, and operation accuracy;
- rectifier station and utilities;
- pot repair and maintenance system.

Measurement Campaign

The next step is a thorough measurement campaign. The results are used to calibrate the numerical models described below. All data were gathered into a virtual data room made especially for this project (Fig. 3).

Modelling and Basic Design

RTAP performed magneto-hydro-dynamic (MHD) and thermo-electrical (TE) modelling based on the pot data collected during the off-site review and the on-site mission [3]. This modelling has three phases:

- Model development, in which different modelling software will be used to build different virtual copies of the pots to be used for the TE and MHD models. The information needed for this phase is in the detailed pot drawings.
- Model calibration, which is the most critical phase of the study. It consists of adjusting the model coefficients so that the results of modelling the existing pot design correspond to the actual measured values. This phase ensures that the model developed will show the same behaviour as the actual pot.
- Model use, in which the models are used to evaluate the new operating point corresponding to the modification proposed.

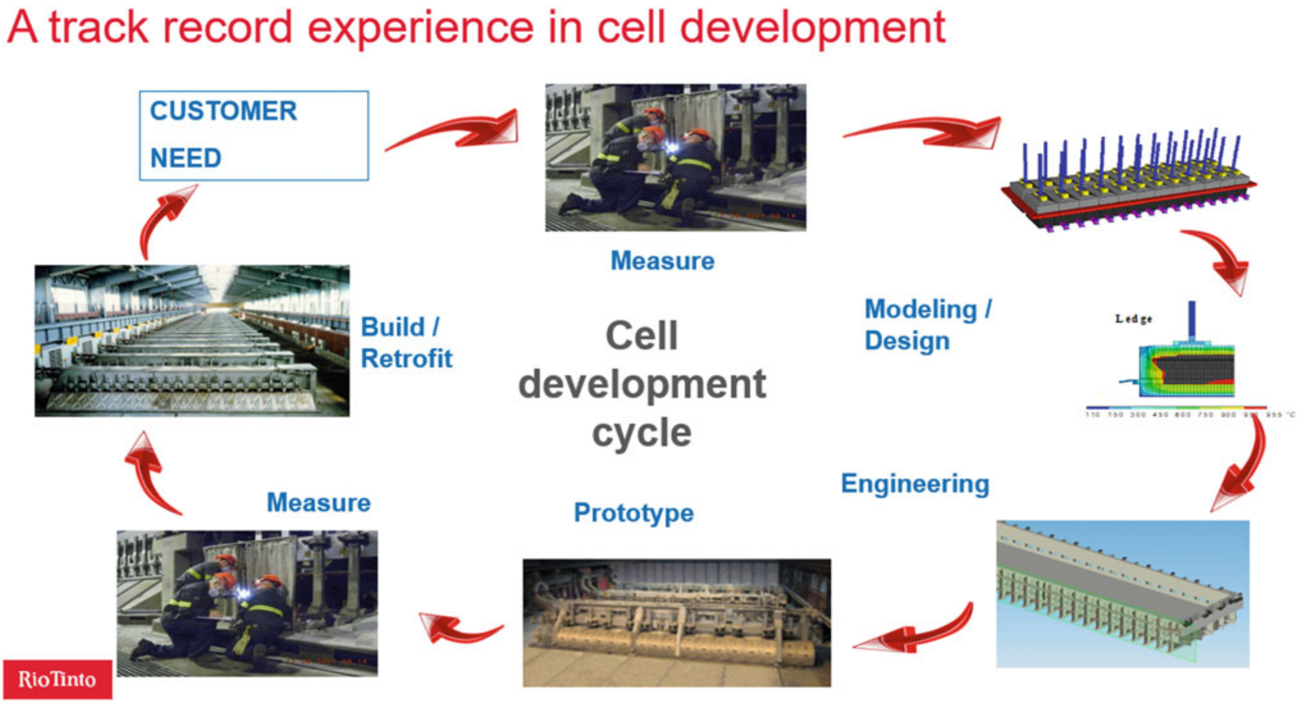


Fig. 1 AP Technology™ cell development cycle. (Color figure online)

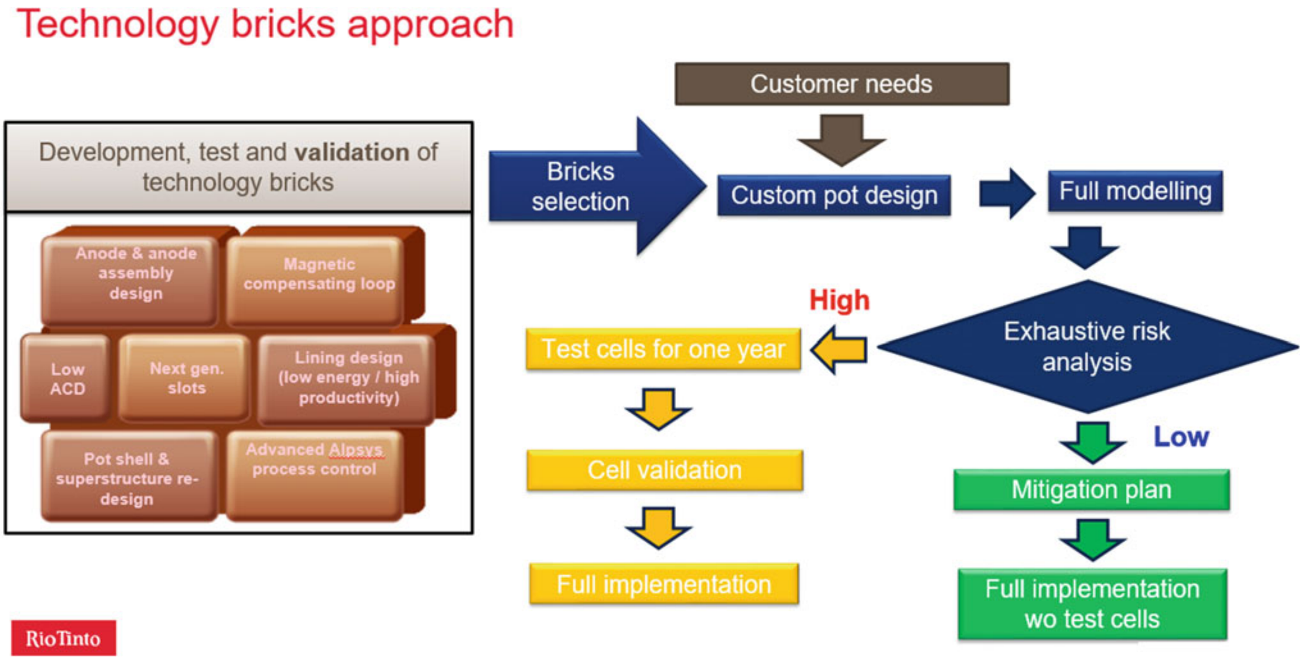


Fig. 2 AP Technology™ bricks approach. (Color figure online)

MHD modelling makes it possible to define and predict the pot robustness and stability, depending on the busbar design and on the pot environment generally. This may lead to modifying the busbars or alternatively adding a compensation loop in order to increase the stability margin. The distribution of the vertical component B_z of the magnetic field (Fig. 4) should ideally be symmetric about both central axes. That for the optimized design, though not ideal in this respect, is clearly better than that of the standard design. Despite this, the optimized design with busbars underneath the cell was abandoned after economic evaluation.

Fig. 3 Ledge measurement at ALRO. (Color figure online)

The TE modelling makes it possible to predict the thermal balance and temperature distribution in the pot, depending on the anode and cathode design solutions implemented, as shown in Fig. 5.

Once the design was adjusted to get the correct thermal balance, the thermoelectric model predicted the performance of the AP12LE compared with that of the AP12 as shown in Table 1.

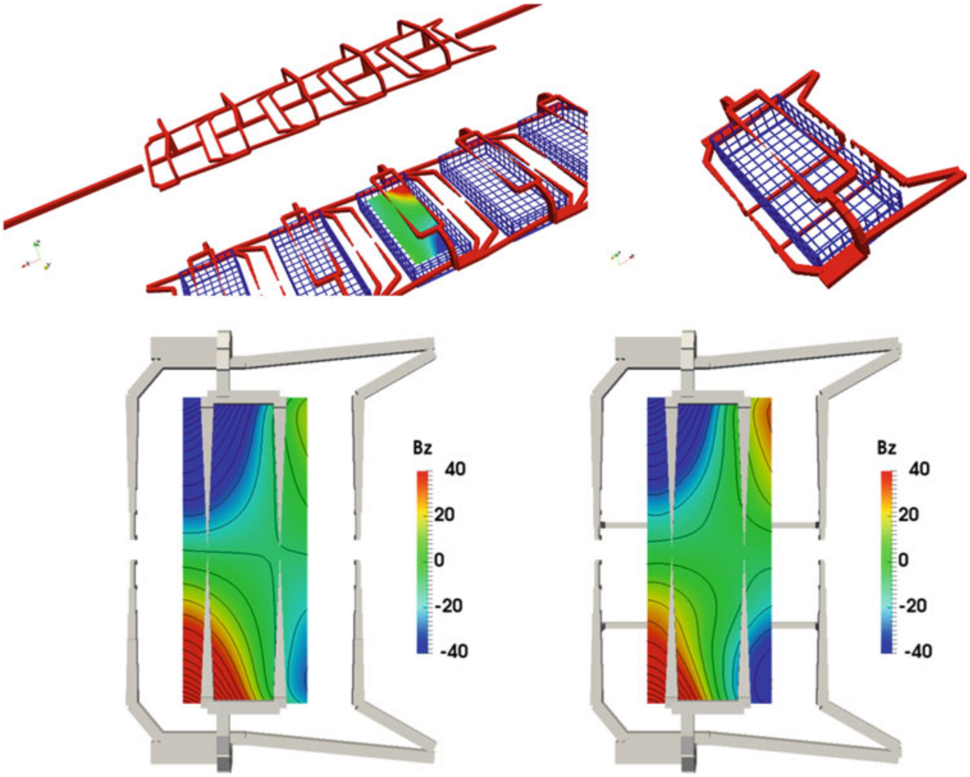
A major output of the thermoelectric model is the operating window, which helps to set the parameters during the change in line current, as illustrated in Fig. 6. The operating points are defined in terms of pot voltage, amperage, specific energy consumption, current efficiency, and anode–cathode distance (ACD) defining the operating windows.

Using these two models made it possible to predict the effect on the pot operating points of the implementation of AP Technology™ bricks that have already been validated for other pot technologies.

Engineering

The basic design resulting from the modelling must now be translated into detailed drawings and specifications, and this is done in the engineering stage. It must be borne in mind that the basic changes decided in the modelling phase may affect many other departments of the smelter, as Fig. 7 shows. For this reason, all the consequent effects were freshly evaluated after engineering. The result of this was that ALRO needed to change a lot of tools and procedures, and also to improve the repairing skills of both its own workers and those of its service suppliers.

Fig. 4 Standard (upper left) and optimized (upper right) busbar design with corresponding (lower) calculated vertical magnetic field Bz (in Gauss). (Color figure online)



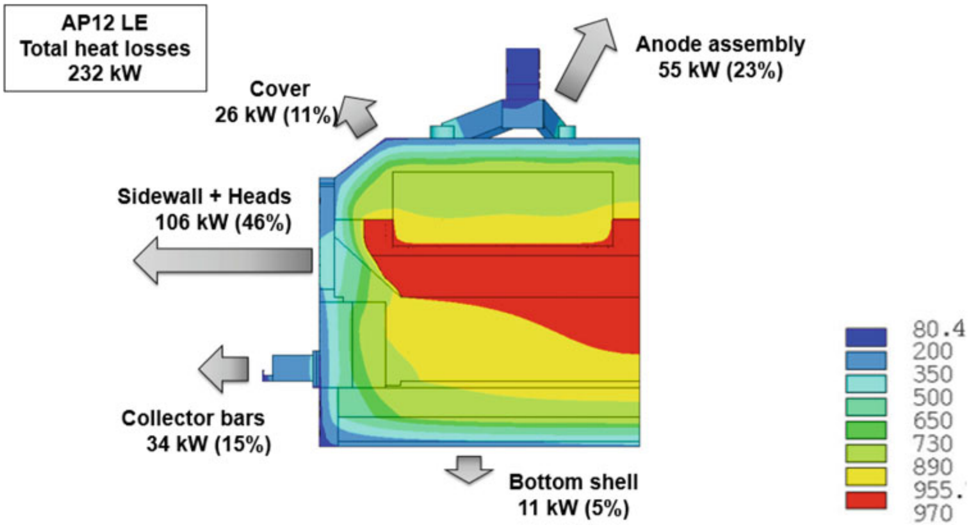


Fig. 5 AP12 LE thermal balance. (Color figure online)

Table 1 Main parameters for the AP12LE technology compared with those of the AP12

Parameter	AP12	AP12LE
Operating point		
Line current (kA)	120	120
ACD (mm)	43.3	44.0
Current efficiency (%)	95.7	95.7
Electrical results		
Micropot voltage (V)	4.138	4.045
Anode resistance (μΩ)	2.82	2.82
Cathode resistance (μΩ)	2.88	2.32
SEC (kWh/t)	13,300	13,000
Heat loss (kW)	243	232
Thermal results		
Ledge toe (mm)	120	5
Average ledge in metal (mm)	70	40
Ledge at BMI (mm)	110	90
Superheat (°C)	4	5
Fraction of cathode $<T_{liq}$ (%)	4	3
Maximum shell temperature (°C)	338	344

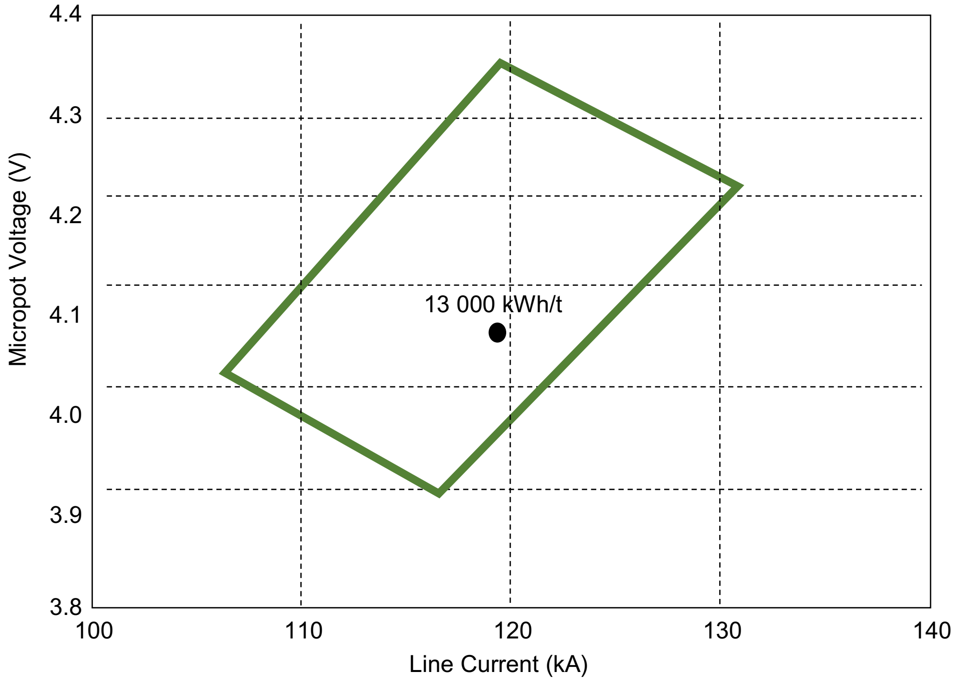
The material purchasing procedures were adjusted to match RTAP requirements. In particular, suppliers were selected from RTAP's list of recommended suppliers, and material acceptance criteria were discussed case-by-case with RTAP to ease procurement without compromising pot performance.

Prototype Pot Lining

After the detailed design had been worked out, the construction and start-up phase followed. At the beginning of the construction phase of the new AP12LE pots, an AP Technology™ lining expert came to ALRO in order to show how to use the new materials, to validate new tools, to give training to trainers (managers and inspectors), to define new inspection and control KPI's and so on. ALRO managers then transferred that knowledge to the workers and service suppliers, ensuring a smooth transition to new practices.

Best practices put in place take into account the fact that at ALRO, the AP12LE project is a brownfield one, with progressive implementation of the new pot design that follows the natural replacement rate of the pots (that is, about eighty pots per year). The first stage of the "building" phase

Fig. 6 Operating window with target set point and sensitivity. (Color figure online)



Parameter	Change in parameter (mm)	Effect on internal power (kW)	Effect on line current (kA)
ACD	+2.9	+10	+2.3
Metal height	-2.4	-9	-2.0

was then to build and start a sufficient number of AP12LE pots to be statistically significant—that is, about—regardless of the problems that might arise. ALRO and RTAP had agreed to perform a statistical study six months after the first AP12LE pot start-up, in order to compare the performance of the first AP12LE pots with the same number of classical ALRO design pots.

An old plant that is to receive a new technology has its own specific needs and constraints related to the way it carries out operations, because shortcuts do appear and habits change over time, and new technologies require a change in mentality. Therefore, to be sure of covering all ALRO specificities, the AP12LE retrofitting was performed in all three potrooms despite the consequent difficulties in demonstrating the results.

Start-Up

Once built, the first AP12LE pots were started with the support of an AP Technology™ start-up expert. The new AP12LE start-up procedure is based on the existing one, with some improvements. The resistive heating of the pots for 48 h uses about 15 MWh. Figure 8 illustrates the central channel average temperature during preheating for the pots that were started first. The pots entered full production after about seven days, by which time the pot voltage and metal production are acceptably close to those of the rest of the pots.

Follow-Up

To ensure a good follow-up, we used a software and a configuration platform (Fig. 9) to gather all the results of the modernized pots, as follows:

- a supervising computer which allowed communication with the pot;
- a database server which memorizes process data;
- desktop clients using a regular PC;
- a web client which gives access from a PC, tablet, or smartphone.

While the AP12LE’s were being built, ALRO’s reduction team and AP Technology™ process experts defined and implemented a remote process support scheme. RTAP created a tool called RADAR—a Business Intelligence application used to analyse data coming from the pot control systems.

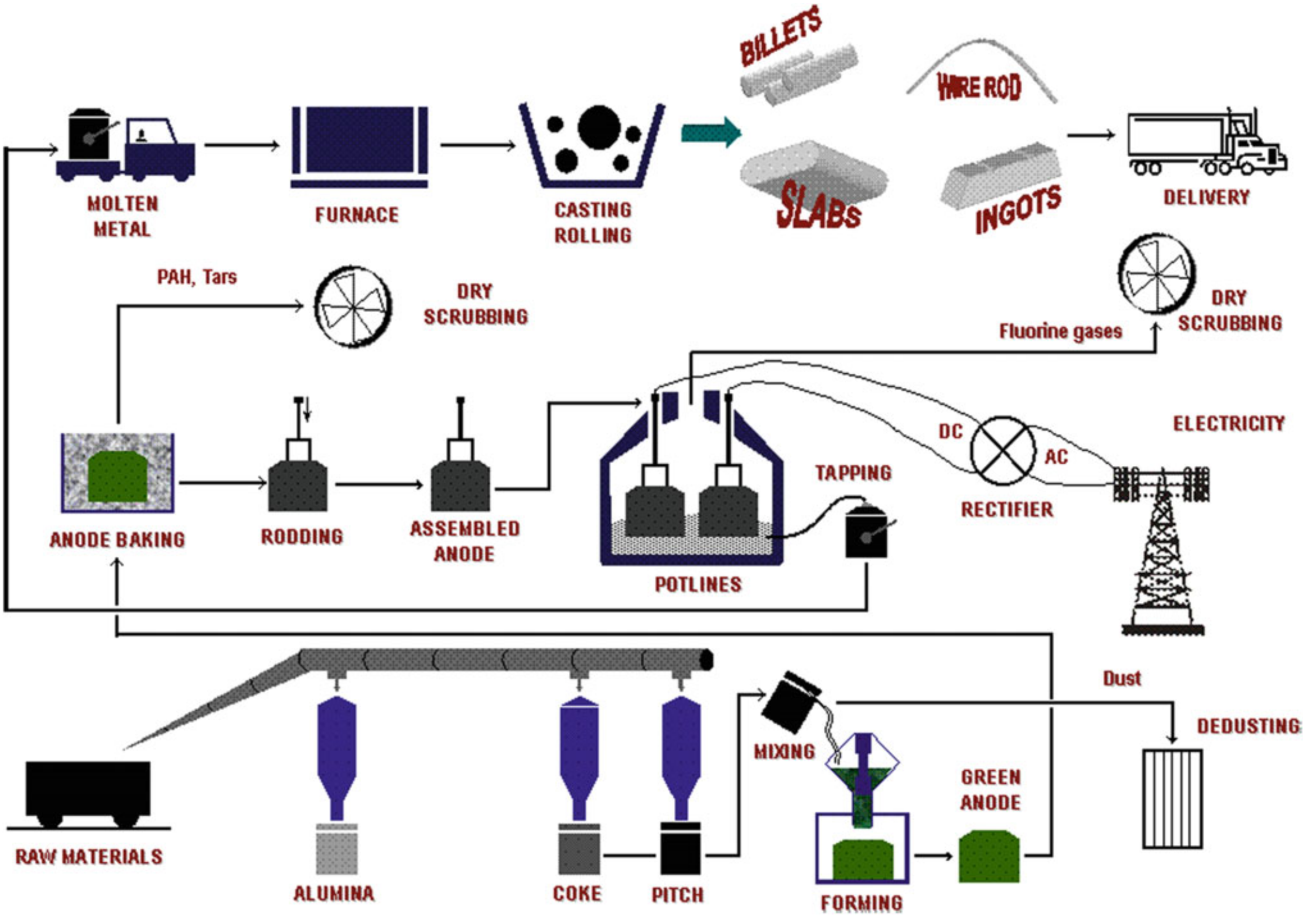


Fig. 7 Assessing the effect of the changes on all departments. (Color figure online)

This application is based on QlikView$^{(R)}$ software and delivers the appropriate level of information for a process expert to be able to make relevant analysis, draw adequate conclusions, and recommend appropriate adjustments. A typical RADAR screenshot shows the very high degree of detailed surveillance available to the support reduction team even remotely, from thousands of kilometres away.

Remote support was mainly for adjusting AP12LE process parameters to make sure start-up and stabilising were progressing according to plan. Remote support took the form of two phone conferences a month between the ALRO technical people and RTAP experts using the following standard agenda:

- following the evolution of the relevant KPI's, which are superheat, instability, temperature, voltage, feeding, metal height, temperature, AlF_3;
- the different analyses performed, presentation of arguments, and discussion of the results leading to consensus on what is to be done;
- RTAP's analysis and corresponding recommendations resulting from the last meeting;
- the action plan follow-up.

All analyses were performed remotely from the various RTAP facilities where the specialists are located, providing RTAP's designated process expert on this project with almost continuously updated data and analysis.

During the phone conferences, it was also possible to share real-time information using RADAR to focus on the situation of any individual pot or group of pots.

RTAP ability to provide efficient remote process support is essential for a project like ALRO AP12LE that will last about seven years.

Parameter Adjustment

A "go-no go" process as shown in Table 2 was defined and put in place to make sure everything is under control before further progressing with the project. On-site support was focused on the operational side, making sure all the delivered procedures were correctly followed.

Regular measurements have to be carried out and energy consumption closely followed in order to make sure the AP12LE pots stay under control.

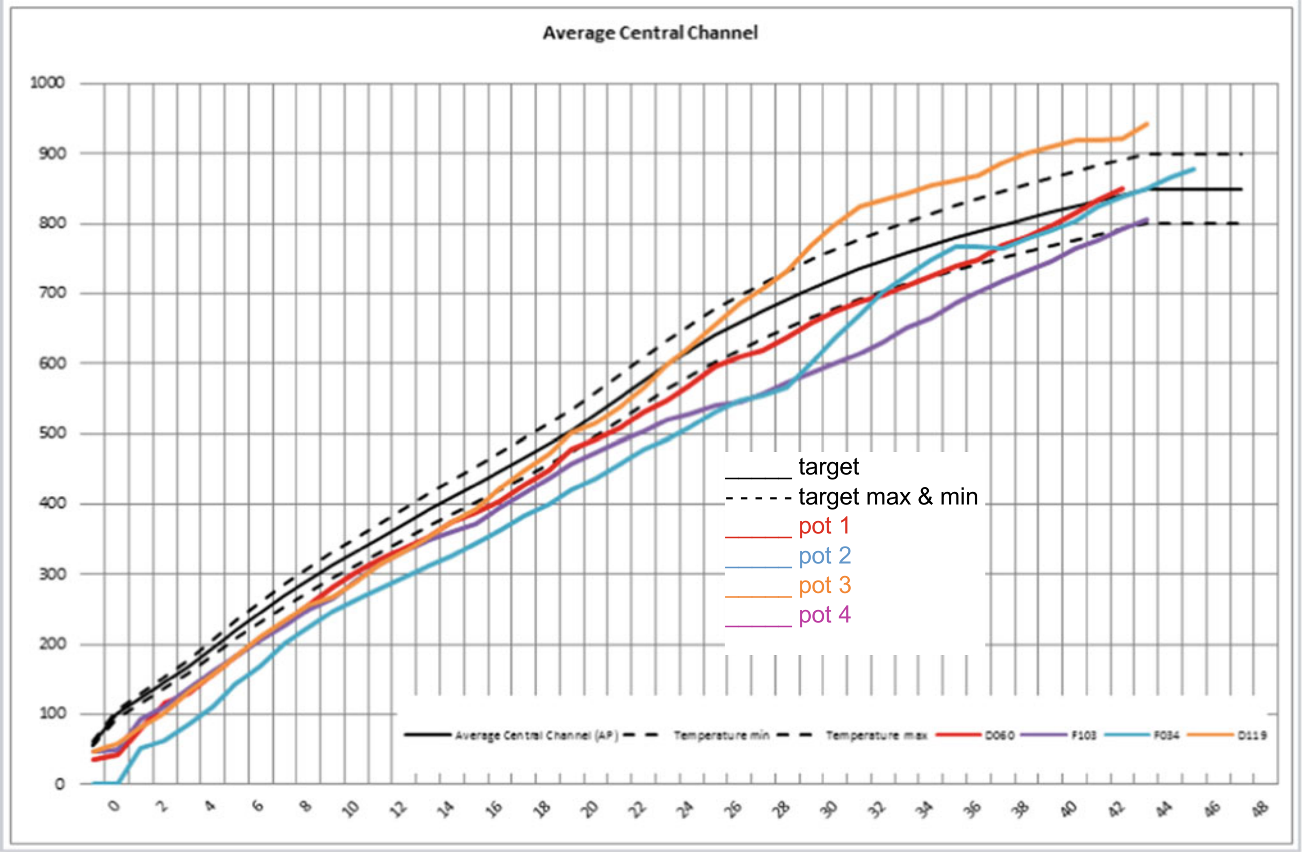


Fig. 8 Central channel average bath temperature (°C) during preheating (hours). (Color figure online)

Fig. 9 The platform for process monitoring

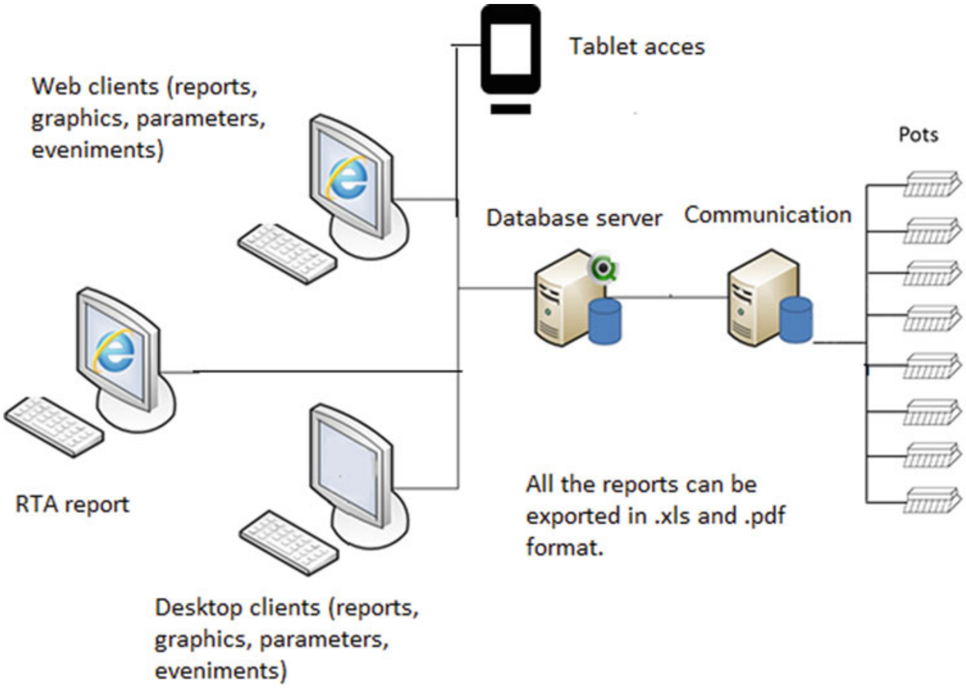


Table 2 Example of Go/No Go tool

GO/NO GO criteria		
Production	*GO*	NO GO
Thermal balance	*GO*	NO GO
Instability	*GO*	NO GO
Power	*GO*	NO GO
Bath height management	*GO*	NO GO
Process measurements	*GO*	NO GO
Sick pots/pots failures	*GO*	NO GO
Operations	**GO**	NO GO
All operations done on schedule	**GO**	NO GO
Anode change compliance past two weeks	**GO**	NO GO
Anode covering audits past two weeks	**GO**	NO GO
Anodes	***GO***	NO GO

GO—process, **GO**—operations, ***GO***—anodes

During the validation process, technology risks are assessed and tests are performed as required to verify the performance of the modified pots. Figure 10 illustrates the continuous improvement of the AP12LE cells compared to the standard ones. It needs at least six weeks to set the AP12LE cells parameters optimally.

Validation

ALRO and RTAP agreed to perform, six months after the first pot start-up, a statistical study on a representative number of AP12LE pots in comparison with the same number of classical ALRO design in order to assess their respective performances.

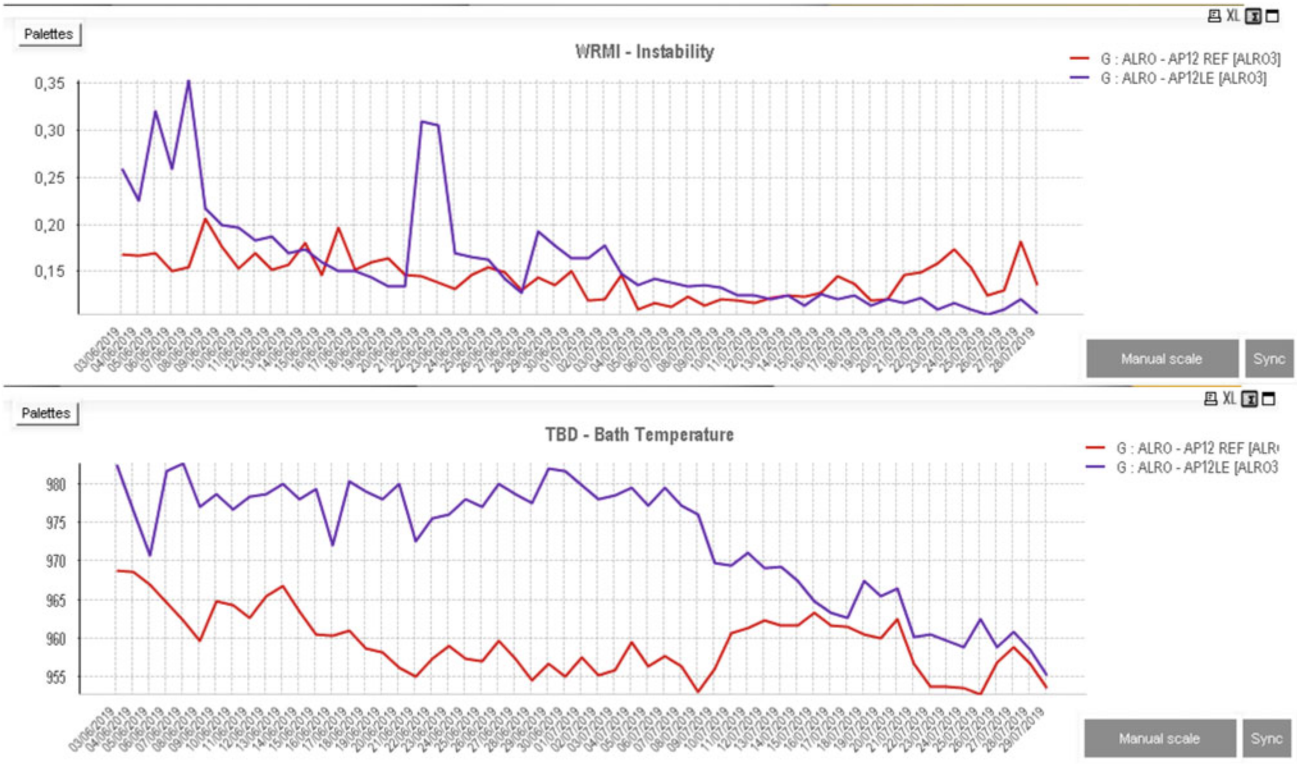


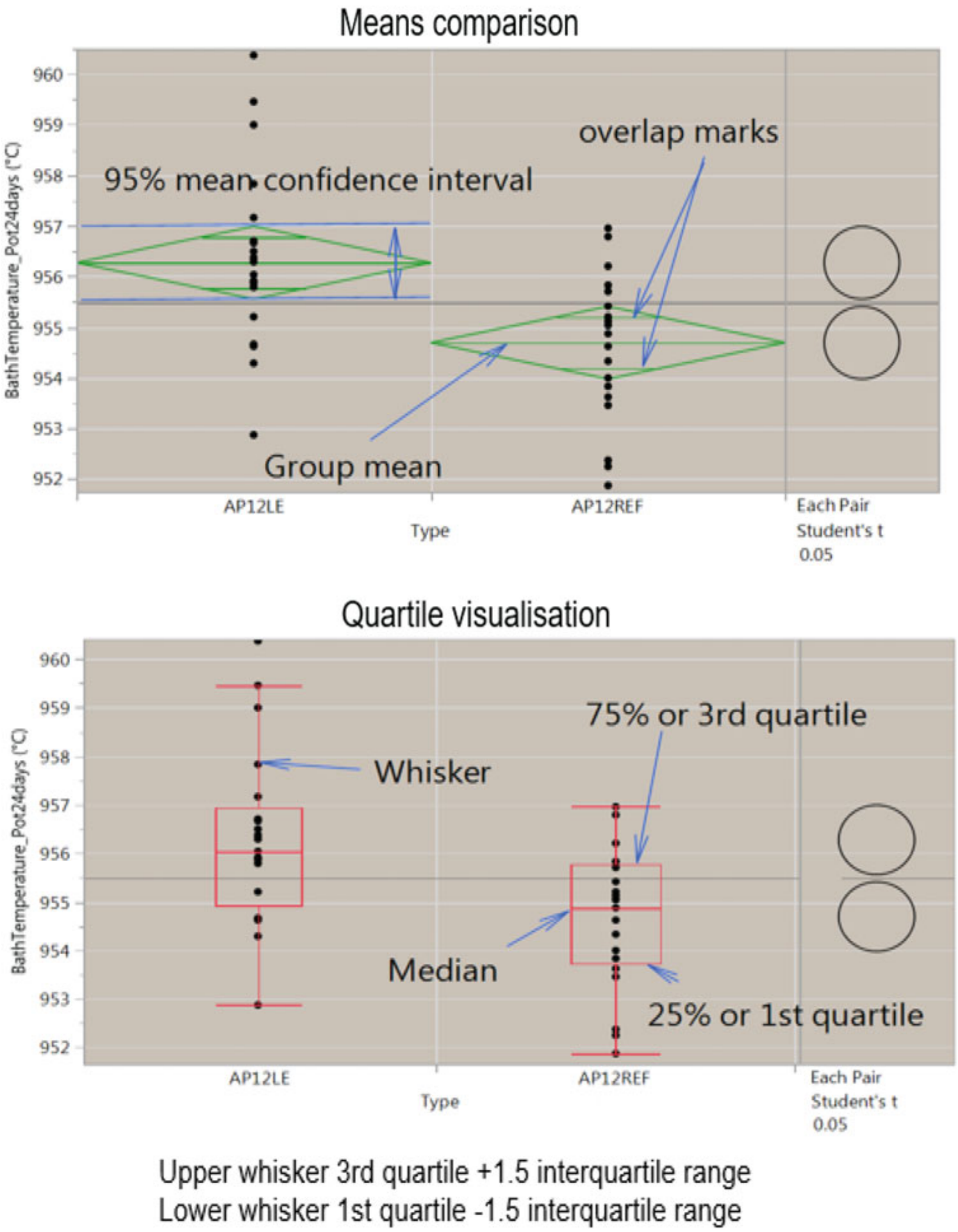
Fig. 10 Evolution of the instability (upper graph in micro-ohm) and bath temperature (lower graph in °C) of the AP12LE cells compared with those of standard cells. Observations made every day for eight weeks

Due to the economic situation at the date of the work, ALRO had been operating its potlines at reduced amperage (around 114 kA) for several months. ALRO and RTAP agreed at the end of 2019 to perform this statistical evaluation at the beginning of 2020, despite the reduced amperage (24 days' evaluation from 7–30 January 2020).

We performed the statistical performance evaluation under the following conditions, as illustrated in Fig. 11:

- 24 days evaluation period from January 7 to January 30.
- Metal pad measurement on all AP12LE at the beginning and at the end of the evaluation period.
- Issued our standard follow-up report comparing the 21 AP12LE with the 21 references over this period.
- For each pot main indicator (voltage, heat loss, energy consumption, CE, AlF_3, temperature, cathode resistance, anode effect, number of shots…), we compared the

Fig. 11 Statistical graphs (JMP®software) used to compare AP12LE cell performance with that of standard cells: here, the example of bath temperature



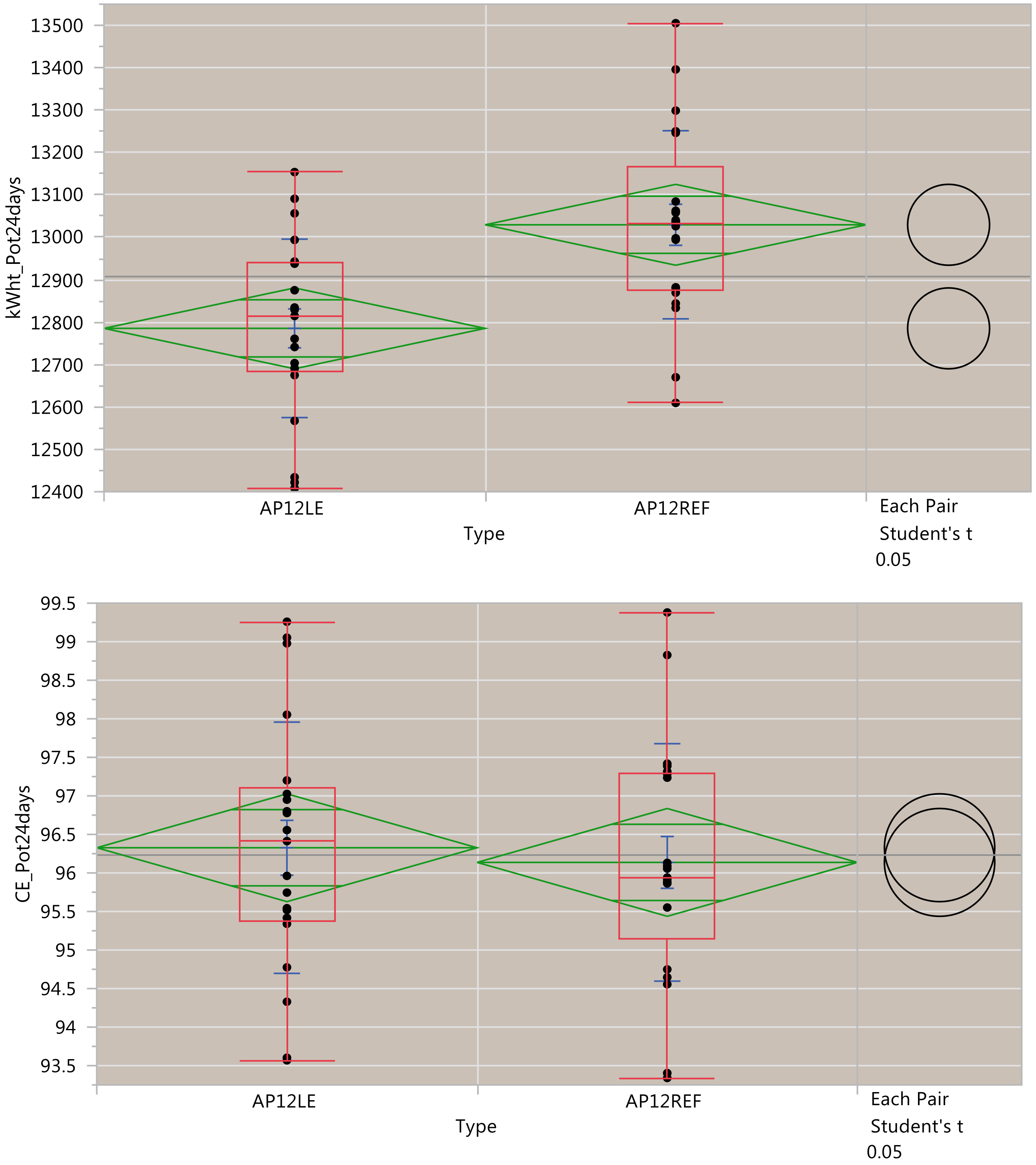


Fig. 12 Statistical comparison (JMP® software) of the AP12 LE values with standard cell current efficiency (lower, in %) and specific energy consumption (upper, in kWh/t). (Color figure online)

variances of the two populations with a Fisher test. If they were not close enough, we removed the outlying values until they were.

- If the variances of the two groups were close enough, we compared the means between the AP12LE and the reference group using a t-test (unpaired). Otherwise, we used a Welch test although it is less powerful.

The statistical comparison between the AP12LE group and the AP12 reference group was done and the results were in the expected ranges, AP12LE cells being as productive as standard cells with a significant reduction in specific energy consumption, as illustrated in Fig. 12.

Conclusions

With the AP12LE project, ALRO and Rio Tinto Aluminium Pechiney have added another successful project to their joint history. Optimal design was obtained by selecting the appropriate technology bricks in the AP Technology™ portfolio in accordance with the plant's technical and economic constraints.

One major conclusion can be drawn from this experience in reducing SEC: thanks to a selective use of retrofit technology bricks and twenty-first-century tools, a 55-year-old smelter can remain competitive on the market for the years to come.

Vertical integration and orientation toward high-value production are the main pillars to preserve the competitiveness of our plant in the present difficult legislative and market conditions. Another important aspect, because the project extends over about seven years, is related to the efficiency of the remote process support provided by RTAP.

After full implementation of the AP12LE, ALRO will have specific energy consumption equal to that of the world's best primary aluminium companies.

References

1. Cilianu M, Dobra G, Sterie F, Stanescu C, Mihaescu I (2015) Changes in operating practice and vertical integration boosts ALRO performance. 7th Krasnoyarsk Conference 2015—Nonferrous Metals & Materials, p 359–370.
2. Allano, B, Molinier, B, Jaouen, G (2017) Online Support for Amperage Creeping and Technology Brick Implementation, Travaux 46, Proceedings of 35th International ICSOBA Conference, p 851–862.
3. Steve Langlois et al. (2015) 3-D coupled magneto hydrodynamic and thermoelectric modelling applied to AP technology™ pots, Light Metals 2015, p 771–775.