AP12 LE – A PROJECT FOR REDUCING THE ENERGY CONSUMPTIONS AND IMPROVE THE ENERGY EFFICIENCY OF THE ELECTROLYSIS POTS

PROIECT PENTRU REDUCEREA CONSUMURILOR DE ENERGIE ȘI ÎMBUNĂTĂȚIREA EFICIENȚEI ENERGETICE A CUVELOR DE ELECTROLIZĂ

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Abstract: ALRO Group is the biggest industrial power consumer from Romania with about 9% produced in the country. The profile of consumption is almost flat 24 hours /day 365days/year, despite that group has four different operational divisions due to equilibration achieved among them. Incessantly increasing energy prices and low London Metal Exchange (LME) aluminium prices have forced aluminium smelters to reduce energy consumption all over the world. Electricity direct and associated costs (associated means – green and CO2 certificates, cogeneration tax, injection fee, transportation, distribution, system services, reactive energy) are the most important differentiators of the competitive structure of the aluminum industry. Over the last few years, successive cost cutting plans have reduced the in-house technical resources available to ALRO smelter. Meanwhile, ambitious projects such as progressively reducing the anode-cathode distance (ACD) so as to lower specific energy consumption (SEC) have tended to further reduce the consumptions of electrolysis, process developed in different ways by well-known players as Norsk Hydro, Rio Tinto, Gami, etc. Rio Tinto Aluminium Pechiney (RTAP) and ALRO entered an agreement in 2018 for the supply of the AP12LE technology to ALRO. 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 will present the project for progressively improving performance and describe some of those benchmark tools, including operating window, low ACD operation assessment and development plan, transition plan for moving from the present situation to the new one, go-no go process and remote support.

Keywords: Aluminium Electrolysis, Cell design, Low energy, Technology transfer and validation

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Rezumat: Grupul ALRO este cel mai mare consumator industrial de energie din România cu un consum de aprox. 9% din energia produsă în România. Profilul de consum este aproape liniar 24 ore/ zi 365zile/an, deoarece Grupul are patru sectoare operaționale diferite si poate realiza o echilibrare între acestea. Prețurile la energie care au crescut neîncetat și prețurile scăzute la aluminiu pe Bursa de Metale din Londra (LME) au forțat producătorii de aluminiu pe plan mondial să își reducă consumul de energie. Costurile cu electricitatea directe și asociate (costurile asociate se referă la certificate verzi și certificare CO2, taxa de cogenerare, taxa de injectare în sistem, de transport, distribuție, servicii de sistem, energie reactiva) sunt cele mai importante elemente de diferențiere a structurii competitive a industriei de aluminiu. În ultimii ani, planurile succesive de reducere a costurilor au scăzut resursele tehnice interne ale uzinei de aluminiu ALRO. Între timp, proiecte ambițioase precum reducerea progresivă a distanței anod –catod (ACD) în vederea reducerii consumului specific de energie (SEC) au vizat reducerea în continuare a consumurilor din electroliză, proces dezvoltat de companii bine-cunoscute precum Norsk Hydro, Rio Tinto, Gami, etc.. Rio Tinto Aluminium Pechiney (RTAP) și ALRO au încheiat în 2018 un acord pentru furnizarea tehnologiei AP12LE către ALRO. Pentru a îndeplini o astfel de provocare și pentru a garanta o îmbunătățire constantă și sigură a performanțelor, RTAP a dezvoltat o serie de instrumente de referinta, inclusiv suport tehnic dintr-o locație aflată la distanță față de uzină. Acest articol prezintă proiectul de îmbunătățire progresivă a performanțelor și descrie unele dintre aceste instrumente de referinta, incluzând zona de operare, evaluarea și planul de dezvoltare pentru funcționare cu distanță anod – catod redusa, planul de tranziție de la situația actuală la o nouă situație, procesul de confirmare sau neconfirmare a continuarii proiectului și suport de la distanță.

Cuvinte cheie: electroliza aluminiului, proiectarea celulei, consum redus, transfer tehnologic și validare

1. General introduction

Aluminum is the second most important material used in the world economy after steel. Aluminum is used mainly in the transportation equipment, construction, and packaging industries, which account for 75% of total world use. Additional sectors that consume aluminum include consumer durables, capital equipment, and electrical conductors. Aluminum is the second most common element in the earth’s crust after silicon. The vast majority of today’s supplies are obtained from bauxite ores, which occur widely in the tropical regions.

Alumina refining involves dissolving bauxite in a hot caustic soda solution followed by solid/ liquid separation and the subsequent recovery of pure alumina by precipitation from the liquid fraction. Alumina refineries are essentially chemical plants. Between two and three tons of bauxite are required to produce each ton of alumina. Primary aluminum smelters convert alumina into pure metal by electrolysis. Power is supplied via a carbon anode that is suspended over a pot containing alumina and various bath materials.

As liquid aluminum is produced, the carbon anode is consumed in the following basic reaction:

$$2AL2O3 + 3C \rightarrow 2AL2 + 3CO2 \qquad (1)$$

In practice, approximately 1.92 tons of alumina and 0.45 tons of carbon are required to produce each ton of aluminum [1]. Aluminium smelting is an energy intensive process where energy cost contribution is around 40 % of the total cost of production.

The nature of aluminum smelting technology is such that these plants need to run on a continuous basis. If power supply is interrupted for more than 3.5 hours, there is a risk that the molten metal will freeze in the pots. If this happens, the reconstruction of many of the pots in the line will be required which is a very expensive proposition. On the other hand, an orderly, planned shutdown of the smelter involves tapping all of the liquid metal from the pots, a process that takes no more than 5 days. Even this is not risk-free. As the pots cool to room temperature, the thermal stresses involved can damage the cathode linings and result in reduced life.

All that above production chain is represented in ALRO Group by a bauxite mine in Sierra Leone from where 1,2mio tons are transported by sea and barges to the alumina refinery in Tulcea. About 400 000t of alumina go to ALRO smelter from which 260000tons of primary aluminium and 30 000t of aluminium scrap are transformed in value added product. Wire rod, rolling mills products and extruded products are produced at Slatina. Continuous improvement principles guide us to invest in assets which update our competitiveness and increase our worker skills. Investing in rectifiers, in substation, in energy efficiency, implementing ISO 50001, just to name few aspects linked to Foren Event, show our concern for resisting in one of most hostile environments for smelter in Europe.

ALRO Slatina has four potlines out of which three are functioning with a number of 600 pots today in operation, together with all the supporting shops consisting of green anode shops, anode baking furnaces, rodding shop, rectifiers and utilities, casthouse, spare parts plant, gas treatment centers with all additional infrastructure handling alumina, coke and pitch, etc.

In 2017-2018 ALRO entered in discussion with RTAP to study the possibility of specific energy consumption reduction despite that this smelter is one of the most efficient plant of its age. Rio Tinto has a solid track records in this field, with almost all of its plants operating at higher amperage than their initial design. For example, in ALRO based on some modification done in house on the AP8 technology now it is operated at 120kA.

2. Project development chain

The project development cycle is used to ensure that the proposed design will be optimal considering the technical and economic constraints of the plant. The project development cycle consists of eight different stages; these means:

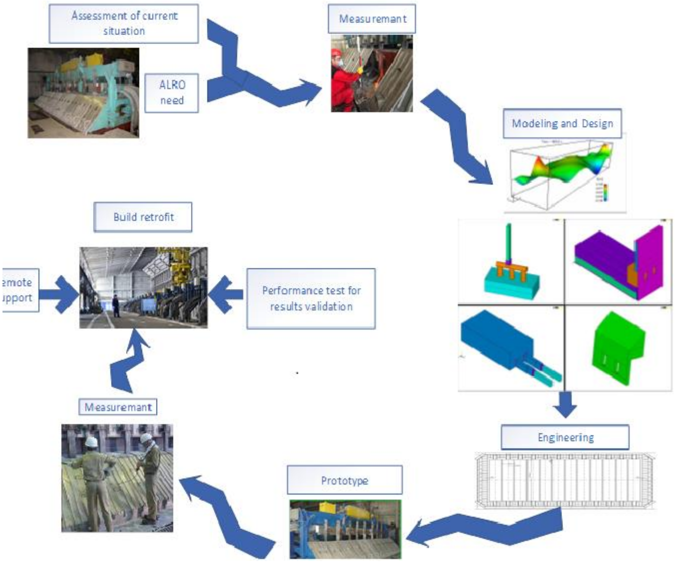

Figure 1. Project management chain AP12 LE
Process: 1. Assessment of actual situation; 2. Measurement; 3. Modeling and design; 4. Engineering, 5. Prototype construction, 6. Measurement, 7. Build and retrofit; 8. Process optimization and assessment of results for a representative group of pots. After these eight stages a management decision for go or not go should being taken for the actual solution; 9. Remote support

The Customer's Needs. 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, optimum anode slots; etc. Their main targets are either to lower the pot energy consumption or to increase its productivity. ALRO's preference was to use Low Energy bricks.

2.1 Assessment of current situation.

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 sector with all main area of activity paste plant, anode handling and storage, anode baking including fume treatment, anode rodding including bath and carbon recycling
- Reduction sector with potlines and gas treatment centers, metal transportation, registration, raw material handling and operation accuracy
- Rectifiers station and Utilities
- Pots repairing and maintenance system

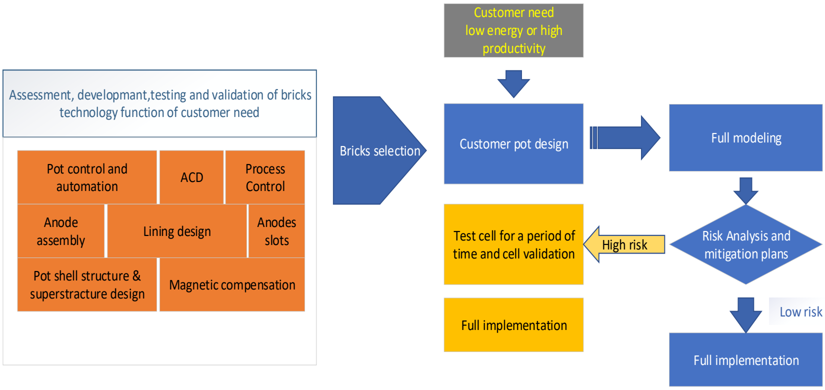

Figure 2. AP Technology™ Bricks (courtesy of RTAP)

2.2 Measurements

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.

Figure 3. Ledge measurement in an AP12 LE.

2.3 Modeling and Basic Design

RTAP performed a magneto-hydro-dynamic (MHD) and a thermo-electrical (TE) modelling based on the pot data collected during the off-site review and the on-site mission. These include:

- MHD modelling enables to define and predict the pot robustness and stability, depending on the busbar design and more generally on the pot environment MHD stability assessment, which may lead to modifying the busbars or alternatively adding a compensation loop in order to increase the stability margin.

- Thermoelectric behavior. The TE modelling enables to define and predict the thermal distribution in the pot, depending on the anode and cathode design solutions implemented. A major output of the thermoelectric model is the *operating window* which will help set the parameters during the increase in line current, as illustrated in Figure 4.

By using these two models, it was possible to predict the impact on the pot operating points of the implementation of AP Technology™ bricks that have already been validated on other pot technologies.

Basically, the model has three general phases:

- **Phase 1 – Model development:** in this phase different modelling software will be used to build different virtual copy of the pots to be used for the TE and MHD models. The information needed for this phase is the detailed pot drawings.
- **Phase 2 – Model calibration**: this is the most critical phase of the study. It consists in adjusting the model's parameters so that the results correspond to the real values when modelling the existing pot design. This phase ensures that the model developed will have the same behavior as the actual pot.
- **Phase 3 – Model use:** in this phase, the models are used to evaluate the new operating point corresponding to the modification proposed**.**

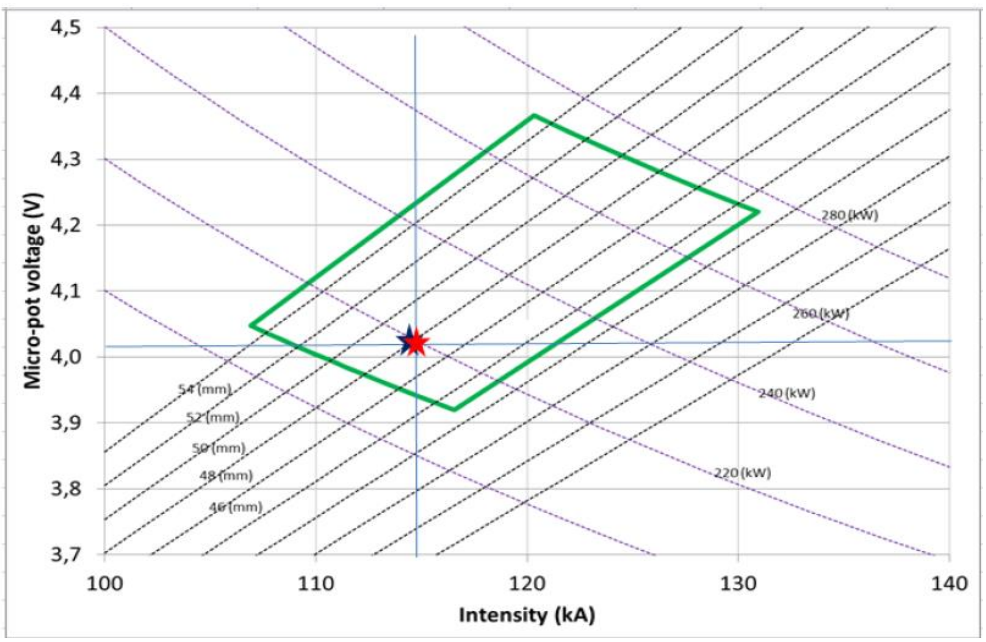

Figure 4. Operating window with set points

The operating points are defined in term of pot voltage, amperage, specific energy consumption, current efficiency and anode cathode distance (ACD) defining the operating windows.

2.4 Engineering

The AP12LE pots design is based on the "AP Technology™ Brick" approach, developed by RTAP and using new lining materials, new cathodes and metallic bar assemblies and slotted anodes.

The basic design resulting from the modeling must now being 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 modeling phase may affect many other departments of the smelter as shows Figure 5. So, a new impact evaluation was done after engineering. ALRO needed to change a lot of tools, procedure and increase his repairing skills for its worker and its service supplier.

The material purchase procedures were adjusted to match RTAP requirements. In particular, suppliers were selected within RTAP list of recommended suppliers and material acceptance criteria were discussed on a case by case basis with RTAP to ease procurement without compromising pot performances.

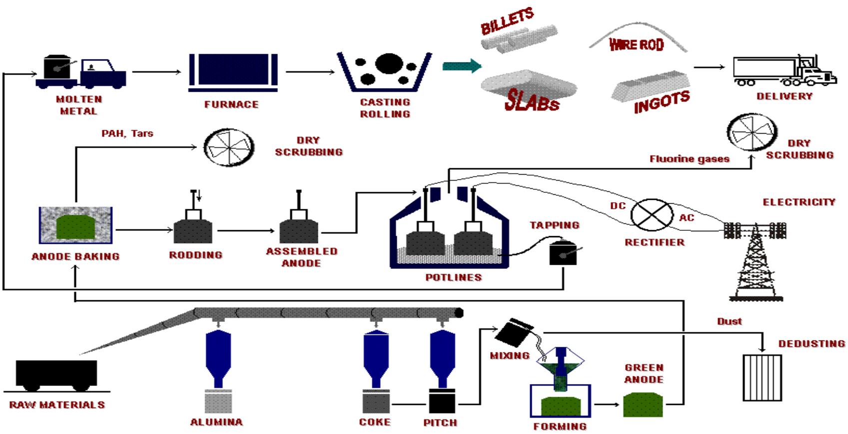

Figure 5. Assessing the effect of the changes on all departments.

2.5 Prototypes

After detailed design has been worked out, the construction and startup 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 the usage of new materials, to validate new tools, to give a training to trainers (managers and inspectors), to define new inspection and control KPI etc. ALRO managers then transferred the knowledge to the workers and service suppliers, insuring a smooth transition to new practices.

Once build, the first AP12LE were started with the support of an AP Technology™ start-up expert. The new AP12LE start-up procedure is based on the existing one and provides some improvements. The resistive heating of the pots for 48 hours uses about 15MWh. The full entering in production is from about 7 days when the voltage and production of metal/cell is in acceptable range compared with rest of the pots.

2.6 Measurements and validation of the AP12LE technology.

Regular measurements and close energy consumption monitoring has to be performed to make sure the AP12LE pots stay under control. The AP12LE design is based on the most advanced AP Technology™ bricks to make sure the best solution is delivered and delivers performances meeting ALRO's expectations

During the validation process, technology risks are assessed and if required, tests are performed to verify the performance of the proposed solution, as illustrated in Figure 2.

2.7 Build and retrofit

Best practices put in place are considering the fact that at ALRO, the AP12LE project is a brownfield one, with a progressive implementation of the new pot design that follows the natural replacement rate of the pots (about 80 pots per year). The first stage of the "building" phase was then to build and start a significant number of AP12LE pots in order to be relevant from statistical point of view, regardless of the issues that may appear. ALRO and RTAP has agreed to perform 6 months after the first AP12LE pot start up, a statistical study comparing the performance of the first 20 AP12LE pots with 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 more to its operations as some shortcuts or habits might appear over times. New technologies require change of mentalities. So, to be sure to cover all ALRO specificities, we decided to spread the AP12LE retrofitting in all the potrooms despite of the difficulties in demonstrating the results.

Other constraints were the need for a software and a configuration platform (figure 6) to gather all the modernize pot results as follows:

- A supervising computer which allowed communication with electrolysis cell
- Database server which memorize process data
- Desktop clients which allow access from a regular pc
- Web client which give access from a pc, tablet or smart phone

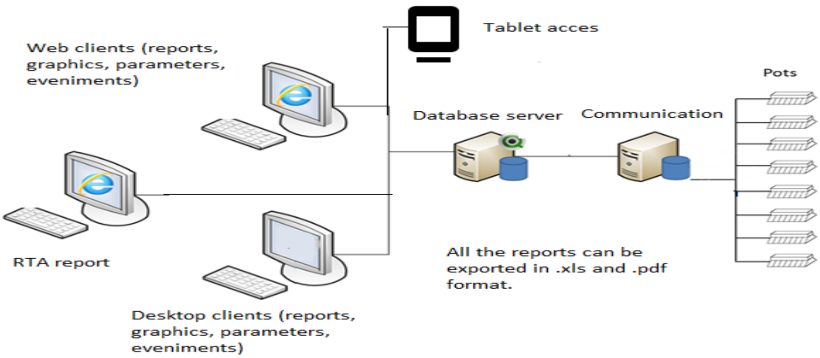

Figure 6. Configuration platform for process monitoring

A "go-no go" process was defined and put in place to make sure everything is under control before further progressing with the project.

Table 1. 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 last two weeks	**GO**	**NO GO**
Anode Covering audits last two weeks	**GO**	**NO GO**
Anodes	**GO**	**NO GO**

2.8 Parametrization and assessment of results for a representative group of pots – on site support

During this period of construction of AP12LE, ALRO's reduction team and AP Technology™ process experts defined and implemented a remote process support scheme.

Onsite support was focused on the operational side, making sure all the delivered procedures were correctly followed. The main expected performances of the AP12LE are detailed:

Table 2. Main parameters compared

ALRO	2017	AP12LE
Current(kA)	119.4	120
CE%	95.7	95.7
Specific energy consumption (MWh/t)	13.28	< 13
Slots in anodes	none	2/300mm
Rcathodes(microohm)	2.9	2.3
Voltage (V) on microcomputer	4.15	4.045

ALRO and RTAP agreed to perform, 6 months after the first pot start up, a statistical study on a representative number of AP12LE pots in comparison with same number of classical ALRO design to assess their respective performances.

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

The statistical comparison between the AP12LE group and the AP12 reference group was done and the results were in the expected ranges, allowing to the project to go ahead.

2.9 Remote support

RTAP created a tool call RADAR - a Business Intelligence application used to analyze data coming from pot regulation systems.

This application is based on QlikView 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, show very high degree of detailed surveillance available to the support reduction team even from remote, thousands of kilometers away.

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

- The evolution of relevant key performance indicators (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 to be presented at the next meeting
- Action plan follow-up.

All analyses were performed remotely from the different facilities from RTAP where specialists are located, providing almost continuously RTAP's designated process expert on this project with 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 the group of pots

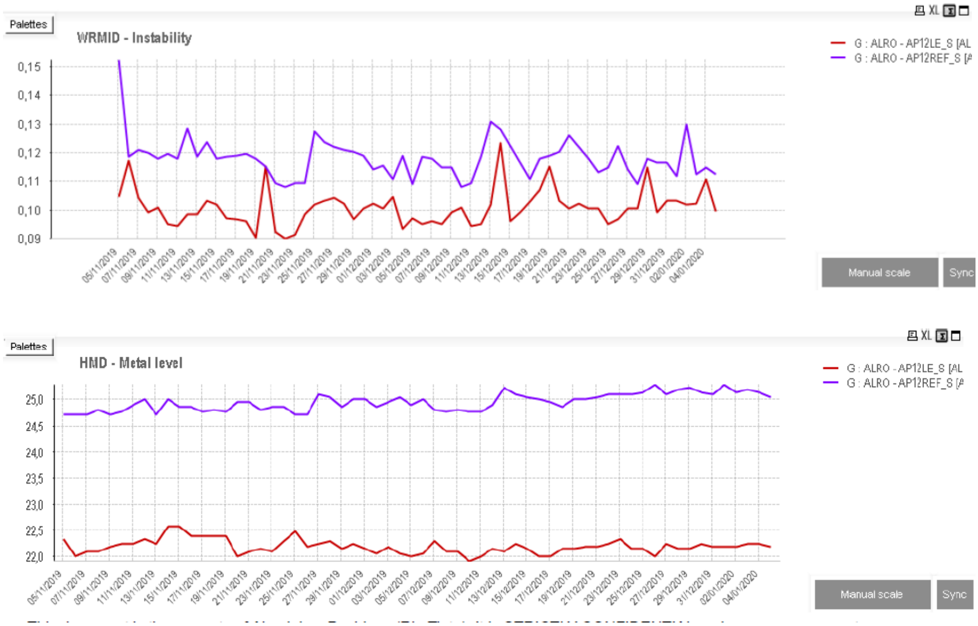

Figure 7. Performance of the new ALRO AP12LE comparative with reference pots under remote technical support.

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

3. Conclusion

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

One major conclusion can be drawn from the amperage and production increase experience: thanks to a selective use of retrofit technology bricks and 21st century tools, a 55-year-old smelter can remain competitive on the market for the years 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 of characteristic of the project that is extended to about seven years, is related to the efficiency of the remote process support provided by RTAP.

After AP12LE implementation, ALRO will be amongst the world's best of primary aluminium companies in terms of low specific energy consumption

R E F E R E N C E S

[1] *B. Allano, B. Molinier, G. Jaouen,* "Online Support for Amperage Creeping and Technology Brick Implementation", Icsoba Conference Hamburg 2017

[2] *M. Cilianu, Gh. Dobra, F. Sterie, C.Stanescu, I. Mihaescu,* "Changes in operating practice and vertical integration boosts ALRO performance"

[3] *S. Langlois et al.*, "3D coupled magneto hydrodynamic and thermoelectric modeling applied to AP technology™ pots", *Light Metals* 2015, 771-775.