

Successful Implementation of INALUM Pilot Cells Using EGA Cell-Upgrade Technological Know-How

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<https://doi.org/10.71659/icsoba2024-al048>

Abstract

EGA and INALUM signed a Technology License Agreement on 21 December 2020 to upgrade INALUM Potline 1 reduction cells consisting of S170 Sumitomo technology at Kuala Tanjung smelter. The purpose of the agreement is to use EGA technological know-how to increase the smelter's hot metal production. In the first stage of the project, five pilot cells were upgraded in Potline 1 and are now operating at 215 kA, which is 20 kA higher than the nominal Potline 1 amperage of 195 kA. The key technological upgrade of the pilot cells included improvement of potlining design, superstructure with point feeders, busbar network, and replacement of existing cell control system with EGA's PLC-based cell control system. Process improvements based on EGA know-how and experience included preheat, start-up, early operation, and normal operation.

INALUM's project team faced various challenges during the project execution to implement the upgraded design. The challenges were caused by limited resources and facilities, regulations, the COVID-19 pandemic, raw materials supply, and modification of cathode ring busbar without disturbing the operation of Potline 1. Despite all these challenges, with good project management and collaboration between EGA and INALUM, the start-up of the five pilot cells was completed safely from 25 May 2023 to 9 June 2023.

The Technology License Agreement included a contractual obligation to carry out a performance test on the five pilot cells for a period of 4 weeks with metal production of 1 619 kg/cell-day at 215 kA. The performance test took place from 27 August to 24 September 2023.

EGA's operation and process technology advisors were on-site to lead, supervise and provide necessary support during the cell start-up and performance test. The pilot cells successfully achieved a performance of 1 641 kg/cell-day at 215.4 kA during the performance test. The successful completion of the performance test is a landmark achievement reflecting efficient collaboration and teamwork between EGA and INALUM. The success of the pilot cells is the

starting point for EGA and INALUM to upgrade all 298 cells in Potline 1 (128 cells) and Potline 3 (170 cells) in Kuala Tanjung smelter.

Keywords: INALUM upgrade pilot cells, EGA cell upgrade technological know-how, Cell performance test.

1. Introduction

Emirates Global Aluminium is the world's leading 'premium aluminium' producer with operations from mining and refinery to smelting and casting. EGA is also a smelting technology provider for greenfield and brownfield projects. PT Indonesia Asahan Aluminium (Persero), INALUM, is a 100 % state-owned enterprise since 2013 whereas before, since its establishment in 1976 it was a Joint Venture Company between the Government of Republic of Indonesia (GOI) and 12 Japanese investment companies.

EGA and INALUM signed a Technology License Agreement on 21 December 2020 to upgrade INALUM reduction cells operating with S170 Sumitomo technology at Kuala Tanjung smelter. The pilot section consists of five test cells installed in the existing Potline 1 (Cells R117 to R121), connected to an existing booster rectifier intended to operate cells at 215 kA. Potline 1 was operating at 195 kA at the start of the project.

The INALUM upgrade project went through various phases described in this paper.

The start-up of the pilot cells began on 25 May 2023 at 195 kA, and was completed on 9 June 2023 at 196 kA. The amperage was increased to 215 kA from 21 June to 10 July 2023.

2. EGA Feasibility Study of INALUM's Existing Cells

EGA has great experience in upgrading existing potlines with continuous development of its own technologies in EGA for production increase and environmental protection, as well as in the design and operation of advanced high amperage technologies [1]. Of particular relevance for the INALUM project is EGA's upgrading of Kaiser P68 to D18, and to D18+ technology, since P69 was similar to S170 Sumitomo technology with end anode risers and similar amperage [2-4]. EGA also has full mathematical modelling capability for cell design and amperage increase strategies [5-6]. EGA has an advanced PLC-based cell control system [7].

The feasibility study consisted of modelling, measurements and design validation of INALUM's existing cells and the evaluation of the existing potline operation and control practices as well as the selection of the pilot section for five test cells in Potline 1 (Cell R117 to R121) for convenient connection to an existing booster rectifier.

The feasibility study was based on the requirement to increase INALUM production capacity from 250 000 to 300 000 t/a through the upgrade of the existing Potlines 1 and 3, which would require an amperage increase to 215 kA.

The pilot project plan envisaged EGA modelling and cell design, engineering of the proposed upgrade, and onsite support by EGA engineers for construction, start-up and early operation of the five pilot cells. The new cell technology was named S170+. The scope of the upgrade project is shown in Figure 1

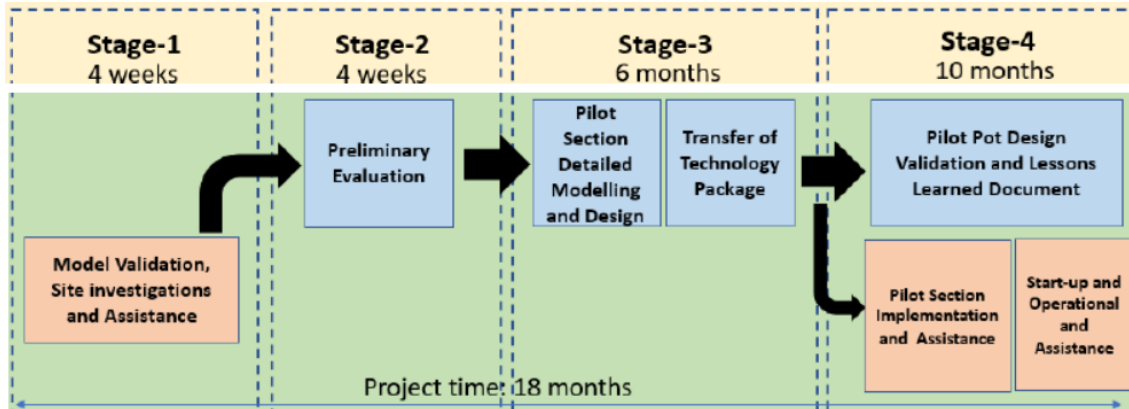


Figure 1. Scope of the pilot project accepted in August 2020.

The target performance KPIs for upgraded S170+ technology, based on the modelling study, compared to existing S170 cells, are given in Table 1.

Table 1. INALUM existing S170 cells and proposed S170+ pilot cells KPIs.

Parameter	Unit	S170 Current Operation	S170+ Target Range
Amperage	kA	193	215
Current efficiency	%	92.5	93.5
Production per cell	t/day	1.440	1.619
Anode current density	A/cm ²	0.79	0.81–0.87
Average DC voltage	V	4.415	4.17–4.36
DC specific energy consumption	kWh/kg Al	14.2	13.3–14.0
Lining design	--	D5-1	EGA
Alumina consumption (typical)	kg/t Al	1 920	1 920
Net carbon consumption	kg/t Al	445	445
AlF ₃ consumption	kg/t Al	21.56	21.56

3. Technology Package

EGA delivered the Technology Package to INALUM in October 2021. Key upgrades for the pilot cells are [8]:

- Upgrade of potlining design, including copper insert collector bars, potshell with additional cooling fins, sidewall with silicon carbide bricks instead of ramming paste, and reduced insulation layer at the bottom of potlining. Provide potlining tools and equipment to handle these upgrades.
- Replacement of the old Alesa Blue Box Pot Control System with EGA’s PLC based Pot Control System.
- Installation of a linkage busbar system from an existing booster to the pilot section (Figure 2).
- Changes in the superstructure to replace the centre-break feeding system with point feeding system with the breakers equipped with chisel-bath sensing technology, which reduces bath accumulation on breakers, saves some compressed air and increases breaker life.

- Addition of busbars to the existing cathode ring busbar and anode beam to lower current density in the busbars, and addition of some flexible leaves to anode risers to improve magnetohydrodynamics and lower busbar temperature.
- Design of a temporary busbar bypass of the pilot cells to make busbar welding possible.
- Replacement of INALUM's gas preheating method with EGA's electrical preheating for pilot cells. Electrical preheating includes the use of a graphite bed as a resistor and anode preheat flexibles instead of clamping of anodes to the anode beam.
- Introduction of EGA's operating procedure and tools for cell preheat, startup, and cell operation.

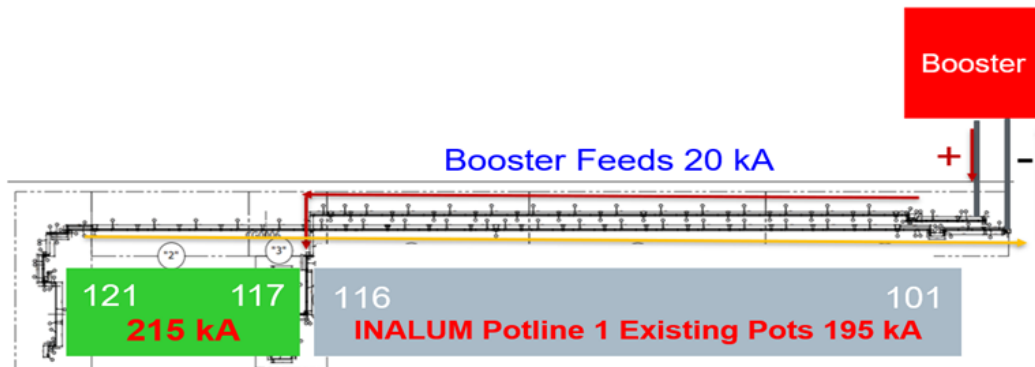


Figure 2. Pilot cells in Potline 1 [8].

4. Project Challenges

During the project implementation many challenges were identified and mitigated without compromising the quality and design specifications.

4.1 Material Handling

- Sufficient storage space was not available for procured items for the project execution. During the project planning stage, storage area for the new project had to be allocated and available when material was arriving at the site.
- Some ordered lining materials were expired due to a delay in the project execution because of COVID-19 restrictions.

4.2 Cathode Block Rodding

- Cathode preheating frame had to be changed according to the change in cathode block dimension, which impacted cathode casting time.
- The design of the shot blasting machine was changed to handle the change from full collector bar to split collector bar. The blasting roller distance was too far for each split collector bar, and required modification.
- The risk of cathode block handling failure after cast iron pouring was mitigated with new safe lifting device tools.
- The additional area to do the cast iron pouring had to be provided.
- A cathode castable material mixer had to be added on cathode casting tools list.
- During the cathode block rodding, to cover the cathode block to prevent direct contact with fire, a galvanised steel plate was used instead of mineral wool used previously.
- In the future, new cathode assembly equipment for installation in the shell should be considered.

4.3 Superstructure Modification

During the operation of the intermediate chute for alumina, there was a risk of clashing with the point breaker solenoid valve. For the future, it is recommended to design the point breaker solenoid valve with a cover.

4.4 Lining Work

The collector bar window plate for sealant was welded with difficulty on the outside of the potshell during the lining work in the potline because of limited space.

4.5 Busbar Modification and Linkage Busbar Installation

The five pilot cells (R117 to R121) were bypassed using a temporary bypass busbar system from Cell R116 to section cross over downstream of Cell R121 (Figure 3) in order to make busbar welding possible.



Figure 3. Temporary bypass for the construction of the pilot cells.

4.6 Pot Control System Customisation

INALUM's existing pot control system (PCS) was replaced with EGA's PLC based PCS for the pilot section (Figure 4). The PCS package included HMI operator manuals and cell control operational logics, which were customised to the pilot cells. Comprehensive remote and onsite training was organised for INALUM PCS and operation team on operation and maintenance of PCS.

Prior to the project execution, EGA has conducted a series of site surveys to evaluate the existing infrastructure to determine its reusability and the adaptation to the potline configuration. The survey covered several aspects such as operation practices, control strategy, electrical equipment, and overall control system architecture.

EGA's Pot Control System solution is based on standard general-purpose PLCs (Programmable Logic Controllers) that are widely used in industrial applications. EGA's control system

architecture consists of a group of electrical panels equipped with HMI (Human Machine Interface) used by operators to manage the cell and a main PLC that interconnects the group of electrical panels that runs EGA's cell control through a robust industrial network.



Figure 4. EGA Pot Control System (left) replaced INALUM Pot Control System in pilot cells.

5. Pilot Cells Energisation and Start-Up

5.1 Energisation of the Pilot Cells

A short circuit test of the pilot section was planned with a gradual booster amperage increase to 40 kA after the start-up of the first pilot cell (which provided minimum voltage for the booster). The purpose of the test was to confirm the integrity of the pilot section cathode ring busbar and linkage busbar system. It was planned that the start-up of the remaining four cells would be made at 415 kA. However, at first energisation of the booster, the booster circuit switch sparked and damaged the switch plates, which had to be repaired. Instead of delaying the cell start-up, it was carried out without the booster at 195 kA. There was no busbar continuity problem, and the booster came on power 11 days after the last cell start-up when the switch was repaired.

5.2 Conversion of Preheat from Gas to Electrical

One of the key changes in INALUM operation was the transformation of the existing gas preheat (Figure 6) to EGA electrical preheat (Figure 5). EGA's electrical preheating method uses graphite grains as a resistor. The preheating method was customised for pilot cells for anode size and preheat flexibles were designed according to superstructure configuration. Figure 7 shows the resistor bed, and Figure 8, a cell ready for cut-in. Thermocouples were installed in the centre channel and were routed to data logger for continuous monitoring of the cathode surface temperature during preheat.

5.3 Cell Cut-in and Preheat

Cell cut-in (energisation) was carried out using INALUM's existing method and equipment. In this method, potline amperage is reduced to 130 kA for around 5 to 6 minutes. This power reduction

aims to facilitate smooth extraction of wedges using INALUM existing wedge extraction equipment which is operated using compressed air on tap and duct end simultaneously. The preheat team continuously frequently measured anode current distribution, voltage drop between flexible tabs and anode rods, and main clamp of the flexibles and anode beam. The cathode surface temperature in the centre channel was recorded in a data logger every 15 minutes, and hourly cathode surface temperatures were entered manually into HMI for monitoring of cell preheat rates (Figures 9 and 10).



Figure 5. EGA electrical preheat arrangement in pilot cells.



Figure 6. INALUM existing gas preheat arrangement.



Figure 7. Graphite bed and set anodes



Figure 8. Cell sealed with crushed bath and ready for hooding and energization.



Figure 9. Data entry of cathode surface temperature into HMI.

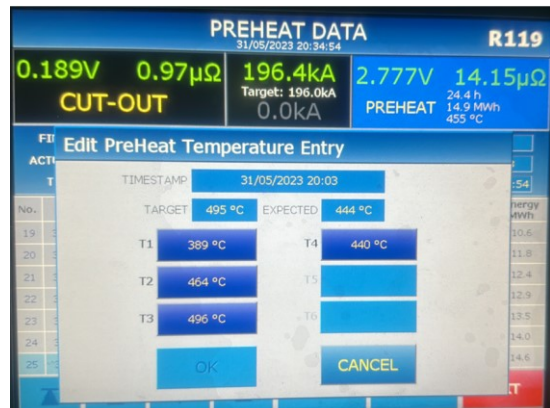


Figure 10. Data Entry of cathode surface temperature into HMI.

Preheat data are given in Table 2, and preheat temperatures in Figure 11. At the end of preheat at 71 h, the average preheat temperature was 882 °C.

Table 2. Preheat data.

	Graphite used (kg)	Cut-in max voltage (V)	Cut-in kA	Average preheat voltage (V)	PH duration (h)	PH amperage (kA)	PH energy (MWh)	Average cathode surface temperature (°C)
Average	58	4.87	130.0	2.87	71	196	39.8	882
Min	50	4.48	130.0	2.68	63	195	37.7	826
Max	60	5.25	130.0	3.03	78	196	42.0	918

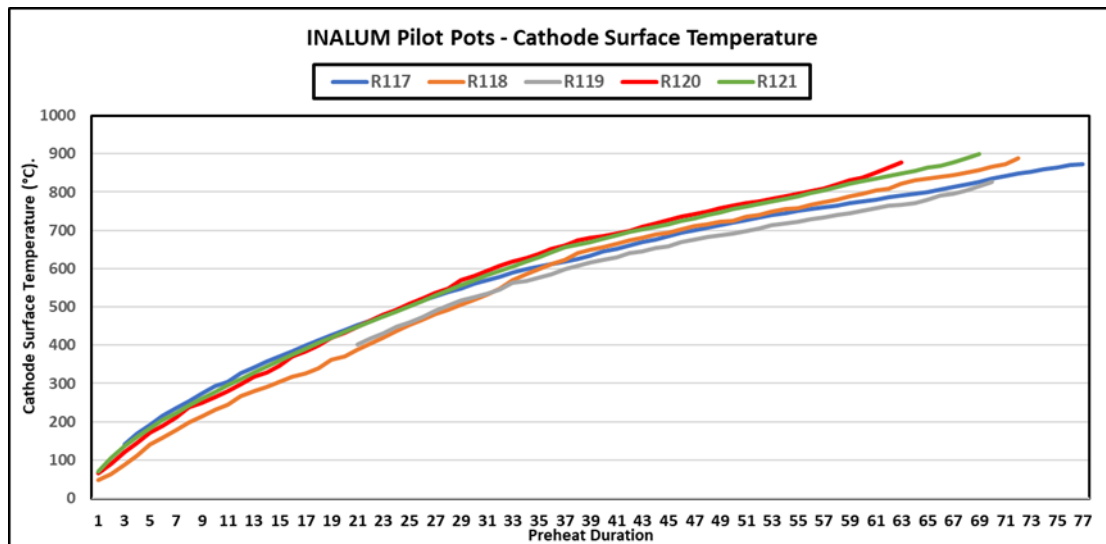


Figure 11. Average preheat cathode surface temperature.

5.4 Cell Bath-Up

Cells were bathed up with 12 t of liquid bath, generated in five donor cells. During cell preparation for bath up, the tap end tap hole area was cleared of material for smooth bath flow, and the duct end centre channel area was also cleared for visibility of bath flow on the cathode surface. The bath-up was completed in 15–20 minutes (Figure 12).

Cell bath up process was smooth for R121, R120 and R118 but the bath shrank in Cell R119. The average voltage during bath-up was 6.6 V. Only Cell 117 had high voltage of 15 V due to lose clamps. Adding 300 kg soda ash decreased the voltage rapidly to 10 V, and tightening of the clamps to 6.6 V.

5.5 Metal Pouring

Approximately 10 t of metal was poured in 17 h after bath-up to accelerate cell normalization and control bath temperature. An average bath temperature reduction of 25 °C and average bath height reduction of 3–4 cm were observed after metal pouring. Figure 13 shows metal pouring, and Table 3 metal pouring data.



Figure 12. Pilot cells bath-up.



Figure 13. Pilot cells metal pouring.

Table 3. Cell metal pouring (MP) data.

	Bath-up average voltage (V)	Bath up max voltage (V)	Bath T after bath-up (°C)	Anode effects before MP	Bath T before MP (°C)	Bath T after MP (°C)	Cell volts before MP (V)	Bath-up to MP interval (h)
Average	6.2	8.4	949	1	1008	983	5.37	17.3
Min	5.6	6.6	932	0	988	971	5.21	14.3
Max	7.4	15.1	963	0	1041	994	5.92	19.8

6. Optimisation of Operational and Process Control Activities

As per the technology license agreement, EGA issued potline operation and process control procedures using EGA best operational practices. EGA advisors conducted multiple comprehensive knowledge transfer sessions remotely and onsite for INALUM operation teams.

The work schedule for key operational activities like anode setting, anode covering, metal tapping, beam raising were the same as in the rest of Section 1 where the pilot cells are located. However, all the operational activities were performed using EGA operational procedures and PCS operational logics. EGA introduced anode redressing every two days to avoid air burn (Figure 14), seen in existing cells (Figure 15). This practice contributed to lower net and gross carbon consumption of the pilot cells than in the rest of Potline 1 while using the same anodes.



Figure 14. Pilot cells anode cover condition with redressing practice.



Figure 15. Existing cells anode cover condition without redressing practice.

Cell cavity cleaning at anode change is done with a cavity scoop in pilot cells (Figure 16), and manually in the rest of the potline (Figure 17).



Figure 16. Pilot cells cavity scooping using PTM cavity scoop.



Figure 17. Existing cells manual cavity skimming.

7. Amperage Increase from 196 kA to 215 kA

During the start-up phase of the pilot cells, Potline 1 amperage was increased from 195 kA to 196 kA. The pilot cells amperage was increased immediately after the repair of the booster switch plates, from 21 June to 10 July from 196 kA to 215 kA. At 215 kA, the pilot cells were fed 196 kA from Potline 1 current and 19 kA from the booster. Figure 18 shows the amperage increase progression and Table 4 target parameter for heat balance.

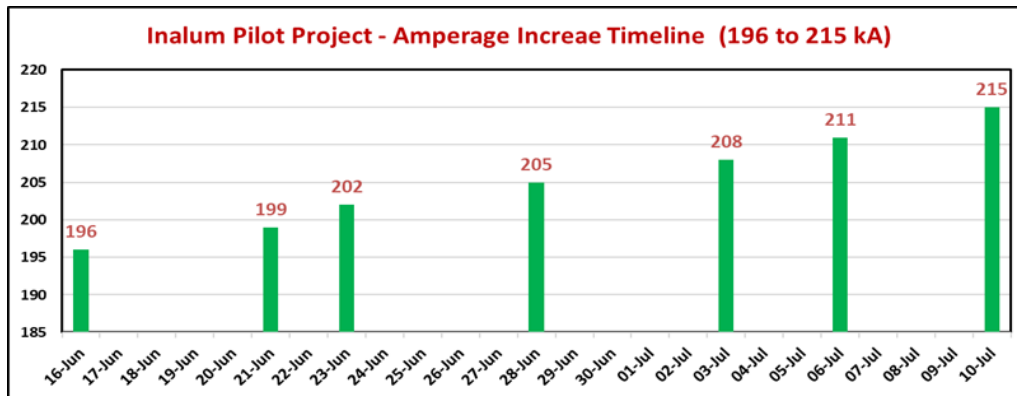


Figure 18. Pilot cells amperage increase.

Table 4. Parameter targets during amperage increase. Q_{in} is internal heat as in [6].

Date	(kA)	BRSP ($\mu\Omega$)	Cell voltage (V)	Busbar voltage (V)	Q_{in} (kW)	Metal height (cm)	Anode top cover (cm)
16-Jun	196	13.22	4.29	0.273	380	22	16
21-Jun	199	13.22	4.27	0.278	381	22	16
23-Jun	202	13.22	4.26	0.282	385	22	16
28-Jun	205	12.92	4.25	0.286	388	23	16
03-Jul	208	12.68	4.24	0.290	390	24	16
06-Jul	211	12.45	4.23	0.294	392	24	16
10-Jul	*215	12.22	4.21	0.300	394	24	16

Go-No-Go criteria, judging the cell condition, stability and other KPIs, for every step of amperage increase were checked to ensure that amperage increase was carried out safely without harming cell performance. However, for the INALUM pilot cells, these criteria were always met and the amperage increase went as planned. Table 5 shows the KPIs of Go–No-Go criteria checked for amperage increase.

**Table 5. INALUM pilot cells - Amperage increase from 196 kA to 215 kA
Go–No-Go criteria.**

Line kA 211 → 215						Updated on: 10/06/2024
Criteria	Target	Actual	Go	Score	No-Go Target	
Average noise, V (All cells)	0.020	0.021			0.030	
Net cell voltage, V (Cells age > 28 days)	4.28	4.340			4.380	
Max No. of cells with average noise > 30 mV	0	1			2	
Average bath temperature, °C	957	963			967	
Max No. of cells with bright red shell & shell T > 430 °C (In last 2 days audit)	0	0			2	
If any of above criteria is not met, amperage increase will be no-go						
No. of cells with bath level > 20 cm	≤ 2	2		15	2	
Max No. of anode spikes (Average per week)	≤ 2	0		20	2	
Anode effect frequency per cell-day	0	0.40		15	1	
Daily No. of cells with Si > 500 ppm (Age >28 days)	800	0		10	2	
Max No. of cells with bath temperature > 970 °C	≤ 1	0		25	2	
Max No. of cells with bright red shell (sum of bright red shells in last 2 days audit of all cells)	≤ 2	0		15	2	
Note: IF total score is < 75, amperage increase will be No-Go.						

The pilot cells were monitored closely for red shell, shell temperature, cell stability, bath temperature and bath generation. The cells responded well to amperage increase from 196 kA to 202 kA and BRSP was not adjusted during this period of amperage increase. However, a slight increase in bath temperature and bath generation was observed from 203 kA onward and BRSP of the pilot cells was decreased as shown in Figure 19, in order to keep the right heat balance. This reduced anode-cathode distance (ACD) by 9 mm, calculated as per [9]. Metal height was increased from 20 cm to 24 cm in steps while anode top cover was kept constant at 16 cm.

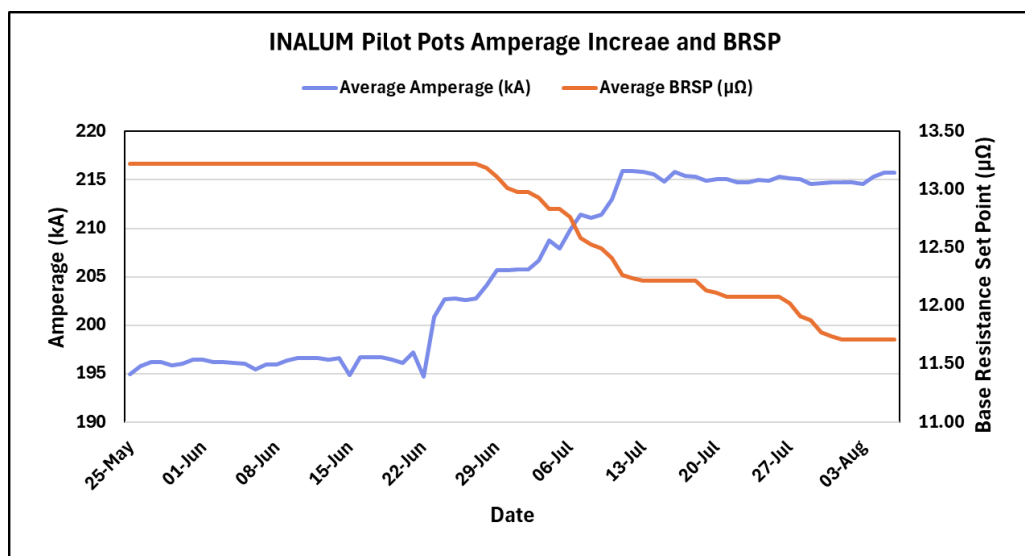


Figure 19. Pilot cells amperage increase and base resistance set point (BRSP) adjustment.

8. Performance Test

As per the Technology Transfer Agreement and the agreed Performance Test Protocol, a Performance Test of the INALUM pilot cells was carried out at 215 kA on the pilot section of five cells over a period of 28 days from 27 August 2023 to 24 September 2023. EGA advisors were present (shift coverage) during the test period to monitor the test cells in collaboration and support of Potline 1 operation and process teams.

The two performance criteria were to be met by the test cells as per the Technology License Agreement:

- Pilot cells operation at 215 kA,
- Average aluminium production per cell and per day greater or equal to 1 619 kg.

The performance achieved by the test cells during the test period met and exceeded the above guaranteed performance criteria as follows:

- Pilot cells operated at the amperage of 215.4 kA,
- Average aluminium production per cell and per day of 1 641 kg (after inventory and metal correction from crucible cleaning and skimming), which is 22 kg above the target.

In addition to the guaranteed performance criteria, the following key performance indicators (KPIs) were also achieved during the test period (Table 6):

Table 6. Comparison of main performance KPIs achieved during the performance test.

Parameter	Unit	EGA design	INALUM existing design
Amperage	kA	215.4	196
CE	%	94.61	92.3
Net SEC	kWh/kg Al	13.58	14.05
Gross carbon consumption (GCC)	kg/t Al	620	677
Net carbon consumption (NCC)	kg/t Al	421	472
CO ₂ -eq. of PFCs, kg/t Al	kg/t Al	48	531

- Current Efficiency of 94.61 %, after inventory and metal correction from crucible cleaning and skimming as compared to 92.3 % for Potline 1 at 196 kA,

- Net specific energy of 13.58 kWh/kg Al based on adjusted current efficiency as compared to 14.05 kWh/kg Al for Potline 1,
- Gross carbon consumption of 620 kg/t Al (55 kg less than Potline 1),
- Net carbon consumption of 421 kg/t Al (51 kg less than Potline 1),
- PFC Emissions (CO₂-eq.), as per calculation in [10], of 48 kg/t Al as compared to 531 kg/t Al of Potline 1.

9. Conclusions and Way Forward

The INALUM pilot cells upgrade project achieved performance above the contractual obligations. Five pilot cells were retrofitted with minimum disturbance to the existing potline infrastructure, such as building, crane, feeding system, etc. The upgrade of superstructure, busbar network, potlining, potshell was managed onsite with local contractors. The cell control system was supplied and commissioned by an external EGA approved contractor. The great collaboration and teamwork between EGA and INALUM project and operation teams contributed greatly to the success of the project.

The successful upgrade of five pilot cells using EGA upgrade technological know-how will pave the way for the upgrade of INALUM's existing 298 cells in Potline 1 and Potline 3. EGA is continuously monitoring the five pilot cells remotely from Jebel Ali office and is providing technical support to INALUM operation for stable operation of the pilot cells.

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