

Behavior of Different Lining Designs with Forced Convection Network in High Productivity Pots in Alba

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Abstract

At Aluminium Bahrain (Alba), one of the world's largest single-site aluminium smelter outside of China, in reduction Lines 4 & 5, line amperage successfully increased from 400 kA to 412 kA in a short record period after Forced Convection Network (FCN) installation. During the amperage increase journey, two different lining designs were used. Alba is planning to increase amperage further to 415-420 kA during the next 2 - 3 years. In line with this amperage increase plan, two more lining designs were added. Both lines are currently operating at 412 kA, and three of these lining designs are in operation. The behavior and challenges of different lining designs with amperage increases after FCN installation along with the future preparation are discussed in this paper.

Keywords: Aluminum smelter, Forced Convection Network (FCN), Amperage increase, Different lining designs.

1. Introduction

Alba embarked on a journey towards high productivity and high amperage technology with Line 4 in 1992, featuring 288 reduction cells using AP30 technology. This was followed by Line 5 - the longest potline at that time (2005), with 336 reduction cells using AP30 technology [3]. In the year 2021, Alba achieved a significant milestone by increasing the current in both potlines to 400 kA without implementing FCN [1]. At present, Alba has introduced three different lining designs with copper insert—Alba copper design, AP40A design, and CP20 design across lines 4 and 5. Alba Copper design was the 1st design when Alba has introduced copper insert collector bar, AP40A design was also a copper insert collector bar design given by Aluminium Pechiney and CP20 design is an increased copper cross section design developed along with CAETE. Each design, implemented at different intervals, has the objective to optimize thermal and electrical balance in line with the prevailing current increase strategy. The integration of cutting-edge technology enabled Alba to increase potline current while maintaining commendable current efficiency, setting a global benchmark among AP30 potlines.

As Alba strived to surpass the 400 kA threshold, FCN implementation became necessary for its two AP30 potlines, i.e., Lines 4 and 5, comprising a total of 624 reduction cells. FCN exhibited

varying behaviors across different lining designs, prompting Alba to devise tailored strategies and to adapt accordingly.

2. Technical Background

Maintaining optimal operational conditions and current efficiency while managing current increase presents a notable challenge in sustaining the thermal balance of reduction cells. This balance is crucial for maximizing both technical and economic benefits. Alba has effectively tackled the thermal balance of its reduction cells through various ways of small and big improvements.

2.1 Journey of Line 4-5 Current Increase

Line 4 commenced operations with the AP30 design in 1992 at 295 kA, whereas Line 5 commenced operations with the AP30 design in 2005 at 330 kA. Between 1992 and 2005, Line 4 underwent amperage increase from 295 kA to 333 kA. The strategies and modifications implemented to accommodate the demands of current increase in Line 4 are detailed in Table 1.

Table 1. Strategies and modifications implemented in line 4 during 1992-2005 [3].

Strategies and Modifications	Benefits
Second generation cells started with graphitized cathode.	• Cell voltage reduced by 30 mV due to lower cathode resistance.
Anode length increased from 1450 mm to 1500 mm	• Saving of 100 mV.
Double anode slot of 150 mm was introduced.	• Saving of 50 mV.

Since the establishment of Line 5, the lining design of Line 4 has also been modified to align with Line 5 design, indicating that both lines have operated with the same lining design since 2005. From 2005 to 2014, in Lines 4 & 5, the amperage increased from 333 kA to 360 kA in Line 4 and to 370 kA in Line 5. The strategies and modifications implemented to address the demands of current increase in both Lines 4 & 5 are outlined in Table 2.

Table 2. Strategies and modifications implemented in line 4 during 2005-2014 [3].

Strategies and Modifications	Benefit
Lines 4 & 5 started with graphitized cathode block of 450 mm height, which changed to 490mm height. Steel collector bar cross-section changed from 150 mm x 100 mm steel bar to 122 mm x 122 mm squared steel bar.	• Higher cathodes and lower height of collector bar (without compromising cross section) contribute to reduce current density gradients, and thus improving stability level of cells at higher currents.
SiC side wall was replaced by composite side wall of SiC and prebaked carbon side wall.	• The carbon insert used in the sidewall improves the heat flux from the inside to the outside. This effect is essential to have a secure ledge profile at the sidewall.
Anode slot increased from 150 mm to 270 mm.	• Saving of 50 mV.
Anode length increased from 1520 mm to 1600 mm.	• The heat loss from the top increased.

To address the requirements of current increase, Alba initiated significant alterations in the lining design of Lines 4 & 5 since 2014. Various design types, along with their initiation, stoppage, and continuation periods, are illustrated in Figure 1.

These major modifications and improvements in cell design and auxiliary units were conducted to facilitate amperage increase, all based on in-house technical studies and the implementation of state-of-the-art innovations.

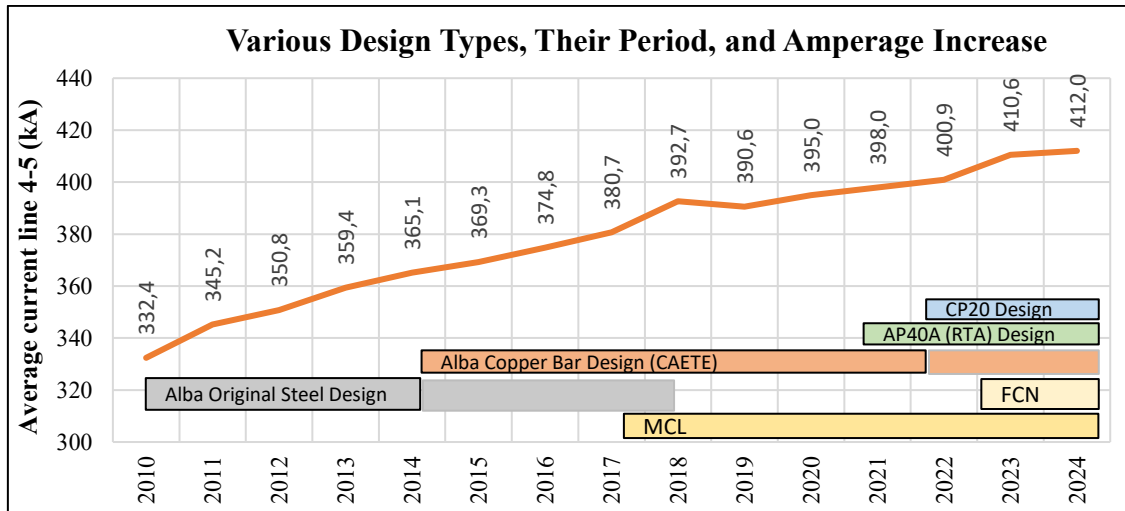


Figure 1. Various lining design types, along with their initiation, stoppage, and continuation periods. Line current is the orange line.

A short description of each design with its potential benefit is explained below.

2.2 Alba Copper Design

In collaboration with the consulting company CAETE Engenharia, Alba developed its own lining design, introducing the innovative concept of a copper insert collector bar for the first time. This design, known as the "Alba copper design" encompassed several additional modifications. A brief description of the primary changes in the lining design and their associated benefits are outlined in Table 3.

Table 3. Main changes in the lining design and their benefits (Alba Copper Design).

Strategies and Modifications	Benefit	Heat balance impact (kW)
Replacement of steel bars with copper insert steel bars.	<ul style="list-style-type: none"> Uniform current density on the cathode top, enhancing pot life. Reduced cathode voltage drop. 	<ul style="list-style-type: none"> Increased heat loss by 56.9 kW, facilitating current increase to 380 kA. CVD reduced by 39 %.
Replacement of side wall semi-graphitic carbon block with 100 % graphitic side wall.	<ul style="list-style-type: none"> Increased heat loss. 	
The bottom insulation was reduced while aligning the isotherm at the upper layer of refractory brick.	<ul style="list-style-type: none"> Increased heat loss. 	

These modifications in the lining design facilitated a current increase up to 380 kA. However, the progression of current increase did not halt there. Additional current increase from 380 kA to 390 kA was attained by elongating the anode length and adjusting the metal level, as described below:

- Anode length increased from 1600 mm to 1630 mm, enabling more heat loss from anode top and reducing current density.
- Anode height was also increased by 20 mm and, accordingly, anode cycle was changed from 80 to 76 shifts and then to 72 shifts (8-hour shifts) to maintain target butt thickness under stub [1].
- Metal level target has been increased gradually from 18 cm in 2017 to 22 cm in 2019, as metal level optimization was necessary for the purpose of heat balance and for maintaining pot stability [1].

Another current increase from 390 kA to 400 kA was coupled with some additional steps of improvements:

- Implementation of upgraded pot control logic with alumina auto adaptive feeding robustness.
- Improving noise control with separation of low frequency and high frequency noise and applying course of action in respective area to maintain the stability.
- Alba incorporated a Magnetic Compensating Loop (MCL). The purpose of a compensating loop is the creation of a magnetic field which compensates the vertical magnetic field created by the adjacent pot rooms. MCL enables to maintain lower bath and metal velocity, symmetrical eddies in the metal pad circulation and flatter interface thus improving pot stability.
- Metal level target has been increased gradually from 22 cm in 2019 to 24 cm in 2021 [1].

As a result, the Alba copper design successfully sustained its operation at 400 kA without requiring a FCN. Observing the heat balance limitations in the Alba Copper design for further current increase, in 2019, when Alba was operating at 390 kA in Line 4-5, the company approached the renowned technology provider Rio Tinto Alcan (RTA) to develop a robust design and operating configuration with the potential for additional current increase. In order to have a competitive environment and not to rely only on one design for current increase, in 2020, when Alba was operating at 395 kA in Line 4-5, Alba approached consultant CAETE (the design provider of the "Alba copper design") to develop another lining design on view of possibility of further current increase. Details of both new designs are illustrated in the next subsections.

2.3 AP40A Design

RTA proposed a new lining design called the AP40A design, which incorporates pot control logic with alumina auto adaptive feeding robustness, noise control with separation of low frequency and high frequency noise and MCL during AP40A modeling. This design enables current increase from 390 kA to 400 kA without the need for FCN and without operating at a higher metal level. The AP40A design features numerous modifications compared to the original AP30 design and the Alba copper design. Below are brief descriptions of the primary changes in the lining design and their associated benefits, as outlined in Table 4.

Table 4. Main changes in the lining design and their benefits (AP40A design).

Strategies and Modifications	Benefit	Heat balance impact (kW)
Copper insert steel bars.	<ul style="list-style-type: none"> • Ensured uniform current density on the cathode top, enhancing pot life. • Reduced cathode voltage drop. 	<ul style="list-style-type: none"> • Increased heat loss by 24 kW, facilitating current increase from 390 kA to 400 kA.
Replacement of side wall semi-graphitic carbon block with graphitized side wall.	<ul style="list-style-type: none"> • Increased heat loss. 	<ul style="list-style-type: none"> • Metal level reduced from 25 cm at copper pot to 18 cm in AP40A.
The bottom insulation was reduced while aligning the isotherm at the upper layer of refractory brick	<ul style="list-style-type: none"> • Increased heat loss. 	<ul style="list-style-type: none"> • CVD is almost equal to the Copper design of same age.

2.4 CP20 Design

CAETE proposed a new lining design called the CP20 Design. This design enables current increase from 395 kA to 420 kA without the need for FCN and without operating at a higher metal level. The CP20 Design incorporates numerous modifications compared to the original AP30 design and the Alba Copper Design. Below are brief descriptions of the primary changes in the lining design and their associated benefits, as outlined in Table 5.

Table 5. Main changes in the lining design and their benefits (CP20 design).

Strategies and Modifications	Benefit	Heat balance impact (kW)
Length and width of cathode increased slightly.	<ul style="list-style-type: none"> Allowed a bigger anode and reduced current density increasing pot life. 	<ul style="list-style-type: none"> Increased heat loss by 78 kW, facilitating current increase from 395 kA to 420 kA. Metal level maintained at 17 cm in CP20 as compared to 25 cm in Alba Copper Design. CVD reduced by 17 mV.
Copper insert with bigger cross- section of Cu. Steel part cross- section also increased. Length of Cu bar toward center of cathode increased.	<ul style="list-style-type: none"> Ensured uniform current density on the cathode top, enhancing pot life. Reduced cathode voltage drop and increased heat dissipation. 	
Replacement of side wall 100% graphitic carbon block with graphitized side wall.	<ul style="list-style-type: none"> Increased heat dissipation. 	
Increase height of SiC side wall and deeper in cathode zone	<ul style="list-style-type: none"> Increased heat dissipation. 	
The bottom insulation was reduced while aligning the isotherm at the upper layer of refractory brick	<ul style="list-style-type: none"> Increased heat dissipation. Allowed to increase cavity depth thus increasing anode cover to increase current without having impact in the anode consumption (air burn). Allowed to increase metal height to reduce magnetic instability thus operating at reduced ACD and higher current. 	
Extra fins added at long side shell plate and first-time fins added at short side	<ul style="list-style-type: none"> Reduced shell temperature without using FCN thus increasing heat dissipation. 	

In CP20 design, maximum cross section of copper insert in the collector bar were used in the lining design for a current increase from 395 kA to 420 kA, the potline is operating at 412 kA without the use of forced convection network and giving the confidence that these pots in future could be operated even at around 420 kA without the use of FCN.

The thermal balance of the reduction cells in Line 4-5 for different lining designs, such as the "Alba copper design" and "AP40A design," have been achieved at 400 kA line current by inherent property of each lining design along with adjusting process parameters as stated earlier. Nevertheless, such strategies have been found to have limitations at higher stages of current increase. Therefore, Alba has decided to implement FCN in these designs. The primary objective of FCN is to dissipate the excess heat generated by higher current while maintaining process key performance indicators (KPIs), most notably current efficiency at a good level.

3. Behavior of Different Lining Design with FCN

In 2022, Alba implemented FCN in Lines 4 & 5. Alba team faced the challenge of optimizing each pot design based on its own specifications and features. Thermal balance, current efficiency, energy consumption, and metal purity were some of the main key performance indicators to be monitored and optimized. In the following paragraphs, the main challenges and modifications will be discussed for each lining design.

3.1 Copper Design Optimization

The copper lining design was one of the focus areas for Alba as it was designed to operate at 380 kA. However, Alba was confident that with the correct adjustments and with FCN, copper pots can go further in current increase. As preparation for the FCN start up, the first step was to

drop metal level by 1 cm as FCN was expected to increase heat loss by 50 kW [2]. This step was crucial for establishing thermal balance as copper pots were having higher metal level due to previous current increase modifications [1], as shown in Figure 2. The presence of FCN gave the flexibility to operate at lower metal level which helped in maintaining bath level and reducing anode effect frequency.

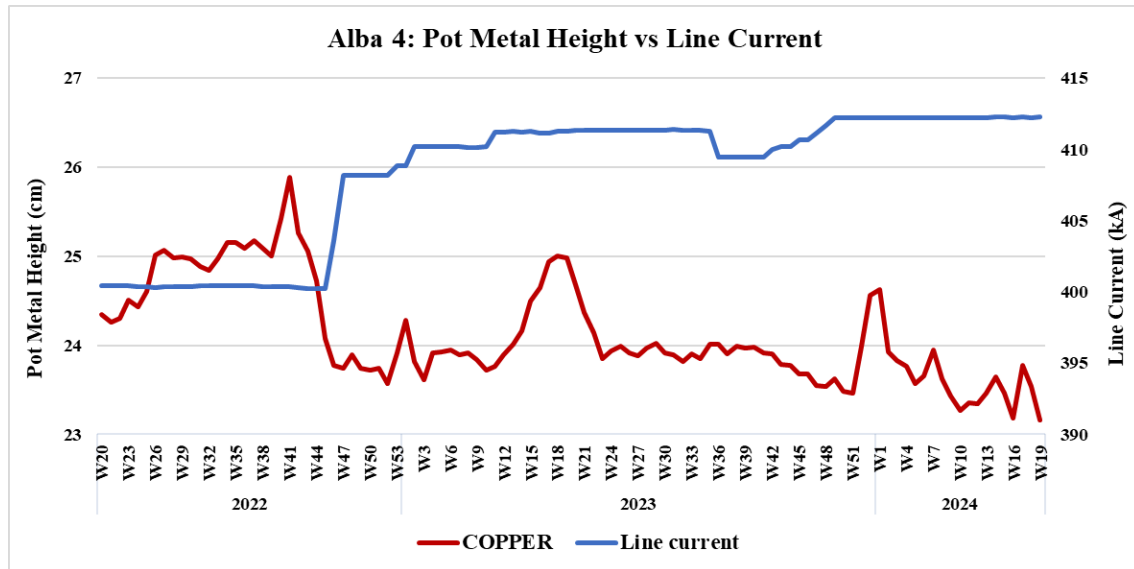


Figure 2. Metal level trend in potline 4 vs line current for copper design.

At the same time, no anode-cathode distance (ACD) changes were planned at the beginning. After FCN start up, copper pots showed good performance in terms of thermal balance and current efficiency. However, during summer season – approximately 4 months after the current increase - COPPER pots had several operational disturbances and were running at high instability (Figure 3). Alba team investigated the issue and found a link between pot age and instability. At the same time, it was found that the bottom ledge was forming in copper pots and causing the high instability. Based on these findings, FCN air flow was adjusted and ACD was opened (Figure 4). Moreover, different settings were applied for copper pots based on their age. This method was found successful in bringing back copper pots instability to normal level.

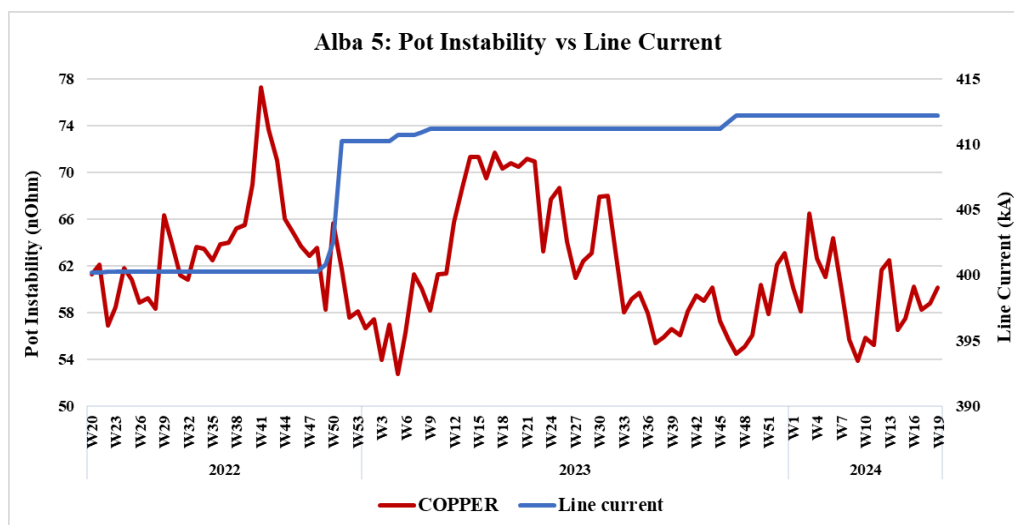


Figure 3. Average pot instability trend in potline 5 vs line current for COPPER design.

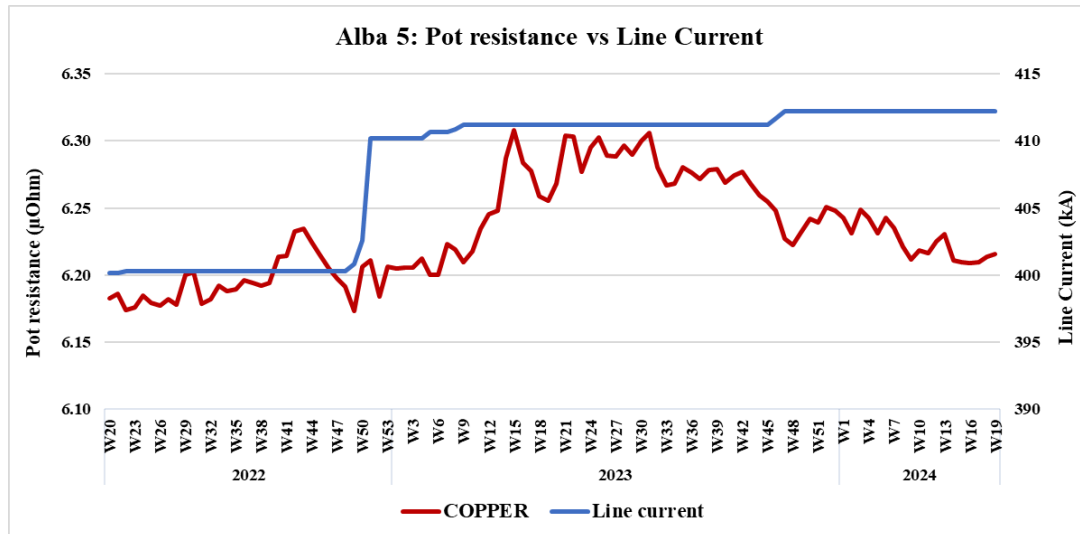


Figure 4. Average pot resistance trend in potline 5 vs line current for copper design.

3.2 AP40A Design Optimization

For the AP40A design, the same preparation of the previous case was performed in terms of metal level. Metal level was dropped by 1 cm in each line. At the same time, Alba took the providence of increasing ACD to achieve higher current efficiency (Figure 5). The AP40A pots showed significant improvements in instability and general performance after current increase operating at higher ACD. The proper FCN air flow setting was found corresponding with AP40A design and thus instability of the pots was running at good level (Figure 6).

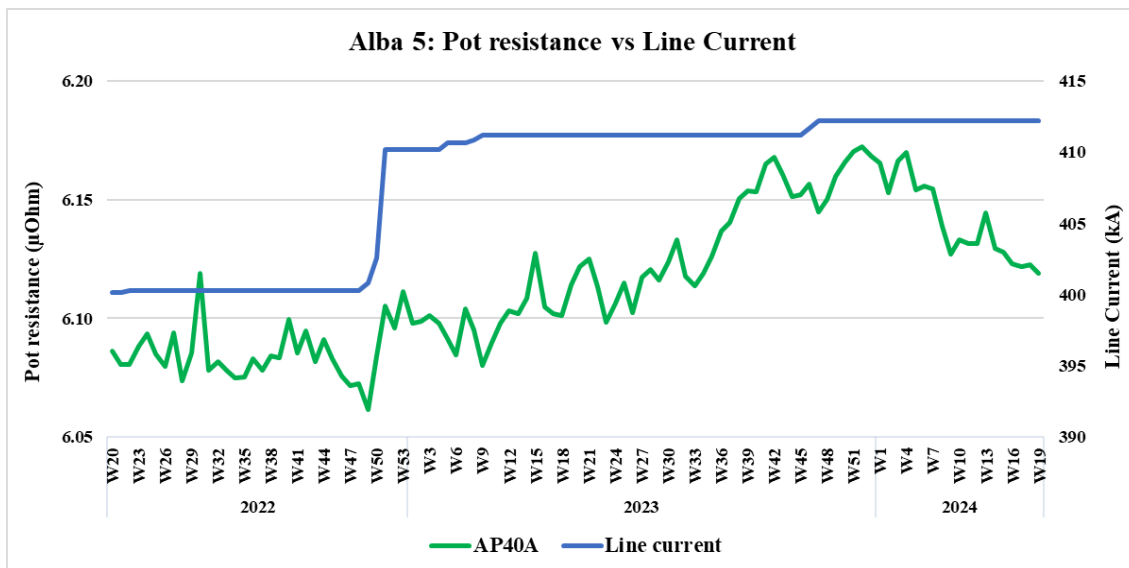


Figure 5. Average pot resistance trend in potline 5 vs line current for AP40A design.

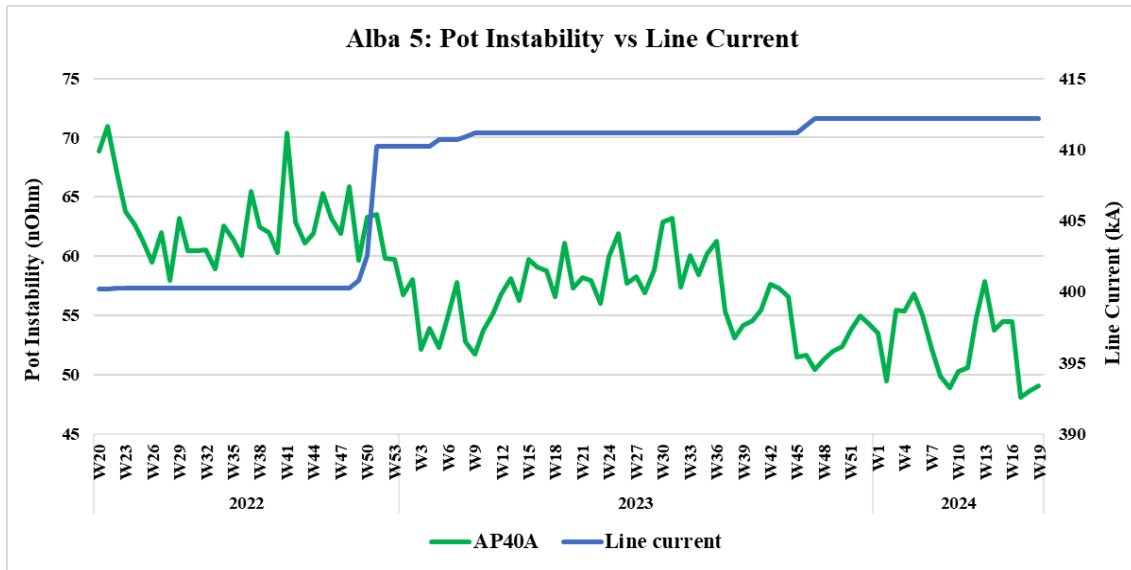


Figure 6. Average pot instability trend in potline 5 vs line current for AP40A design.

One of the main concerns for this lining design was to maintain the bath level. Bath level was given special operational focus prior to FCN start up in terms of measurements accuracy and bath level adjustments. With good follow up from all parties, bath level was maintained 0.5 cm above target before the FCN start up, and then gradually, it was brought back to target when confidence was established about the FCN operation (Figure 7).

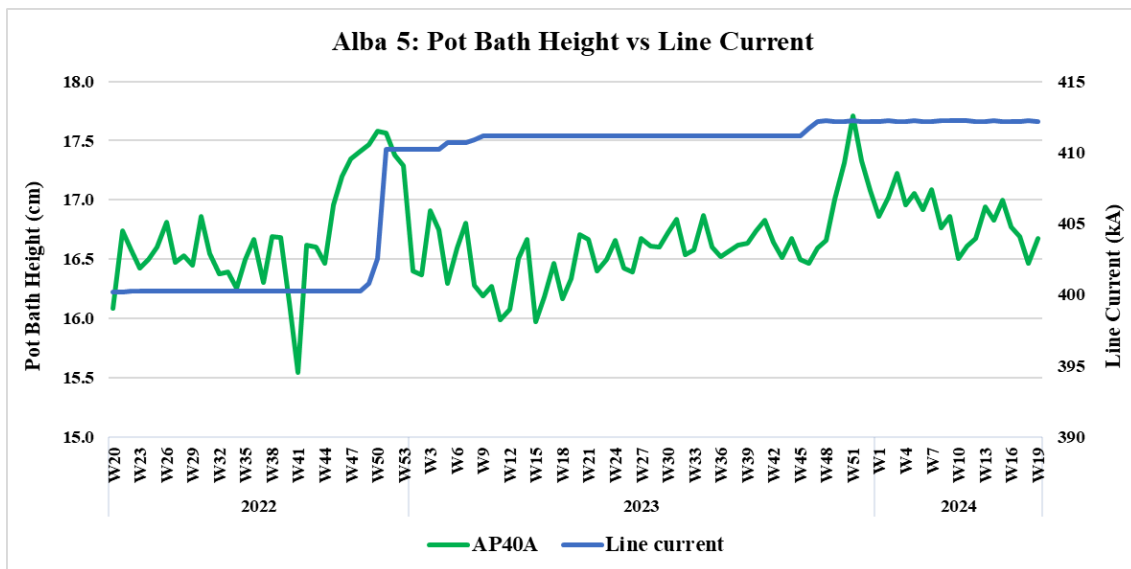


Figure 7. Average bath level trend in potline 5 vs line current for AP40A design.

3.3 CP20 Design Optimization

AP40A and copper designs were operating under FCN after current increase. On the contrary, CP20 design does not require FCN at this level of line current. CP20 FCN valve was shut down since start up and it is planned to operate CP20 under FCN above 420 kA with another ACD setting. CP20 design presents much higher heat dissipation ability and thus ACD was operating at high level before increasing the current to maintain thermal balance of the pot. When the current was increased, the ACD was then reduced. Later, it was further adjusted and increased again for a middle level as this design was still dissipating higher heat at 412 kA and good operating ACD

was found for this design (Figure 8) where all pots experienced improvements in instability and other process KPI's.

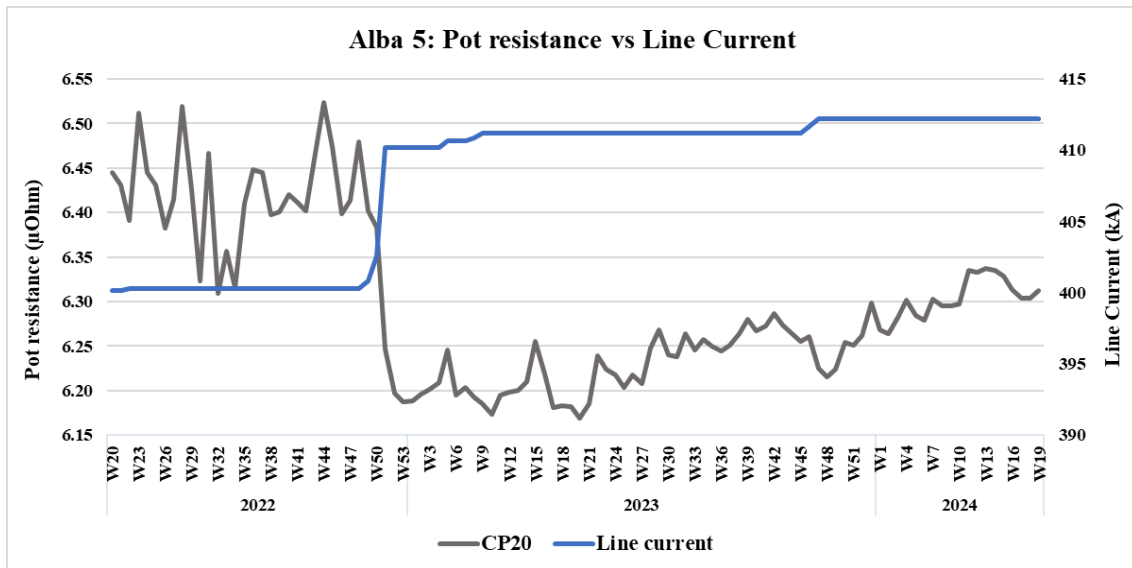


Figure 8. Average pot resistance trend in potline 5 vs line current for CP20 design.

In terms of metal level, it was decided to reduce metal level target by 2 cm for CP20 design. The reduction in metal level supported the thermal balance of this design and was corresponding to the higher heat dissipated by these pots which resulted in improved alumina dissolution and well heated cathode surface and hence better instability and current efficiency. Moreover, bath level target was reduced by 1 cm as it was noticed that high bath level was causing instability and iron contamination to the metal.

Another modification was to increase alumina concentration in bath by manipulating feeding parameters; this modification helped reducing the anode effect frequency and pot instability (Figures 9–10).

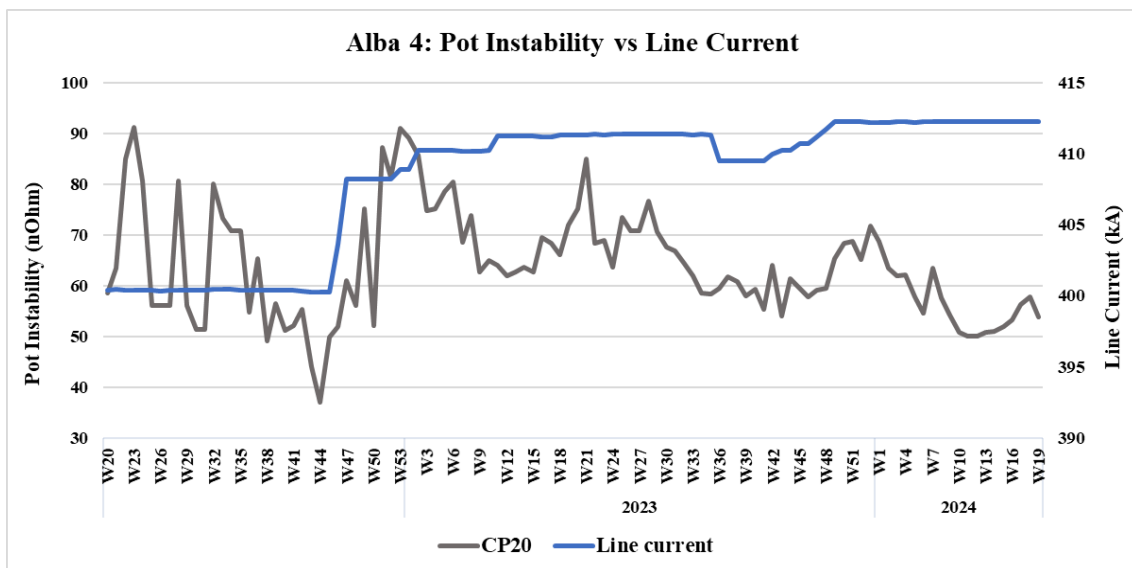


Figure 9. Average pot instability trend in potline 4 vs line current for CP20 design.

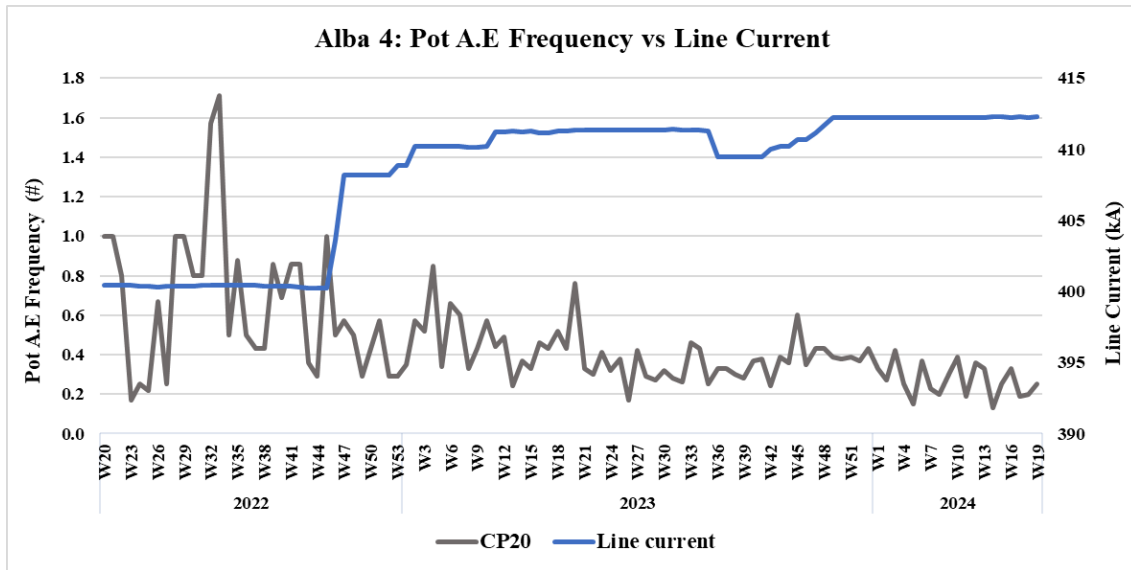


Figure 10. Pot A.E frequency trend in potline 4 vs line current for CP20 design.

4. Results

As a result of the abovementioned optimization steps, line current was successfully increased to 412 kA and has been maintained at this level since December 2023. While current increased, alba managed to maintain major KPIs under control. Current efficiency has been sustained at a high level above 94.5 % and it is considered as a benchmark among all AP smelters around the world (Figure 11). Alba took advantage of operating at higher ACD under FCN along with other modifications to achieve higher current efficiency at higher current. And thus, achieving the highest production record of 1 620 665 t of high purity aluminium.

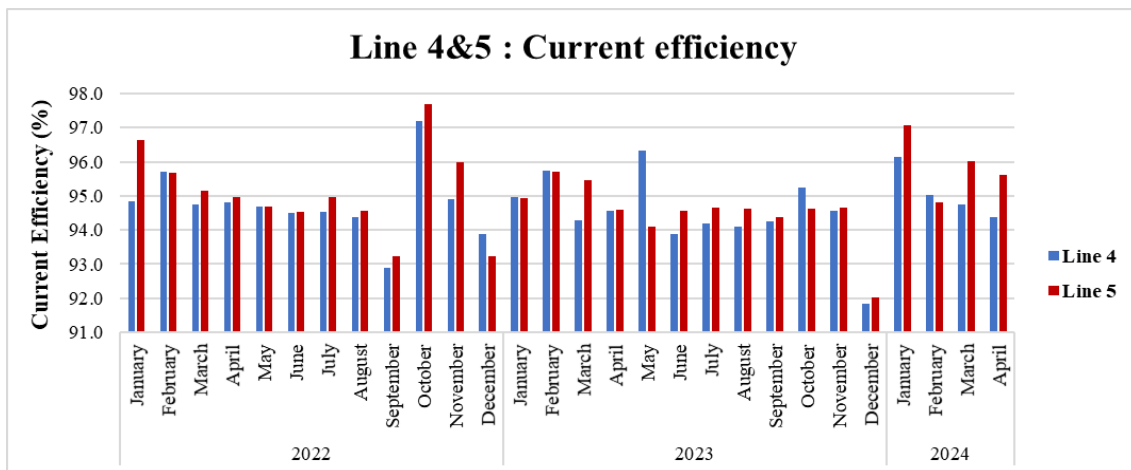


Figure 11. Lines 4 & 5 current efficiency 2022-2024.

On the other hand, having higher ACD and higher line current resulted in an increase in specific energy consumption (Figure 12). The specific energy consumption increased by 0.3 kWh/kg Al in each line in the first year of current increase. Subsequently, since the beginning of 2024 and with the latest Alba optimization steps, the specific energy consumption has been reduced by 0.1 kWh/kg Al in potline 4 and by 0.2 kWh/kg Al in potline 5. Even though Alba is still working on reducing the energy consumption, this increase in specific energy consumption is justifiable, as the increase in pot productivity is estimated to be 91 kg/day due to higher operating current and higher current efficiency. Pot productivity was running at 3.06 t/pot·day in Line 4 and at

3.07 t/pot-day in Line 5 before operating FCN. While in 2024, pot productivity has increased to 3.15 t/pot-day in Line 4 and 3.18 t/pot-day in Line 5 up to April 2024.

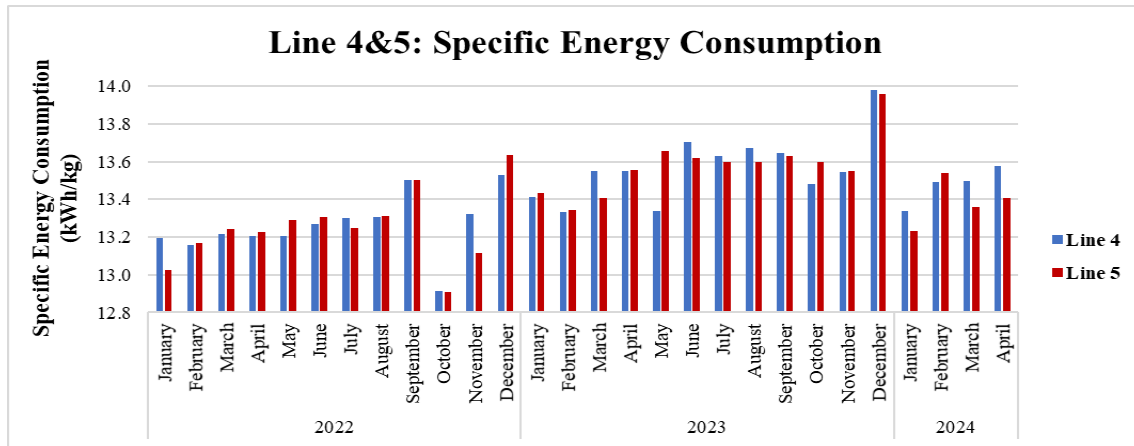


Figure 12. Lines 4 and 5 specific energy consumption 2022-April 2024.

Another major benefit of all these optimizations steps using FCN was having higher shell protection; the shell temperature has dropped by 73 °C in Line 4 and by 75 °C in Line 5, as shown in Figure 13. This will support a higher pot life and improved operating conditions. At the same time, it is contributing to the purity of produced metal by having less attack on pot shell and lining components and hence less silicon and iron contents in metal.

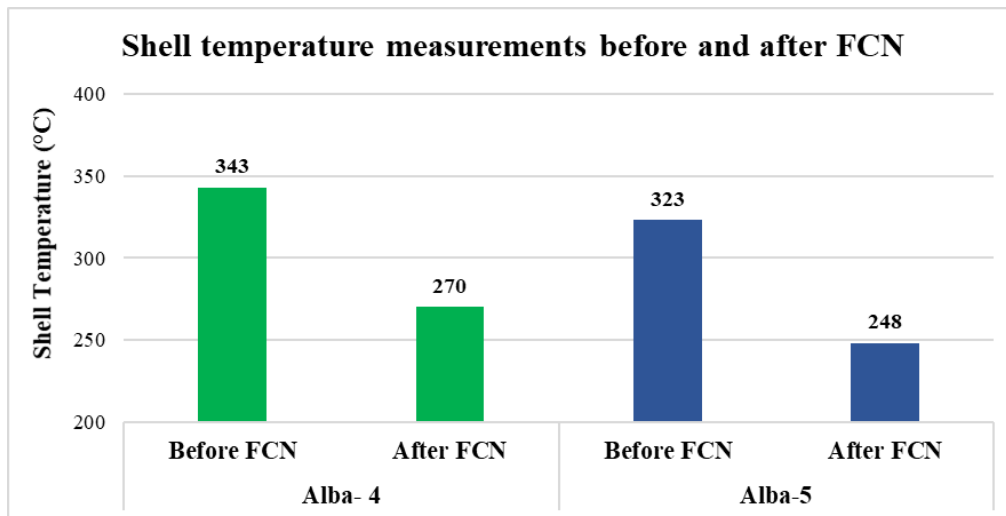


Figure 13. Average shell temperature measurements of AP40A pots in Alba Lines 4 & 5 [2].

The impact on internal heat with respect to current increase and evolution of heat balance for different lining designs are shown in Figures 14, 15 and 16.

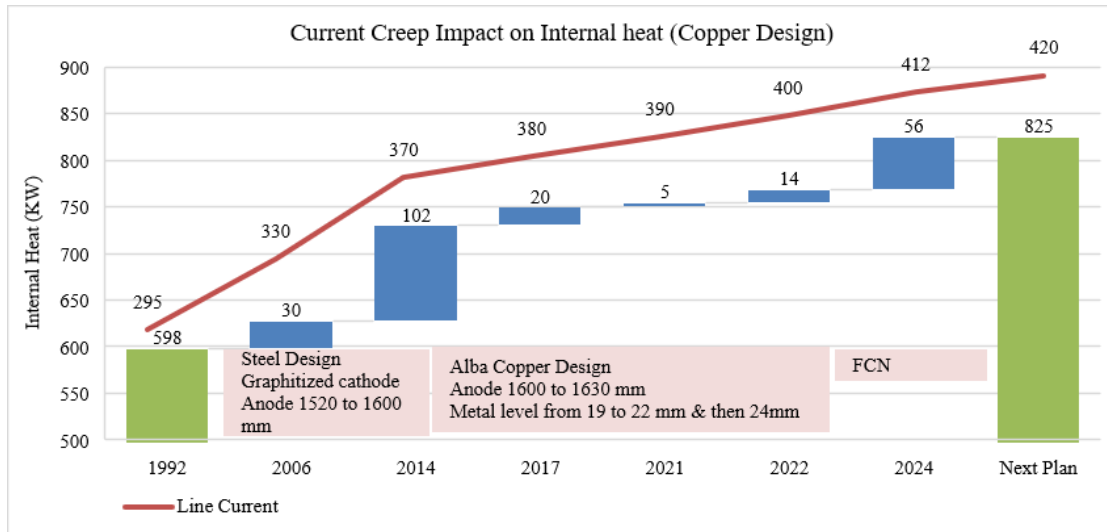


Figure 14. Current increase impact on internal heat (copper design).

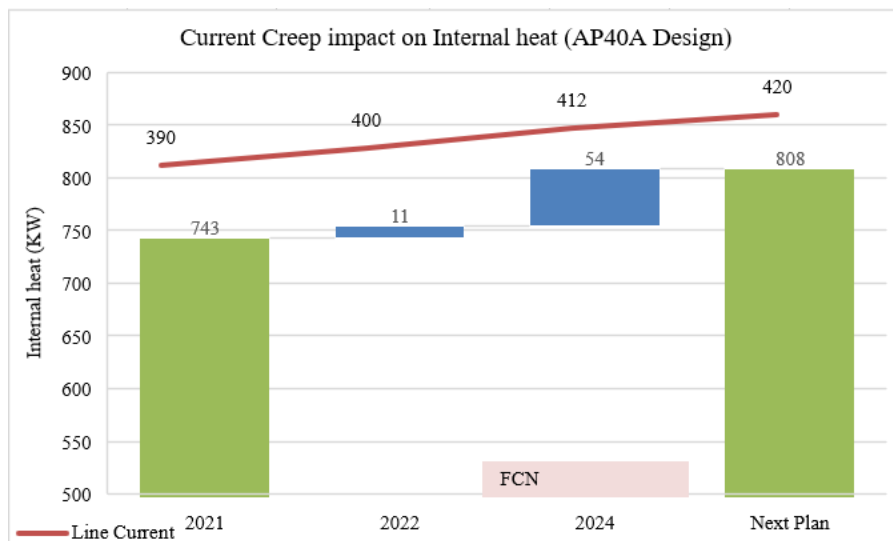


Figure 15. Current increase impact on internal heat (AP40A Design).

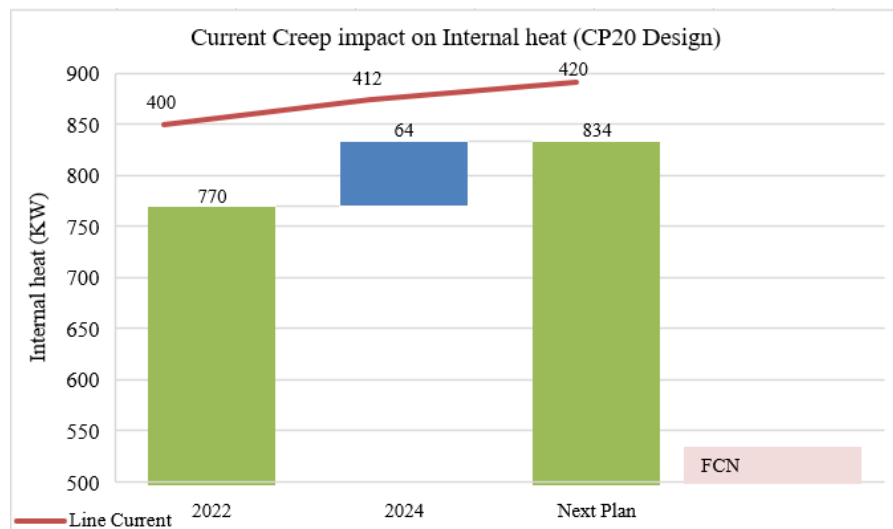


Figure 16. Current increase impact on internal heat (CP20 design).

5. Conclusion

Alba has successfully increased line current by 12 kA with implementation of FCN. While doing so, different lining designs were operating successfully in both lines 4 and 5. Technical expertise, operational proficiency, and organized teamwork helped Alba team finding the optimal settings and operational practices to operate and advance different lining designs with different specifications. The journey of current increase is anticipated to continue in the soon upcoming years and the target is set to reach 420 kA and beyond in Alba potlines 4 and 5.

6. References

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