AL06 - Introducing Forced Convection Network in AP Potlines in Aluminium Bahrain (Alba)

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Abstract

This paper presents the successful implementation of a Forced Convection Network (FCN) project in the AP30 potlines at Aluminum Bahrain B.S.C. (Alba), the world's largest aluminum smelter ex-China. As part of a continuous program of expansion and technology upgrades, Alba has implemented various strategies to increase the line current while maintaining the pots thermal balance. The FCN project involved introducing a network of ducts around the four sides of the pots to provide forced air convection around the pot shell. The success of the project was validated based on airflow measurements which enabled an amperage increase of 11 kA in both AP30 Lines 4 and 5. This paper outlines the approach developed, project execution, and the results achieved after introducing the FCN.

Keywords: Forced convection network, Current increase, Thermal balance, AP technology.

1. Introduction

Aluminum Bahrain B.S.C. (Alba), established in 1971 as the first aluminum smelter in the Middle East, is now consisting of 6 reduction potlines producing over 1.6 Mtpa. Alba started Line 4 with 288 reduction pots as its first potline with AP30 technology in 1992 followed by Line 5 - the longest potline at the time - with the same technology consisting of 336 reduction pots in 2005. Alba has successfully increased the current in both potlines to 400 kA by 2021 without the implementation of FCN as a result of a chain of current increases through the years. Introducing cutting edge technology has enabled Alba to increase current while maintaining good current efficiency which is considered as a benchmark among all AP30 potlines around the world [1].

As the journey continues, Alba's ambition to increase current beyond 400 kA found the necessity to implement FCN to its two AP30 potlines consisting of 624 reduction pots. The design of this system comprises of two main networks: the pot duct networks (PDN) for each pot; and the Air Distribution Network (ADN) comprises of 4 main headers, with each header connected to the pots shells of a specific potline set, and 6 fans connected to each main header, installed at almost equal distance. Proper implementation of FCN requires a combination of concept design, successful installation, and an efficient start-up strategy.

2. Technical Background

One of the most important constraints in aluminum production using the Hall-Héroult process is to maintain the thermal balance of reduction pots in order to achieve optimum operational conditions, current efficiency and the best technical and economic benefits. The thermal balance of the reduction pot has been achieved by adjusting process parameters and implementing design modifications. However, such strategies have proven to have their limitations at higher stages of current increase. The main objective of the FCN is to dissipate the excess heat generated by higher current while maintaining process key performance indicators (KPI's) and most important, current efficiency at a good level. In 2001, Aluminum Pechiney; a global leader in aluminum technology patented the FCN [2] with the intention of introducing a technology to cool down the pot side shell temperature and provide reliable protection for reduction pots to operate at higher current. Modelling tools, such as a computational fluid dynamic (CFD), a finite-element thermo-electric model, pressure loss calculations and other design tools were used by Pechiney to obtain the optimum FCN design [3].

Pot shells are typically protected by a frozen layer of cryolite, called ledge profile, formed naturally due to the temperature gradient inside the pot. The FCN works through a series of nozzles connected around the pot shell providing localized air blown, ideally at the bath-metal interface which is considered the weakest point of the ledge profile inside the pot shell. By applying the FCN, Alba managed to increase current by 11 kA in both Line 4 and Line 5 without the need to squeeze the anode-cathode distance (ACD). One of the main advantages of the FCN is to improve the robustness in operating potlines.

3. Preparation and Installation

A team consisting of Alba process control, engineering and operation was formed to implement the FCN. To properly plan and validate the FCN effect, several measurements were taken prior to current increase and FCN start up:

- Pot shell temperature measurements,
- Ledge profile measurements,
- Superheat measurements,
- Metal inventory,
- Collector bar temperature,
- Clad temperature,
- Total anode voltage drop,
- External voltage drop.

Prior to current increase, FCN was tested - air velocity measurements and static pressure measurements were taken at different damper openings from the PDN and at different number of operating fans to assess the fans performance. Moreover, the same measurements were taken from the nozzle outlet. The air velocity measurements at this stage were useful and were employed at later stages to find the interpolated value between fan damper opening and air velocity, to determine the FCN setting required at the desired air flow (see Figure 1).

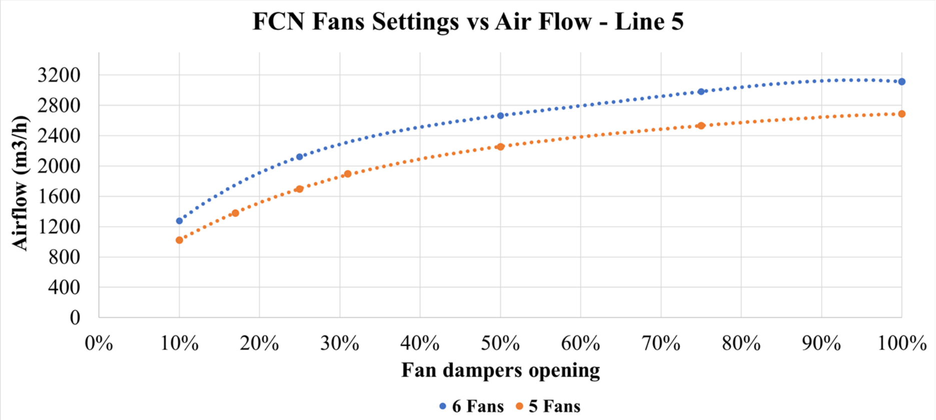

Figure 1. FCN fan damper opening vs air flow on polynomial trendline.

3.1 Pot Duct Network (PDN)

The FCN for the walls of the pot shell consists of a set of mild steel ducts that rings the 4 sides of the pot shell. The PDN has two parts and was developed by RTA. The first part is located against the pot shells and has ejection nozzles to inject air towards the walls of the pot shell to dissipate the heat. There are 4 ejection nozzles per cradle-to-cradle space. The second part is located under the basement which provides a link with the ADN. The duct network has been designed and manufactured carefully to ensure the following functions:

- Interchangeability of the complete system from one pot to another,
- Identical amount of air delivered by each ejection nozzle,
- Speed and ease of fitting to a pot in operation,
- Seal of connections between the different sections of ducting,
- Low fabrication cost,
- Installation without pot shell modification.

A 3D representation is shown in Figure 2. The PDN is intended to cover the entire pot and to be operated continuously. The PDN has been manufactured in two lots. Lot 1 consists of the rigid metal ducts whereas Lot 2 consists of the duct supports, flexible ducts and accessories. Rigid metal duct package contains circular ducts, rectangular tubes, ejection nozzles, and accessories. Even though RTA recommended to use X2CrNi18-10 stainless steel, a non-magnetic material for the PDN to ease the installation, Alba selected mild steel considering the reduction in fabrication cost. Each section of the PDN was marked to facilitate quick assembly at the site. Controlled PDN velocity ensures a sufficient airflow applied on the pot shell for cooling the side walls by improving the heat dissipation from all 4 side walls.

Figure 2. Pot duct network 3D representation.

3.1.2 Pot Duct Network Prototype Fabrication and Testing

The PDN prototype fabrication and assembly is an important step in the implementation of FCN on aluminum pots. The purpose of this process is to test the performance of the cooling network and ensure that it meets the required specifications. A factory acceptance test (FAT) is conducted to verify that the cooling network functions as intended, and a site acceptance test (SAT) is performed to ensure that the cooling network can be safely installed and operates correctly at the actual site.

The prototype is fabricated and assembled at the manufacturing facility. Once the prototype is fabricated and assembled, a factory acceptance test (FAT) is performed. The FAT is a series of tests that are conducted to verify that the cooling network functions as intended. This includes physical inspection, testing the flow rate, and air velocity at each ejector nozzles of the network. Any issues that are identified during the FAT are addressed and resolved before the cooling network is installed at the site.

After the FAT is completed, the PDN is installed on a running aluminum pot to perform a site acceptance test (SAT). The SAT is designed to ensure that the PDN can be installed safely and operates correctly at the actual site where it will be used. Any issues identified during the SAT are addressed and resolved before the cooling network is put into service.

3.2 Air Distribution Network (ADN)

The ADN is an essential component of the forced cooling network. The primary purpose of the ADN is to deliver low pressure fan air (from fans installed next to the potroom in the courtyard) to the individual pot duct network (PDN) through a main header duct.

Each potline is divided into 4 sub-assemblies, each with 6 equidistant fans. Each sub-assembly consisting of 72 pots in Potline 4 and 84 pots in Potline 5. For each sub-assembly, the fans are all connected to a header to convey the forced air to pots. Each fan is equipped with an inlet guide vane damper. The dampers are regulated during commissioning based on the average reading of pressure (and flow of 2250 Nm3/h) at the inlet of each PDN. When one fan is out of operation, the damper for the remaining fans is maneuvered to increase the flow from the operating fans to deliver 1800 Nm3/h to each PDN. The worst-case N-1 scenario is when either F1 or F6 is out of operation.
The main header of the ADN operates at ground potential, whereas the PDN network operate at a pot potential. Electrical insulating pipe sections and regulating valves are provided for isolation purposes.

The most important constraint while designing ADN was to get the minimum air flow to each PDN while optimizing the fan power requirements.

Sizing criteria for the fans were considered below:

a. Deliver uniform 2250 $Nm^3/h/PDN$ with minimum fan power when all fans are in operation.
b. Deliver a minimum 1800 Nm^3/h to the last PDN when F1/F6 is out of power (with no excessive loses of air and power, to nearby PDNs while delivering 1800 Nm^3/h to the last PDN).
c. Total FCN subassembly power requirements should be similar in 6 and 5 fans operation.
d. For Line 4 and Line 5 individual fan power requirements were limited to 55 kW and 75 kW respectively.

Accordingly, a FCN network was modelled in AFT Arrow software. Fans were modeled using actual fan curves of fans that are close to the final fan selection during design. Then, the minimum duct diameter was established with all operating fans. It should be noted that as the duct diameter increases, the fluctuations of pressure drop in the header will reduce. Using this scenario, the minimum duct diameter was DN600 for Line 4 and DN700 for Line 5. Then F1 or F6 was forced off and minimum flow requirement of 1800 Nm^3/h at the last PDN was imposed. Several duct diameters were iterated to evaluate the flow to each in between PDN till the last PDN and fan power requirements were established for each duct diameter.

The shortlisted duct diameter was where the fan power with 6 fans (DN600) was similar to the fan power with 5 fans.

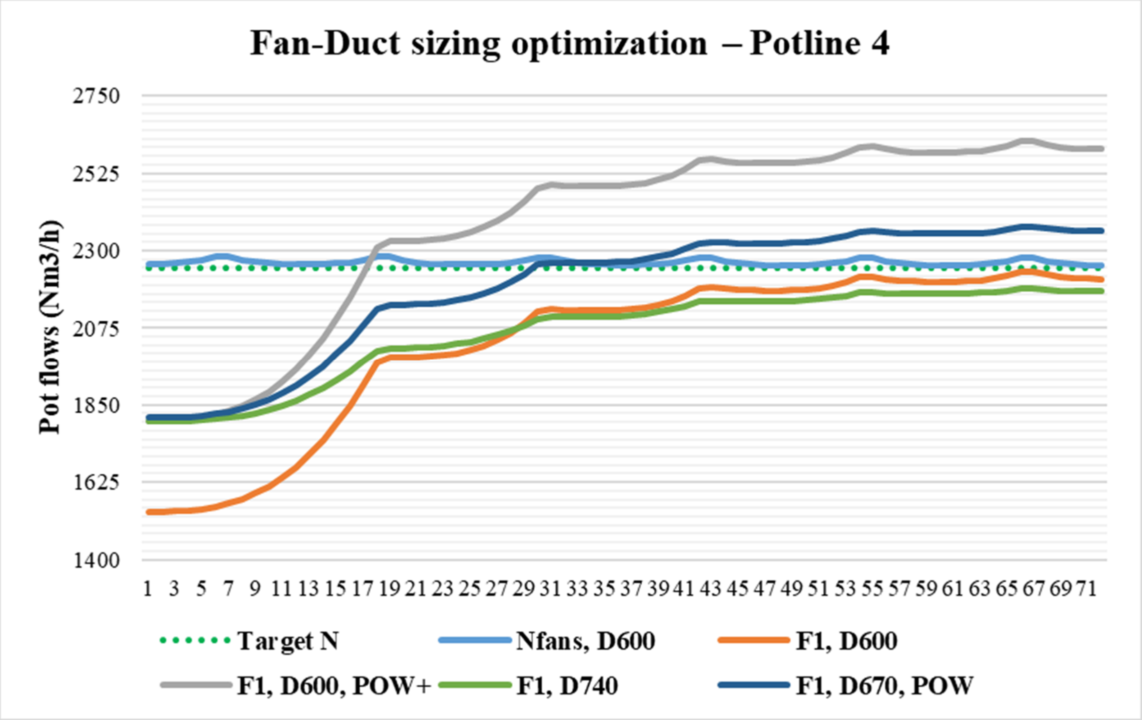

Figure 3. Fan-duct sizing optimization – Line 4.

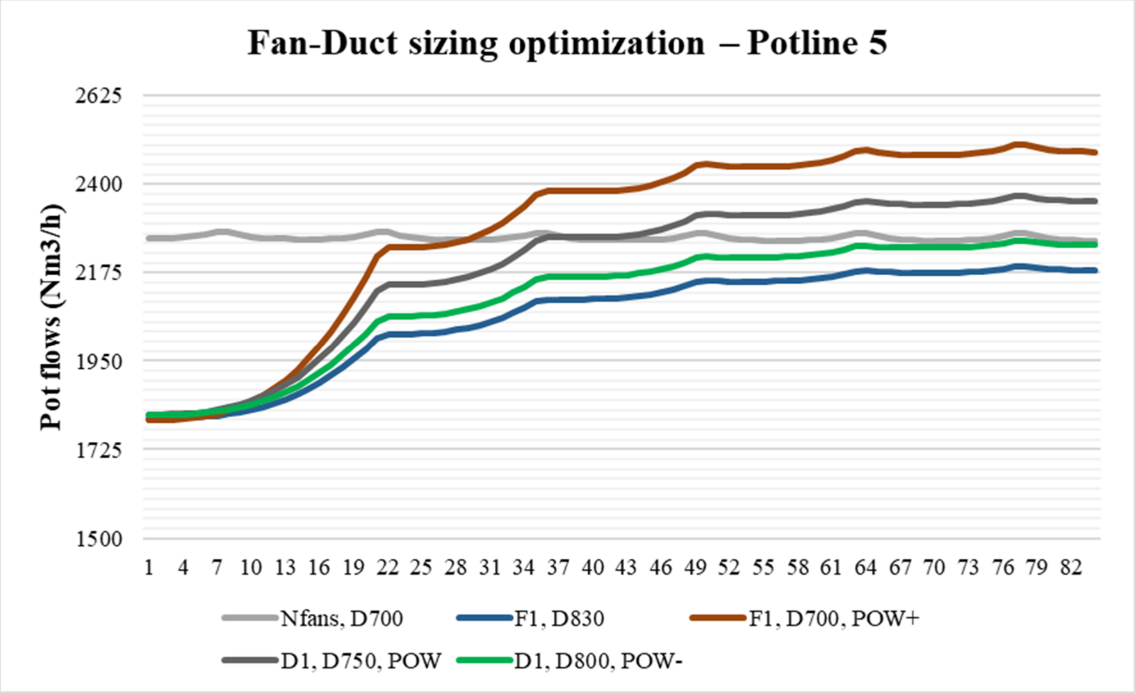

Figure 4. Fan-duct sizing optimization – Line 5.

3.3 FCN Installation and Safety

The installation of a PDN on an aluminum pot is a critical process that requires careful planning and execution. Magnetic material used for PDN has increased the installation challenges and priority was given to adhering to high standards of safety. During the mock trial a prototype was installed on a dead pot shell outside the potroom prior to its first installation on a live pot. Identification marks were given to each part of the PDN and actual space availability measurement between the pot shell cradle and pot busbars was done on 20 sample pots in each pot room. This activity helped to recognize that less gap exists at two positive pot riser B1-B2. Based on the space constraint at positive risers B1-B2, the standard PDN duct design was modified and installed on the down-stream sides only.

To avoid direct contact with positive risers, electrical insulating screens were installed on the PDN ducts located on the downstream side, between the pot and positive risers A and B1-B2.

During the ADN installation, priority was given to install main header ducts to avoid delays due to non-availability of grounding trolley, followed by installation of fans and fan plenums. Fan plenum is the connection piece between the fan and the main header which contains the guide vanes to change the direction of fan discharge air flow with the minimum pressure drop. During the installation of the basement PDN and ADN tie-in branch, a grounding trolley was installed on the pot. Additional care was taken due to the presence of an existing magnetic compensation loop in the basement, to avoid any bridging.

3.4 Operational Setting

Alba has adopted the GO/NO-GO strategy in its current increase decision-making, which considers 21 KPIs that determine the possibility of increasing current. Since FCN intervenes with pot thermal balance, Alba team modified the thermal settings of different pot lining designs in operation. The FCN is expected to dissipate approximately 50 kW from the side shell at 100 % of nominal flow, reducing the side shell temperature by 50-150 °C. So, the focus was to maintain pot internal heat with current increase, based on the GO/NO-GO indicators to ensure minimal disturbance and good control. Additionally, it was important to determine the right air flow in FCN. Optimum air flow will give good thermal balance at pot parameter targets, ensure optimum ACD, keep metal level on target, and reduce excess aluminum fluoride variations accordingly. Too high air flow may cause a thicker ledge on the side and bottom of cathode, causing higher instability and more disturbances to the process. Simultaneously, it was essential to determine the proper time to increase benefits.

4. Results

When FCN was ready for startup and after running the GO/NO GO indicators, Line 4 current was increased by 8 kA within 9 days followed by FCN adjustment and a ramp up of current until 411 kA was reached. While in Line 5, current was increased one month later by Alba team to 8 kA within 6 days and is currently operating at 411 kA as shown in Figure 5. Before increasing the current, the metal level was decided to be reduced by 1 cm as shown in Figure 6 to ensure pots operating within their desired target thermal operating window.

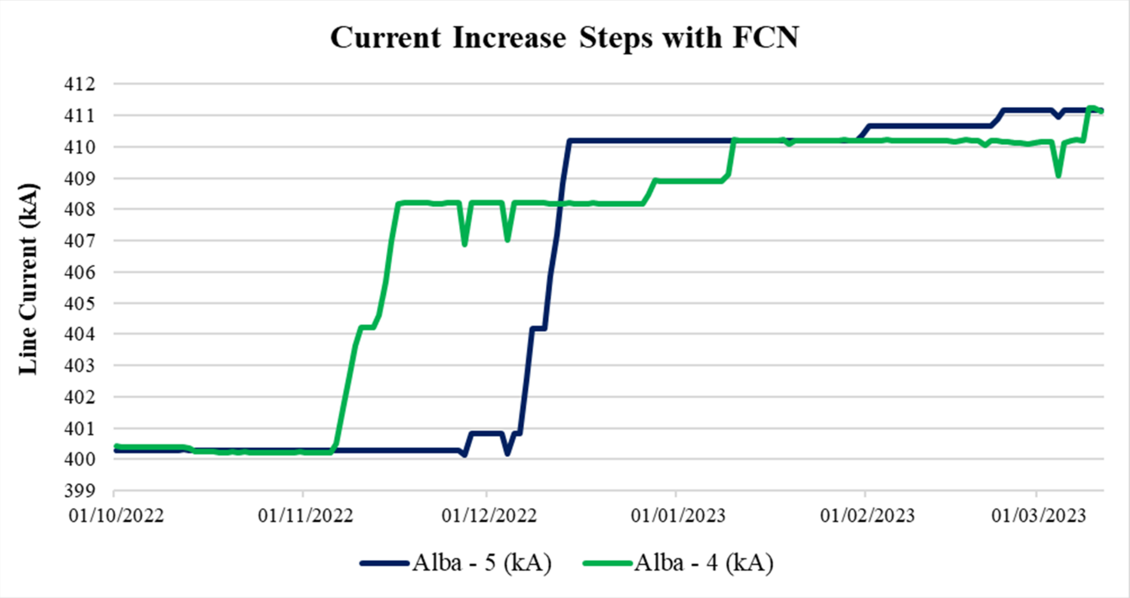

Figure 5. Line current increase after FCN operation in Alba lines 4 and 5.

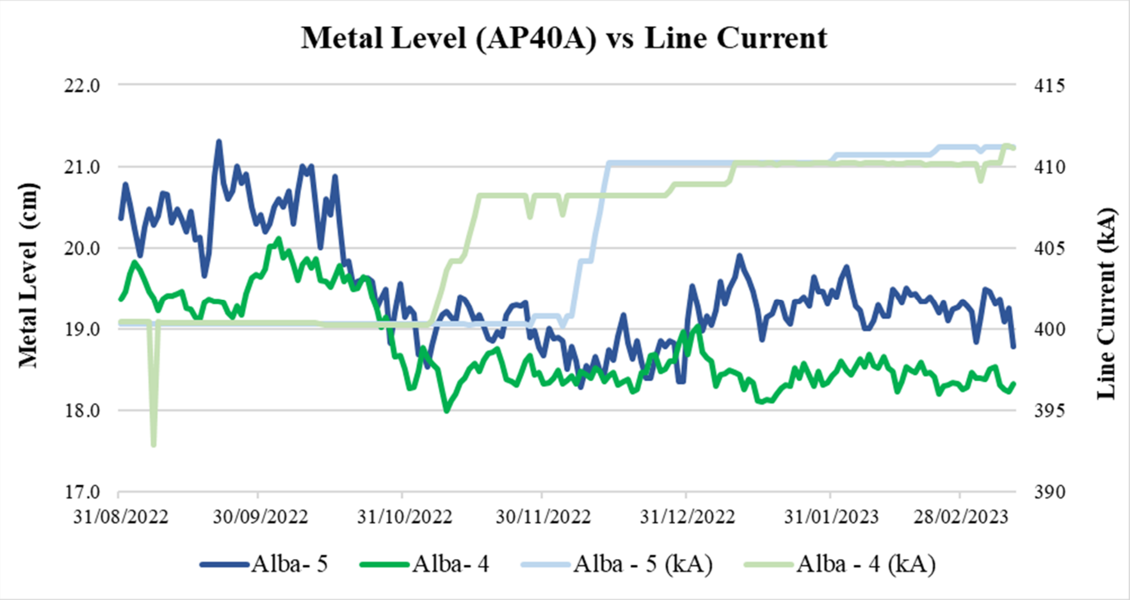

Figure 6. Average Metal level of AP40A pots in Alba lines 4 and 5.

In addition, optimizing anode cathode distance resulted in good performance of instability after current increase, as shown in Figure 7.

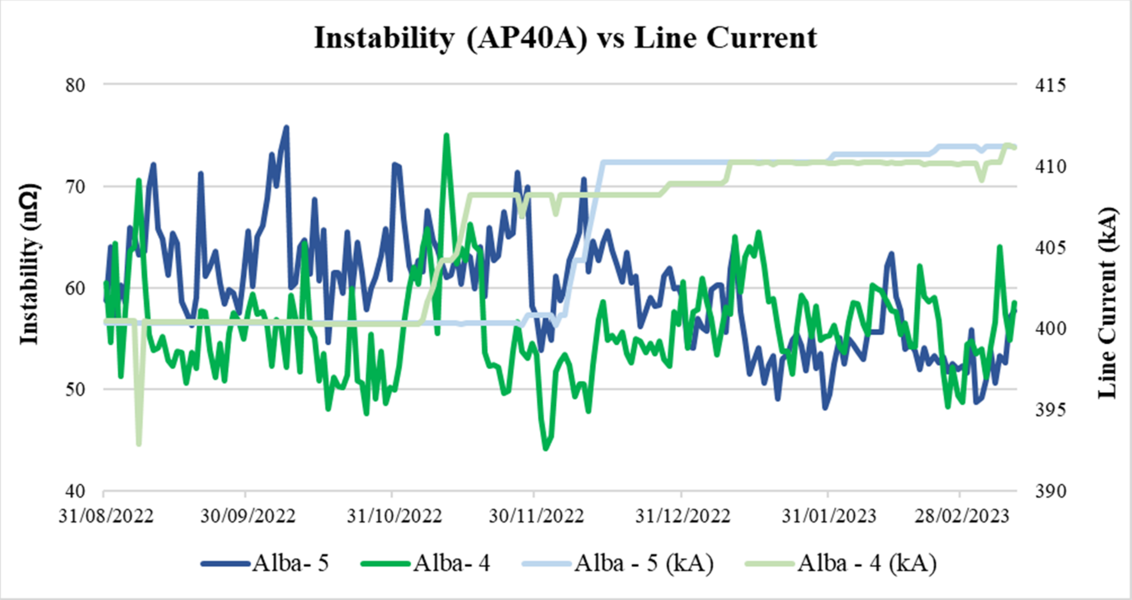

Figure 7. Average instability of AP40A pots in Alba lines 4 and 5.

To validate shell protection, shell temperature measurements were taken and were found to be reduced by 73 °C in Line 4 and by 75 °C in Line 5, as shown in Figure 8. Furthermore, silicon content in metal showed good improvement, decreasing by approximately 40 ppm in both potlines (Figure 9), which is a good indication that the side wall is having better protection.

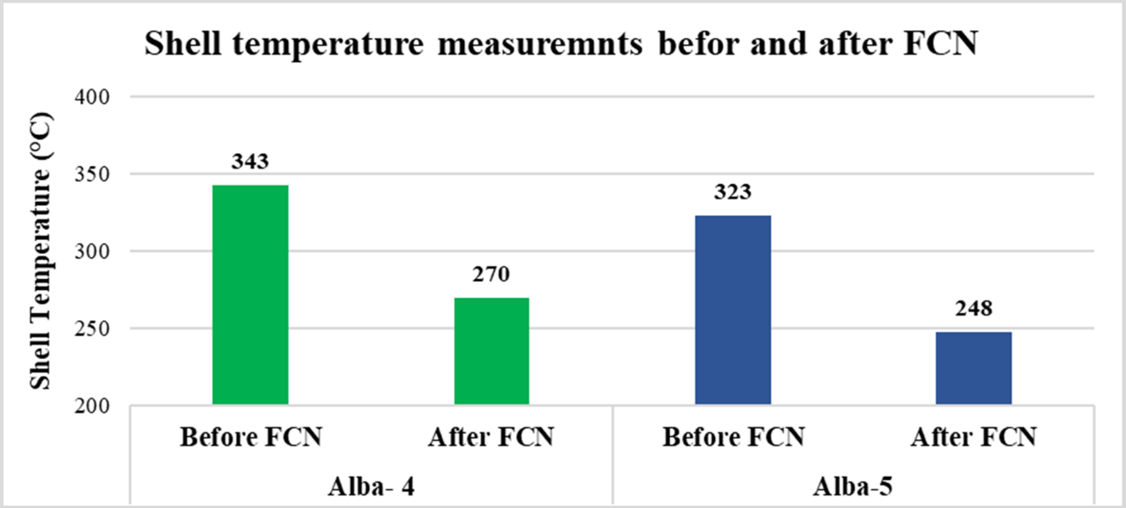

Figure 8. Average shell temperature measurements of AP40A pots in Alba lines 4 and 5.

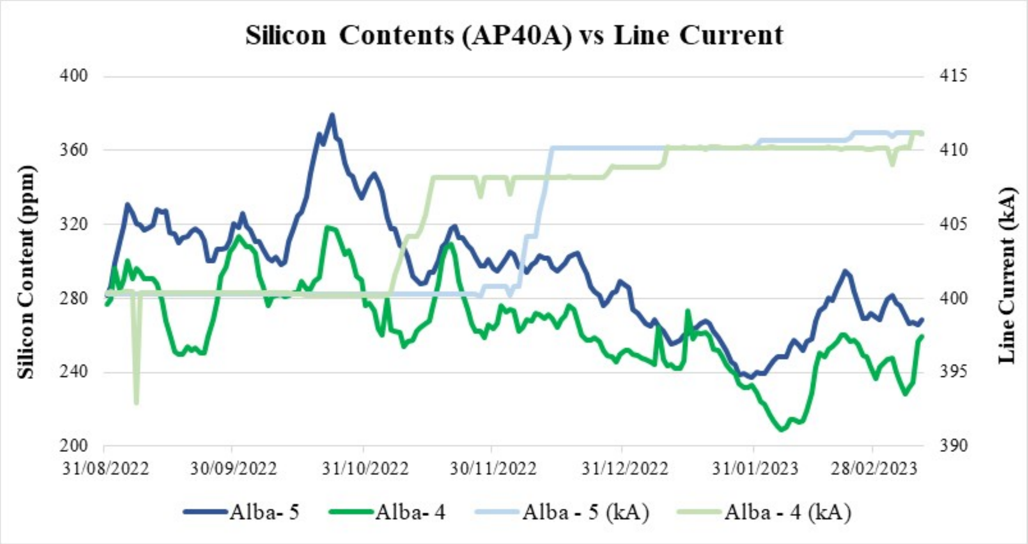

Figure 9. Average silicon content of AP40A pots in Alba lines 4 and 5.

After 6 months of FCN implementation, both pot lines have achieved excellent performance in current efficiency - above 94 %, as shown in Figure 10.

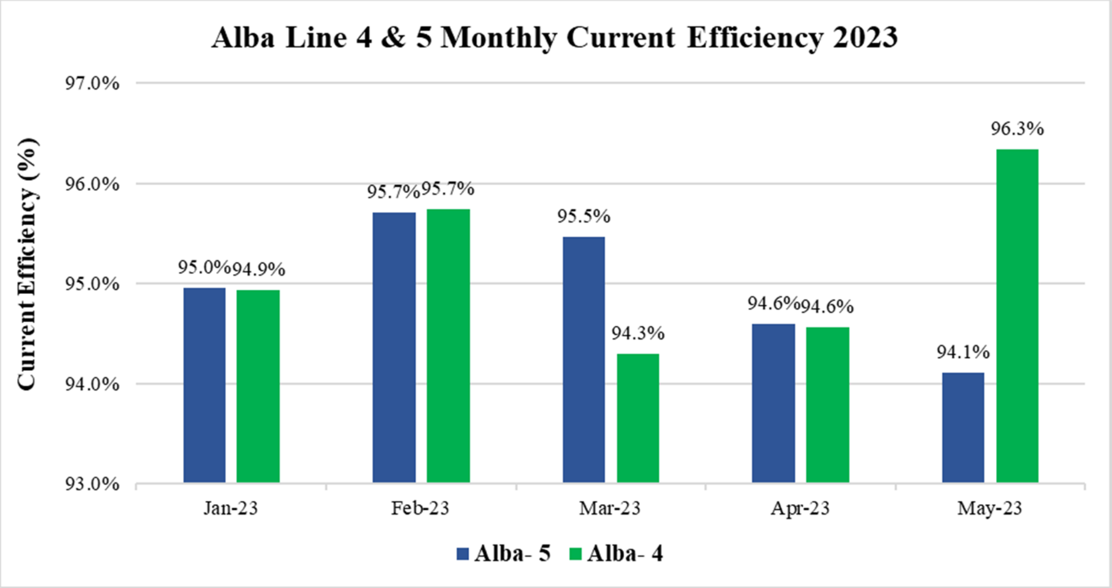

Figure. 10 Monthly current efficiency in Alba lines 4 and 5.

The specific energy consumption increased due to higher current and higher ACD. In 2022 the specific energy consumption was averaging at 13.19 kWh/kg Al in the first 5 months in both lines. While in 2023 after FCN, it has increased to 13.44 kWh/kg Al in Line 4 and to 13.48 kWh/kg Al to Line 5 Figure 11. The increase in energy consumption is justifiable, as the increase in pot productivity is estimated to be 84 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. While in 2023, pot productivity has increased to 3.15 t/pot/day in both lines up to May 2023.

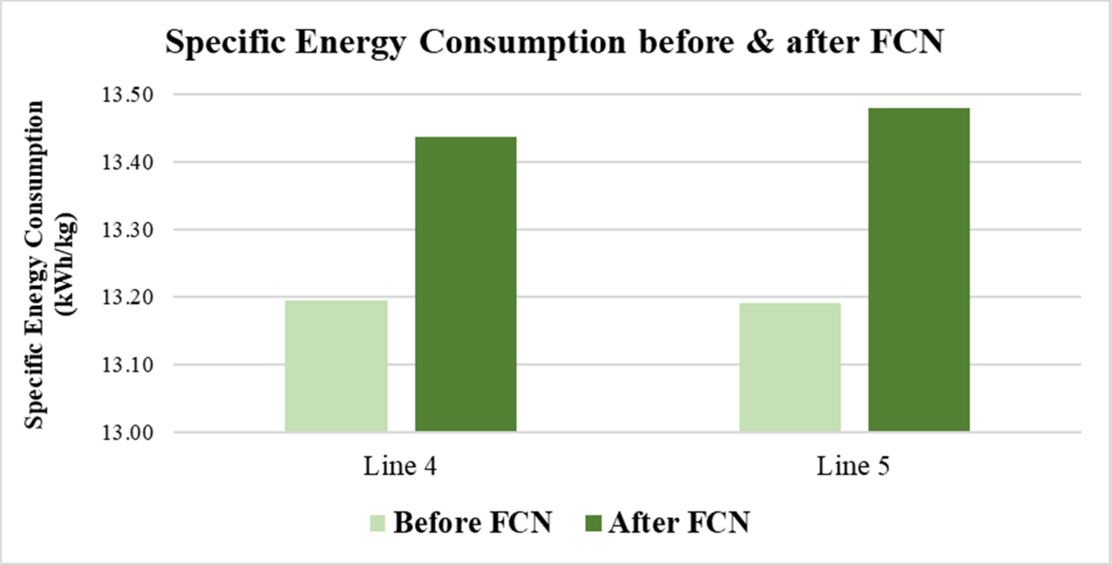

Figure. 11 Alba specific energy consumption before & after FCN.

5. Conclusion

Alba has successfully and safely implemented FCN in both of its AP30 potlines taking into consideration concept design, successful installation, and an efficient start-up strategy. As a result, potline operational conditions were improved, better protection of the side shell was gained, and high current efficiency was achieved.

6. References

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