

## Design and Performance of a Full Copper Collector Bar Pot at EGA

Mustafa Anwar Mustafa<sup>1</sup>, Bernard Jonqua<sup>2</sup>, Abdalla Alzarooni<sup>3</sup>, Fatma Albastaki<sup>4</sup> and Alexander Arkhipov<sup>5</sup>

1. Area Engineer - Reduction Engineering

2. Former Manager Technology Potlining

3. Vice President

4. Former Engineer I – R&D

5. Manager – Modelling, Technology Development & Transfer  
Technology Development & Transfer, Midstream

Emirates Global Aluminium (EGA) Jebel Ali, Dubai, United Arab Emirates

Corresponding author: mamustafa@ega.ae

### Abstract

Cathode voltage drop (CVD) is an important component of pot voltage. Many initiatives to lower CVD have been implemented in the industry. One of them are copper inserts in the collector bars which have been implemented successfully in many smelters. Recently, this idea has been pushed further by using full copper collector bars that are sealed in the cathode blocks in new, innovative ways without the need for cast iron rodding. This paper describes the design, preheat, start-up and performance of the proprietary and patented full copper collector bar design test pot in Emirates Global Aluminium (EGA). Detailed measurements of several critical parameters were made during all stages of the pot start-up and operation. The CVD in the test pot is approximately half the value of the CVD in regular steel collector bar pots. Plus, the observed value is also much lower than in pots with copper inserts. The performance of full copper collector bar pot is comparable to regular pots, except for the fact that it results in a considerably lower specific energy consumption for the same pot technology. Building on the success of the first pot, several other full copper collector bar pots have been put in operation in different EGA pot technologies.

**Keywords:** Full copper collector bars in aluminium reduction pot, Cathode voltage drop, Low specific energy consumption, Advanced potlining.

### 1. Introduction

Cathode voltage drop (CVD) is an important component of pot voltage. Many initiatives to lower CVD have been implemented in the industry. Cathode block grades have migrated from anthracite to graphitic, and then to graphitized, which have progressively lowered the electrical resistivity [1]. Nowadays, predominantly graphitic and graphitized grades of carbon cathode blocks are used because of an additional advantage that the CVD changes little with pot age. Another initiative for CVD reduction is the use of copper inserts in the collector bars that today have been successfully implemented in many smelters. A typical CVD reduction of 60 – 80 mV has been reported with copper inserts [2-4] and the gain obviously depends on the copper insert design, particularly its cross-section and length.

Recently, the concept of decreasing the resistance of collector bars has been developed further and now full copper collector bars have been proposed by EGA [5-7] and others [8-11]. In references [8-11], copper collector bars in test cells have steel terminations outside the potshell in order to limit not only the heat loss through the collector bars but also the collector temperature at the connections to aluminium flexibles. However, this really limits the large potential of a reduction of CVD with full copper collector bars. The main advantage of a full copper design is that there is no cast iron rodding between copper collector bar and cathode carbon block needed. The steel portion at the end of the copper collector bar has been proposed to be eliminated and

replaced by reduced cross-section of copper outside the potshell [12], but the implementation of this design in industrial cells has not been published.

EGA has invented its own proprietary full copper collector bar design [5-6] and built a test pot. This is described in this paper together with results from operation of these pots.

The potential benefits of full copper collector bar pots as they are designed by and implemented at EGA, are numerous, ranging from safety to environmental and financial [7]:

- Eliminates requirements for cathode casting operation meaning this is:
  - Safer
  - Requires less manpower
  - A lower energy cost
  - Requiring less materials, and
  - Requiring less space for making the cathode assembly
- Significant energy savings
- Enhanced potlife meaning:
  - Possibility of higher cathode carbon thickness, and
  - Possibility of lowering maximum cathode current density
- Easily recoverable resulting in more valuable scrap sales
- Creates a valuable know-how and the potential for technology transfer.

## **2. EGA Full Copper Collector Bar Pot Design and Modelling**

A major concern with the full copper collector bar is the lower melting point of copper (1080 °C) than of cast iron (1070-1150 °C, depending on composition) and steel (1425-1540 °C). Furthermore, there is a minor concern whether there will be sufficient pressure between the collector bar and the carbon block to make good electrical contact to obtain a low contact resistance. These concerns are addressed by EGA in cathode design, pot preheat, start-up and operation by an innovative design, upgraded pot start-up procedures and detailed measurement follow-up.

### **2.1 Collector Bar and Cathode Block Design and Installation**

Before implementing the new design in a full pot, a crash test was conducted in a D18 pot where 4 conventional cathode assemblies were replaced with the new, innovative full copper design. This pot was planned to be stopped after a few months of operation in order to convert the pot to D18+ technology. This crash test gave the initial indication that the copper can safely survive startup and early operation. Importantly, it also showed very low contact voltage drop between copper collector bar and carbon block. The 4 blocks were autopsied after stopping the pot and found in very good condition. This test gave the greenlight to the first full pot test with EGA's new full copper collector bars design.

The first test pot is D20 Technology Pot 5B269 in EGA Jebel Ali's Potline 5B. It operates under a line amperage from 270 to 275 kA. The most distinguished feature of pot 5B269's design is the use of full copper collector bars that are directly inserted into the cathode block slots without any cast iron. The design of the cathode block and the collector bars is shown in Figures 1 – 3 [5-6]. It can be seen that in the center of the cathode carbon block there is a gap between the collector bars that is filled with ceramic fiber (16 in Figure 1).

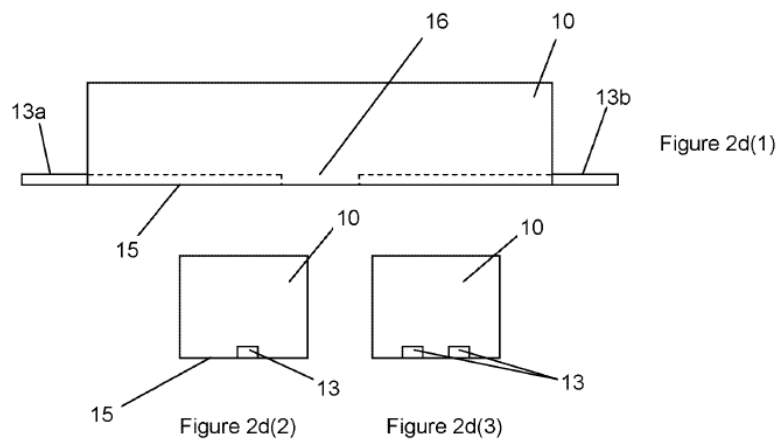


Figure 1. Extract from [5], showing one of the copper collector bar arrangements.

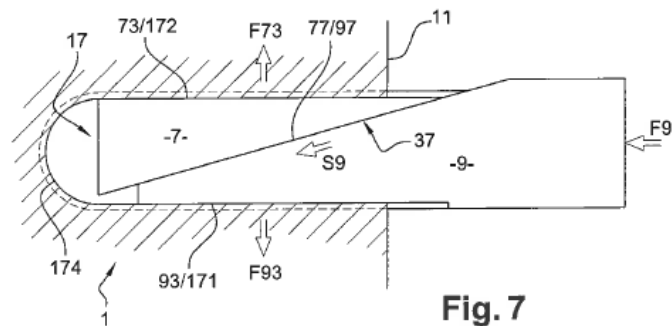


Figure 2. Sketch from [6] showing the way to install the copper bars inside the cathode block slots.

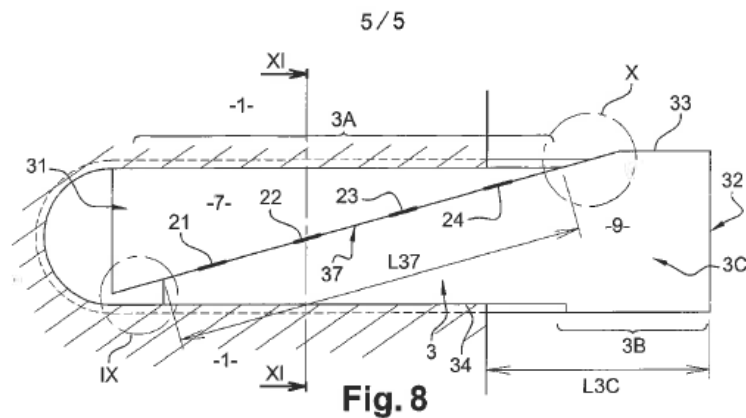


Figure 3. Final arrangement of the copper collector bar [6].

Cathode flexibles are attached to the copper collector bars with a bolted copper tab, which makes for a good copper-to-copper contact. This is confirmed in the field by the measurements of the bolted voltage drop. The value is 6 mV on the average across the whole joint.

## 2.2 Mathematical Modelling

3D thermo-electric finite element mathematical modelling of a cathode slice model with full copper collector bar was developed using the commercial software ANSYS Mechanical combined with ANSYS Parametric Design Language (APDL). The model consists of a pot shell,

cathode lining, collector bar and cathode flexibles. The trial for first full copper collector bar pot was selected to be in D20 Technology. A D20 pot with copper insert in collector bars was modelled and taken as a base case to compare CVD and heat loss with the full copper collector bar. The base case model was validated against measurements and the contact resistance at the cast iron-carbon interface was fine-tuned to match the measured CVD of the pot.

Cathode lining of the pot with full copper collector bars is similar to that with copper inserts except for a few minor changes in the side and bottom lining. Both designs use graphitized cathode blocks. Due to smaller height of the copper collector bar, an additional layer of refractory brick was added. Bath temperature in the model was 962 °C and the super heat 10 °C.

Combined convection and radiation boundary conditions were applied to all external surfaces. The end of the cathode flexible connects to a busbar. Electric current proportional to the slice was applied to the busbar and zero voltage was applied to top surface of the cathode block.

The contact resistance between the copper bars and cathode blocks is unknown, hence, it was initially assumed to be similar to that between cast iron and cathode block. This gave higher voltage drop than measured and subsequently the model was readjusted with lower contact resistance for copper-carbon interface than for cast iron-carbon interface to match the measured CVD of copper collector bar pot.

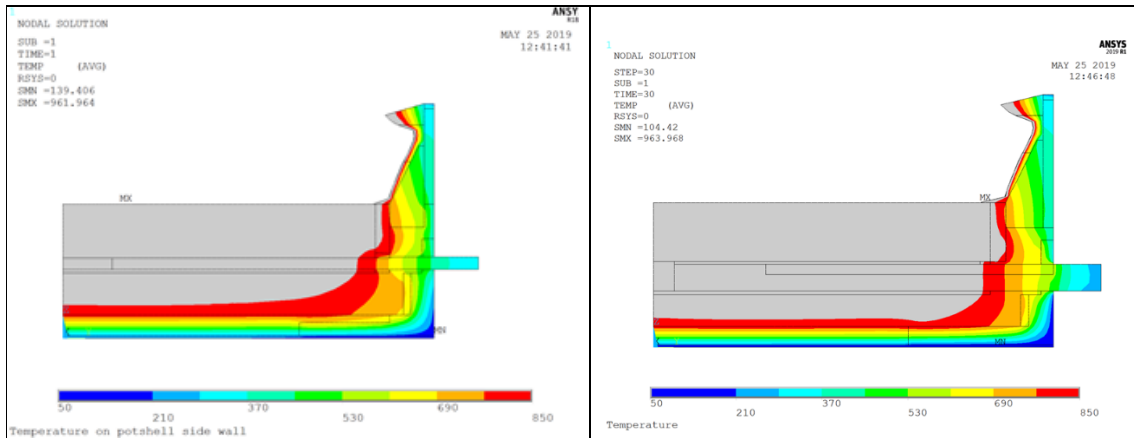
Table 1 compares heat loss and CVD of copper insert (Base Case) and full copper pots for D20 technology, calculated with a model, validated with CVD measurements.

**Table 1. Model calculated heat loss from the copper collector bar pot and from base case in a D20 pot.**

Heat loss from cell (kW)	Base case, copper inserts	Full copper collector bars
Sidewall deckplate	31	30
Upper part of sidewall	99	97
Lower part of sidewall	52	60
Collector bar and flexes	65	83
<b>Side walls total</b>	<b>249</b>	<b>270</b>
<b>End wall</b>	<b>60</b>	<b>60</b>
<b>Bottom of the shell</b>	<b>43</b>	<b>37</b>
<b>Cathode total</b>	<b>350</b>	<b>368</b>
<b>Anode</b>	<b>204</b>	<b>180</b>
<b>Total heat loss, cathode + anode</b>	<b>554</b>	<b>547</b>
<b>Anode Cover (cm)</b>	<b>7</b>	<b>13</b>
<b>CVD (mV)</b>		
Cathode block voltage drop	53.0	56.4
Collector bar	104.6	61.7
Cast Iron	4.9	0.0
Contact copper - carbon	37.9	22.0
<b>CVD total (mV)</b>	<b>200.4</b>	<b>140.1</b>

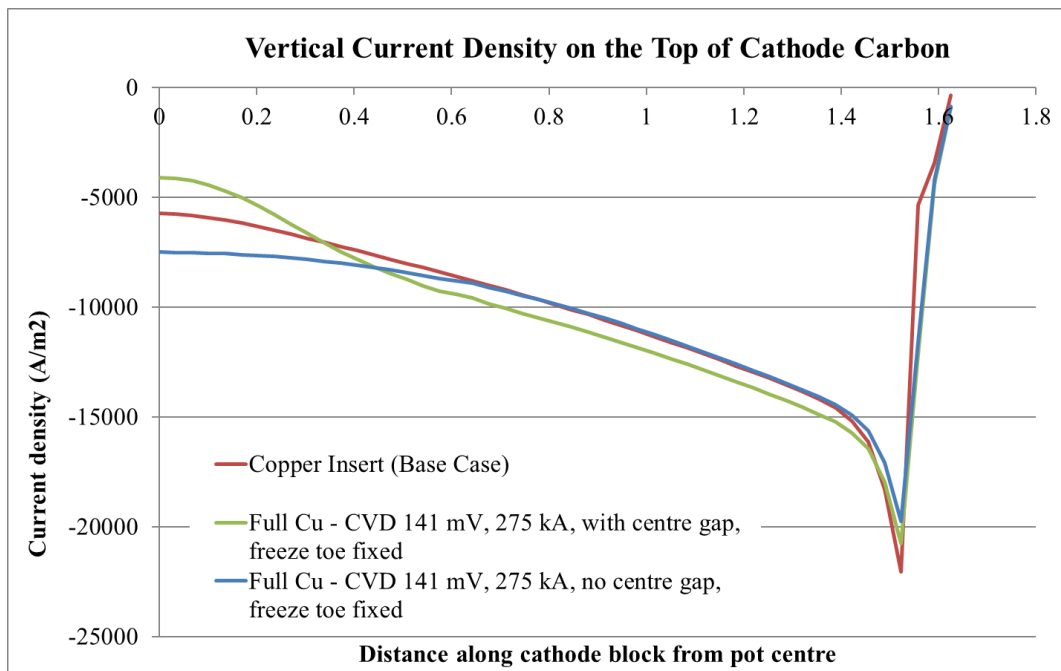
This table shows that cathode heat loss is 18 kW higher using full copper collector bars when compared to pots with copper inserts. Higher heat loss from the cathode is compensated by an increased anode cover thickness, which decreases the anode heat loss.

Figure 4 shows the temperature isotherm of the full copper collector bar pot (left) and the copper insert pot (right). The full copper collector bar pot 850 °C isotherm is similar to that of the copper insert pot. It is in the firebrick layer in both designs, which helps reduce the rate of bath penetration into the insulation bricks.



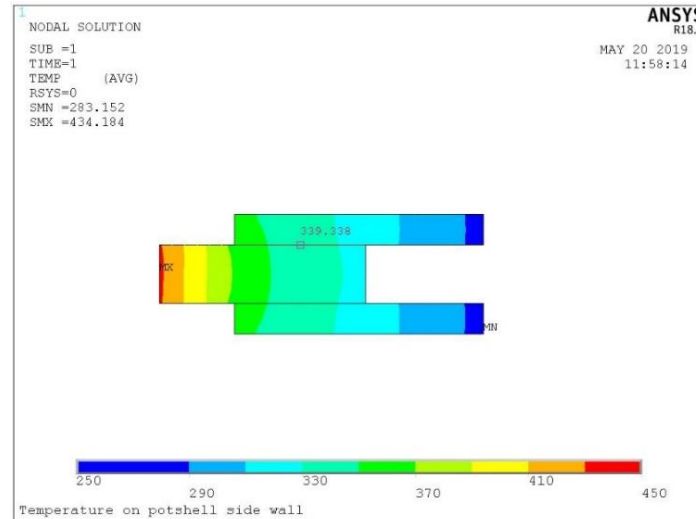
**Figure 4. Temperature contours in the cathode of full copper collector bar pot (left) and copper insert pot (right). 850 °C isotherm is the boundary between grey and red.**

Figure 5 shows that vertical current density on the top of cathode block surface is more uniform in a copper insert pot than in a full collector bar pot. Maximum current density is at the edge of the freeze and is approximately 10 % lower in the full copper bar pot than in the copper insert pot. It shows that more or less current than in base case enters the copper pot in the central area of the cathode (Figure 5), depending on the length of the gap with no collector bars at the pot center.



**Figure 5. Vertical current density on the top of cathode block. The CVD is the measured average over 1002 days.**

Additionally, modelling results show that the full copper collector bar temperature at the cathode flexible bolted joint is approximately 340 °C at 270 kA (Figure 6). Actual measurements presented later showed lower temperature of 298 °C, which can be explained in part by better actual ventilation at the time of the measurement than in the model.



**Figure 6. Temperature of the cathode flexible bolted joint.**

### 3. Pot Preheat and Start-up

#### 3.1 Preheat Set-up

Cell preheat is important with the aim to create a uniform temperature distribution in the cathodes before bath-up. A good preheat will have a positive impact on the operation of the cell and life expectancy of the pot. Hence, pot preheat modelling was done in advance to design the preheat graphite bed template. The details of the preheat practices at EGA are explained in [13].

In order to closely monitor and assess preheat, detailed measurements were carried out as follows:

- 1) Cathode surface temperature (Figure 7): Five thermocouples were embedded into different five cathode blocks and connected to a data logger.
- 2) Cathode voltage drop (CVD) and collector bar temperature (Figures 7 and 8): Three voltage probes were embedded in the same cathode blocks; one in the center of the block and two at an equal distance away from the center. A total of 15 probes were connected.
- 3) Anode voltage drop (Figure 8) is measured from below the anode beam on the rod to a fixed point on the anode (approximately 5 cm above the bottom). Temperature is measured on the outer stub.
- 4) Preheat bed voltage drop is measured from the side of the anode to the top of cathode block (Figure 8).
- 5) External voltage drop is defined as being between the end of collector bars to the to the anode rods below the anode beam of the next pot. For measurements an intermediate reference point on the cathode busbar is used. The voltage was measured from several collector bars to the reference point and from there to several anode rods.
- 6) Copper tab temperature was measured on every collector bar before bath pouring.

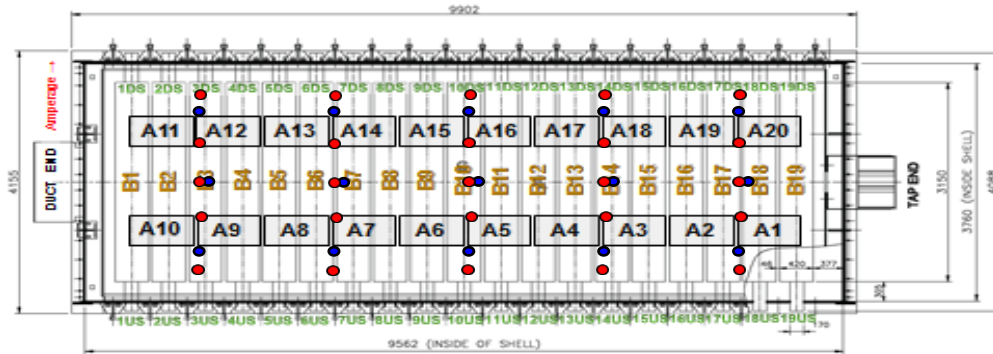


Figure 7. Sketch to indicate location of thermocouples (red) and voltage probes (blue).

### 3.2 Preheat

Preheat started at full amperage of 275 kA. Overall, the full copper collector bar pot had very good preheat. Final preheat temperature (average of 5 locations on the center channel) was excellent, and measured at 960 °C, which was reached in 44 hours of preheat. For some time preheat shunts were used after 19 h of preheat to slow down the preheat rate. This can be seen in the preheat temperature curves. Figure 10 shows the average cathode surface temperature in the center channel and at all other points as well as preheat rate of the pot.

Figure 10 shows that the measured cathode voltage drop during preheat was initially decreasing but then started to stabilize. Cathode flexible voltage drop was measured to get an indication of the cathode current distribution on the basis that the voltage drop is proportional to the current in the flexes. Figure 11 shows that the central collector bars carried more current than the end ones. It is believed that the curvature reflects on the anode current distribution.

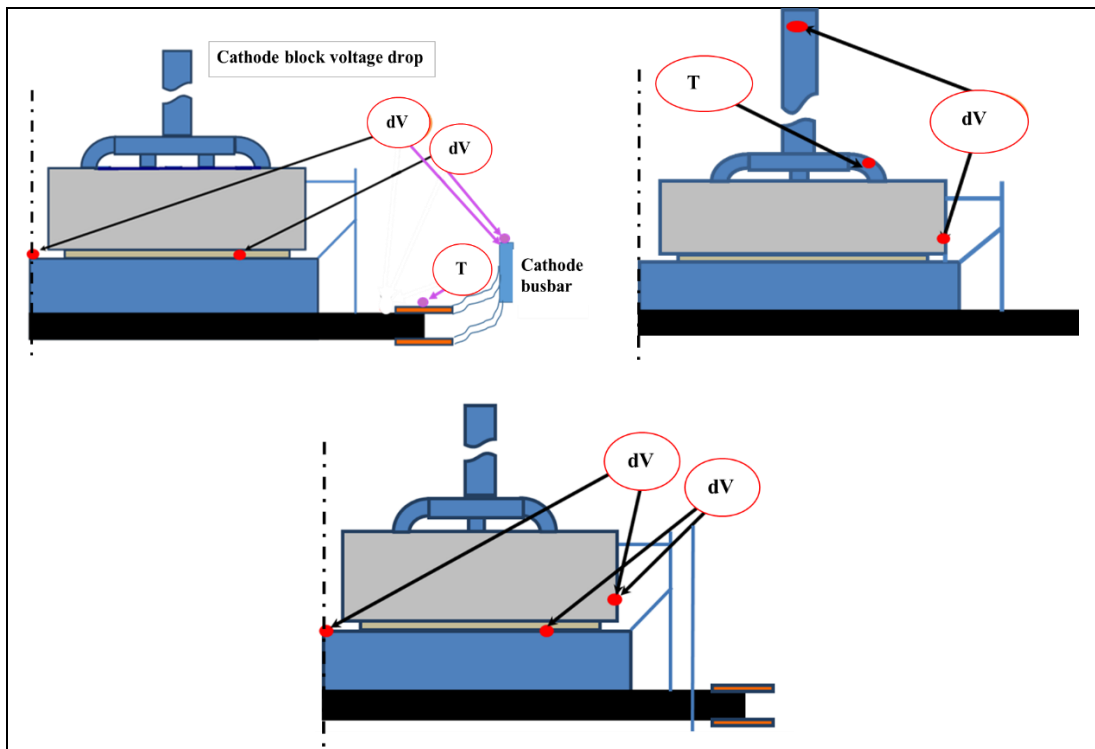


Figure 8. Measurement of cathode voltage drop and collector bar temperature (top left), anode voltage drop and stub temperature (top right, and graphite bed voltage drop (bottom) [modified from 13].

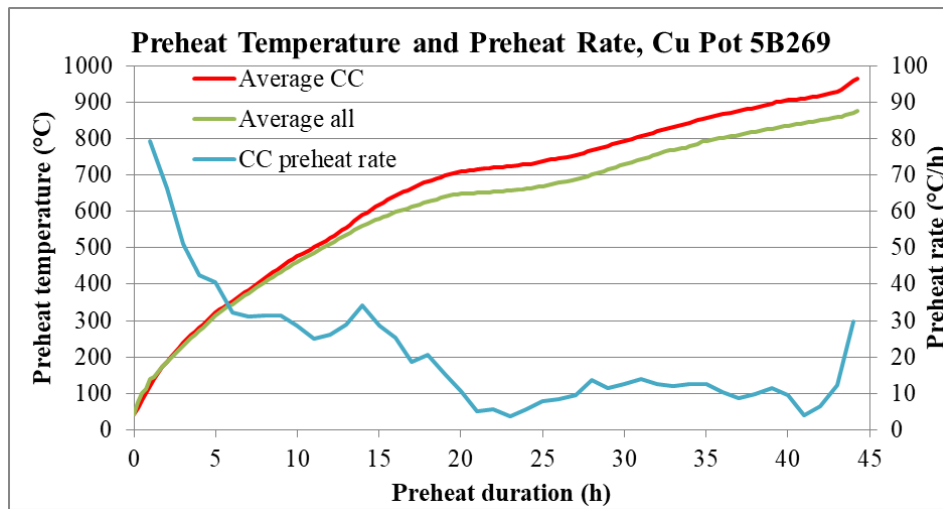


Figure 9. Pot preheat rate and average cathode surface temperatures. CC = Centre channel.

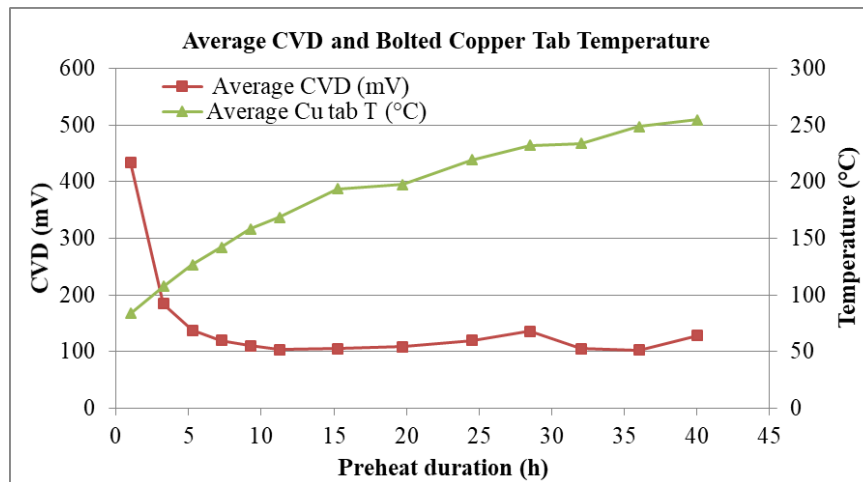


Figure 10. Cathode voltage drop and bolted copper tab temperatures during preheat.

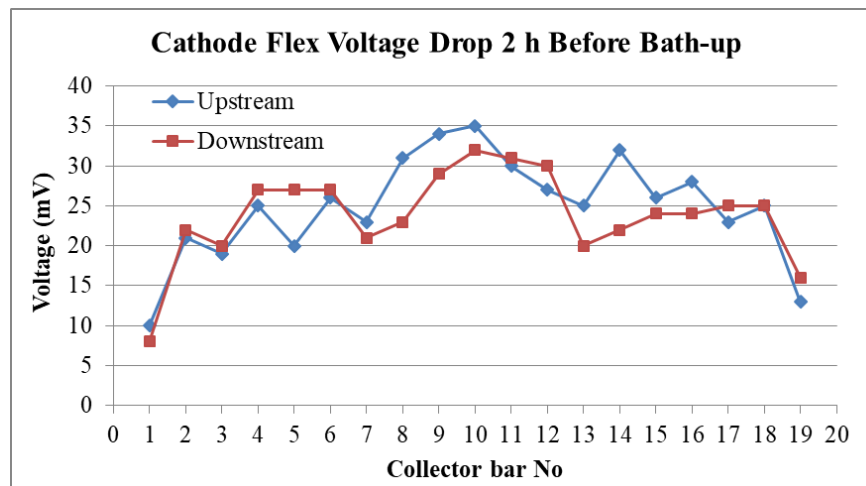


Figure 11. Cathode flex voltage drop 2 h before bath-up. The flex voltage drop is proportional to flex current.

### 3.3 Bath-up, Metal Pour and Afterwards

At the end of preheat, compressed air was used to cool the sidewall and cathode flexibles as precaution. The pot was bathed up on 10 May 2018 with 9 tonnes of bath. Then, 16 hours after bath up, 6 tonnes of metal were poured.

Figure 12 shows that two hours after bath-up the collector bar current distribution was very similar to the one at the end of preheat. Just before metal pouring the current distribution was more uniform, even though more current was drawn at the tap end (collector bars 11 – 19) than at the duct end (collector bars 1 – 9). After pouring the metal the current became well balanced and remained so all the time after (See Figure 13), which was measured nearly a full year after the pot start-up. With the metal pad in the pot, cathode current distribution was no more influenced by anode current distribution but rather by the good condition of the cathode itself.

The pot was quite stable between bath-up and metal pour. After that it became even more stable whereas in contrast the control pots took 8 days to completely stabilize to the long-term values. This is probably related to an excellent collector bar current distribution after the metal pour and a more uniform current distribution in the metal pad as shown by modelling (Figure 5).

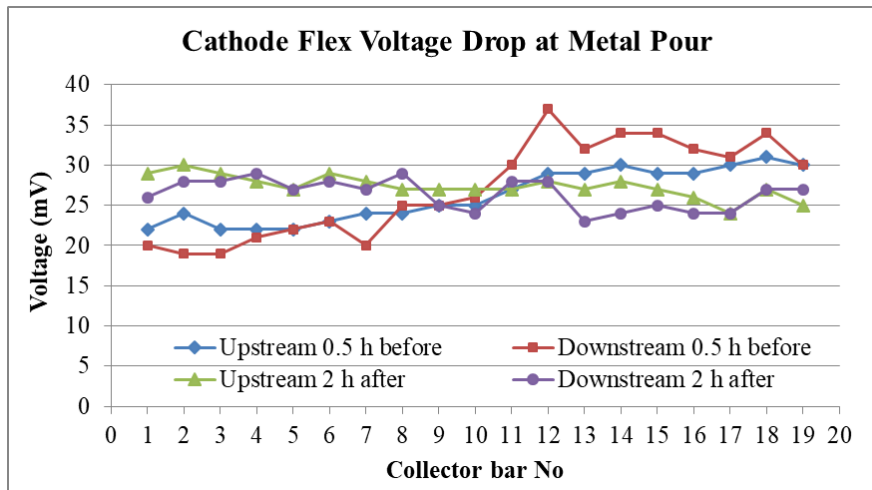


Figure 12. Cathode flex voltage drops before and after metal pour at 275 kA.

Another indicator of good full copper collector bar performance is the temperature distribution in the bars, which was quite uniform at the end of preheat and remained very uniform over time as measured nearly one year after bath-up (See Figure 14).

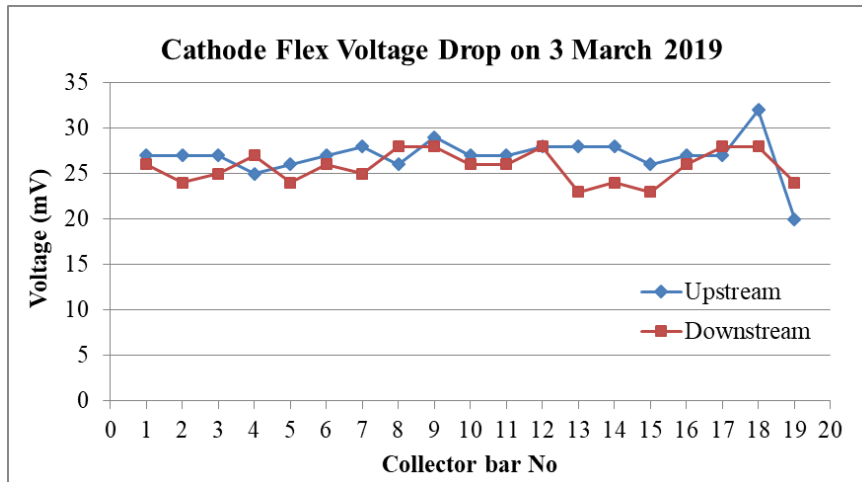


Figure 13. Cathode flexible voltage drops at 270 kA on 3 March 2019.

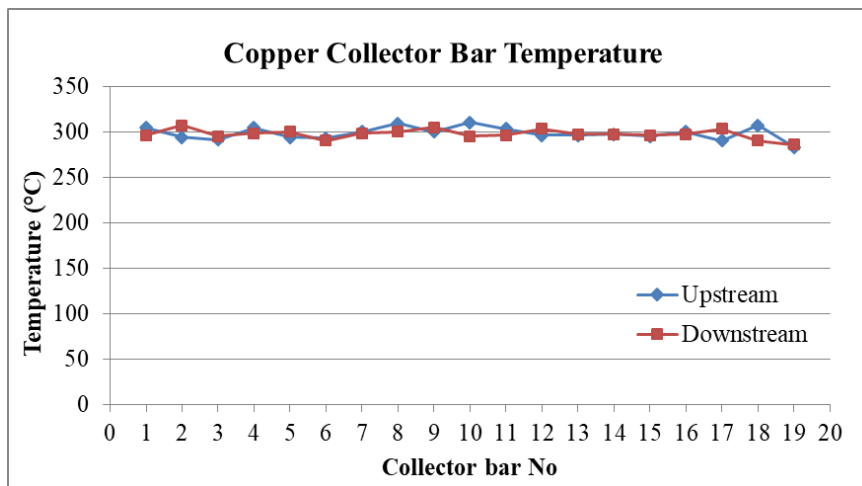


Figure 14. Copper collector bar temperature on bolted joint at 270 kA on 25 March 2019.

#### 4. Pot Performance

The main objective of this test was to evaluate the concept and the performance of the full copper collector bar pot in comparison to regular D20 pots with steel collector bars. Hence, four control pots in the same potline were chosen and compared for the same age range.

##### 4.1 Pot Cut-Out and Restart

The full copper collector bar pot was stopped at the age of 1002 days in order to examine the carbon block surface condition and in order to test the pot restart procedures. Figure 15 shows the cleaned surface of the cathode. The following observations are made:

- Very even length-wise erosion
- No apparent heave
- Weak W-shaped erosion for graphitized blocks
- No damage to the (PAH-free) ramming paste
- The sidewall is in good condition and only some upstream SiC blocks need to be replaced

The pot was successfully restarted and by 20 October 2021 had been operating for 212 days without any problem.



**Figure 15. Cathode surface of the first full copper collector bar pot at the age of 1002 days.**

#### **4.2 Cathode Voltage Drop**

Cathode voltage drop is the primary objective of the copper collector bar concept and design. Figure 16 shows the CVD of the copper pot before cut-out at 1002 days and is compared to steel and Cu insert pots of the same potline. The CVD decreased by approximately 60 mV for the transition to Cu inserts and another 60 mV from copper insert to pure copper collector bars. Figure 17 shows detailed evolution of the CVD for the copper pot and the four control pots with steel collector bars. Control Pot 270 was cut-out and restarted as Cu insert pot and shows that the CVD effectively is about 60 mV lower than the previous generation with steel collector bars but 60 mV higher than the copper collector bar pot. The CVD of full copper collector bar pot increased by 40 mV in the first year but then showed no increase for the next two years until the cut-out. After the restart the CVD is by 20-40 mV higher than before cut-out, but there is no observable difference in pot operation or performance. The CVD increase after the pot restart appears to be flattening out, which is a behavior consistent with other pot technologies.

For the whole period from the age of 57 days (EGA established pot age) to cut-out at 1002 days, the average CVD of the copper collector bar pot was 141 mV and the CVD of control pots was 262 mV, a difference of 121 mV at a normalized current of 275 kA. The pot voltage difference was 133 mV, which means that the anode-cathode distance (ACD) of the copper collector bar pot was somewhat more squeezed, however, this did not affect pot stability and neither did the 2.2 cm lower metal height in the copper collector bar pot (Table 2).

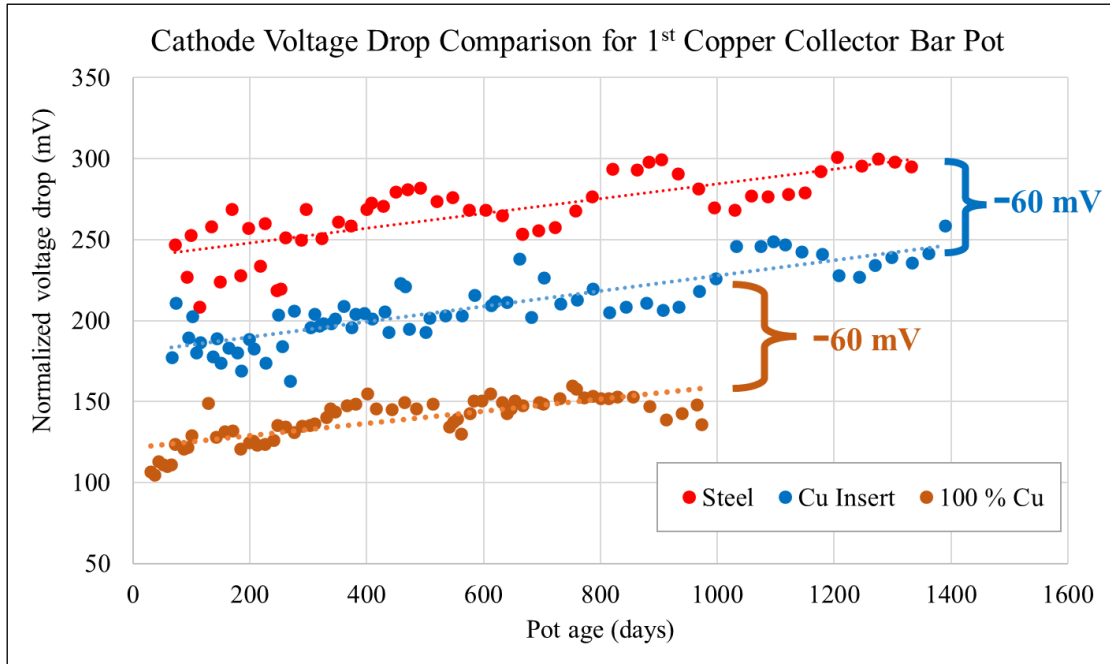


Figure 16. CVD of copper pot, compared to steel and Cu insert pots of the same potline, normalized for the same amperage of 275 kA.

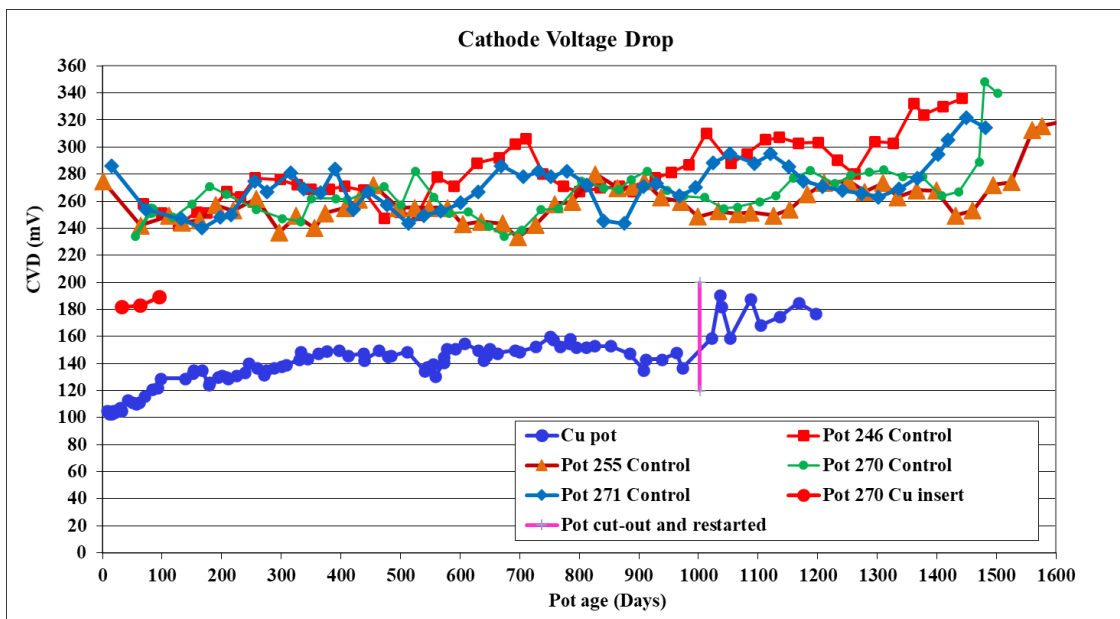


Figure 17. Evolution of CVD with pot age of full copper collector bar pot and control pots, all with graphitized cathode blocks. The pink vertical line shows the copper pot cut-out age. Pot 270 was cut out and restarted as Cu insert pot (Pot 270 Cu insert curve). Data until 20 October 2021.

### 4.3 KPI Summary

Table 2 provides key performance indicators (KPIs). Current efficiency was approximately the same in the copper pot and the control pots as shown in Table 2. However, the net specific energy consumption was by approximately 0.5 kWh/kg Al lower in the copper pot than in the control pots.

**Table 2. KPIs of established pots (age > 56 days) to the cut-out at 1002 days.**

KPI	Units	Cu Pot 5B269, age 57-1002 days	4 control pots, age 57-1002 d	Difference Cu pot– Control
Amperage	kA	272.04	272.66	-0.62
Current efficiency (tapped)	%	92.42	94.19	-1.77
Current efficiency (adjusted)*	%	92.42	92.02	0.41
Metal production	kg/pot-day	2025	2021	4
Net cell voltage	V	4.366	4.498	-0.133
DC net specific energy cons.	kWh/kg Al	14.08	14.57	-0.49
Bath temperature	°C	965	961	4
Excess AlF <sub>3</sub>	%	10.4	11.3	-0.9
Metal height	cm	23.8	26.0	-2.2
Bath height	cm	17.8	17.3	0.5
Fe	%	0.088	0.083	0.005
Si	%	0.031	0.092	-0.061
AE frequency	No./pot- day	0.045	0.048	-0.002
AE duration	s	17.7	11.0	6.6
PFC emissions CO <sub>2</sub> equivalent**	kg/t Al	15	10	5.0
CVD	mV	141	262	-121

\*In control pots, the current efficiency was adjusted downwards by 2.2 %, estimated as the contribution of the metal scrap which is added to the crucibles of control pots and not to copper collector bar pot. The energy consumption is calculated with adjusted current efficiency.

\*\*CO<sub>2</sub> equivalent is calculated as in Reference [14], using the Tier 2 method and SAR (Second Assessment Report).

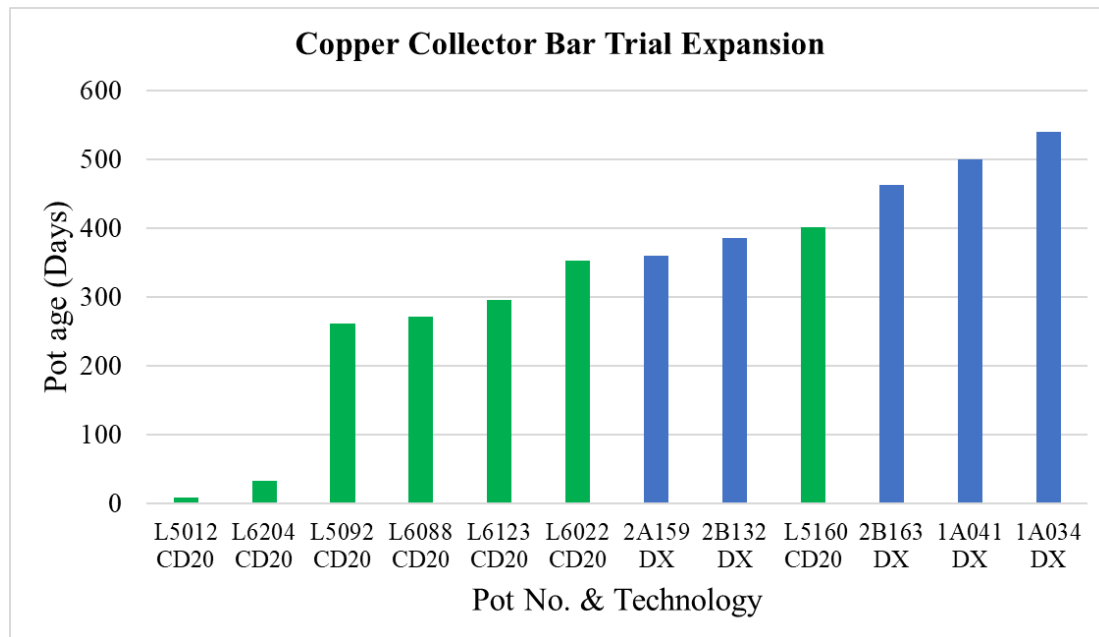
## 5. Expansion of Test Pots

Building on the success of the first pot, several other full copper collector bar pots have been put in operation in different EGA pot technologies and operating at different amperages. The purpose of this is as follows:

- To gain operational and performance experience
- To demonstrate voltage and energy savings
- To further develop the design, and
- To gradually develop a suitable supply base

As examples Figure 18 shows the extensions in CD20 Technology operating at 250 kA and DX Technology operating at 420 kA.

These new copper collector bar pots are operated as other pots in the same potline with no special follow-up and no detailed or more frequent measurements. They show similar characteristics as the first copper pot described in this paper.



**Figure 18. Copper collector bar trial expansion pot age on 22 October 2021.**

## 6. Conclusions

EGA has built and tested a proprietary pot design with full copper collector bars. Due to very low cathode voltage drop (CVD) the pot operates with substantially lower voltage drop and consumes approximately 0.5 kWh/kg Al less energy than the control pots with standard steel collector bars. Copper collector bars and cathode blocks perform well so far, which is witnessed by uniform current distribution in collector bars together with low and uniform collector bar temperatures, and low copper concentrations in the metal. Based on autopsy the cathode surface at the age of 1002 days was in exceptionally good condition showing little erosion and practically no cathode heaving. The trials have been extended to other EGA pot technologies and they show good potential for lowering specific energy consumption, which is the primary objective of these trials.

## 7. Acknowledgment

We would like to thank the various teams involved who contributed in these successful initial trials: Pot repair and potlining process control teams, Potline Operations and technical teams. We would also like to thank Dr. Vinko Potocnik for his input in reviewing this work.

## 8. References

1. Loig Rivoaland, Development of a new type of cathode for aluminium electrolysis, *Proceedings of 34th International ICSOBA Conference*, 3 – 6 October 2016, Québec, Canada, Paper AL28, *Travaux* 45, 757-765.
2. Marwan Bastaki et al., DUBAL cell voltage drop initiatives towards low energy high amperage cells, *Light Metals*, 2014, 451-455.
3. René von Kaenel, Jacques Antille, Louis Bugnion, Impact of copper inserts in collector bars, *Light Metals* 2015, 807-812.
4. Amit Jha et al., Copper insert collector bar for energy reduction in 360 kA smelter, *Light Metals* 2019, 565-572.
5. Bernard Jonqua, Abdalla Zarouni, Cathode block for electrolytic cell suitable for the Hall-Héroult process, WO2016/157021 A1, International Publication Date 6 October 2016.

6. Bernard Jonqua, Mustafa Mustafa, Cathode assembly with metallic collector bar for electrolytic cell suitable for the Hall-Héroult process, UK Patent Application GB, 2558936 A, Publication Date 25.07.2018, (Also WO/2018/134754, Publication Date 26.07.2018).
7. Mustafa Anwar Mustafa, Copper collector bar development at EGA, Gulf Aluminium Council (GAC) Seminar, Virtual, 16 February 2021.
8. Louis Bugnion et al., Copper as a key element in the collector bars of aluminium smelter cells, *International Aluminium Journal*, 1-2 2018, 70-74.
9. René von Kaenel et al., The use of copper in cathodes of aluminium reduction cells, *Proceedings of 35th International ICSOBA Conference*, Hamburg, Germany, 2 – 5 October 2017, Paper AL11, *Travaux* 46, 879-889.
10. Markus Pfeffer, Oscar Vera Garcia, Louis Bugnion, and Laure von Kaenel, Ready-to-use cathodes for the Hall-Héroult process, *Light Metals* 2020, 1291-1298.
11. Markus Pfeffer et al., A novel cathode design using copper collector bars for high amperage technologies, *Proceedings of 39th International ICSOBA Conference*, Virtual, 22-24 November 2021, Paper AL17, *Travaux* 50
12. Markus Pfeffer and Rene Von Kaenel, Cathode current collector/connector for a Hall-Héroult cell, patent WO2018/019888 A1, International Publication Date 01 February 2018.
13. Alexander Arkhipov et al., Cell electrical preheating practices at DUBAL, *Light Metals* 2014, 445-449.
14. Ali Al Zarouni et al., DX+, an optimized version of DX Technology, *Light Metals* 2012, 697-702.