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ALUMINUM REDUCTION TECHNOLOGY

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Potline Operations – Cell Operations

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CELL ELECTRICAL PREHEATING PRACTICES AT DUBAL

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Abstract

DUBAL has extensive experience of electrically preheating cells since its initial operation in 1979. The electrical preheating at DUBAL has evolved, including the type of material used, the setup of the cell and the equipment needed to carry out preheat. Traditionally, a thick coke bed fully covering the surface below the anodes was used. In order to reduce the amount of material and energy for preheat, the grain size and shunt design were optimized. Further progress, which allowed elimination of the shunts, was achieved by using low resistivity material partially spread over the surface below the anodes. To minimize heat loss and air burn during preheating and to prepare the cell for bath-up, crushed bath is used at the anode sides and mineral wool and crushed bath are used on the top. Finally, the preheat equipment design was improved. The application of the most recent preheating technique for DX and DX+ technologies is described.

Introduction

Cell preheat is an important stage in cell life. The main goal of preheating is to create a uniform temperature distribution in the cathode, high enough to prevent thermal shock during bath-up and to minimize freezing of the bath on the cathode surface. A good preheat will have a positive impact on early operation of the cell and cell life expectancy [1].

Consequences of a bad preheat could be destruction of cathode integrity even during preheat itself due to following reasons:

- Cracks and de-lamination inside the ramming seams and cathode blocks due to thermal stresses;
- Detachment of inter-block and side ramming seams from the cathode blocks and side lining, which could lead to the leakage of the liquid aluminium to the collector bars and bottom lining;
- Bad baking quality of the seams and subsequently bad mechanical properties of these;
- Uneven sodium expansion and cathode current density that could lead to cathode block de-lamination and MHD-instability after metal pouring.

All these can be induced by uneven thermal expansion of the steel potshell, lining materials, shrinkage of ramming paste, high thermal and sodium concentration gradients along the surface and the height of the cathode blocks.

Consequences of insufficient preheat temperatures are freezing of the cathode surface and subsequent difficulties after bath-up and metal pouring, such as non-uniform current loading of the anodes, destruction of electrical transition joints, long un-controllable start-up anode effects and cell instabilities after metal pouring.

A lot of work has been dedicated to preheat studies within the industry, including DUBAL [2 - 6]. Today, two main types of preheat are used in industry: resistor and flame preheat. Due to its simplicity and short preheating time electrical preheat is very popular and is also used at DUBAL.

Electrical preheat has undergone significant changes over the years. Mathematical modelling has helped a lot in understanding and development of preheat practices in recent years [6 - 10].

This article describes the evolution of the DUBAL preheat practices over the years, the current practice and comprehensive measurements aimed to evaluate performance of the current practice and to validate mathematical models.

History of cell preheat development at DUBAL

Electrical preheat methods, also known as resistor baking, have been used at DUBAL since its start-up in 1979.

The first cells, Kaiser P69 technology, were started at 150 kA in 1979. The electrical preheat was simple and rough. The resistor bed, covering full area under the anodes, consisted of crushed coarse pieces of anode butts. Preheat flexes were not used and anodes were rigidly fixed to the anode ring. To avoid extremely high local overheating and to release pressure which was created by thermal expansion of all materials the preheat crew had to loosen and re-tighten each anode clamp every hour. Average preheat duration was 48 hours.

In the early 1990's with Line 4 start-up, petroleum coke was introduced as the bed material. A full bed of 25 mm thickness was used for the 48 hour preheat. Steel shunts were used to reduce initial amperage through the pot. Preheat anode flexes improved significantly the uniformity of surface temperature due to more equal pressure distribution of anodes on the coke bed. Cryolite, crushed bath and insulation blankets were used for thermal insulation during preheat [2].

In 2005, cell preheat practice at DUBAL was comprehensively reviewed in terms of coke fraction size, coke bed thickness and shunts removal timing. The benefits achieved were: a superior preheat, lower preheat energy consumption, saving in coke and compressed air, elimination of the manual skimming of the coke after bath up, reduction in environmental pollution and faster stabilization of cell after bath-up and metal pouring [3].

In 2007, trials were conducted on D18 and D20 cells with full graphite bed and different graphite/coke mixtures. These trials showed possibility to achieve desirable cathode surface temperature in 48 hours without shunts. The main benefits due to

shunt-free preheat were energy savings: 5 MWh for D18 and 9 MWh for D20 per cell preheat. Additional non-quantified savings in compressed air, reduction in man-hours and crane utilization for cell set-up and handling of the shunts were also achieved as well as improvements in the safety and physical environment of the operation.

The first DUBAL trials with full amperage load and graphite/coke mixture resistor bed were carried out on D18 and CD20 pots in 2006. It allowed pots to be preheated to the desired temperatures without using shunts and drastically reduced the consumption of resistor material.

The first DUBAL trials with partial coverage using 100 % graphite were carried out on D20 cells in 2009. Later, preheat practice with partial coverage using 100 % graphite was cascaded to all DUBAL technologies. Since then, it has been continuously improving and adapting with each technology. In this paper, testing of the current DUBAL preheat method is described for DX Potline 8 cells at 385 kA.

Current DUBAL Preheat Practice

Key features of the current DX preheat practice are:

- In the trials described in this paper, the resistor layer is in the form of two narrow longitudinal strips 24 mm deep (Figure 1). The strips are located below left and right wings of the anode, which has two longitudinal slots. About 14 % of the anode area is covered by graphite. In other trials, different mutual positions and orientations of the two strips have been tested and slotted or un-slotted anodes were used.
- The material of resistor bed is 100 % graphite with 95 % grain sizes in the range -4 to +10 Tyler mesh (1.7 – 4.8 mm).
- Ceramic fibre blanket is put in the side and end channels. Card board covers the sides of the anode around the cell. On the top, inter-anode gaps and the central channel are covered by ceramic fibre blanket. Then the side and end channels are filled with pure crushed bath.
- The top surface of the anodes is covered by finely crushed bath.
- Anode flexibles are used to connect anode rods to the anode beam.
- Hoods are put in place to prevent heat loss and emissions.
- No preheat shunts are used. Duration is typically 48 hours.
- During preheat, anode current distribution is measured every half an hour for the first two hours and every hour thereafter. Overloaded anodes are disconnected for 0.5 – 2 h. Some anodes may also be disconnected to slow down the pot resistance decrease.

Measurements

Detailed temperature and voltage drop measurements were carried out to assess preheat quality, determine resistance and resistivity of graphite bed and collect data for validation of the ANSYS mathematical cell preheat model. The following measurements were carried out on pots 15 and 39 of the DX Potline 8:

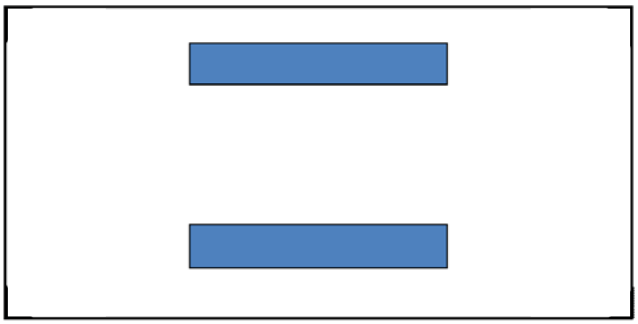

Figure 1. Preheating frame for DX cells

1) Cathode block surface temperatures in 7 positions across the cell on 5 transverse slices between anodes (Figure 2). On Pot 39, these temperatures were measured manually by inserting a thermocouple through the ceramic fibre blanket into the anode slots. On Pot 15, they were measured manually or automatically by fixing thermocouples on the cathode surface and connecting them to a data logger.

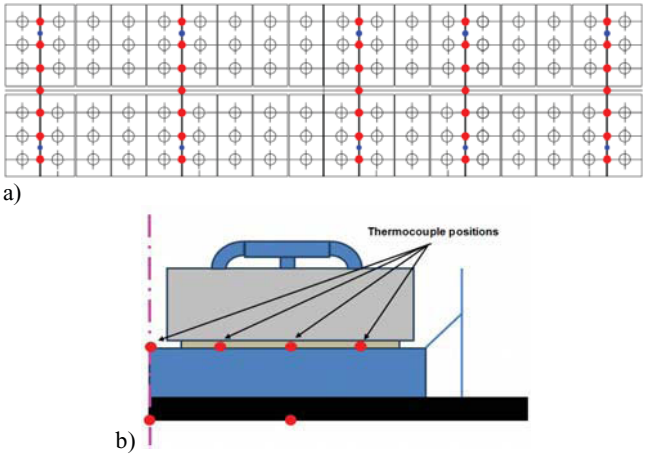

Figure 2. Locations for temperature measurements (blue points show voltage probe location, red ones show thermocouples)

2) Temperatures below the cathode block in three locations (Figure 2) on each block on 5 cathode blocks. These thermocouples were monitored with a data logger. On Pot 39, another five thermocouples were installed in the central channel on the block surface and connected to a data logger on the same blocks as those with thermocouples below the block.

3) Anode voltage drop from the rod below the clamp (by hand-held voltage probe) to carbon side surface 5 cm above anode bottom (by fixed voltage probe) and outer stub temperature on 10 anodes close to temperature measurement sections (Figure 3).

4) Cathode voltage drop and collector bar temperature on 5 cathode blocks, upstream and downstream (blue points in Figure 2a and red points in Figure 4). Voltage probes were attached to the cathode surface during anode installation. The voltage probe on the collector bars outside the potshell was a portable rod with pin.

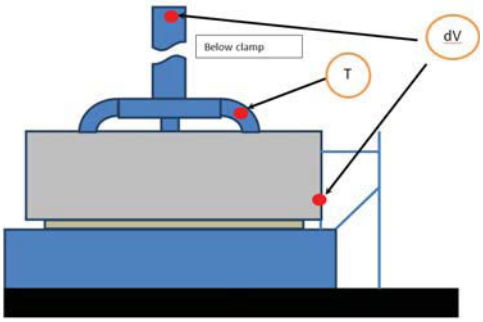

Figure 3. Anode voltage drop measurements

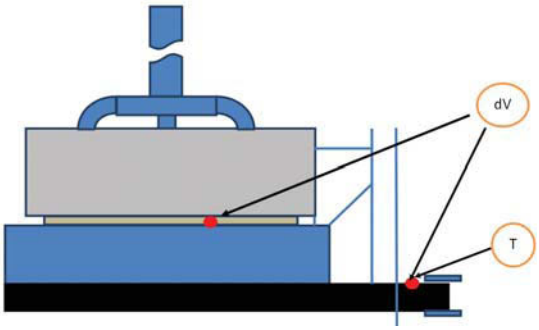

Figure 4. Cathode voltage drop and collector bar temperature measurement.

5) External voltage drop is composed of two parts: a) Anode external from Anode Reference Point (ARP) on the anode cross beam of the preheat cell to the anode rods below the clamps on the same cell, b) Cathode external from cathode collector bars of the preheat cell to ARP of the downstream cell (Figure 5).

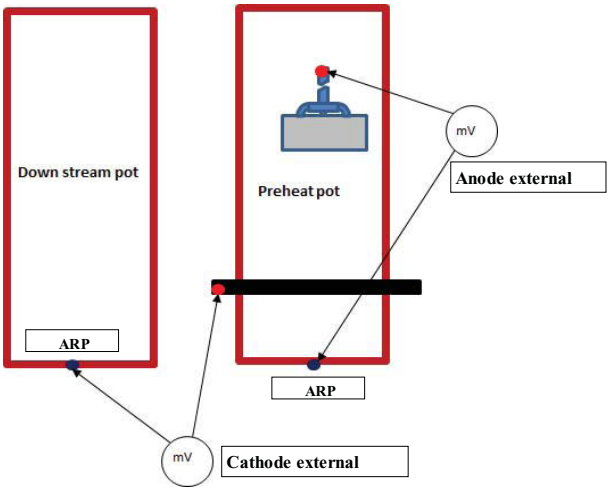

Figure 5. External voltage drop measurement.

6) Cathode potshell temperature approximately 25 cm above the collector bar at 10 locations before bath-up (bath pouring).

7) Each cathode collector bar temperature before bath-up (this is part of standard procedure).

8) Cell resistance and amperage were obtained from recorded Pot Control System one-minute data.

All manual measurements were done every eight hours; those connected to the data logger were recorded continuously. All measurements were done for the same pairs of anodes and cathode blocks, i.e., anode voltage drop was measured for the anode above the cathode block for which cathode voltage drop was measured.

The effective area and thickness of the graphite bed had been previously determined in Potline 8 by placing the anodes on the bed and measuring the compressed dimensions after anode removal (Table I).

Table I. Data for compressed graphite strips

	Unit	Nominal	Compressed
Strip length	m	0.52	0.562
Strip width	m	0.14	0.188
Strip height	m	0.024	0.020
% anode coverage by graphite	%	14.4	18.9

Results

The evolution of cell voltage and resistance from the start-up to just after bath-up in Cell 39 is shown in Figure 6. The cell voltage decreases uniformly from 3.79 V at cut-in to 2.61 V at bath-up. The small voltage increase at 11 – 14 h was due to temporary disconnection of two anodes. Energy input within the cell (excluding heat generation in the busbars outside the cell), during preheat was 50.0 MWh in Pot 39 and 49.4 MWh in Pot 15.

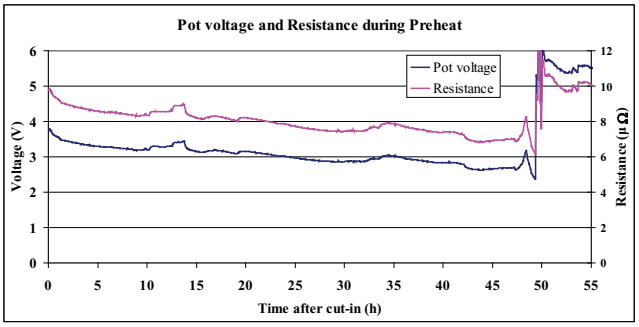

Figure 6. Cell voltage and resistance during preheat and bath-up of Cell 39.

Cathode block surface temperature measurements for Cell 39 were done manually and were successful for almost all planned locations.

In Cell 15 the thermocouples were fixed on the surface before preheat in all locations shown in Figure 2 and connected to data logger. Unfortunately, 20 out of 35 thermocouples failed after 36 hours and only one lasted until the end of the preheat. Therefore the temperatures will be discussed only for the Cell 39. However, the voltage drop measurements were successful in both cells and will be reported here.

Cathode surface temperatures at the end of preheat were in generally in the range from about 800 – 950 °C. End blocks were colder with temperatures of 750 – 900 °C. Very high temperatures of 1000 – 1200 °C were measured at block quarter points 2 and 6 which were between the graphite strips of two adjacent anodes, very close to the area where heat is generated (Figure 7). In

further trials, the two graphite strips in either longitudinal or transversal orientation were more uniformly distributed under each anode and more uniform cathode block surface temperatures are expected. Detailed measurements for these configurations, similar to the ones presented in this paper will be made in the near future.

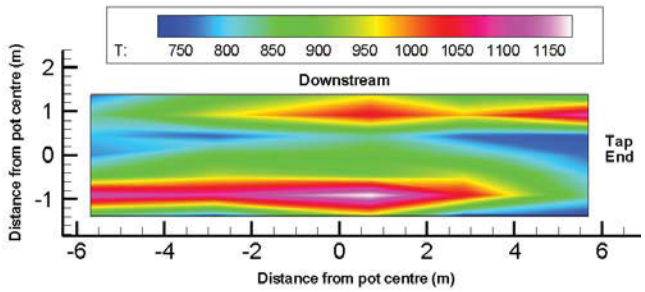

Figure 7. Surface temperature at the last manual measurement at 42.5 h after cut-in.

The surface temperatures below the central part of the anode were not measured, but they should be in the lower part of the previously quoted temperature range, because the distance between the strips in the central part of the anodes was large and no current passed in the part of the anode between the two slots.

At the end of the preheat, the difference between the cathode block surface and cathode block bottom temperatures on the cell centre axis was 21 °C, average of all five blocks (Figure 8). The heating rate on the surface of the pot centreline was 23 °C/h at the beginning of preheat (hours 4 – 7) and 10 °C/h at the end of preheat (hours 45 – 48).

At the block quarter points (positions 2 and 6), the difference between the cathode block surface and cathode block bottom temperatures was from 90 to 280 °C. A more uniform distribution of graphite strips, which has been already implemented, makes this difference smaller and this is expected to be confirmed with planned detailed measurements.

Table II. Comparison of surface and below-block temperatures at the time of final manual measurements at 42.5 h.

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	Position 2			Position 6		
Block	**Under**	**Surface**	**Diff**	**Under**	**Surface**	**Diff**
#	**°C**	**°C**	**°C**	**°C**	**°C**	**°C**
2	890	1125	235	745	835	90
8	926	1100	174	878	955	77
16	942	1190	248	927	1050	123
21	860	1050	190	877	985	108
27	733	832	99	828	1110	282

Potshell temperatures at the end of preheat, 25 cm above collector bars, were in the range of 175 - 240 °C for both cells.

Table III gives a summary of voltage drops and resistances as a function of time after cut-in. The voltage drop in the graphite bed was obtained from the cell voltage by subtracting the anode, cathode and external voltage drop. The graphite resistivity was calculated from the graphite resistance. The cell voltage and resistance decrease with time, but this is largely due to anode voltage drop decrease and to a smaller extent due to cathode voltage drop and graphite bed resistance decrease.

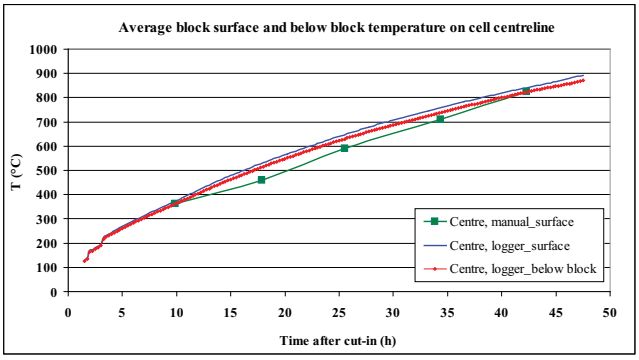

Figure 8. Surface and below block temperatures on cell centerline of Cell 39, average of 5 blocks.

Table III. Summary of voltage drops and resistances with time after cut-in of Cell 39.

Time after cut-in	Cell volts	Anode voltage drop	Cathode voltage drop	External voltage drop
h	V	V	V	V
0.08	3.778			
8.18	3.221	0.857	0.248	0.393
16.18	3.161	0.760	0.219	0.400
25.68	2.937	0.680	0.209	0.405
33.68	2.978	0.634	0.209*	0.405
41.18	2.829	0.610	0.209*	0.398
49.33	2.605			

Time after cut-in	Cell volts	Graphite voltage drop	Graphite resistance	Graphite resistivity
h	V	V	μΩ	μΩm
0.08	3.778		4.62**	1720**
8.18	3.221	1.723	4.48	1668
16.18	3.161	1.783	4.63	1726
25.68	2.937	1.643	4.27	1591
33.68	2.978	1.730	4.49	1675
41.18	2.829	1.612	4.19	1561
49.33	2.605		4.21**	1569**

*These two values are assumed to be the same as the previous one (they were not measured because the wires on the cathode surface were damaged).
**Extrapolated values.

As it can be seen from the table the resistance of the graphite bed was 4.6 μΩ at the beginning, decreasing to 4.2 μΩ at the end of preheat and the estimated resistivity was 1720 μΩm at the beginning, decreasing to 1569 μΩm at the end of preheat, corresponding to a decrease of 9 % during the whole preheat. In cell 15, the graphite resistivity decreased from 2162 μΩm at the beginning to 1763 μΩm at the end of preheat, a decrease of 24 %. These values will be revalidated with mathematical modelling which will compare local values of electrical potential, used in the measurements of anode and cathode voltage drop, to the average potential over the anode bottom and cathode surface.

Conclusions

With continuous development of preheat procedures, DUBAL has eliminated the use of start-up shunts while keeping the final preheat temperatures within the desired range. Further work is in progress, aiming to improve the preheat quality and achieve more uniform temperatures. Possible improvements are: changing the shape and location of graphite bed and preheat duration or using wider resistor strips with a combination of graphite and coke.

ANSYS 3D mathematical model which has been developed will help in selecting the most appropriate combination of preheat parameters to improve the preheat quality further.

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