Development of Vedanta Lining Design

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Abstract

The aluminium industry is facing challenges to improve its sustainability and to reduce carbon footprint. With these goals in mind, Vedanta Limited is improving the cathode lining design used in Jharsuguda plant. The new lining was designed using numerical computational modelling techniques that simulate electrical and thermal behavior of the cell. The concept was to use a copper inserted collector bar associated with a cathode lining insulation in the most efficient way. The prototypes key performance parameters are presented, along with the measurements of cathode voltage drop, collector bar temperature and internal lining temperatures. The initial trials indicate a significant reduction in cathode voltage drop (CVD) and improved current efficiency of the cell. These indicate the possibility of increasing the current as well as reducing the specific energy consumption (SEC) of the cell.

Keywords: Copper collector bar, Energy saving, Cathode voltage drop, Current creepage, Cell numerical modelling.

1. Introduction

Primary aluminium production is an energy intensive process, which amounts to around 1/3 of the production cost. There have been widespread initiatives [1-3] taken by smelters to improve energy efficiency and thereby contribute towards sustainable operations by retrofitting of existing potlines with upgraded busbar systems, cell designs or control systems. Major driving factors are: prolonging pot life, reducing specific energy consumption (SEC), improving current efficiency and volume production with minimal changes in existing infrastructure. Vedanta has continuously been driven for enhanced capabilities and improvements in pot cell operation to achieve productivity excellence with sustainable developments. The performance of the pots depends on 4 major factors which are cell design, cathode construction, pot start-up and pot operations. The cell lining design has a significant contribution in improving energy efficiency, enhancing production and prolong pot life.

Since its inception, the Vedanta potlines were equipped with cathode lining that could deliver specific energy consumption of around 13.8 kWh/kg Al. Gradually, over a journey of 12 years, the lining was modified to designs with higher grade cathode, moving first to graphitic, then to graphitized cathodes, which are now delivering specific energy consumption of 13.1 kWh/kg Al and improved pot life performance. This has also contributed to reduction of hazardous wastes generated associated with cell shutdown.

To achieve further improvements in terms of energy efficiency and pot life, “Vedanta Lining Design” (VLD) concept was proposed. This includes cathodes having copper insert collector bars with cold sealing and modification in lining refractory layers without major changes in materials or methods of construction.

Copper insert bars are being researched by many smelters for use in high amperage cells [4-6], that requires high heat dissipation. However, this needs an evaluation of thermal balance when using in low SEC cells as use of copper increases the heat loss from collector bars [7].

This paper focus on the insights on thermoelectric evaluation of the existing cell design operating at 340 kA and the development of an optimum lining design using copper inserts. 3D thermoelectric modelling results and measurements of existing and new design are shown. The building of prototypes, cell preheating and early life operation, as well as preliminary results are also shown.

2. Modelling Approach

In a first phase, the existing situation was assessed using numerical models and measurements. The performance of the existing lining design as well as the capacity of busbar systems built the basis for improvements in the cell design. The modelling approach included thermal electric modelling (Figure 1) of lining and busbar network, magnetohydrodynamic (MHD) modelling and structural models of pot shell and cradle supports. Modeling results showing current density, heat flux and temperature distribution are presented in Figures 2 and 3.

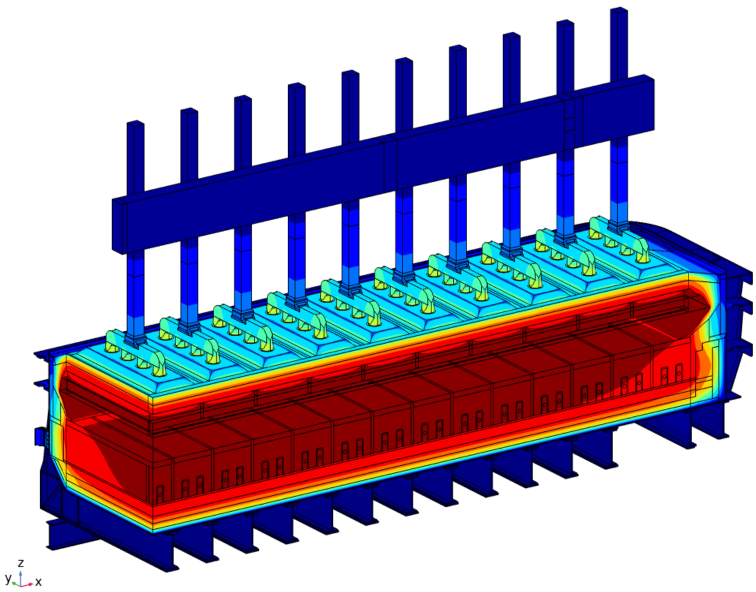

Figure 1. 3D thermal model of existing cell.

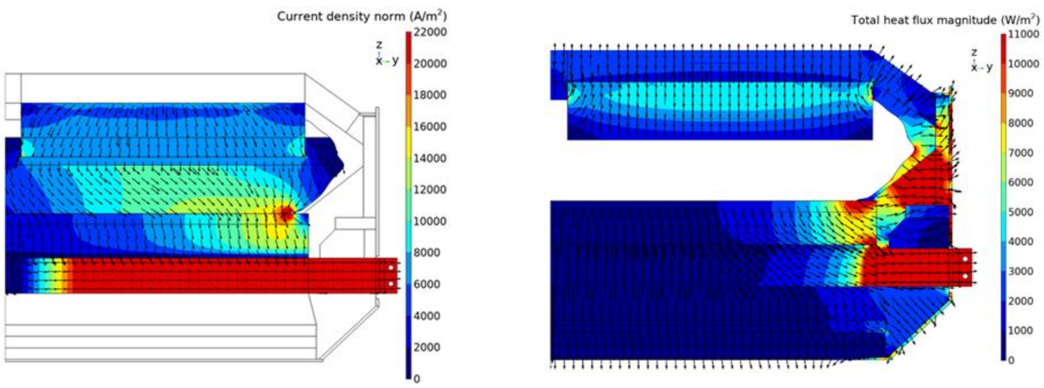

Figure 2. Existing cell sidewall section. Left: current density magnitude and vectors (A/m^2). Right: total heat flux magnitude and vectors (W/m^2).

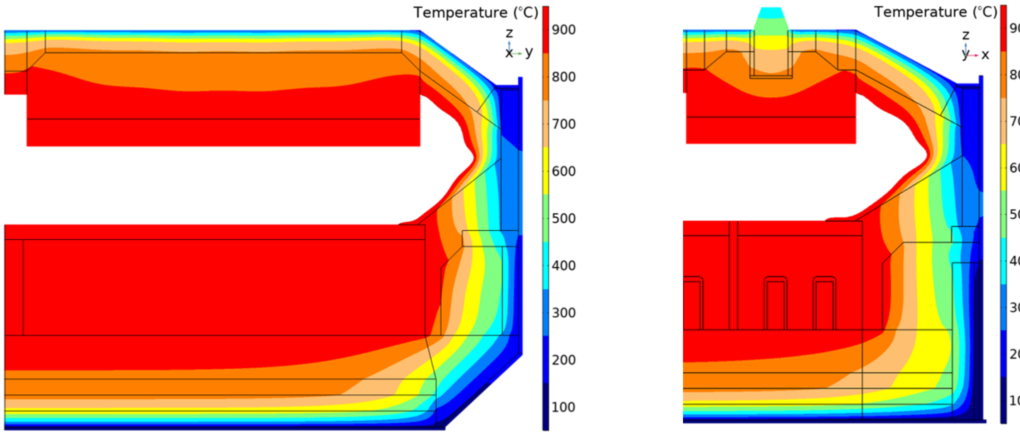

Figure 3. Existing cell, temperature (°C) distribution. Left: sidewall. Right: endwall.

The models were validated using measurements done on operating pots. These were necessary to have reliable prediction of the effect of proposed design changes. Figure 4 shows heat flux measurements as explained in [8]. Figure 5 shows the comparison between the measurements in specific locations and numerical model results. Good agreement has been achieved.

Figure 4. Heat flux measurements. Left: shell bottom. Right: shell between collector bars.

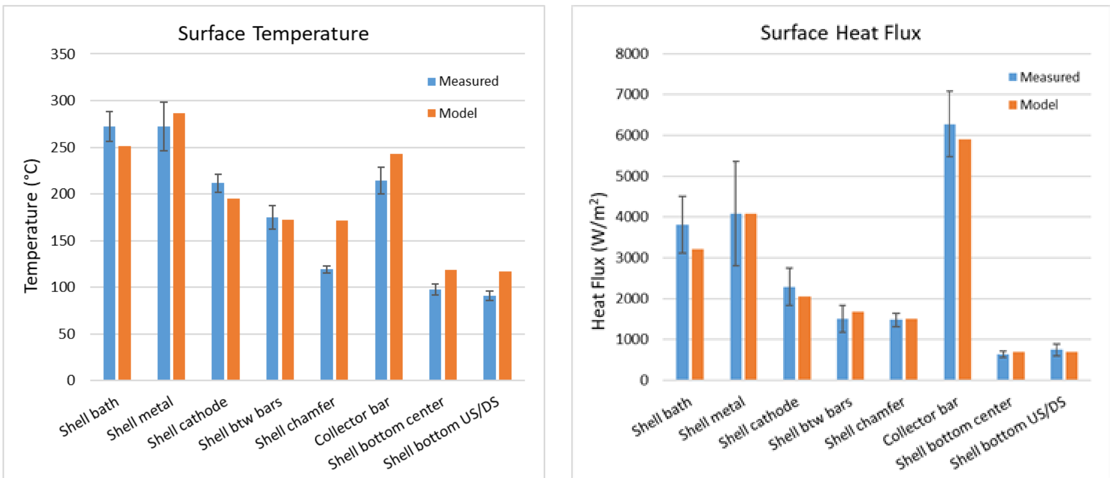

Figure 5. Existing cell modelling validation. Left: temperature. Right: heat flux.

The model results have shown that the existing design has capability to operate at higher current by around 5 kA, with energy efficiency in the range of 13.2 kWh/kg Al, and no modifications is required in existing cell design. Also, no significant changes in shell temperatures were observed.

3. VLD – Vedanta Lining Design

In a second phase, a new lining was designed using electrical and thermal numerical models with copper insert collector bars in cathodes. The study included the complete thermal balance with ledge profile prediction, current density at various sections, temperature profile at shell, heat flux in sidewall, end wall and cathode sections, shell deformation and structural stability. Several model results showing current density, heat flux and temperature distribution for the proposed modified design are shown in Figures 6 and 7.

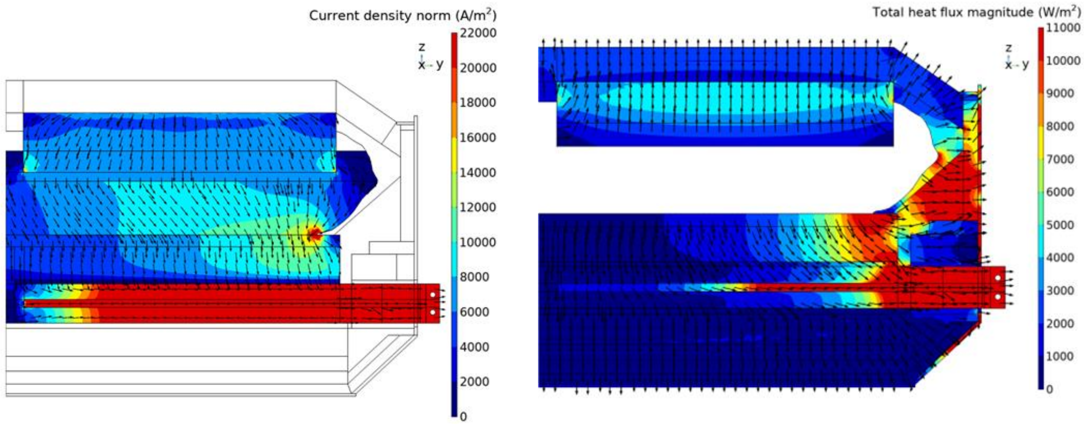

Figure 6. VLD cell sidewall section. Left: current density magnitude and vectors (A/m^2). Right: total heat flux magnitude and vectors (W/m^2).

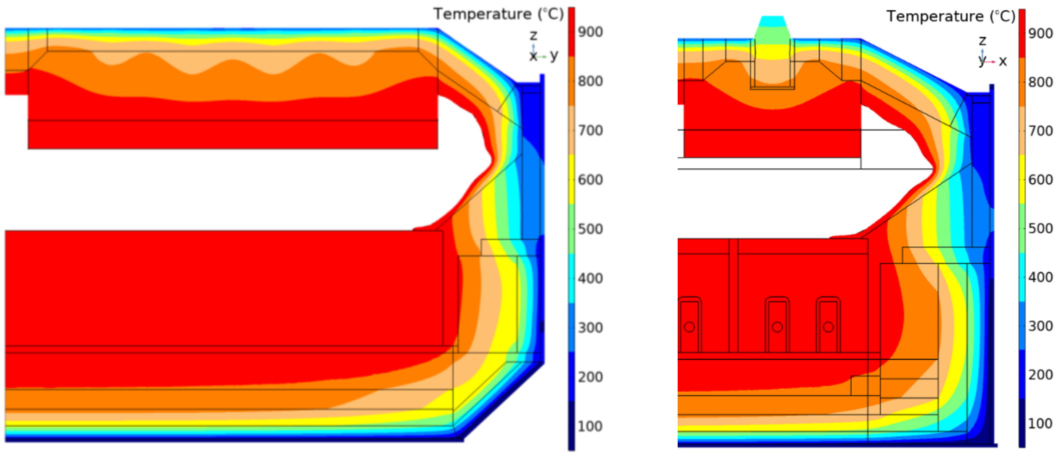

Figure 7. VLD cell section, temperature (°C) distribution. Left: sidewall. Right: endwall.

The model shows that it is possible to run the present cell lining design at the same current updating the collector bar to a copper insert design. As expected, to keep the cell in thermal balance it is necessary to increase anode to cathode distance (ACD). However, using such collector bar, the cell might be able to reach 15 kA more by running at same existing ACD. Thus, changing to copper insert bar cathodes suffices the requirement of current creepage and with the changes in lining layers to compensate the heat losses thereby improving energy efficiency.

The more uniform cathode current density should improve the cathode life from existing 1850 days to 2200 days.

4. Prototype Building

Based on considerations of various options between high current and low specific energy consumption with respect to changes in cathode blocks length, anode length (to accommodate higher current), metal level in pots, pot voltage, current efficiency, it was evident that a partial copper inserted collector bar cathode block and modifications in lining layers was the best option to be implemented. Lining insulation layers for pot bottom were changed with a more insulating design to maintain proper isotherms whereas sidewall lining was also changed to ensure proper thermal balance. The evaluation also took into consideration replacement of lower sidewall material to ensure better resistance against bath attack and to prevent early life metal infiltrations.

A detailed material list and engineering drawings were compiled with a decision to build four prototype cells initially. Collector bar sealing in cathode blocks were done with the same procedure as the existing one with cold paste. To validate the modelled results, 16 thermocouples were installed at various layers inside the cell at bottom lining, lower side wall and end walls for temperature measurements (Figure 8).

Figure 8. Thermocouple installation. Left: bottom. Right: lower sidewall slope insulation.

The major aspects of the VLD lining design are:

- Endwall – addition of more insulation boards;
- Bottom lining – partial replacement of dry barrier mix material by high density refractory bricks. More insulation on pot slope area by addition of CaSi insulation boards;
- Lower sidewall – replacement of low cement castable layer by combination of insulation boards and refractory bricks;
- Upper sidewall – combination of Silicon Carbide blocks and refractory bricks.

Some of the changes done in lining design are shown in Figures 9 and 10.

Figure 9. Lining construction. Left: bottom. Right: lower endwall.

Figure 10. Lining construction. Left: lower sidewall. Right: upper sidewall.

5. Cell Start-up

A detailed cell start-up procedure was developed for these cells with considerations as below:

- Cell preheating - if the time is too long then there is the risk of oxidation damage to cathode surface which subsequently results in high erosion by carbide reaction. So, the electrical resistive graphite bed preheat was changed from 72 to 54-58 hours with changes in bed size and location;
- Bath addition - side and end walls channels were filled with crushed solid bath before pouring liquid bath to protect the ramming paste. Also, an optimized quantity of bath was added;
- Metal addition - The metal was added around 24-32 h after pouring the bath. Time should be allowed for swelling of ramming paste by sodium to seal joints before adding metal. If the metal is added too early it might penetrate the seams or peripheral gaps caused by ramming paste baking shrinkage;

- Normalization rules - early life cell operation rules with guidance on critical parameters such as bath temperature, cell voltage, excess AlF_3 feed, soda addition etc. was prepared for first 60 days operation

For electrical resistive preheating of the cathode panel, a new method of graphite bed laying was proposed. The modifications are shown in Figure 11.

Figure 11. Graphite bed for VLD cell.

Cell preheating was done without use of shunts which was a practice in existing cell start-up with limited number of shunts installed at initial stages. Cell preheating curve as measured by 7 (seven) thermocouples at the top surface of the cathode panel is shown in Figure 12. The results are for the second trial cell and further changes are required to achieve around 900 °C at the end of the preheating.

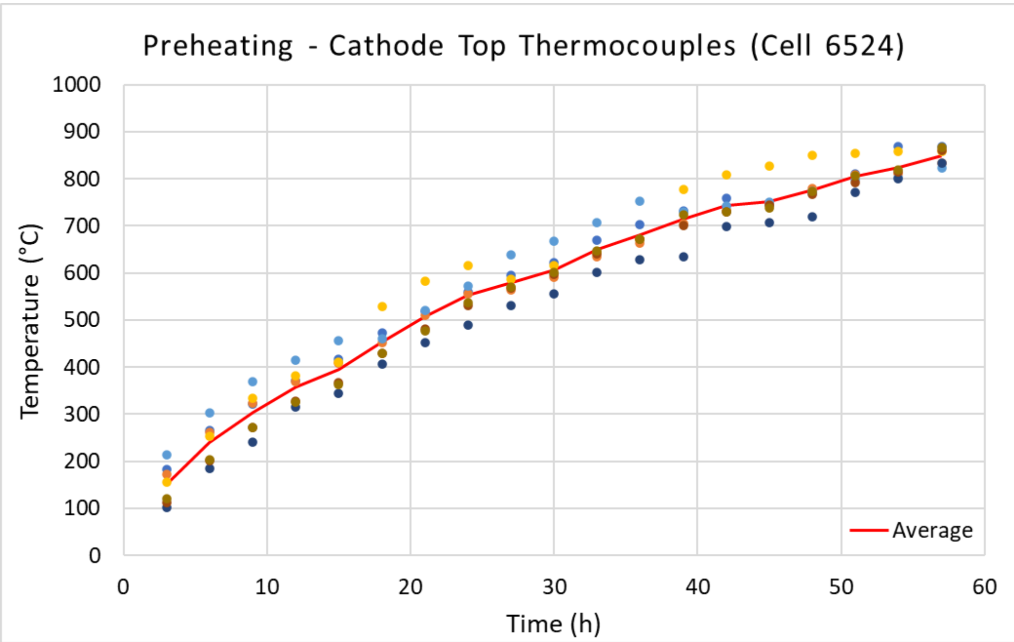

Figure 12. Cathode preheating temperature trend at various locations.

6. Results and Discussion

Vedanta lining design was implemented in 4 cells started over a period of one month. During the trial phase, various critical parameters such as lining layer temperature, bath temperature, noise, average voltage, excess AlF_3, shell temperatures were monitored on daily basis. Two cells each were started in potline with current of 330 kA and 340 kA respectively. The cell performance was compared with two reference cell groups, one for each current, having 5 cells each and started at similar timelines to gauge performance.

Initial cell lining temperature measurements, up to normalization period of 90 days, and cell performance show encouraging results compared to model predictions. Lining layers temperature measurements were recorded, and first 30 days trend show concurrence with modelled results (Figure 13 and Table 1). No abnormal temperature zones and penetration of liquid metal or bath were observed.

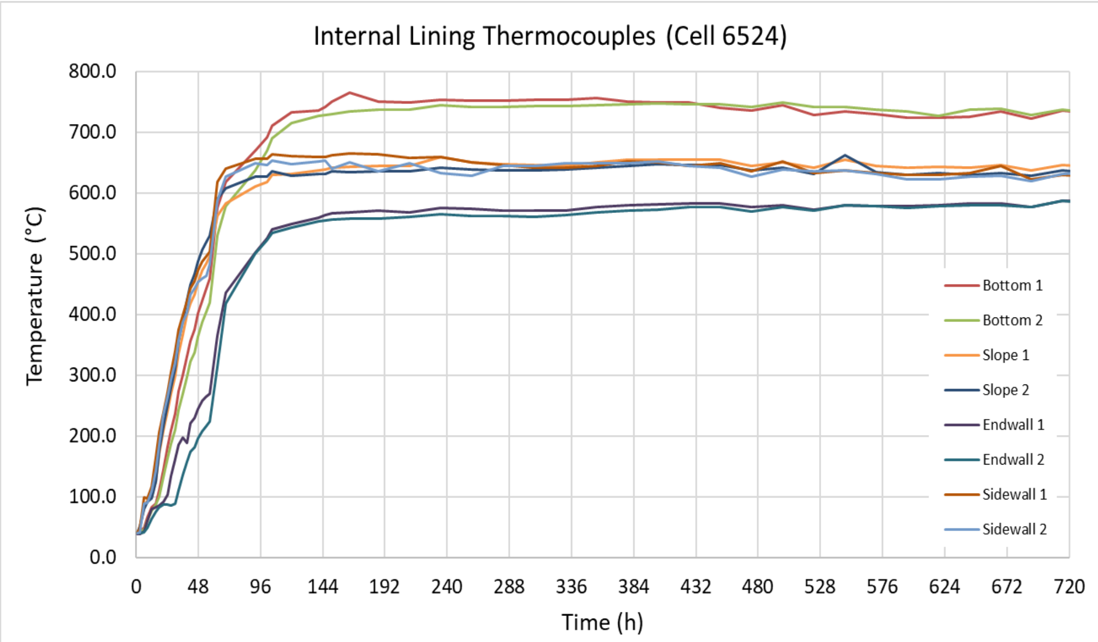

Figure 13. Internal lining thermocouples temperatures during the first 30 days.

Table 1. Lining temperatures average 15 to 30 days versus steady state model.

Location	Average (°C)	Model (°C)
Bottom	735	760
Slope	643	644
Endwall	585	658
Sidewall	630	602

Cathode voltage drop reduction of around 85 mV was achieved. CVD trend and comparison with reference pots is shown in Figure 14.

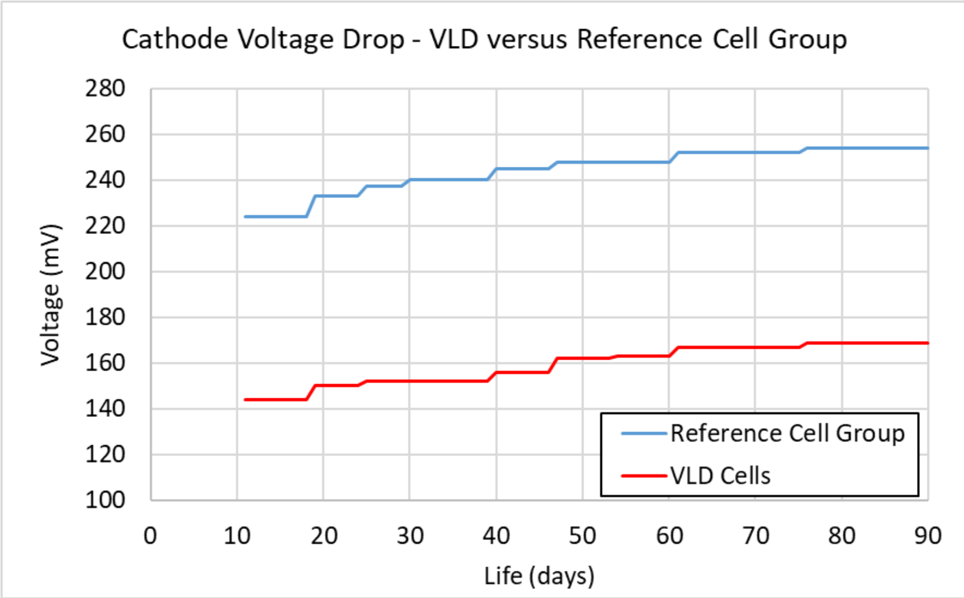

Figure 14. Cathode voltage drop comparison between VLD and reference cell group.

Cell stability in terms of noise during operation is better in VLD cells (expected result due to reduction in horizontal currents), which is reduced from 12-13 mV level to 9 mV. The pot can then be operated at reduced metal inventory levels and further gain on cell operating voltage. Operating voltage reduction by around 75 mV is seen during initial phase, which might reduce specific power consumption of around 0.2 kWh/kg Al. Cell operating voltage and comparison with reference cells is shown in Figure 15.

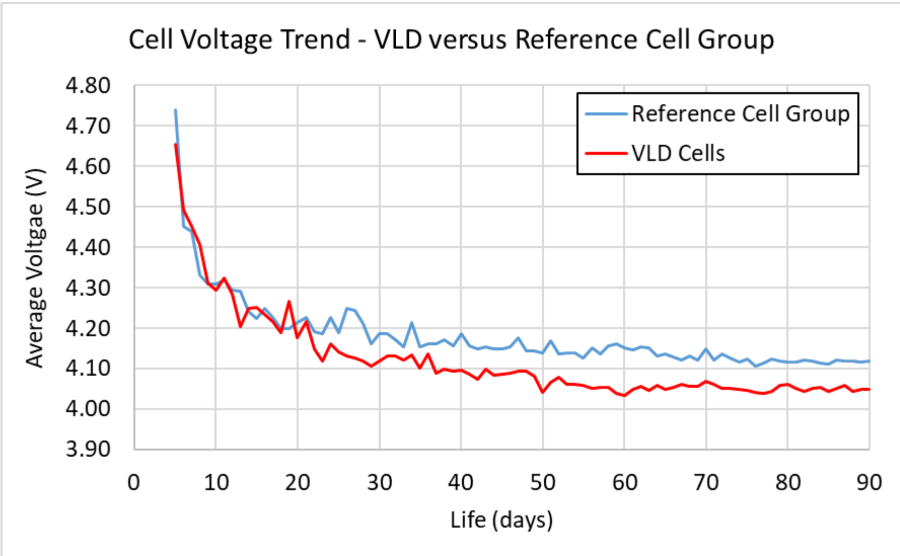

Figure 15. Pot operating voltage comparison between VLD and reference cell group.

Though pots are in trial phase, lining layer measured temperature profiles and stable cell normalization provide indication on improved cathode life. However, the same shall be validated over a period in a next phase. Table 2 shows the performance of VLD cells with respect to the reference pots average. We may notice the increase in collector bar temperature which is expected due to the higher thermal conductivity of the copper.

Table 2. Performance of VLD with respect to reference cell group.

Parameters	Pot 1	Pot 2	Reference cell group	Pot 3	Pot 4	Reference cell group
Current (kA)	330	330	330	340	340	340
CVD (mV)	165	163	250	160	163	240
Average voltage (V)	4.071	4.065	4.143	4.043	4.051	4.125
Collector bar temperature (°C)	276	274	252	263	265	256
Pot bottom shell temperature (°C)	98	94	102	98	92	105
Noise (mV)	12.5	11.5	13.5	8.5	10.1	13.2
Bath temperature (°C)	959	957	956	957	956	958

7. Conclusions

Retrofitting of existing cells with improved cell lining design is the most cost-effective approach for improving energy efficiency and volume throughput in existing set up of potlines. With a net increase of 5-6 % in investment towards lining cost, an improved cell performance with payback within 6-8 months can be envisaged. Also, an improved pot life can be expected.

Vedanta lining design has a unique approach of using partial copper inserted collector bar cathode blocks with cold ramming paste sealing which eliminates the need of setting up a separate cathode sealing shop based on cast iron sealing and the related expenses.

Lining layers modifications in new lining design do not complicate the construction method and it is of ease of installation. Thus, existing working crew can be trained easily in building pots and eliminate workmanship related concerns. No special modifications in existing shells are required. An improved pot life by 200-400 days can reduce specific hazardous waste generation associated with cell shutdowns and further costs incurred on processing. This can be a substantial contribution towards a sustainable operation in addition to improved cell performance.

Modelling results and trial phase performance of cells show reduction in specific energy consumption by 0.2-0.3 kWh/kg Al due to reduction in CVD by 70-80 mV compared to existing graphitized cathode lining design and expected improvement in current efficiency. Design has added the advantage of stable cell operation and running at lower metal inventory.

Design gives flexibility and future readiness for current increase of 15 kA is possible without any changes in the lining design. With few more modifications, the design can also increase currents up to 20 kA. Based on these results, further installation of 6 prototypes in phase 2 and further scaling up is planned in next trials phase.

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