Designing cells for the future – Wider and/or even higher amperage?

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The current approach of increasing amperage simply by making cells longer has introduced operational problems. However, using copper collector bar technology opens the door to a new cathode design that extracts 100% of the current directly on the downstream side. It means we can design a wider cell without generating harmful horizontal current in the metal pad or increasing the cathode voltage drop. This article explores the alternative design here and reveals how it offers spectacular benefits while minimizing practical operating issues.

The modern aluminium smelting industry faces several environmental challenges and commercial limitations. It should have a clean, green energy supply for metal production, it should use the resources available more efficiently, and simultaneously reduce the capital and operating costs, while also meeting more stringent environmental control requirements. Since the advent of point feeders the dominant trend in cell design to address these challenges has been to increase the length of the cell, although operating benefits have also resulted from such features as alumina conveying systems, and use of more intelligent point feeder breaking devices [1, 2]. More recently, limitations arising with increasingly long cells

Fig. 1: Sketch of a cell using 48 such anodes produced by CellVolt from Peter Entner website: http://peter-entner.com

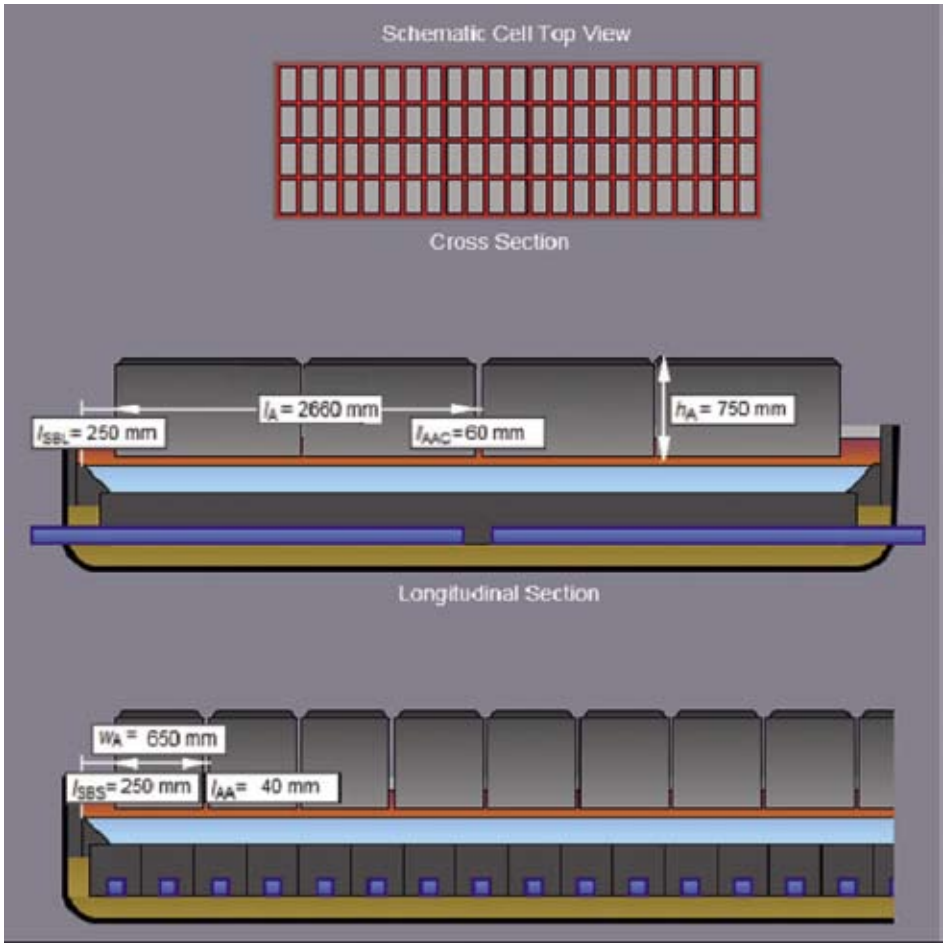


Fig. 2: Anode model temperature solution

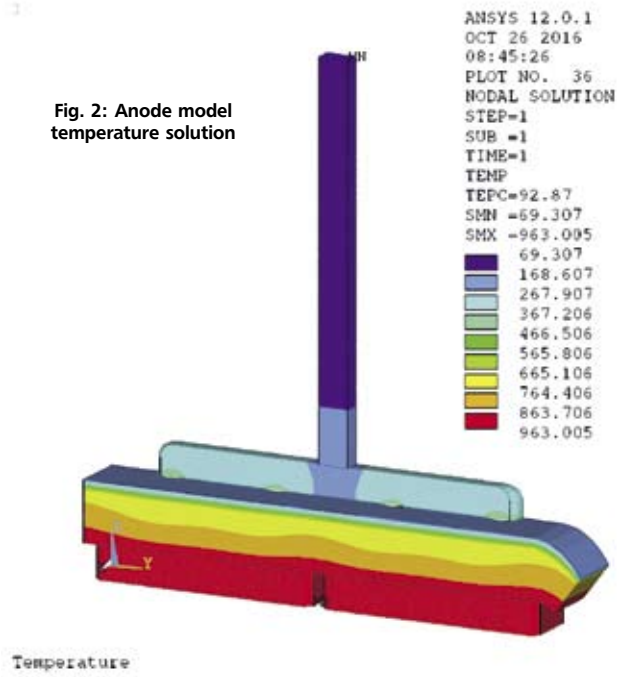
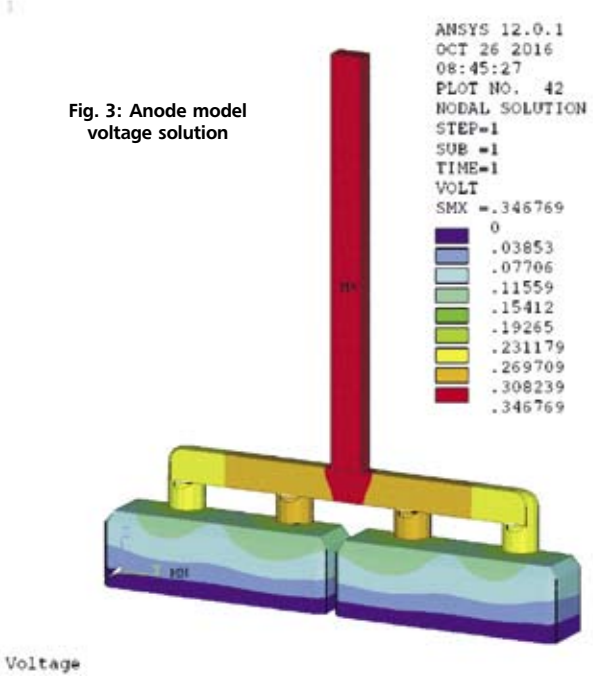


Fig. 3: Anode model voltage solution



have become apparent in both capital cost and operating performance [3]. The reduction in liquid bath volume, combined with the higher amperage load per point feeder, has accentuated the spatial variations within the cell. In some situations this gives rise to almost continuous co-evolution of perfluorocarbons due to the large differences in temperature and alumina concentration within the cell [4-6].

Increasing the amperage through lengthening the cells reduces the heat loss, but this benefit steadily diminishes in an almost exponential decay. This offers little further potential for modern operations and work practices, where the process energy required for the typical work practices and quality of raw materials only varies in a narrow range between 6.5 and 6.65 kWh/kg [7], so future reductions in energy consumption will depend on designs that can lead to lower heat loss. However, as recently presented, copper collector bar technology opens the door to designing a cathode that extracts 100% of the current directly on the downstream side. Such a design change also opens the door to designing a wider cell without generating harmful horizontal current in the metal pad or increasing the cathode voltage drop. This design alternative would also open the door to reducing the heat loss per unit production and also to increasing the productivity of the potroom by minimizing the wasted space associated with the cell-to-cell interconnection.

Criteria applied to new designs

In this article the successful advanced models already developed [8-10] have been applied to basic cell design. The cell is fitted with anodes that extend the width and hence increase the active electrode area per unit cell length. The paper also examines the busbar concept of using reversed compensation current (RCC) so as to of utilize a greater proportion of strategically positioned copper in the collector bars. When originally proposed in 2011 [10], this concept was speculative, but it is no longer so, since Storvik AS [11] presented technology for casting copper inserts into steel at the Iscoba 2015 conference. Furthermore, more recently Kan-nak advocated that copper collector bars do not even need to be protected by a steel shell and rodded to the block with cast iron [12].

The key features of the anode designs envisioned in this analysis are as follows: each anode rod supports two carbon blocks of a standard width and height. The blocks are arranged end on end, giving a total overall length of 2.66 metres. However, the 6 cm gap between the two anodes would be wide enough to enhance electrolyte flow and mixing of the alumina. With strategic anode design refinements the channels could also be used for alumina feeding. This would further minimize concentration gradients, thus minimizing spatial problems and lowering the risk of PFC co-evolution. A central channel would also be maintained. Furthermore, at amperages above approximately 700 kA, the higher consumption rate of alumina opens the way for more innovative alumina feed methods.

The two cell designs we have modelled each require approximately 5.4 metres long cathodes blocks for the anode design described. Their design outputs are based on the cells operating with a nominal current density 0.94 A/cm^2, superheat of 10 °C and 15 cm depth of anode cover material.

The first cell design evaluated has internal dimensions of the cavity 17.02 m long by 5.88 m wide. This would be fitted with 48 anode assemblies with a total operating current of 762 kA. Fig. 1 presents the anode layout and a cross-section of the cathode.

The second 1 MA design maintains the width of the cell, but it would be extended to a similar length-to-width aspect ratio as is currently applied in most designs.

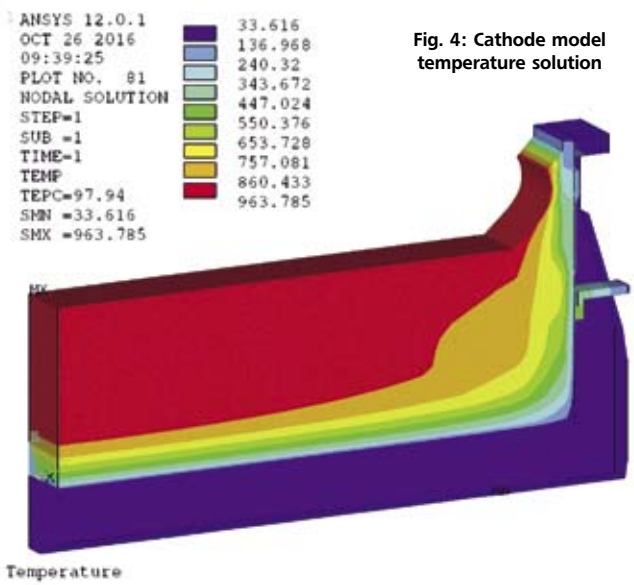


Fig. 4: Cathode model temperature solution

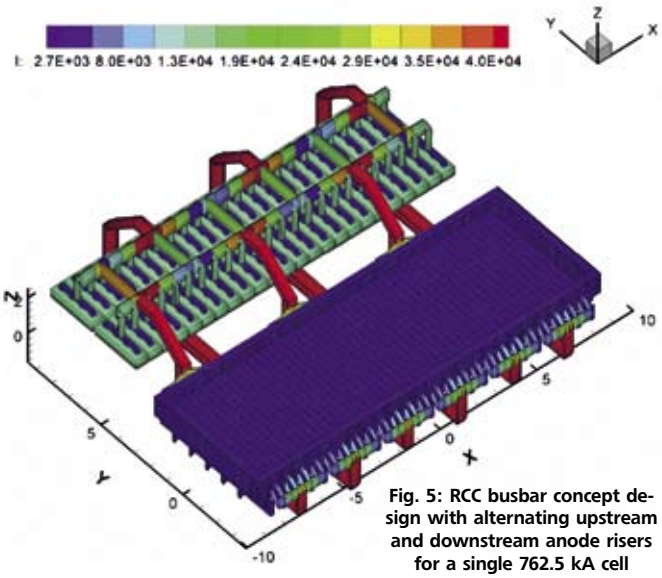


Fig. 5: RCC busbar concept design with alternating upstream and downstream anode risers for a single 762.5 kA cell

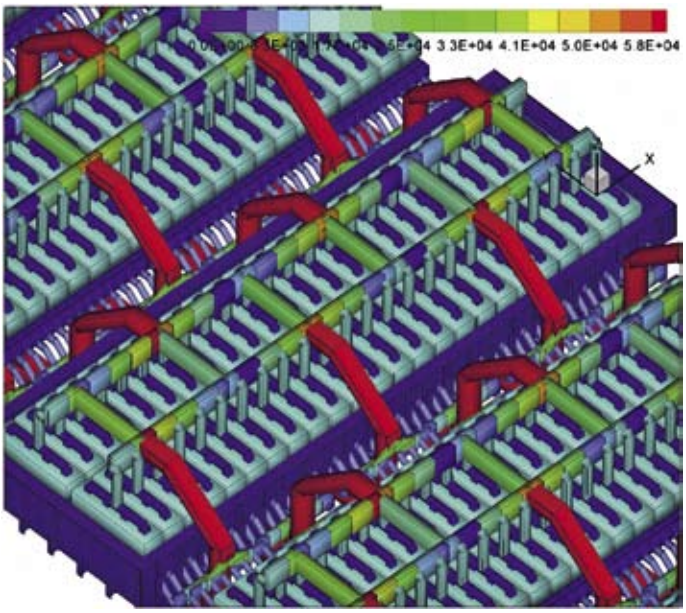


Fig. 6: RCC busbar concept design with alternating upstream and downstream anode risers for a full 762.5 kA potline

The 760 kA cell

Fig. 2 shows the thermal profile of the wide anode, while Fig. 3 shows the voltage solution. Each anode assembly is predicted to have a resistance of 22 µΩ, giving a voltage drop of 347 mV at 0.94 A/cm^2 anodic current density. Calculations are based on two stubs per block, each with a diameter of 21 cm. Like the anode presented in [10], that anode is using the anode stub hole design presented recently [13]. An anode panel made of 48 such individual blocks would dissipate 550 kW with 15 cm of a typical anode cover material.

Fig. 4 shows the thermal profile generated by the cathode side slice model. The cathode voltage drop is predicted to be 118 mV when the cell operates at 762 kA. Assuming an operating anode-to-cathode distance (ACD) of 3.0 cm and a busbar drop of 300 mV, this predicts a global cell resistance of 0.395 µΩ, which corresponds to a cell voltage of about 4.10 V. Current efficiencies of 95% have been achieved at similar and even slightly lower model-based ACD's. This combination of operating conditions would correspond to comparable and achievable energy consumption of 12.8 kWh/kg. The consequential cell heat loss would be approximately 1,300 kW, which is consistent with both the thermodynamic dynamics of the process and the modelling output for the proposed anode cover depth.

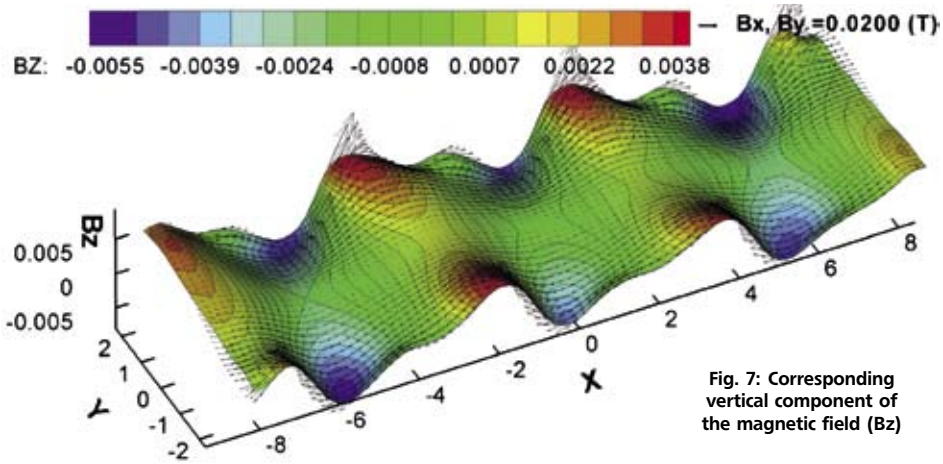


Fig. 7: Corresponding vertical component of the magnetic field (Bz)

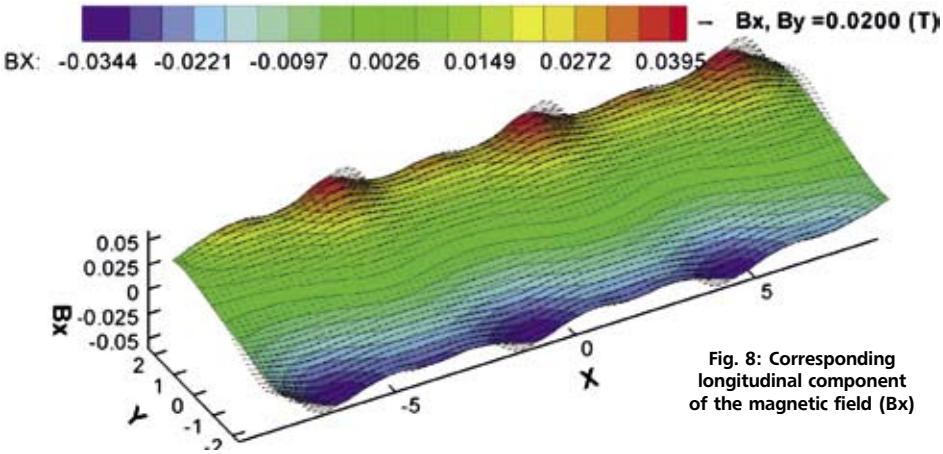


Fig. 8: Corresponding longitudinal component of the magnetic field (Bx)

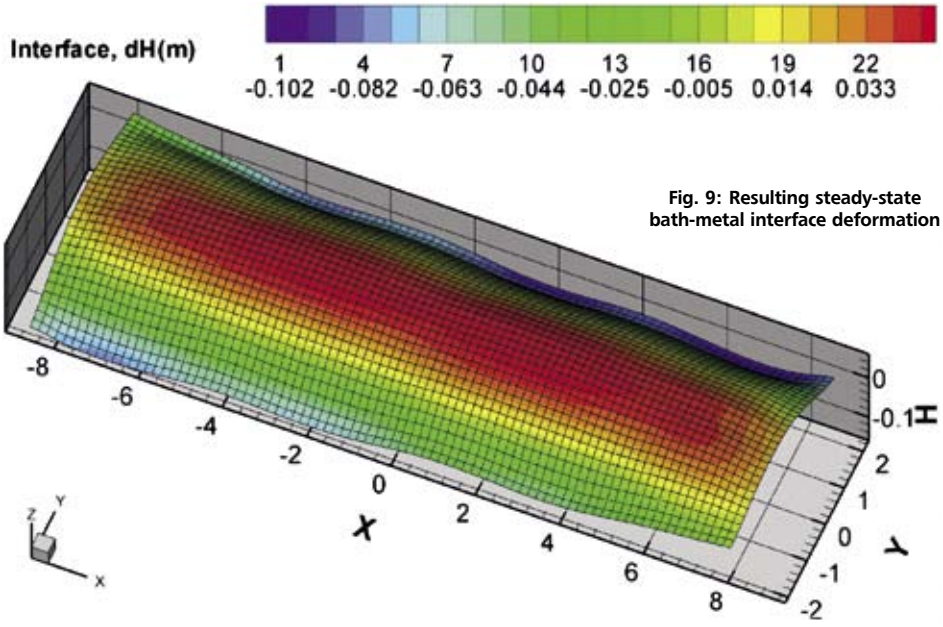


Fig. 9: Resulting steady-state bath-metal interface deformation

Benefits of the RCC busbar concept design

The reversed compensation current (RCC) busbar concept used in the modelling incorporates alternating upstream and downstream anode risers, as illustrated in Figs 5 and 6. This configuration helps to produce an anti-symmetric longitudinal magnetic component (Bx), which in turn produces a symmetric bath-metal interface deformation. It also helps by producing a metal flow circulation that should promote alumina dissolution and minimize the risk of sludge formation [14, 15]. An added benefit is that it helps reduce the busbar weight by enabling a smaller cell-to-cell distance. The cell-to-cell distance achieved in this study is 7.6 metres. This has the dramatic benefit of increasing the productivity per potroom area by significantly more than 10% because less space is not filled with electrodes.

Since the original proposals for the RCC concept [16], the alternating upstream and downstream anode risers design has been combined with a second innovation, a cathode concept where 100% of the current is extracted by copper collector bars located on the downstream side of the potshell. Copper collector bars have been shown to allow this kind of design for cells of typical width [14, 15]. Also, copper collector bars permit the design of much wider cells if these regular cathode designs combine equal upstream/downstream current extraction.

This paper presents for the first time the results of such a RCC busbar concept applied to a regular yet wider cathode design using alternate upstream and downstream anode risers. Fig. 5 shows the alternative busbar layout for a single cell without the compensation busbar. Globally, all the potline current is passing in cathode busbar located under the cell. The compensation busbars, which are located in tandem under those cathode busbars, are also passing the full potline current, but in the

opposite direction. Fig. 6 shows the full potline busbar layout.

Fig. 7 shows the resulting vertical component of the magnetic field (Bz) while Fig. 8 shows the obtained Bx. Fig. 9 shows the bath-metal interface deformation, while Fig. 10 shows the metal flow. Globally those results are quite good.

Extrapolation to a longer 1 MA cell

As previously demonstrated in [16], the RCC busbar concept is applicable to any cell length. The above wider 762 kA cell has close to a 3 to 1 aspect ratio, while a regular width cell of a similar amperage would rather have close to a 4 to 1 aspect ratio. Clearly, before thinking of designing a still wider cell, it is possible to take advantage of the RCC busbar concept to design a bigger cell just by extending the cell length.

Fig. 11 shows the RCC busbar layout of a 1 MA cell with 64 anodes and eight anode risers. That cell is simply 5.52 m longer that the 762 kA cell, making room for 16 extra, same-size anodes. Figs 12, 13 and 14 show the corresponding Bz, bath-metal interface, and the metal flow solutions, demonstrating once again that the RCC busbar concept is directly applicable to any cell length. At that new cell length, we are back to close to a 4 to 1 aspect ratio.

Discussion

The modelling outputs clearly show several advantages of the combination of RCC, increasing the width of the shell and simultaneously increasing the number of channels for a distributed alumina feeding system.

From an operational perspective, the combination of the fairly flat metal pad at such a high current density, and the presence of risers on either side of the cell will minimize the adverse upstream that verses downstream swing in the metal pad during regular anode change. This would enable even lower anode cathode distances if the cell heat balance permits, and so reduce the tendency for low energy cells to form spikes and other anode protrusions. There are three more very conservative figures in this modelling and energy balance calculation that can be readily changed to enable further reduce the energy used. These are:

- the external bus bar resistance, which can be reduced by increasing the conducting cross-sectional area
- the number of stubs in each anode block, which can be increased to lower the resistance
- and the level of strategic insulation on zones of the pot shell that will both increase the ease of operation and lower heat loss.

Environmentally the cell will also have the potential to perform much better. The new anode and superstructure design features enable introduction of features that can minimise the spatial variations in temperature and alumina concentration which are the root cause of the perfluorocarbon emissions in the long, narrow, high-amperage cells. At the proposed current the average alumina consumption rate will exceed 8 kg/min and, as demonstrated by Andrews [17], these mass-flow rates enable accurate control and metering. So, when combined with a distributed feeding system, the new cells have the potential to avoid sludge formation.

Handling the longer anode assembly presents a potential obstacle if the anode-change work practice still depends on the multipurpose cranes. However, it has been pointed out [18] that robotic systems could perform the anode change work and so would overcome such obstacles. Such a change is clearly desirable if the waste heat and energy associated with anode changes is being used to pre-heat the incoming anodes.

Conclusions

The innovative practical design features modelled here clearly open the door to significant advantages. Reductions in capital and operating costs of greenfield smelters are likely, while the new cells would give new benchmark levels of environmental performance.

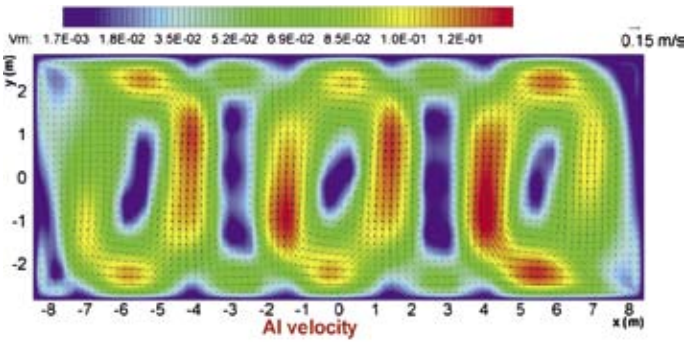


Fig. 10: Resulting steady-state metal flow

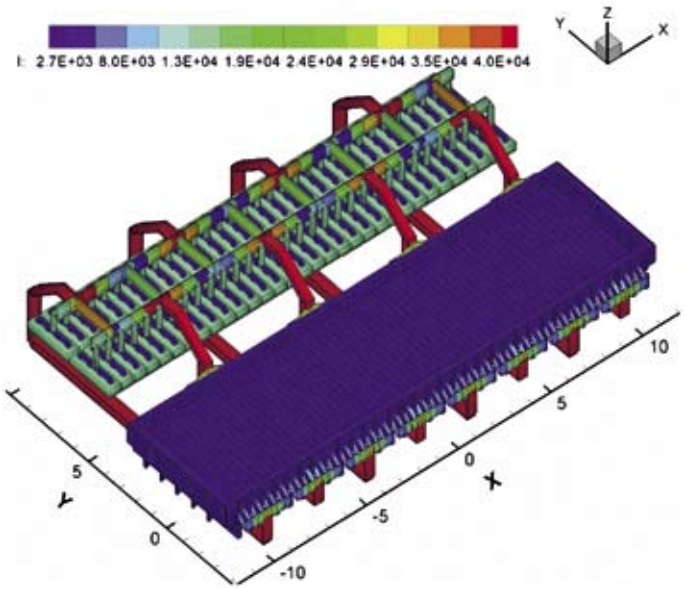


Fig. 11: RCC busbar concept design with alternating upstream and downstream anode risers for a single 1 MA cell

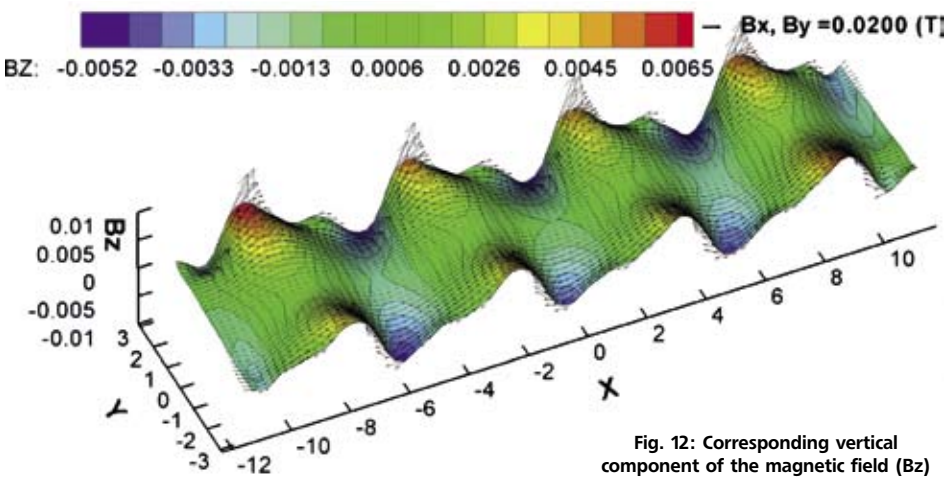


Fig. 12: Corresponding vertical component of the magnetic field (Bz)

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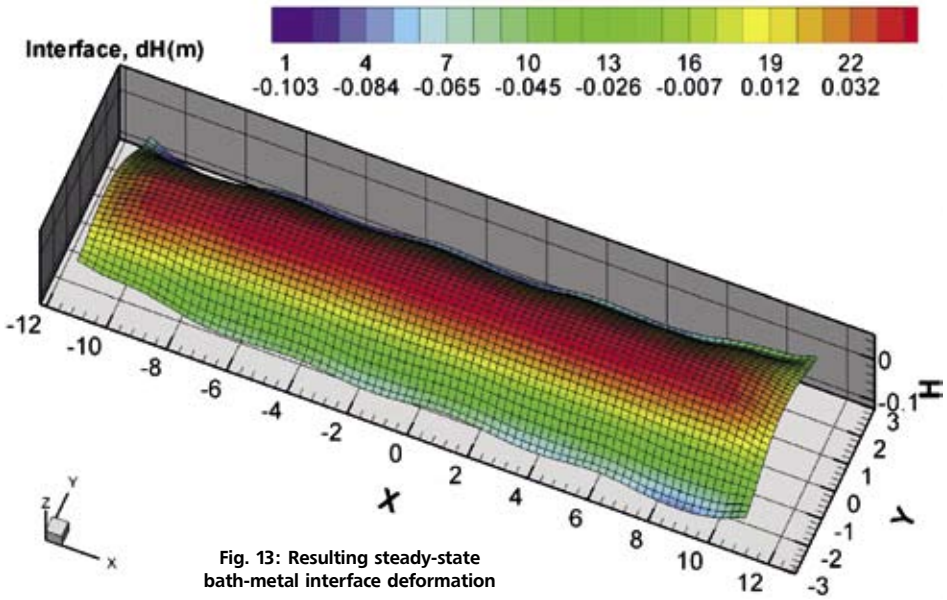

Fig. 13: Resulting steady-state bath-metal interface deformation

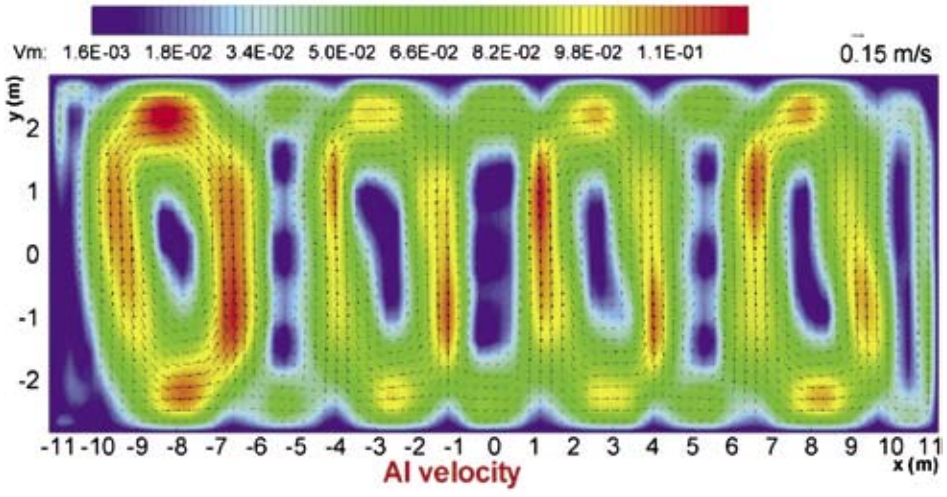

Fig. 14: Resulting steady-state metal flow

Authors

Dr. Marc Dupuis is a consultant specialized in the applications of mathematical modelling for the aluminium industry since 1994, the year when he founded his own consulting company GeniSim Inc (www.genisim.com). Before that, he graduated with a Ph.D. in chemical engineering from Laval University in Quebec City in 1984, and then worked 10 years as a research engineer for Alcan International. His main research interests are the development of mathematical models of the Hall-Héroult cell, dealing with the thermo-electric, thermo-mechanic, electro-magnetic and hydrodynamic aspects of the problem. He was also involved in the design of experimental high-amperage cells and the retrofit of many existing cell technologies.

Dr. Barry Welch completed his Ph.D. in high temperature thermodynamics, and then spent several years researching high-temperature extractive metallurgical processes, including three years with Reynolds Metals Company, before becoming an academic at the University of New South Wales (UNSW), Australia There he established a research group for electrochemical extractive metallurgy from ores and oxides dissolved in molten salts. In 1980 he accepted the Chairmanship of the Department of Chemical and Materials Engineering at the University of Auckland, NZ, (UoA) where his group's research broadened to include high-temperature electrochemical cell design, transfer processes, dissolution kinetics and secondary processes, emissions and energy minimization. On becoming an Emeritus Professor in 1998 he assisted in establishing the Light Metals Research Centre at UoA, before returning to UNSW as a part-time visiting Professor to continue research, while also working with industry on performance optimization and energy minimization.