INTRODUCTION

Improving the Hall-Héroult aluminum process has different implications, depending on whether the work is performed on a new cell design or to upgrade an existing cell. In either case, the goals are lower unit material and energy usage and improved labor productivity. For existing cells, with their limits imposed by the original installation, the problems are unique to each smelter. Several areas of cell development are being addressed, and retrofitted cells are of particular interest.

The modern reduction cell operates at a current efficiency of 90-95% and an energy efficiency of 13-14.5 kWh/kg, with net carbon consumption ranging from 395 to 440 kg/t. Most cells are operated at current densities of approximately 0.8 A/cm² with bath ratios between 1.10 and 1.20 in conjunction with point/puncher feeders. In all cells exhibiting excellent performance, the anode setting operation and metal level control are a focus of preeminent attention. The more efficient cells utilize relatively sophisticated computer systems to precisely handle anode effects, feed and voltage. An essential element of the process is a well-designed, energy-efficient cathode capable of over 2,000 days of operating life with a cavity depth sufficient for the proper protection of the upper anode surface with alumina or crushed bath. Low reactivity anodes with minimal tendency to produce dust are essential to operational stability.

For designers of new cells, two further variables available for modification are amperage level and busbar configuration. New cells being installed today range from the 150 kA Kaiser cell to the 300 kA Aluminium Pechiney cell.

CATHODE DESIGN AND OPERATIONS

Magnetic Considerations

The magnetic environment of the reduction cell affects the production of aluminum in three significant ways. The first is the magnetic field's effect on the metal pad topography. An uneven metal pad indicates a poorly designed equilibrium between gravity and the cell's electromagnetic forces. Under such circumstances, the anode changing operation exacerbates cell disturbance. This disturbance takes a certain amount of time to settle down, resulting in changes to the anode current distribution with the consequent potential for temporary current inefficiency. A further consequence of the distorted metal pad is the inability to maintain the interelectrode spacing at the optimum distance, thereby wasting voltage.

The second impact is the effect on metal pad movement. The metal pad velocity is an important consequence of the magnetic environment because of the contribution to the stirring action in the cell, which helps to keep sludge in contact with bath and ensures even distribution of the heat and alumina throughout the electrolyte. Too high a velocity can result in waves and splashing, which can cause shorting of the anodes, again contributing to current inefficiency and the inability to optimally reduce the interelectrode space.

Vortices and eddies in the metal pad are the third major impact of the magnetic environment. These will promote localized stirring and the tendency to mix the metal pad and electrolyte bath, especially when the operational strategy calls for a bath chemistry with a density close to that of the metal pool. This results in cells with a tendency to voltage instability. It also promotes metal redissolution and reoxidation. The erosive effects of the eddies and vortices can foster localized erosion in the cathode lining and, thus, reduce cathode life.

With the increased capability of available modeling tools, the negative impact of magnetic effects on the metal pad may be largely eliminated. The resulting quiescent metal pad may have an impact on operations, requiring anode setting operations including dredging the metal pad to remove anode cover debris in the bath.

In a presentation on alumina dissolution, Welch discussed the integration of cell design, feed strategy and electrolyte chemistry on the operation of the cell and gave some insight into the requirements for efficient design. He reviewed the impact of changing dimensions through retrofit on the availability of bath for the feed action and the attendant consequences on sludge formation as well as the role of alumina quality.
and the effects of cell conditions on the dissolution of alumina. Kuschel examined the laboratory investigations of alumina dissolution with a view to understanding how the structure of the alumina influences its dissolution. This work will also provide criteria for the optimum design of feeders and feed strategies.

Other studies have elaborated on criteria relating to designing the packing arrangement of anodes in the cell for optimum alumina distribution in the electrolyte. All these approaches are of benefit to the designers of retrofit technology.

For the plant seeking to upgrade its cell technology, it is possible to design out some of the magnetic imbalance. However, the costs of implementation have always been prohibitive. With computer modeling tools, the possibility now exists for the development and execution of new concepts in this area. (Figure 1 shows the results of magnetic compensation on an older cell design.) Designing retrofit upgrades for existing cell technology, therefore, requires a cost-effective compromise between the requirements of operability and the perfect magnetic environment.

Thermal Design

The development of thermal modeling capabilities has also kept pace, with the result that very precise designs of the thermal envelope are now possible. These ensure that the critical isotherms are in locations which will minimize or eliminate the effects of freeze disruption on the cathode blocks and maintain the integrity of the cathode insulation over the life of the cathode. Due to the short term fluctuations in the heat balance of the cell, if the critical isotherm occurs inside the cathode block, the freezing or melting process will cause spalling of the block material. If it occurs in the insulation, the chemical attack of the electrolyte on the insulating material will destroy its properties over time, increasing the cell’s heat loss.

These modern designs require a correspondingly precise operation of the cell. This can leave little flexibility to cope with external perturbations to the heat balance. For example, work done at the New Zealand Aluminium Smelters and the University of Auckland found that there is a significant correlation between the frequency and extent of cell voltage excursions and the cathode sidewall life (Figure 2).

Cavity Design

The geometry of the cell’s operating cavity plays an important role in the heat balance characteristics of the cell as well as being one of the most important contributors to the ability to protect the upper surface of the anodes during operation. The anodes’ surfaces contribute significantly to the heat loss from the cell. Thus, the use of a good, insulating cover serves two very useful functions.

Work has been done to show the impact of anode-to-cathode configurations on carbon consumption, which makes the consideration of the cavity necessary for the retrofit designer (Figure 3). This requires the extensive use of thermal modeling. Given the physical limitations of the original design, this poses a significant challenge to achieving a cost-effective improvement.

Retrofit technology designers working on the thermal envelope of the cell are constrained by the physical limits of the existing cell. The optimal solution requires the careful balancing of operational flexibility and the dictated long-life designs to achieve the lowest possible anode current density while optimizing the heat balance of the cell to the minimum interelectrode spacing.

SUPERSTRUCTURE DESIGN AND OPERATIONS

The latest superstructure designs incorporate the puncher/feeder and alumina reservoir, fluoride addition systems, anode bus beam, jack mechanisms and anodes together with the gas collection and hooding equipment. From an operational point of view, the puncher/feeder system design has the most impact on the ability to carry out the alumina addition strategy.

Another facet of the design of the cell is the anode size and piece count. The tendency to maximize anode size while minimizing piece count in the cell for a given current density is not without its drawbacks, even though maximizing the area of anodes changed out in one operation enhances productivity. The larger the proportion of the area area changed for a given anode life, the fewer the interventions to the cell, with a consequent reduction in the number of disturbances to the operating equilibrium. Furthermore, the operator requirements for the anode change activity are minimized.

Published work has shown that in the modern, highly tuned thermal designs, immediately after anode change, electrolyte solidification can occur under the entire bottom surface of the anode. This can result in operational instability and require operator intervention. Retrofitting larger anodes to a cell must therefore be done in conjunction with the thermal design, and usually requires extensive thermal modeling to arrive at the optimal packing density and configuration.

ANODE QUALITY

One key to the operation of modern reduction cells at high efficiency is a consistent supply of high-quality anodes. Older cell designs are often more forgiving of the results of poor anode quality (e.g., dusting, airburn and carbon chunks in the bath). The new, energy-efficient cell usually will not tolerate such situations.