Monitoring the Operation of Aluminium Smelter Cells using Individual Anode Current Measurements

Cheuk-Yi Cheung, Chris Menictas, Jie Bao*, Maria Skyllas-Kazacos and Barry J. Welch
School of Chemical Engineering, The University of New South Wales,
UNSW, Sydney, NSW 2052, Australia

Keywords: Aluminum smelting, Individual anode current, Anode effect, Fault detection

In recent years, productivity and flexibility of aluminium smelting are becoming important economic drivers due to the changing cost structure. In modifying operating practices to meet these requirements there is an increase in occurrence of abnormalities, such as anode effect, which impacts control strategy as well as cell performance [1]. Therefore it is important to monitor the cell conditions during operation to detect the anomalies that will adversely affect the efficiency of operation. Monitoring and control in the Hall Heroult process are commonly based on the continuous measurements of cell voltage and line current. They reflect global process behaviour, and are used to regulate average alumina concentration, and to maintain voltage balance as well as overall heat balance in the cell [2]. Nevertheless, the Hall Heroult process is highly distributed and exhibits a strong internal coupling between process parameters. This makes cell control based on the cell voltage and line current measurements difficult to address changes in local cell conditions and to isolate process abnormalities at a localised level, especially for large modern cells, since spatial variations are more significant as cell dimensions increase [3].

Supported by the CSIRO Cluster on Breakthrough Technologies for Aluminium Reduction, the UNSW team investigated an approach to cell monitoring and fault detection based on the measurements of individual anode current, including an instrumentation scheme and analysis tools for different abnormal conditions. The use of individual anode current signals to increase observability of local cell conditions has been proposed in literature (e.g. [4]). Although monitoring individual anode current signals holds a great potential for cell supervision and control, its application in industrial reduction cells has been limited [5], perhaps due to the lack of cost effective instrumentation schemes and analysis tools.

**Instrumentation scheme development.** A high-speed anode current distribution measurement system was developed to sample all anode currents (at the rate of 10 to 30 samples per second). The system was designed to cope with the harsh environment in the potrooms (high temperature and strong magnetic fields). The individual anode current signals on the anode rods were determined by measuring the voltage drop over a set distance between the bottom of the anode beam and above the cell hood. The voltage drop is amplified and fed into a data acquisition system as differential voltage input. In order to correctly estimate the individual anode current from the measure anode rod voltage drop readings, the anode rod temperatures are measured to calibrate the resistance of the anode rod material at the locations of the voltage drop measurement. All wiring was secured in high temperature wiring looms and held securely in place to limit possible damage during cell operation. The system was successfully trialled at one of our industrial partners’ premises. The data acquired from the operating cell includes real-time individual anode currents, cell voltages, anode rod temperatures at different locations, and event logs during normal operating conditions, certain measurements of bath temperatures, superheat and bath composition analysis.
Anode current analysis. To characterize the individual anode current signals during different operating conditions (normal and abnormal conditions), a series of experiments were conducted where deliberate disturbances were introduced to an industrial operating cell. Individual anode current signals were recorded together with other cell measurements. Some interesting observations were obtained. In addition to time domain analysis, frequency domain analysis was carried out to study the “features” of anode current dynamics. Here are some of the highlights:

- **Anode setting.** The current pick up profile over time for a new anode from the time of setting till approximately 12 hours after setting is shown in Fig. 1. The trend has three distinct regions. The first region involves an initial fast uptake of current and cracking of freeze may be occurring which makes more of the anode accessible to the bath and able to carry current. The second region shows a slowdown of the initial current uptake rate and the anode may initially be consumed more at the sides. Region 3 shows the steady uptake of current up to the full current carrying capacity. A frequency response of the anode current at different regions is presented in Fig. 2. Region 3 shows the typical anode current dynamics where the peak at 0.8-1.2 Hz is associated with bubble release at the surface of the anode. The amplitude of the peak is seen to increase as the newly set anode approaches stage 3.

![Figure 1: Anode rod voltage drop readings](image1)

![Figure 2: Frequency response of a newly set anode](image2)

- **Anode effect.** An anode effect arises when anodes are passivated by an insulating layer of bubbles produced by carbon side reactions when the alumina concentration at the anode surface is depleted, leading to concentration polarization and the discharge of fluoride ions [6]. An anode effect often starts at a localized level due to local depletion of alumina before it propagates across the cell. Its occurrence is undesirable as it disrupts normal reaction, leading to reduction of current efficiency, increase of energy consumption as well as PFC emissions. An onset of an anode effect is normally detected from a sudden increase in cell voltage [7]. This method, however, only provides a warning when the cell goes into anode effect, leaving little time for remedial actions to be carried out. In noisy cells, voltage noise can sometimes mask the cell voltage increase. In addition, early anode effect detection based on the cell voltage signal may fail as the cell voltage only reflects the overall cell condition. To obtain the anode current signal at the onset of an anode effect, a feeder near anodes 4, 5, 14 and 15 was manually blocked to reduce alumina concentration. The changes in the cell voltage and the current profiles of the anodes located in the vicinity of the blocked feeder as the cell approached AE are shown in Fig. 3. Note that only the anode current of Anode 15 shows a variation before the onset of the AE.
Although a slight increase in cell voltage (4.75 V) is also observed, it only occurred less than one minute prior to the onset of the AE (taken when the cell voltage has reached 21.77 V). On the other hand, a current reduction at Anode 15 is observed at almost two and a half minutes, as marked by the arrow in the figure, before the sudden increase in the cell voltage and the aggressive oscillation of the anode currents. However, a similar anode current redistribution can also be caused by other events such as a slipped anode. The frequency responses for Anodes 15 and its immediate neighbour (Anode 14) at different stages are shown in Fig. 4. In Stage A, both power spectra of Anodes 14 and 15 (Figs. 4(a) and (d) respectively) show significant peaks formed in the frequency range of 0.8 to 1 Hz, similar to the typical response depicted in Figure 2 (Region 3). As the anode current of Anode 15 is reduced in Stage B, the peak in the frequency range of 0.8 to 1 Hz, is seen to reduce significantly, as shown in Fig. 4(e). However, the peak in the spectrum of Anode 14 in Figure 4(b) is founded at a similar frequency and amplitude as in Stage A. Fig. 4(c) and (f) show both responses in Stage C before the cell entered anode effect. The peak in the spectrum of Anode 15 further reduces while the peak of Anode 14 remains, showing anode effect is occurring at Anode 15.

The present work shows that anode current signals can provide rich information about the operation of aluminium smelters and can be used for detection of abnormal operating conditions such as anode effect. It is shown that bubble dynamics is closely related to the local condition within the cell, and is reflected by the frequency response of the individual anode current signals. Some of the results are reported in [8-9].

References