The Role of New Sensors for Hall-Héroult Process Control, Optimization and Advanced Analytics

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Abstract

The Hall-Héroult process is controlled using individual cell voltage and line current as the only continuous online signals. Other variables such as bath characteristics, liquid levels or metallic impurities are only periodically measured, normally every few days. Other visual observations are also performed by operators but generally not entered within databases and can have questionable reliability. This limited amount of process data constrains the extent of process control and hinders capability to identify common faulty conditions that require manual intervention from operators such as anode spikes, collapsed crust, bad hooding position, etc. Over the last decade, aluminium producers started to test big data, or advanced statistical techniques, to better diagnose and intervene on reduction cells. Yet, such techniques are also limited by the restricted amount and limited quality of data available to properly train data driven algorithms. On the other hand, the industry is developing new sensors to enrich the information available around the reduction cells. This will pave the way for real time alarms for some process faults and increase effectiveness of advanced statistical techniques to identify other process upsets not easily detectable with common process control schemes. This paper reviews big data initiatives tried at Alcoa within the smelting process and discusses factors preventing success. It also presents an update on sensors, developed internally and off-the-shelf, aiming to improve process control by providing better process insights for advanced analytics initiatives.

Keywords: Process control, Big data, Sensors, Hall-Héroult, On-line measurement.

1. Introduction

Until further development of the inert anode process or other alternative routes, aluminium will continue to be industrially produced using the Hall-Héroult process. In this process, alumina (Al_2O_3) powder is electrolysed into aluminium (Al) and oxygen (O), based on the following overall reaction:

$$2Al_2O_{3(s)} + 3C_{(s)} = 4Al_{(l)} + 3CO_{2(g)} \quad (1)$$

This reaction happens inside metallurgical reactors, called reduction cells or pots, where high continuous electrical current flows between carbon anodes and cathodes. The carbon anodes (C) react with the oxygen and produce gaseous carbon dioxide (CO_2). Molten aluminium, which accumulates at the bottom of the pot, is periodically siphoned and delivered to the cast house. The alumina powder is dissolved within a molten electrolyte, called bath, which is a mixture of cryolite (Na_3AlF_6), aluminium fluoride (AlF_3), calcium fluoride (CaF_2) and some other additives. This process typically operates between 950-970 °C.

The cells electrically connected in series (potline), are typically controlled using the potline current and individual cell voltage as on-line signals. High magnetic fields, corrosive molten salts and acidic vapors, high temperature and abrasive dust produce different challenges to develop and deploy cost efficient on-line sensors to measure other key variables to improve process monitoring and control. Therefore, other measurements such as electrolyte condition, liquid levels or metallic impurities are periodically measured manually to complement the information available for process control.

The bath chemistry, temperature and superheat are periodically monitored using samples and thermocouples or using in-situ measurements such as STARprobe™ [1]. These variables are controlled to maintain heat and mass balance to achieve high productivity and extended pot life. They also provide great insights on the pot state.

Liquid levels are monitored using a dip stick and a ruler [2]. Metal level is maintained to a specific height range to control magnetic stability and thermal balance. Metal pad height can be used to determine the amount of metal to be tapped from a given cell. The electrolyte level is also maintained to a specific height range to prevent liquid bath dissolving the steel part of the anode assembly while ensuring sufficient bath volume for alumina dissolution. Bath can be added or tapped from a given cell to adjust its level.

Metal pad metallic impurities are measured using samples poured and frozen into molds. The samples are later analysed using spectrometer analysis [3] to determine chemical elements present in each cell. This is required to monitor the cell condition and to determine how to blend metal from different cells to fulfill casthouse orders. Metallic impurities are also used to determine various cell conditions [4].

Other routine measurements are carried-out by operators to diagnose the pot condition and process faults. Those measurements are not typically used as inputs for process control and are not systematically collected within databases. Anode rod voltage drop are measured to detect anodes carrying too much or too little current [5]. Side ledge or heat flux are measured to assess the sidewall condition and the general heat balance of the cells [6]. Sludge (undissolved alumina) surveys or cathode voltage drops are performed to assess the cathode condition and dust surveys [7] can be performed to assess anode performance within the pots.

So far, no on-line real-time sensors are available to monitor alumina concentration within the electrolyte, which control is of prime importance to avoid PFC gas evolution and sludge formation. Instead, it is controlled using an overfeed/underfeed strategy, relative to the nominal alumina consumption rate, based on the time derivative of the cell pseudo-resistance or voltage drop [8]. The same pseudo-resistance or voltage is also used to control the power input to the cell and the anode-cathode distance (ACD) that is critical to the cell magnetic stability and productivity [8].

Aiming to get the most out of the collected data and to better understand their processes, aluminium producers have used advanced analytics, big data, machine learning and digital twins to study the large amount of collected data. Recent examples have been published within the literature. Moreover, technology development teams have pursued the development of new sensors to monitor other parameters around the reduction cells.

This paper reviews some published and in-house advanced analytics initiatives, pertaining to the smelting process, and discusses factors preventing success. It also presents an update on in-house developed and off-the-shelf new sensors, aiming to improve process control and to provide better process insights for advanced analytics initiatives.

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