360 kA Hall-Héroult Cell Retrofit Using Inert Anodes and Stable Cathodes

Louis Bugnion[1], René von Kaenel[2] and Laure von Kaenel[3]
1. Project Manager
2. CEO
3. Junior Project Manager
KAN-NAK SA, 3960 Sierre, Switzerland
Louis.Bugnion@kannak.ch

Abstract

Experiments more than one decade ago demonstrated the feasibility of operating a Hall-Héroult cell with metallic anodes at 25 kA. In March 2019, ELYSIS confirmed the existence of stable anodes and cathodes during the TMS annual meeting in San Antonio. It was often claimed that the reduction of alumina demands one extra volt per cell when operating with Inert Anodes, which represents about 3 kWh/kg Al in addition to the amount currently required by the traditional Hall-Héroult process. This paper gives a potential solution to achieve a specific energy consumption comparable to the best in class Hall-Héroult cells using metallic inert anodes and cathodes. The engineered solution is for the retrofit of a typical 360 kA cell.

Keywords: Inert anode, inert cathode, specific energy consumption in aluminium reduction cells, cell retrofit, Hall-Héroult process.

1. Introduction

Since the early days of aluminium smelting, the dream of operating a Hall-Héroult cell producing oxygen as a by-product rather than carbon dioxide has been pursued. The fundamental difference between both solutions comes from the reduction of the alumina. Traditionally, the oxygen burns the anode leading to the well-known chemical equilibrium [1]:

$$2\eta Al_2O_{3(diss)} + 3C_{(s)} = 4\eta Al_{(l)} + 3(2\eta-1)\,CO_{2(g)} + 6(1-\eta)\,CO_{(g)} \quad (1)$$

where:
η Current efficiency, fraction.

The use of a so-called inert anode allows realizing a direct reduction of the alumina by equation (2), avoiding both carbon monoxide and carbon dioxide emissions [2]. In this paper, we shall use the term "inert anode" even if it is not strictly inert and may need to be replaced every few months or years.

$$\tfrac{1}{2}\,Al_2O_{3(diss)} = Al_{(l)} + \tfrac{3}{4}\,O_{2(g)} \quad (2)$$

The challenge when using an inert anode is to design a cell operating at low specific energy consumption at the right thermal equilibrium. In thermal equilibrium the net heat generated in the cell and connecting busbars is equal to the heat loss. Considering the enthalpy (heating and formation) of reaction (1) at 960 °C [3] and the Faraday equation, the net heat generation for the carbon anode Hall-Héroult cell is equal to:

$$Q_{HH} = \left[V_{Cell} - (1.6493\eta + 0.48032)\right] I \quad (3)$$

where:
Q_{HH} Hall-Héroult cell total heat generated, kW
V_{Cell} Cell voltage, V
I Cell current, kA

By considering the enthalpy of reaction (2), it is easy to show that the inert anode process leads to the net heat generation:

$$Q_{IA} = (V_{Cell} - 3.108\eta)I \quad (4)$$

where:
Q_{IA} Inert anode cell net heat generation, kW.

The last two terms in Equation (3) in round bracket and the last term in Equation (4) represent the equivalent voltage to make aluminium, derived from the enthalpy of reactions (1) and (2), respectively, which is subtracted since the reactions are endothermic. In the inert anode cell, the voltage to make aluminium is obviously much higher (2.953 V at 95 % current efficiency) than in the carbon anode cell (2.047 V at 95 % current efficiency), and this is because burning carbon is exothermic and gives energy back to the process. The difference is 0.91 V or 2.85 kWh/kg Al.

Therefore, the net heat generation in the inert anode cell is much lower for the same current and voltage drop. This is to say that also heat loss from the inert anode cell must be much lower. In order to quantify the difference between both technologies, let us consider a 360 kA cell operated at 4.15 V with 95 % current efficiency. This means a specific energy consumption of 13.02 kWh/kg Al, which can be qualified as best-in-class. The Hall-Héroult cell operates with 757 kW net heat generation and loss, while the inert anode technology must operate with 431 kW net heat generation and loss to achieve the same voltage drop and, consequently, comparable specific energy consumption. The challenge is how to keep the heat loss of the inert anode cell so low and keep the desired bath temperature, mentioned below.

We believe that it is possible to operate both technologies with comparable voltage drops, current and current efficiencies while keeping the aforementioned difference in heat loss. Reference [4] presented potential concepts to achieve such a task. More than a decade ago, operation with metallic anodes in a 25 kA cell [5] confirmed the possibility to produce primary aluminium with inert anodes and gave a basic understanding for retrofitting cells. The announcement of the availability of stable anodes and cathodes during the TMS conference 2019 in San Antonio by ELYSIS gave us the motivation to study the retrofit of a 360 kA cell satisfying the low heat loss constraint while operating with the same specific energy consumption, current and current efficiency.

1.1. Economical Constraints for the Retrofit

Let us first define a number of constraints giving an economical sense to the retrofit solution. The retrofitted cell will consider the following:

- Same line current: 360 kA;
- Same current efficiency: 95 %;
- Minor changes to the existing busbars (flexes to main busbars, shortcuts between busbars);
- Potshell kept as existing, however, shorten by 50 % in length (cut and weld);
- Superstructure kept as existing, however, modified feeders;
- Solid crust above liquid bath covered with pure alumina (held by a structure);
- Low temperature bath chemistry:

CaF_2	6.0 %
Al_2O_3	4.2 %

4. References

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