Energy Consumption Evaluation - Different Practices and Possible Approaches to Their Harmonization

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Abstract

Specific energy consumption (which is expressed in direct current, or DC) is a key economic indicator, since it directly reflects power expenses in monetary terms. In contrast, current efficiency (CE) and voltage are not directly expressed in monetary values but they directly affect power consumption: a decrease in voltage or an increase in current efficiency reduces power consumption. Therefore, all the world's leading aluminium producers take efforts to optimize said parameters to reduce the production cost. At industry conferences, energy efficiency is one of the main subjects; however, issues related to voltage and its precise measurement are cursorily discussed. In the literature and patents, it is taught that the mean, or average, voltage comprises the electrochemical reaction and losses in conductors but there are no clear methods for measuring the voltage, including information on where measuring wires are to be located. This leads to the following discrepancies: some publications consider only individual components, such as the voltage required for the reaction or partial losses in conducting elements. Many companies use compensation circuits (or loops) but they are silent on whether their voltage value considers the voltage drop in said circuits, or loops. Lack of standardization makes it difficult to compare results and develop universal approaches.

This paper researches the influence of the location of voltage measurement points in the cell on the voltage value that we have. This research may serve as a basis for developing standards and methods for measuring voltage, which will help obtain an objective picture when assessing energy efficiency in the aluminium industry.

Keywords: Aluminium electrolysis cell, Voltage drop, Energy consumption, Energy efficiency calculation, Comparison of energy efficiencies.

1. Introduction

The following three components form the voltage in an aluminium reduction cell. The first component is a decomposition voltage, i.e., the voltage required for the electrochemical reaction. The second component is an excess (or polarization) voltage; it occurs due to polarization at the electrode boundaries. The third component is an Ohmic voltage drop, which is caused by resistance in different parts of the cell. Since we have only limited influence on the first two components, the main attention should be paid to reducing the Ohmic voltage drop.

Although, global aluminium producers control the cell voltage, the question is how accurate such control is. There is often no information on whether they take into account the voltage drop in the cell busbar (as well as in the magnetic field compensation busbar, or loop). For example, if the voltage drop in the busbar is only partially taken into account (excluding, for instance, a value of 100 mV from calculations), this will lead to an underestimation of energy consumption; in numerical terms, one may list a value of 12 800 kWh/t Al but the actual energy consumption will be close to 13 100 kWh/t Al. So, when taking into account the overall (total) voltage drop (including the busbars), the energy efficiency indicators may become comparable with the average numbers in the industry, and no expected benefits will be seen. Thus, ignoring the above in calculations may lead to incorrect energy consumption values (the values on which all global aluminium manufacturers focus).

This paper proposes to consider using a unified approach by taking into account the balance between voltage and energy consumption.

2. Methods for Measuring the Voltage

This paper considers various voltage measurement methods that are used in the course of aluminium electrolysis, or aluminium reduction. Figure 1 shows a voltage measuring circuit for both the total voltage of one potline and the voltage of a single potroom.

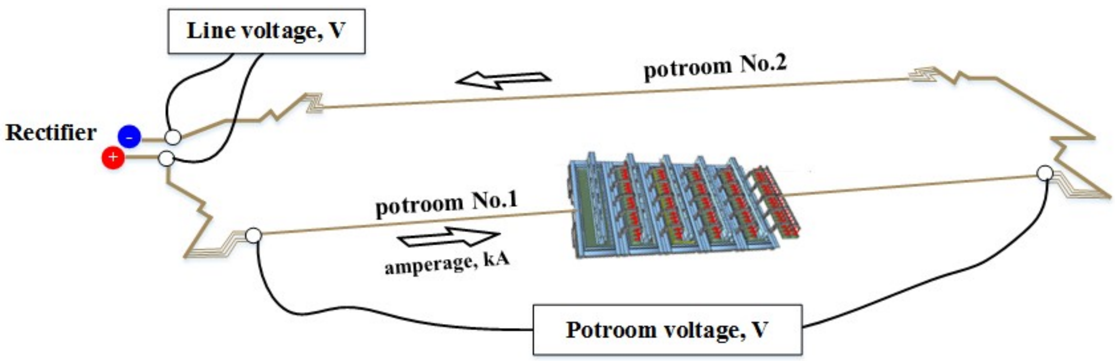

Figure 1. Voltage measuring circuit for both the total voltage of one potline and the voltage of a single potroom.

As can be seen from Figure 1, measuring the voltage at the (+) and (-) terminals of the rectifier allows determining the total voltage of a potline, which includes both the electrochemical component and all Ohmic losses when the current passes through all the parts of the busbar. If dividing this value by the number of cells, one can determine the average voltage per cell; this voltage value serves as a key indicator of the efficiency of the process at the moment of measurement and reflects the actual performance achieved.

In the case of using a compensation busbar (or loop) for a process with low resistance to MHD instability, it is necessary to take into account voltage losses in said loop [1-5].

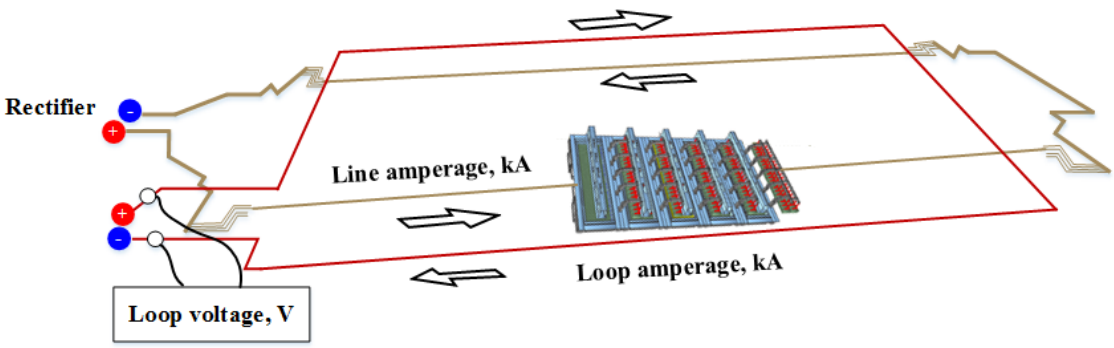

Figure 2. Voltage measuring circuit for the compensation loop.

Based on the automated process control system (APCS) voltage (3.71 V), the specific energy consumption is 11 613 kWh/t Al (current efficiency = 95.2 %). However, if taking into account the total voltage comprising the voltage drop in the cathode and anode busbars (4.07 V), this value increases up to 12 740 kWh/t Al (the difference is 1 127 kWh/t Al). Taking into account the voltage drop in the line busbar, including transition buses (ΔU ~ 18 mV), the overall (total) voltage of the cell will be 4.088 V, and the specific energy consumption will be 12 796 kWh/t Al for the RA-550 cell technology. This value reflects the real operating costs (OPEX), considering all losses in the infrastructure. These data emphasize the importance of accounting for all voltage components for an objective assessment of the actual energy consumption of the process.

5. Conclusions

The evaluation of the energy efficiency of cell technologies requires taking into account the total voltage drop, including the busbars (both anode and cathode), transition buses (buses between potrooms), as well as all deviations from the target voltage. This ensures the accuracy of calculations, helps avoid the underestimation of the energy consumption and shows the actual energy efficiency. If magnetic field compensation loops are used, the voltage drop in such loops should be distributed between the cells installed and included in a calculation of energy consumption.

For an unambiguous interpretation of data in publications, it is proposed to use the following wording:

- Cell internal voltage: Net cell voltage minus external (cell-to-cell busbar) voltage drop. This voltage is used for cell thermal balance calculations.
- Computer control voltage: Measured cell voltage between two points on the busbar of two adjacent cells, used for cell resistance control. This may include only a partial busbar voltage drop, depending on technology, e.g., between points 3 in Figure 3.
- Net cell voltage: Full cell-to-cell voltage, which is measured between two identical positions on two adjacent cells.
- Gross cell voltage: Full voltage, including all voltage drops in the cell current-carrying elements and line busbars, which is equal to “net voltage + voltage drop in busbar linkages”. This is equal to the potline voltage divided by the number of cells.
- Magnetic compensation loop voltage per cell. This is used for the calculation of energy consumption in the compensation loop, which has to be added to the energy consumption in the cell.

In this paper, we emphasized the importance of having a clear methodological approach to the presentation of voltage data; in particular, when publishing values of the specific energy consumption, it is necessary to indicate what voltage was included in calculations.

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