A Cell Simulator for optimizing the operation practices and the process control

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Abstract

The Hall-Heroult process can be described by a wide range of complex chemical and physical phenomena. Using MatLab-Simulink software, a mathematical model has been developed to solve the dynamic status of an aluminium reduction cell. Simulink provides a very powerful graphical user interface for building sub-models as block diagrams. The cell simulator determines various process interactions. The key operating parameters such as alumina concentration, bath temperature, ledge thickness, cell voltage and many others are computed as a function of time. Raw materials and process variations effects are predicted. The model can be used for improving operating strategies, can be implemented in the process control or can help at understanding the effect of various actions on the cell. Applications such as the variation of ledge thickness, specific energy, bath level, AlF_3 emissions are presented.

Keywords: Cell simulator; process control; process optimization; energy saving.

1. Introduction

Despite the fact that the Hall-Heroult process is based on a simple theory, there is a wide range of complex physical-chemical phenomena that must be taken into consideration when modeling the overall process. Many of these are dynamic, either periodic or transient and the dynamics of the process has important implications on process efficiency. Several dynamic cell simulators have been published with different objectives from increasing the understanding of the process to development and analysis of process control [1 – 6]. These simulators are using in-house programming. Contrary to this, the simulator described in this paper is based on MatLab-Simulink software, which is an open modelling system.

The objective of this work is to develop a mathematical model of a Hall-Heroult reduction cell as well as develop a better understanding of the reduction process itself. The effects of variations in operational parameters on the dynamical behavior of an aluminum reduction cell are predicted. Various couplings exist between the complex physiochemical phenomena. Compromises have to be made between simplicity and accuracy of the model. The most relevant aspects of the Hall-Heroult process are preserved. The cell simulator is structured in three main modules:

- Material balance model,
- Cell voltage model,
- Thermal balance model.

The three modules are then combined into one overall cell model which can be used for improving control strategies, cell operation as well as developing a predictive tool for the process itself. The model is not limited in the period of prediction. Operations such as anode change, tapping, alumina and aluminum fluoride feeding can be defined easily by the user. A period of 26 days can be simulated in less than 15 minutes. The simulation of one hour operation needs about 1 second computer time. The model can therefore be used online to help in process control strategies.

The cell simulator uses MatLab-Simulink software capabilities which integrate:

- Computation visualization programming of problems which are expressed in familiar mathematical notation,
- A graphical user interface (GUI) for building models as block diagrams, allowing you to draw models as you would with pencil and paper,
- A tool for simulating dynamics systems,
- Block diagram windows, in which models are created an edited by mouse driven command.
- Interactive graphical environment simplifying the modeling process, eliminating the need to formulate differential equations,
- Open modeling system to add new algorithms such as smoothing of cell resistance or anode effect detection.

2. Material balance module

The properties of the bath depend on the chemical composition of the electrolyte, so the dynamic change in the concentration of each chemical constituent involved is of great importance to the overall cell model. The mass conservation law for a system with a chemical reaction is:

Input + Generation = Output + Accumulation

2.1. Aluminum production rate

The aluminum electrolysis process is governed by Faraday's law of electrolysis and for aluminium can be expressed as:

$$\frac{dm_{Al}}{dt} = 9.321472 \cdot 10^{-8} I\eta \qquad (1)$$

m_{Al} Mass of aluminium produced at the electrode [kg]
I Current in the cell [A]
η Current efficiency [fraction]
t Time [s]

2.2 Carbon consumption rate

The aluminum (1) oxide is decomposed into aluminum and oxygen. The oxygen formed then reacts immediately with the carbon anode to carbon dioxide and carbon monoxide described by the two principle electrolysis equations:

$$2Al_2O_3 + 3C = 4Al + 3CO_2 \qquad (2)$$

$$Al_2O_3 + 3C = 2Al + 3CO \qquad (3)$$

Pearson and Waddington assumed that the loss in current efficiency is only due to the internal recombination of aluminum and carbon dioxide. By modifying the two principal equations with this assumption results in the modified electrolysis equation:

$$2\eta Al_2O_3 + 3C = 4\eta Al + 3(2\eta-1)\ CO_2 + 6(1-\eta)\ CO \qquad (4)$$

9. References

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