An Overview of Mathematical Modelling of Anode Baking Furnaces

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Abstract

Carbon anodes are used in electrolytic cells in which aluminum is produced. They are consumed and replaced after about 20-25 days. One of the critical stages of anode production is baking in large furnaces. This is where the pitch in green anodes is baked and anodes attain their final properties. A good anode quality is important for a stable operation of the electrolysis cells. It also has an impact on energy and carbon consumption, and subsequently on environment.

Trials on these furnaces are costly; thus, there are few studies in which experimental data on such furnaces are available. Mathematical modelling has become a useful tool to analyze these furnaces, giving insight into the baking process. A variety of models have been published for anode baking furnaces, ranging from an approach based on overall heat and mass balances to three-dimensional models representing the geometry in detail and accounting for multiple phenomena occurring in the furnace.

In this article, an overview of the phenomena occurring in baking furnaces and their representation in various models, depending on the level of complexity considered, is presented. A number of examples will be given.

Keywords: Anode baking furnace, Carbon anodes, Aluminum production, Mathematical modelling

1. Introduction

Carbon anodes are regularly consumed during the reduction of alumina by electrolysis in the Hall-Héroult process for the primary aluminum production. Their physical, electrical, chemical, mechanical, and thermal properties define their quality, which has a strong influence on cell stability, metal quality, energy and carbon consumptions, and environmental emissions. Anode quality depends on raw material properties and all the process parameters. The prebaked anodes go through a number of stages before their use in the electrolysis cells. Green anode production in the paste tower starts with the preparation of anode paste by mixing coal tar pitch (the binder) with the dry aggregate (calcined petroleum coke, recycled carbon materials: butts from the electrolysis and rejected baked and green anodes). Then, the paste is compacted in a press or a vibrocompactor to form green anodes. After cooling and storage, the anodes are baked in large furnaces. Baking fixes the anode properties. The last step is rodding. The anode assemblies are sent to the electrolytic cells for aluminum production. The costliest step of the anode manufacturing process is baking which is also the last determining step for the anode quality.

Two types of furnaces are generally used for baking anodes: horizontal and vertical. These furnaces consist of usually 34 to 70 sections arranged in two rows. Each fire cycle consists of up to 17 sections; thus, each furnace has a minimum of two fire cycles. The vertical furnaces (or closed-top furnaces) were more popular early on because of the better control of the furnace. The horizontal furnaces (or open-top furnaces) had low energy efficiency due to the lack of appropriate control. With the improvements in furnace control, the horizontal furnaces became the technology of choice for the past number of decades due to lower construction and operational costs. The focus of this article is the modelling of the horizontal type anode baking furnaces.

Each section of the furnace consists of pits and flues. Pits are used to pack the anodes in multiple rows and columns depending on the size of the anodes and the pit dimensions. The remaining space is filled with packing coke. Each pit has a channel for gas flow on each side, and these channels are called flues. The pits and the flues are separated by refractory walls. The gases pass through the flue, heating or cooling the pit contents depending on the sections. The packing coke has multiple purposes: it maintains the physical integrity of the anodes; they minimize the infiltration of air and are consumed by combustion in the hot sections, acting as sacrificial material protecting the anodes; the coke bed provides a medium for heat and mass transfer (the granular media allow the passage of volatiles that evolve from the anodes from the pit to the flue where they are burned). The furnaces act like counter-current heat exchangers. The anodes remain stationary; however, the ramps are moved around to regulate the flow of gases. Anodes are first preheated and then heated to final anode temperature which varies from plant to plant. This is followed by the cooling till the anodes reach low temperatures. The flue contains baffles and tie bricks to provide a flow field that will result in a heat flow distribution as uniform as possible for the baking of anodes.

Anodes are placed in the pits at room temperature and heated to around 1100-1200 °C at a given heating rate, and then they are cooled slowly. The entire cycle usually takes two to three weeks. Each cycle involves 13-17 sections, as shown in Figure 1. The ramps on the gas side are shifted after a 20-30-hour fire cycle. Figure 1 shows a typical cycle with 3 preheating, 3 heating, and 6 cooling sections. This may vary from one plant to another. Additional sections of the cycle are needed to remove baked anodes (the section after section 13), the preparation of anodes for baking (the section preceding section 1), and repairs.

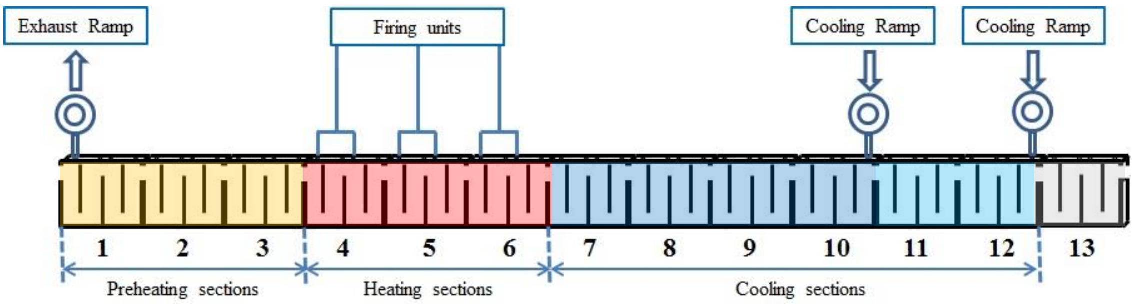

Figure 1. A typical fire cycle.

These furnaces are fed oil or natural gas as fuel in the heating sections. In the preheating section, volatiles evolve from the anodes due to the baking of pitch. The volatiles are made up of tar (the heavier components), methane, and hydrogen. The heat released due to the combustion of volatiles provides nearly half of the energy need of the furnace. The packing coke also burns partially in the high-temperature regions. This is undesirable, but it cannot be avoided. The heating necessary for the anodes, refractories, and the packing coke is provided by these sources. Detailed information can be found on the design and construction of these furnaces in [1].

Even though it is possible to do some experimental work in the plant, carrying out detailed measurements is quite costly due to the furnace geometry and size. To study various design options and the impact of the operational parameters on the furnace performance, mathematical modelling could be highly useful. It helps gain insight into the furnace behavior by providing the

6. References

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