Effects of Fire Cycle Time on Heat Transfer Characteristics and Energy Consumption in Anode Baking Furnace

Abdul Raouf Tajik[1], Rashid K. Abu Al-Rub[2], Mouna Zaidani[3], Zahid Ahmed Qureshi[4] and Tariq Shamim[5]
1. Ph.D. Student
2. Department Head and Associate Professor
3. Postdoctoral Researcher
4. MSc. Student
5. Professor
Institute Center for Energy (iEnergy), Department of Mechanical and Materials Engineering, Khalifa University of Science and Technology, Masdar Institute, Abu Dhabi, U.A.E.
Corresponding author: tshamim@masdar.ac.ae

Abstract

Anode Baking is an expensive and a very important step during carbon anode production. Numerical modeling is an imperative tool to investigate the effect of different parameters on anode baking process. In the present study, a high-fidelity and novel computational software ABKA (Anode Baking Kiln Analysis) has been developed which simulates heat transfer and flow distributions of the entire anode baking process. Fire cycle (*FC*) determines the production output of a kiln. Faster *FC* produces more anodes while slower *FC* slows down anode production. But both extremes have limitations. Using ABKA, effects of varying *FC* with different average flue-gas soaking temperature and flue-gas soaking time are studied. The results are expressed in terms of fuel consumption, and anode maximum, minimum and average temperature for each layer of anode-pack separately. Furthermore, the baking uniformity for each case is quantified. Considering multiple factors, desirable combinations of *FC*, soaking time, and soaking temperature can be identified. Finally, for varying *FC*, soaking time, and soaking temperature, it is observed that by increasing *FC*, baking homogeneity can be improved with a slight increase in fuel consumption; however, higher *FC* reduces the furnace production which should be taken into consideration at the same time.

Keywords: Anode-baking, fire cycle time, soaking temperature, soaking time, packing coke.

1. Introduction

In aluminium industry, for each ton of aluminium to be produced approximately 0.4 ton of carbon anodes are consumed in the reduction cell. Green (unbaked) anodes should be baked (heat treated) in advance to obtain particular mechanical, thermal and electrical properties that make them suitable to be used as anode in the aluminium production process. The anode baking process takes generally 390-480 hours, and several phenomena occur during the process. Effects of operational-geometrical parameters on the performance of the furnace by plant tests are usually expensive and disrupt the baking process. Therefore, numerical-mathematical modelling is an imperative tool to study the effect of different parameters on the anode quality and furnace performance. Ultimately the optimum baking process and furnace geometry can be proposed. Several studies on modelling the anode baking process are reported in the literature [1-14]. The main objectives of the developed computational model are to study the effect of material properties on the baking process, to investigate the effect of various parameters on anode temperature distribution, and to investigate the temperature evolution through the width of the pit.

2. Model Description

Anode baking furnace is a circular kiln with pits, analogous to a closed chain. As shown in Figure 1, a fire group usually consists of three preheating sections, three firing sections, six cooling sections, one unloading section, one or two sections for the loading of green anodes and one or two sections for the sake for maintenance. After each fire cycle time (typically 24-32 hours), the fire group equipment is displaced one section forward in the direction of the fire advance which is typically clockwise direction. A furnace comprises of two fire groups where the sections are arranged in two rows side by side, joined at the two ends by the crossover. The fire advance direction and the flow direction of combustion air and flue gases in the flue walls is the same. Simulating this intermittent movement of the fire group along with all the other simultaneous and transient phenomena involved in the baking process is very challenging and at the same time computationally very intensive since the initial and boundary conditions are continuously varying from one section to another. In a view to overcome this difficulty, all the sections from preheating, firing to cooling are treated as a whole and the baking furnace is assumed to be a semi-continuous counter flow heat exchanger between the stepwise movement of the solids in the pit and continuous flow of the gas in the flue. However, to avoid the virtual movement of the anodes, the solids are fictitiously subdivided into a number of finite slices along the length of the furnace. The velocity of the gas is varying and is determined by considering the local mass flow rate, temperature and pressure. The constant velocity of the solids is equal to a section length divided by the fire cycle time (about 5 m per day).

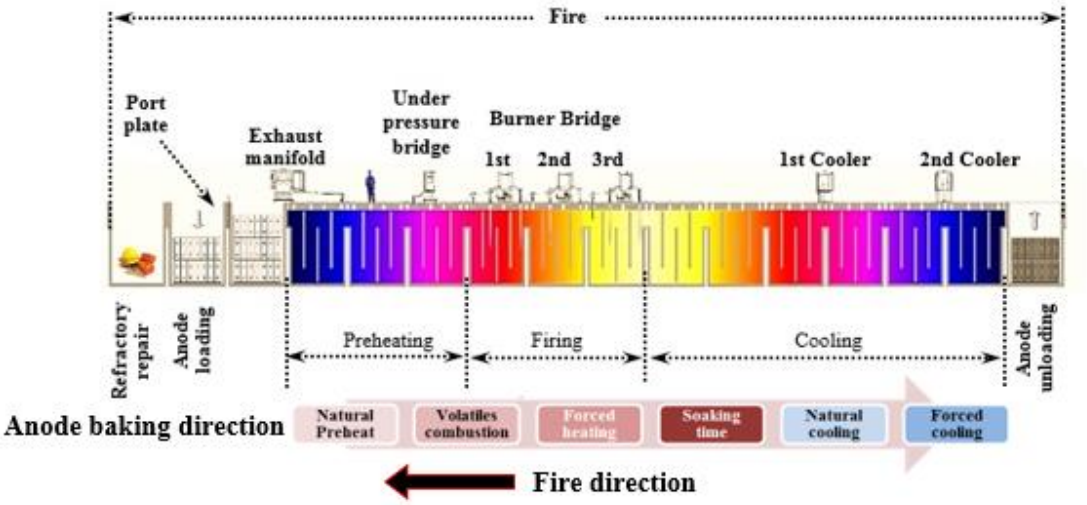

Figure 1. Longitudinal view of all the sections in a fire group [9].

2.1. Coupling of the flue and pit models

The transient nature of the anode baking process should be taken into consideration while developing the computational algorithms for the model. Assuming symmetry, only half of the flue and half of the pit can be considered for the computation. The time scale of the gas is much smaller than that of the solid materials (i.e. the solid components take more time to respond to changes in boundary conditions whereas gas responds to variations quickly). Combustion of fuel and volatiles in the flue along with gas flow combined with air in-leakage and ex-leakage can be modelled independent of time. However, the transient (time-dependent) heat conduction equation should be solved for the pit sub-model (i.e., heat transfer through the flue-wall, packing coke, and anode pack). Thus, the developed numerical model consists of two sub-models: flue and pit (flue-wall, packing coke, and anode pack). As shown in Figure 2, the pit

4. Conclusions

In the present study, a numerical model is developed for the anode baking process. Using this numerical model, effects of varying *FC*, with different flue-gas soaking temperature and soaking time are studied. The results are expressed in terms of fuel consumption, and anode maximum, minimum and average temperature for each layer of anode-pack separately. Furthermore, the baking uniformity for each case is investigated by calculating anode temperature standard deviation, and percentage of under-baked and over-baked areas. Considering multiple factors such as anode temperature, fuel consumption and baking homogeneity, desirable combinations of *FC*, $T_{g\text{-}soaking}$ and $t_{g\text{-}soaking}$ can be located on illustrated two-dimensional contour maps. Finally, for varying *FC* and $t_{g\text{-}soaking}$, and fixed $T_{g\text{-}soaking}$, it is observed that by an increase in *FC*, baking homogeneity can be improved with a slight increase in fuel consumption; however, it reduces the furnace production which should be taken into consideration at the same time.

5. Acknowledgements

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6. References

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