THE EFFECTS OF FLUE-WALL THERMAL CONDUCTIVITY ON ANODE BAKING HOMOGENEITY FOR ALUMINUM ELECTROLYSIS

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ABSTRACT
Despite all the flue-wall design modifications, carbon anodes in the flow downstream are experiencing a higher temperature gradient, which results in variability of the carbon anodes. This non-homogeneity in the properties of anodes leads to various difficulties in aluminum production cell resulting in overconsumption of carbon and energy. In the present study, it is proposed to design flue-walls of different thermal conductivity. In the flow downstream, the anodes experience overbaking. Thus, bricks of lower thermal conductivity are used. For flow upstream, bricks can have higher thermal conductivity. There is a heat loss issue at the top of the flue-wall. Hence, bricks of lower thermal conductivity can be used. A combination of LP50S (2.55 W/mK) and AK 46 S (1.5 W/mK) is used which are available in the market. The average anode temperature is slightly reduced, and it is observed that the hot spots at the flow downstream are also reduced which means enhanced baking uniformity. Furthermore, the bricks thermal conductivity at the flow downstream is further reduced (0.5-1.5 W/mK), and it is remarked that flue-wall of 0.5 W/mK results in an almost same uniform temperature in both flow upstream and downstream. The results provided in the current research can be used by the aluminum industry as a benchmark to consider building flue-walls of bricks with different thermal conductivity to enhance anode baking homogeneity.

Keywords: Anode baking furnace, flue-wall, baking homogeneity, aluminum production.

1. INTRODUCTION

Green (unbaked) anodes should be baked (heat-treated) to obtain desired mechanical, thermal, and electrical properties that make them suitable to be used as anodes in the aluminum production. In the overall anode manufacturing process, baking contributes to ~ 44 % of the total processing cost. Anode baking furnace process models represent all the phenomena taking place in the furnace by using simple energy balance. However, these simple process models may not be able to assist in design modification [1-3]. CFD modeling provides a better alternative [4-12]. In the present study, it is proposed to design flue-walls of different thermal conductivity. Fig 1 shows a 3D model of a flue-wall which is constructed of bricks with different thermal conductivity. In anode baking furnaces, heating by flame jets are preferred over the induction heating techniques because of their high convective heat transfer, faster heating response time, but it suffers high baking non-homogeneity [13-16].

In the flow downstream, the anodes experience overbaking. Thus, bricks of lower thermal conductivity can be used. For flow upstream, brick can have higher thermal conductivity. There is a heat loss issue at the top.

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of the flue-wall. Hence, bricks of lower thermal conductivity can be used. A combination of LP50S (2.55 W/mK) and AK 46 S (1.5 W/mK) can be used which are available in the market. Furthermore, the exploratory investigation is also conducted on constructing flue-walls of varying thermal conductivity of bricks on the top of the flue-wall in the range of 2-15 W/mk.

2. MODEL SPECIFICATIONS

A mesh sensitivity study is performed, and it is seen that after increasing the number of elements from 30,000 to 410,000 the difference in anode average temperature is found to be less than 1% for grid size above 150,000 elements. Hence, for the present study, the selected mesh is constituted of 179,669 grid elements. In practice, the generated grid is done at “fine” level (in terms of COMSOL internal grid definitions) such that the average element quality being on the order of 0.7. Finite element-based software COMSOL 5.1 Multi-physics model is used. To solve governing equations, segregated solvers are used to calculating the fluid flow (velocity and pressure) and heat transfer (temperature) variables. Generalized minimal residual (GMRES) iterative method solver is used to calculate the parameters with a tolerance of $10^{-6}$ and a factor in error estimate of 20. As a preconditioner, Geometric Multigrid solver is used with PARDISO (Parallel Sparse Direct Linear Solver) fine solver.

3. RESULTS AND DISCUSSIONS

The computational model has been validated versus experimental data based on comparing the anode temperature [4]. Fig 2 presents the temperature distribution at the anode interface for three different configurations: using only LP50S (high thermal conductivity bricks) for all the flue-wall structure, using only AK 46 S (Low thermal conductivity bricks) for all the flue-wall structure, using a combination of high and low thermal conductivity bricks for the left and the right side of the flue-wall structure.

The combined flue-wall structure is used to maintain the homogeneity baking on the right side of the anode using a high thermal conductivity bricks LP50S and avoid the high zone temperature near the second burner using the low thermal conductivity bricks AK 46S. Moreover, as shown in Fig 3, a high thermally conductive brick on the right side of the flue wall using LP 50S, and a parametric study is performed using a low thermally conductive bricks in the range of (0.5-1.55 w/mK) on the left side of the flue wall to ensure a homogeneous baking and to avoid the hot spot creation.

![Fig 3 Anode temperature at the midplane using a different thermal conductive tie brick on the left side of the flue-wall](image)

The hot spot area shrinks by the decrease of the brick wall thermal conductivity on the left side of the flue-wall. However, there is an increase in the under-baked area on the top of the anode for the low thermal conductivity values. Fig 4 displays the evolution of the anode volume average temperature and the anode temperature standard deviation as a function of the bricks thermal conductivity.

![Fig 4 Anode average temperature and standard deviation as a function of different thermal conductivity](image)

Based on this investigation, we can identify the range of the thermal conductivity between 0.7 and 0.9 as an optimum range for an optimized standard deviation and average anode temperature for a more homogeneous anode baking and better anode
temperature distribution. To investigate further the improvement of the flue-wall design, we considered a separate top part of the flue-wall. A three parts flue-wall design is developed, with different brick wall thermal conductivity to avoid the low zone temperature on the top, to maintain the homogeneity baking on the right side of the anode and to avoid the high zone temperature near the second burner (see Fig 5). For this configuration, we kept the constant thermal conductivity for the right side of the flue-wall (LP50 S), and the optimized thermal conductivity for the left side of the flue-wall, considered 0.9 W/mK based on the previous results, and we considered a second parametric study for the top part of the flue-wall by varying the brick wall thermal conductivity within the range of 2-15 W/mK in order to improve the baking of the colder area on the top of the anode.

Fig 5 Schematic representation of the improved flue-wall design

Fig 6 displays the average anode temperature and the anode temperature standard deviation for varying thermal conductivity on the top of the flue-wall. The anode average temperature increases by the increase of the top thermal conductivity and reach a maximum of 1149°C corresponding to the thermal conductivity of 4 W/mK.

From this value of 4 W/mK, the average anode temperature starts decreasing by the increase of the top brick wall thermal conductivity. On the contrary, the anode temperature standard deviation decreases with the increase of the top brick wall thermal conductivity and reaches a minimum of 84 correspondings to the thermal conductivity of 7.5 W/mK. Above this value, the standard deviation starts increasing by the increase of the thermal conductivity.

Fig 6 Effect of varying thermal conductivity of bricks on the top of the flue-wall (2-15 W/mK)

4. CONCLUSIONS

In the present study, a fully coupled 3D multi-physics computational model is developed which takes into account a large number of physical phenomena that play vital roles in the baking process and are affected by the flue-wall deformation mode. In the present study, it is proposed to design flue-walls of different thermal conductivity. In the flow downstream, the anodes experience overbaking. Thus, bricks of lower thermal conductivity are used. For flow upstream, brick can have higher thermal conductivity. There is a heat loss issue at the top of the flue-wall. Hence, bricks of lower thermal conductivity can be used. A combination of LP50S (2.55 W/mK) and AK 46 S (1.5 W/mK) is used which are available in the market. The average anode temperature is slightly reduced, and it is observed that the hot spots at the flow downstream are also reduced which means enhanced baking uniformity. Furthermore, the bricks thermal conductivity at the flow downstream is further reduced (0.5-1.5 W/mK), and it is remarked that flue-wall of 0.5 W/mK results in an almost same temperature
gradient in both flow upstream and downstream. The results provided in the current research should encourage the aluminum industry to consider building flue-walls of bricks with different thermal conductivity to enhance anode baking homogeneity and reducing energy consumption.

This study enables us to optimize the anode baking homogeneity by improving the flue-wall design using different thermal conductivity bricks to improve the baking of the critical zone of the anode and improve the baking homogeneity. Further analysis will be conducted in the future to improve the design of the flue-wall by varying the thickness of the flue-wall, the thickness of the packing coke to identify the best strategy to follow for improving the flue-wall design and achieve more homogeneous baking.

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REFERENCES


