International Conference on Applied Energy 2019
Aug 12-15, 2019, Västerås, Sweden
Paper ID: 857

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

Abdul Raouf Tajik[1,2], Mouna Zaidani[1], Tariq Shamim[3], Rashid K. Abu Al-Rub[1,2*]
[1]Mechanical Engineering Department, Khalifa University, P.O. Box 127788, Abu Dhabi, UAE
[2]Aerospace Engineering Department, Khalifa University, P.O. Box 127788, Abu Dhabi, UAE
[3]Mechanical Engineering Department, College of Engineering and Engineering Technology, Northern Illinois University, IL 60115, USA
*Corresponding author: rashid.abualrub@ku.ac.ae

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].

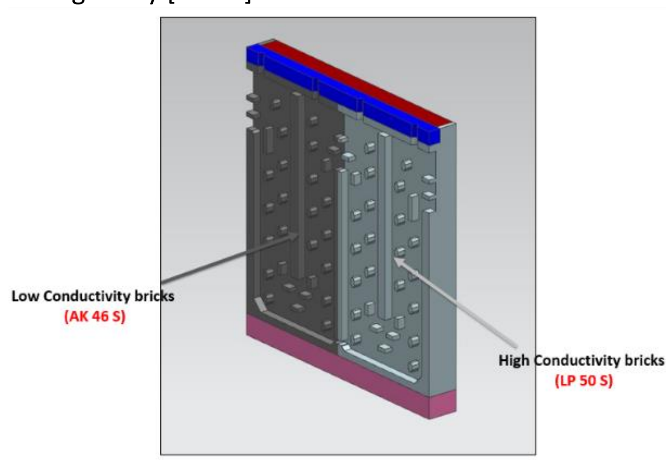

Fig 1 Flue-wall of bricks with different thermal conductivity (LP 50S and AK 46S)

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

Selection and peer-review under responsibility of the scientific committee of the 11th Int. Conf. on Applied Energy (ICAE2019).

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 gird 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.

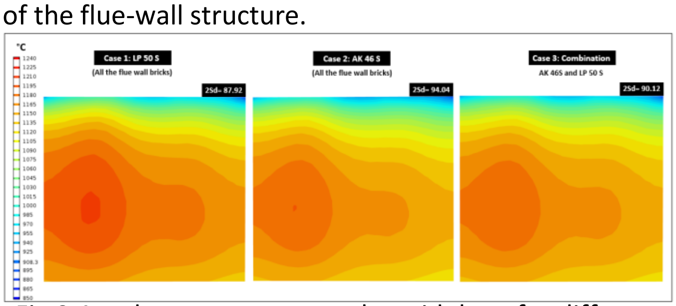

Fig 2 Anode temperature at the midplane for different thermally conductive tie bricks distribution

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.

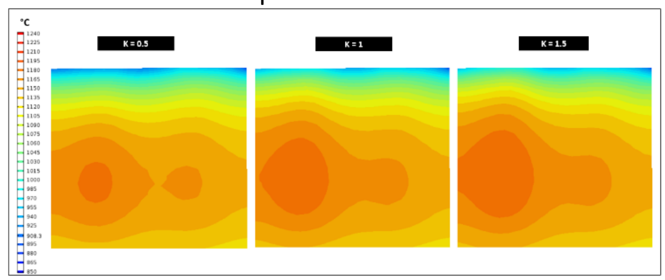

Fig 3 Anode temperature at the midplane using a different thermal conductive tie brick on the left side of the flue-wall

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.

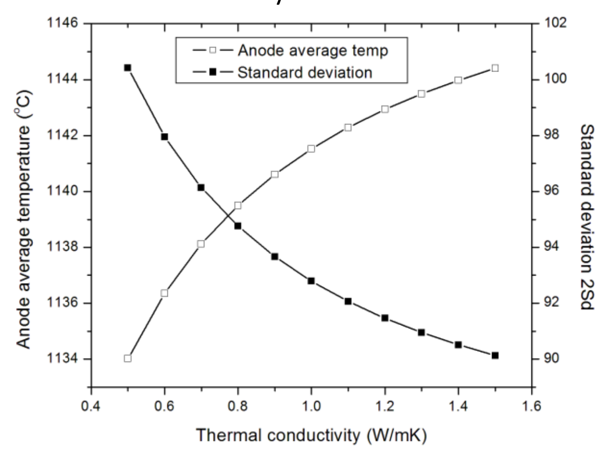

Fig 4 Anode average temperature and standard deviation as a function of different thermal conductivity

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.

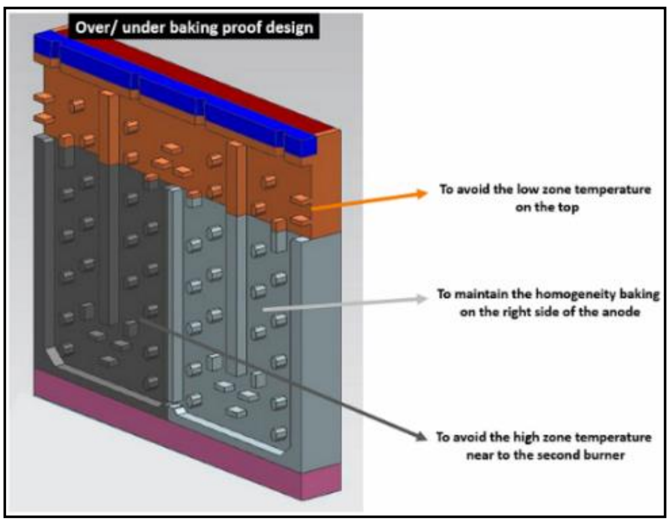

Fig 5 Schematic representation of the improved flue-wall design

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^{o}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.

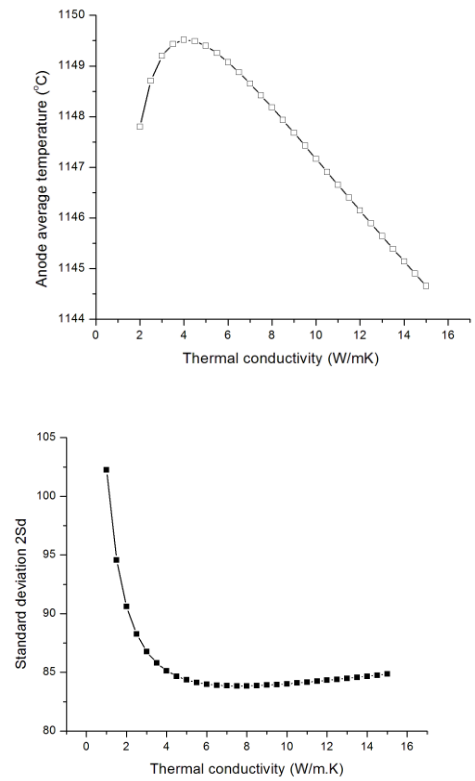

Fig 6 Effect of varying thermal conductivity of bricks on the top of the flue-wall (2-15 W/mK)

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.

ACKNOWLEDGMENTS

The authors acknowledge the financial support provided by the Emirates Global Aluminium (EGA) in UAE under the direction of Dr. Mohamed O. Mahmoud. Also, the authors acknowledge the support and help of the carbon anode team at EGA.

REFERENCES

[1] Tajik AR, Shamim T, Ghoniem AF, Abu Al-Rub RK. Multi-objective Optimization of Aluminum Anode Baking Process Employing a Response Surface Methodology. Energy Procedia. 2019 March 15; 158: 5541-5550.

[2] Tajik AR, Shamim T, Al-Rub RK, Zaidani M. Performance Analysis of a Horizontal Anode Baking Furnace for Aluminum Production. In ICTEA: International Conference on Thermal Engineering 2017 Mar 15 (Vol. 2017).

[3] Severo DS, Gusberti V, Pinto EC. Advanced 3D modeling for anode baking furnaces. Light metals. 2005; 2005:697-702.

[4] Zaidani M, Tajik AR, Qureshi ZA, Shamim T, Abu Al-Rub RK. Investigating the Flue-wall Deformation Effects on Performance Characteristics of an Open-Top Aluminum Anode Baking Furnace. Applied Energy. 2018 Dec 1; 231:1033-1049.

[5] Tajik AR, Shamim T, Zaidani M, Al-Rub RK. The effects of flue-wall design modifications on combustion and flow characteristics of an aluminum anode baking furnace-CFD modeling. Applied Energy. 2018 Nov 15; 230:207-19.

[6] Tajik AR, Shamim T, Ghoniem AF, Abu Al-Rub RK. Multi-objective Optimization of Aluminum Anode Baking Process Employing a Response Surface Methodology. Energy Procedia. 2019 March 15; 158: 5541-5550.

[7] Zaidani M, Abu Al-Rub RK, Tajik AR, Shamim T. Computational Modeling of the Effect of Flue-Wall Deformation on the Carbon Anode Quality for Aluminum Production. In. Proceedings of the ASME's Heat Transfer Summer Conference, Paper No. HT2017-5063, pp. V001T02A010; 11 pages, 2017.

[8] Tajik AR, Shamim T, Zaidani M, Al-Rub RK. The Effects of Flue-Wall Design Modifications on Combustion and Flow Characteristics of an Aluminum Anode Baking Furnace-CFD Modeling. Applied Energy. 2018 Nov 15; 230:207-219.

[9] Tajik AR, Shamim T, Al-Rub RK, Zaidani M. Two-Dimensional CFD Simulations of a Flue-wall in the Anode Baking Furnace for Aluminum Production. Energy Procedia. 2017 May 31; 105:5134-9.

[10] Tajik AR, Al-Rub RK, Zaidani M, Shamim T. Numerical Investigation of Turbulent Diffusion Flame in the Aluminum Anode Baking Furnace Employing Presumed PDF. Energy Procedia. 2017 Dec 31; 142:4157-62.

[11] Zaidani M, Al-Rub RA, Tajik AR, Shamim T. 3D Multiphysics model of the effect of flue-wall deformation on the anode baking homogeneity in horizontal flue carbon furnace. Energy Procedia. 2017 Dec 31; 142:3982-9.

[12] Tajik AR, Shamim T, Ghoniem AF, Abu Al-Rub RK. CFD Modelling of NOx and Soot Formation in Aluminum Anode Baking Furnace. In. ASME's International Mechanical Engineering Congress and Exposition (IMECE), 2018. Paper No. IMECE2018-88390, pp. V08AT10A016; 8 pages.

[13] Hindasageri V, Kuntikana P, Tajik AR, Vedula RP, Prabhu SV. Axis switching in impinging premixed methane-air flame jets. Applied Thermal Engineering. 2016; 107:144-53.

[14] Tajik AR, Kuntikana P, Prabhu SV, Hindasageri V. Effect of the preheated mixture on heat transfer characteristics of impinging methane-air premixed flame jet. International Journal of Heat and Mass Transfer. 2015; 86:550-62.

[15] Kadam AR, Tajik AR, Hindasageri V. Heat transfer distribution of impinging flame and air jets–a comparative study. Applied Thermal Engineering. 2016; 92:42-9.

[16] Tajik AR, Hindasageri V. A numerical investigation on heat transfer and emissions characteristics of impinging radial jet reattachment combustion (RJRC) flame. Applied Thermal Engineering. 2015; 89:534-44.