The Influence of Flue Wall Deformation on Anode Baking Homogeneity for the Aluminum Production

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Abstract

In horizontal flue wall carbon baking furnaces, the flue walls consist of brick wall which are usually linked together by mortar. During service, the thermal expansion of flue walls is restrained due the presence of headwalls. This, as well as the effect of the load of the packing cokes and the anodes, promotes the deflection of the flue walls thus limits their life. The development of a 3D computational model able to take into account a large number of phenomena and parameters that play a role in the baking process and affect the flue wall aging process is then justified. In this study, we developed a 3D model that take into account the thermo-hydro-mechanical coupling due to coupled fluid flow, heat transfer and flue wall deformation. The coupled thermo-hydro-mechanical simulations were done by the finite element multi-physics commercial software COMSOL, where only a coupled flow thermal problem is solved. The mechanical problem is coupled indirectly by considering a deflected deformed flue walls. Such a 3D multi-physics modelling can be used as a powerful tool in predicting the effect of flue wall deformation on anode temperature distribution and homogeneity and thus predicting the anode baking quality. The tool may also be used to gain insights on temperature distribution adjustment as a function of the flue wall and furnace design. The main objective of this kind of investigation is to establish a flue wall deformation modes database and link it to the anode baking quality, by developing this tool, we can effectively predict the deformed flue wall reliability under varying operating conditions, and provide useful insights on enhancing the long-term structural integrity through furnace design adjustment.

Keywords: Baking process, aging, deflection, flue wall, thermo-hydro-mechanical coupling.

1. Introduction

The quality of anode used in the aluminum industry depends strongly on the baking process. In general, it is desirable to achieve a more uniform temperature inside the anode during the heating process. The flue walls in carbon bake furnaces deform over time under cyclic heating and cooling, leading to difficulties in loading/unloading anodes, and inconsistent anode baking. It is useful to regularly measure the deformations to establish the rate of deterioration and assist in the prediction of flue wall life. The aging of baking furnace, and the deformation of flue-walls and head-walls lead to non-homogeneous baking of anodes and consequently to a deterioration of the resulting anode quality [1][2][3].

Due to huge size of baking furnace and its very large time constant (in the order of months), it is not always possible to conduct physical experiments in order to determine the influence of the flue wall deformation on furnace's behavior and efficiency. The increasing interest in this topic has heightened the need for a mathematical model as a tool for predicting the influence of flue wall aging on the anode baking homogeneity. However, only a few recent investigation studies have focused on the flue wall deformation modes and their effects on the baked anode quality [4][5] .Most of the research work in this area has been focused on the process modeling considering a straight flue wall without considering the effect of flue wall deformation.

The life of carbon baking furnaces is usually limited by the deflection of its flue walls. This deflection as shown in Fig.1 is promoted principally by the action of headwalls which restrain the free thermal expansion of flue walls, and by the action of packing coke whose weight is partially supported by flue walls [6]. In a horizontal baking furnace, flue walls consist of firebricks linked together by mortar in horizontal joints. During service, the thermal expansion of flue walls is restrained due the presence of headwalls as well as the effect of the load of packing cokes and anodes that promote the deflection of the flue walls; thus, limits their service life [7][8][9].

The focus of this paper is on the development of a numerical tool that can effectively predict the furnace performance considering its deformation. Such a deformation leads to anode baking inhomogeneity, anode overbaking, hot spot formation and creates difficulties in loading and unloading of anodes in the pits. In this study, a multi-physics 3D model is developed. This model is applied to one heating section of the baking furnace in order to explore the effect of flue wall deformation on the baking quality and temperature homogeneity of the anodes. The developed computational tool can be used to explore the different flue wall deformation patterns, and their effects on the anode baking homogeneity. The tool may also be used to gain insights on temperature distribution adjustment as a function of the flue wall and furnace design.

(a) (b)

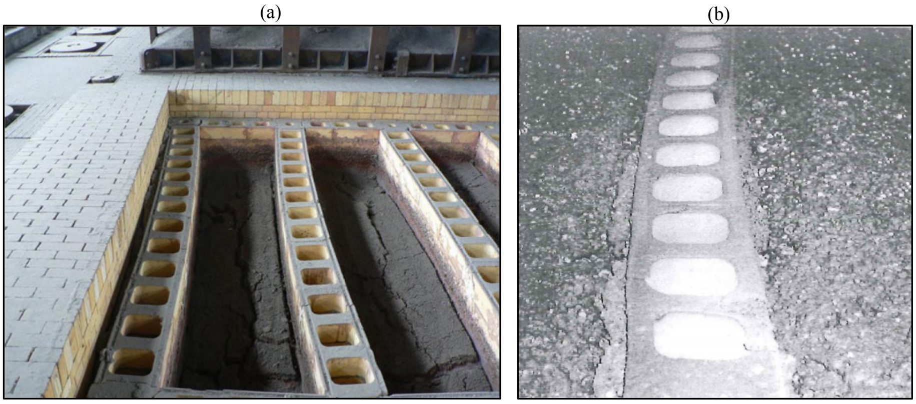

Figure 1. General view of (a) the flue wall deflection [11] and (b) Heavily slagged flue wall covered with metallurgical coke [10].

2. Model and computational method

2.1. Geometry model

A three-dimensional model was built comprising a typical baking furnace firing section between the centerline of a flue and the centerline of a pit. In the pit, 14 anodes of 1600 x 600 x 800 mm size are placed. There are 2 domains, a solid domain composed of flue wall, packing coke and anodes, and a fluid domain for the gas flow. The thickness of the solid domain material layers, flue wall, packing coke and anodes in the direction of the pit length is 100 mm, 100 mm and 300 mm, respectively. Symmetry was assumed on the centerline of the

4. Conclusions

Flue-wall's aging is usually accompanied by its deformation. Such deformations create difficulties in loading and unloading anodes in the pits and to inhomogeneous anode baking. In this work, we developed a tool that can predict the anode temperature distribution, creation of hot spot and anode overbaking in certain area as a function of the flue wall deformation mode. Considering the anode temperature distribution for a straight flue wall as a reference case, the deflection of the flue wall C shape convex affect the anode baking temperature distribution and homogeneity and leads to an under-baking or an overbaking of the anode in certain area. Sometimes, the flue wall deflection leads to a redistribution of the anode temperature based on the original anode temperature distribution for a straight flue wall and on the degree and the shape of the flue wall deflection. Therefore, the expected anode temperature distribution and homogeneity for a deflected flue wall depends on the temperature distribution for a straight flue wall before deflection.

In the future, other flue wall deformation modes will be studied, the main purpose is to explore all the realistic flue wall deformation patterns, and how it affects the anode baking homogeneity, in order to establish a flue wall deformation modes database linked to the consequence on the anode baking quality.

Acknowledgements

This research paper is made possible through the help and support from the Emirates Global Aluminium (EGA). We are also very thankful for the carbon anode area representatives at EGA for providing the needed support.

References

1. F. Grégoire, L. Gosselin, H. Alamdari, Combustion in anode baking furnaces: Comparison of two modeling approaches to predict variability, *The Combustion Institute - Canadian Section, Spring Technical Meeting, At Québec City*, Québec, Canada 2013 338-343.
2. D.S. Severo, V. Gusberti, E.C. Pinto, Advanced 3D modelling for anode baking furnaces, *The minerals, Metals and Materials society (Light metals)* (2005) 697-702.
3. F. Goede, Refurbishment and modernization of existing anode baking furnaces, *Light metals, The minerals, Metals and Materials society* (2007) 973-976.
4. M. Baiteche, D. Kocaefe, Y. Kocaefe, D. Marceau, B. Morais, J. Lafrance, Description and Applications of a 3D Mathematical Model for Horizontal Anode Baking Furnaces, *Light Metals 2015, John Wiley & Sons, Inc.*2015, pp. 1115-1120.
5. Y. Kocaefe, M. Baiteche, N. Oumarou, D. Kocaefe, D. Marceau, B. Morais, Different mathematical modelling approaches to predict the horizontal anode baking furnace performance.
6. F.P. Incropera, D.P.D. Witt, Fundamentals of Heat and Mass Transfer, *4th Edition, Chapter 9*, 1996.
7. C. Allaire, Effect of the type of brick and mortar on the resistance to deflection of the flue walls in horizontal flue carbon furnaces, *Light Metals* (1994) 551-564.
8. P. Quirmbach, Rheinisch-Westfaelische Technische Hochschule, RWTH Aachen, (30 August 1994).
9. F. Brunk, Corrosion and behaviour of fireclay bricks used in the flues of open anode baking furnaces, *The Minerals, Metals & Materials Society, Light Metals* (1995) 641-646.

10. H. Lenz, F. Brunk, Improved anode baking furnace cover material, *Light Metals* (2002) 629-632.
11. A. Yurkov, Refractories for Aluminium, Switzerland, (2015) 245-249.
12. P. Zhou, C. Mei, J.-m. Zhou, N.-j. Zhou, Q.-h. Xu, Simulation of the influence of the baffle on flowing field in the anode baking ring furnace, *Journal of Central South University of Technology* 9(3) (2002) 208-211.
13. T.W. Quan, Numerical Heat Transfer, Xi'an Jiaotong University Press: Xi'an1988, p. 220−231.
14. F. Jian-ren, Q. Ke-fa, Theory and Calculation of Gas-solid Multi-phase Flow in Engineering [M]. *Hangzhou: Zhejiang University Press* (in Chinese) (1989).
15. D.S. Severo, V. Gusberti, User-friendly software for simulation of anode baking furnaces. , *Proceeding of the 10th Australasian Aluminum Smelting Technology Conference*, 2011.