

3D Transient Modelling of a Complete Fire Line for Anode Baking Furnace Design and Optimization

Arnaud Bourgier¹, Sandra Besson² and Jean-Philippe Schneider³

1. Baking furnace product manager

2. Process engineer

3. Carbon Domain Director

Rio Tinto Aluminium, Voreppe, France

Corresponding author: arnaud.bourgier@riotinto.com

Abstract

Computational Fluid Dynamics models have been a precious tool to support the evolution of the Anode Baking Furnace (ABF) designs over the last 20 years. Those models were mainly focusing on the air flow repartition within one fluewall in order to guarantee a good anode baking homogeneity and an efficient combustion. The combustion of the volatile matters and the fuel were usually not taken into account. A new 3D transient model was developed for a complete fire line (preheating/heating/cooling). This model combines the air flow characteristics (distribution, air ingresses/exfiltrations) with the combustion of gas and volatile matters and the heat transfers through the materials. The model results have been compared with measurement done on different furnaces with excellent outcome. It is a powerful tool to better understand the impact of different parameters, and therefore improve furnace design and performance and anode quality. For instance, it is used for modification of existing ABFs to support pot amperage creepings: implementation of higher fluewalls for longer anodes, narrower fluewalls for higher anodes, and shorter time cycle for higher production. In this article, the model will be described and some applications will be discussed.

Keywords: Anode baking furnace, combustion, heat transfer, anode temperature homogeneity.

1. Introduction

The Anode Baking Furnace (ABF) dimensions for new projects tend to increase with the increase in anode dimensions and smelters productivity. In parallel, many furnaces have evolved in the last years in the frame of smelter creeping projects, with the same objective to increase furnace productivity: shorter time cycles, increase of anode height with narrower fluewalls, increase of anode length with furnace raising, change of loading configuration, etc.

The process, design and geometrical changes that are needed to answer to those evolutions have a direct impact on anode quality and furnace performance, which are complex to anticipate.

Unanticipated changes in pitch combustion efficiency or anode final temperature for example can have a deleterious impact on the anodes behavior in the potline (anode reactivity, anode dusting) as well as on the furnace performance (higher gas consumption, incomplete combustion, soot deposits).

Due to the relatively long and complex process of baking the anodes, the trials on ABF to evaluate the impact of those changes are usually time consuming and costly. It is also not always possible to easily test a change in furnace dimensions or design.

Therefore the computational models are valuable tools to support design and process optimization. With the evolution of modeling technologies and computational resources, the models are allowed to become more and more complex to better reflect the process [1 to 4].

Those models have become an essential tool to support production increase in the frame of creeping projects, or to develop the furnace design for a more robust process. They allow the anticipation of process changes in order to decrease project risks and are a reliable tool to compare different technical solutions.

2. Model description

2.1. General presentation

The model is a 3D-transient model describing a full line of fire, from the preheating to the cooling.

The calculations are done on a half - fluewall and a half - pit due to the symmetries of a fire line. The Figure 1 shows a general view of a fire with the cooling sections in the foreground and the preheating sections in the background: the demarcated red area represents the extraction of the geometry done in the model. The fire line includes all the sections from preheating to blowing. Depending on the desired outcome of the model, the fire line might also include the cooling sections (red dotted area in Figure 1).

If the furnace uses a 4th heating ramp during a portion of the cycle, each cycle can be split in two to represent the baking extension and the time when only three ramps are running.

The model combines different phenomena occurring during the baking of anodes, such as:

- Releasing and combustion of anode volatile matters in the preheating zone,
- Combustion of the natural gas in the heating zone,
- Air flow through the fire,
- Heat losses,
- Air infiltration and exfiltration,
- Air flow repartition through each fluewall.

The calculations are done with Ansys[®] softwares, and more precisely with Fluent[®] for the calculation of flow repartition and heat transfers.



Figure 1. General view of an open Anode Baking Furnace and representation of the fire geometry used in the model.

2.2. Model inputs

The inputs of the model are the following:

- Fluewall, packing coke and anodes geometry (including the position of the tie bricks and baffles, but excluding the isolation bricks),
- Air and fumes flow through the fire line,
- Gas flow through each injector in the heating sections,
- Quantity of pitch available in the anodes for the combustion of volatile matters,
- Material properties for bricks, anode, packing coke and top blocs.

Phenomena taken into account

Air flow

The air flow throughout the fire line is calculated for each section based on the hydraulic resistance of the fluewalls and the under pressure in preheating sections. The blowing flow is adjusted to place the zero point (point of equilibrium between the fluewall pressure and the furnace atmosphere pressure) close to the last heating ramp in use.

The air flow is constant for each section during the cycle, except for the first section in preheating where the flow is increased by 10 % when the Alternative Preheating Regulation [5] is used at the end of the cycle.

The Figure 2 gives an example of airflow for a furnace with baffle design using 4 heating ramps.

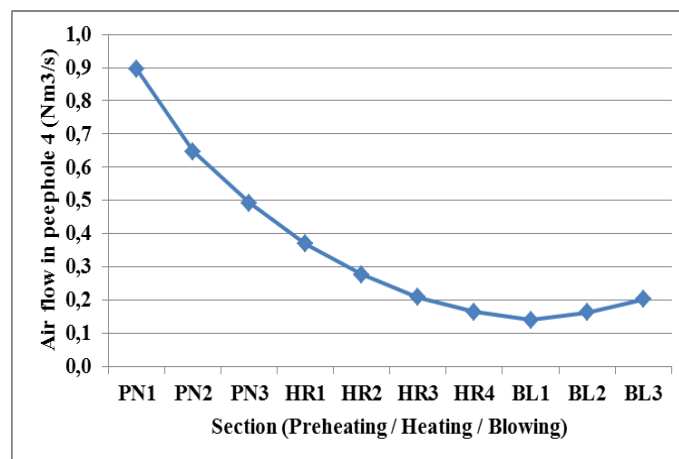


Figure 2. Air flow through the fire line for a furnace using 4 heating ramps and a pit load of 19,5 t (baffle design).

The air flow repartition within one fluewall is calculated in Fluent with a K-epsilon turbulence model. The Figure 3 represents an example of the fumes velocities for a baffle design.

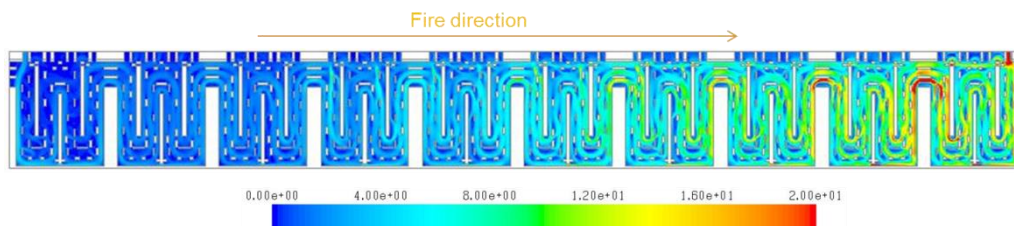


Figure 3. Fumes velocities (m/s) on the mirror plane of the fluewall for a baffle design with a 4th heating ramp running

Air leaks

The furnace surface is not completely tight, especially when the furnace is aging: some air can flow through the top blocs, the peephole covers or the porous packing coke. The infiltration and exfiltration of air is modelled through a fictive slot on top of the fluewalls, placed close to the peephole covers. The calculated leak flow is consequently proportional to the pressure in each section (the leak flow is positive (i.e. infiltration) when close to the exhaust ramp where the pressure is negative and negative (i.e. exfiltration) when close to the blowing ramp). The surface of the slot has been calibrated using measurements done on an existing furnace. The Figure 4 gives an example of air leaks flow along the fire.

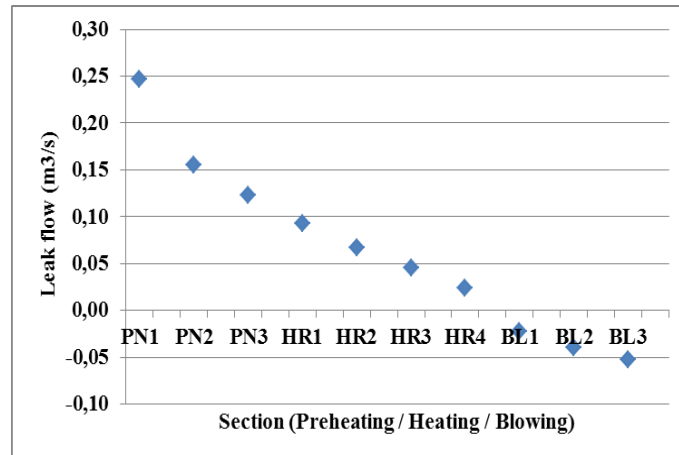


Figure 4. Leaks flows in each section of the fire line for one furnace using 4 heating ramps (baffle design / PN for preheating, HR for heating ramp, BL for Blowing).

Degassing and combustion of volatile matters in the preheating zones

The anodes release volatile matters in the second and third sections of preheating. If the furnace is run properly, those gases will be dragged into the fluewall by the negative pressure and burn in contact with the oxygen contained in the fumes. Those volatile matters provide a considerable amount of energy to the system.

The volatile matters are made of different gases and are difficult to model. An equivalent quantity of CH_4 is calculated based on the amount of energy stored in the anodes in the form of volatile matters. The pack of anodes is then divided in 9 areas: for each area, the energy is evenly released through the fluewall furnace with a flow depending on the temperature (from internal lab measurements).

Gas injection in the heating sections

The burner gas injections are continuous in the model, whereas gas is generally injected in the form of pulses in reality. This choice has been made because the time step necessary to model the pulses was too short, involving too long calculation times.

The velocity of the gas is adjusted depending on gas pressure and injector design. This approach has been validated with a smaller model that represents the diffusion of the pulse flame in one fluewall during few minutes: the length of the flame is similar in both models.

The combustion of gases is modelled with a Non-Premixed Combustion model for a diffusion flame.

Heat losses

The heat losses taken into account concern the surface of the furnace (top of the fluewalls and the pit) and the bottom of the furnace (through the bottom insulation). For each case, the thermal losses are calculated using an exchange coefficient and a reference temperature that are adjusted to fit with real measurements.

2.3. Temperature initialization and convergence

The initialization of temperature is done either based on floor measurements or on the data from the firing system. The initial temperature of the fumes has little impact on the first iteration temperatures, while the temperature of the solid has a bigger impact: the more accurate the temperature for initialization is the fewer cycles will be needed for the convergence of the model.

The calculation is done iteratively: at the end of the first cycle, the field of solid temperatures of section N is projected on section N+1 and so on (see Figure 5).

This operation is reiterated until the convergence of the model is reached. The convergence is judged sufficient when the three following criteria are stabilized:

- Average temperature of the anodes volume at the end of baking,
- Average temperature of the anodes-packing coke interface at the end of baking,
- Standard deviation of the temperatures in the anodes volume at the end of baking.

The convergence usually occurs after 8 to 10 cycles of calculation.

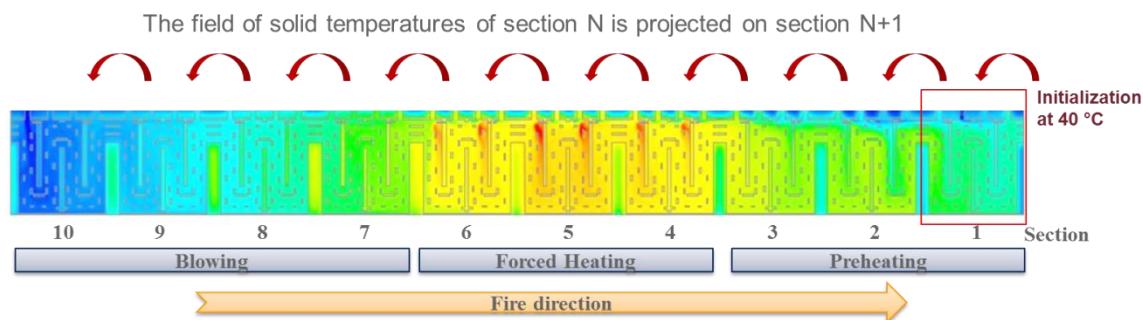


Figure 5. Principle of the model

2.4. The output of the model

The model evaluates the temperature at any point of the solids and the fluids, at any time of the cycle.

Usually the analysis of the results focuses on the temperature at the end of baking or during the degassing. More specifically, the anode temperature heterogeneity at the end of baking can be evaluated with a histogram of temperatures for the whole volume of the anodes.

Figure 6 gives an example of temperature histograms given for two different fluewall designs on the same furnace. It can be observed in that case and for a similar gas consumption that Design #2 exhibits a higher dispersion than Design #1 with a specific low baked zone between $T+150^{\circ}\text{C}$ and $T+200^{\circ}\text{C}$. This kind of information is obviously very useful when optimizing fluewall design and associated process parameters.

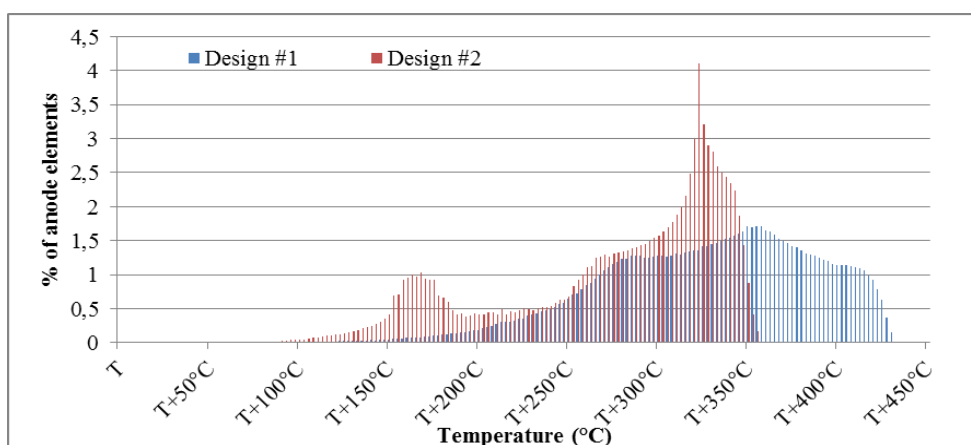


Figure 6. Histogram of temperatures in the volume of the anodes for two different designs on the same furnace (at the end of baking)

The degassing is studied with the model to evaluate the progression of the degassing front and the temperature in the preheating sections. The repartition of O_2 and CO_2 within the fluewalls is also used as an indicator to evaluating the combustion quality.

Depending on the cases, some finer post-treatments can be used such as the residency time of the fumes (see Figure 7) or the heat flux exchanged at the fumes/refractory interface, both good indicators of the quality of the heat transfer.

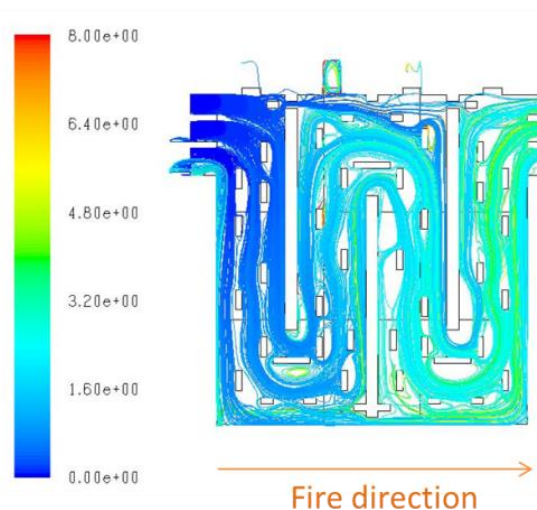


Figure 7. Streamlines of the fumes and residency time in the heating zone (in s)

3. Calibration and validation of the model

The model has been calibrated on two furnaces with two different designs to validate its accuracy. The validation has been made based on thermocouple measurements done at the interface between packing coke and anode or based on Lc-baking level measurements.

The average temperature at the interface between packing coke and anode gave an excellent correlation between the model and the measurements and the baking level measurements give a similar pattern as the one given by the model. The Figure 8 shows an example of correlation for the pattern of temperature given by the model at the end of baking and a pit baking level mapping done on core samples.

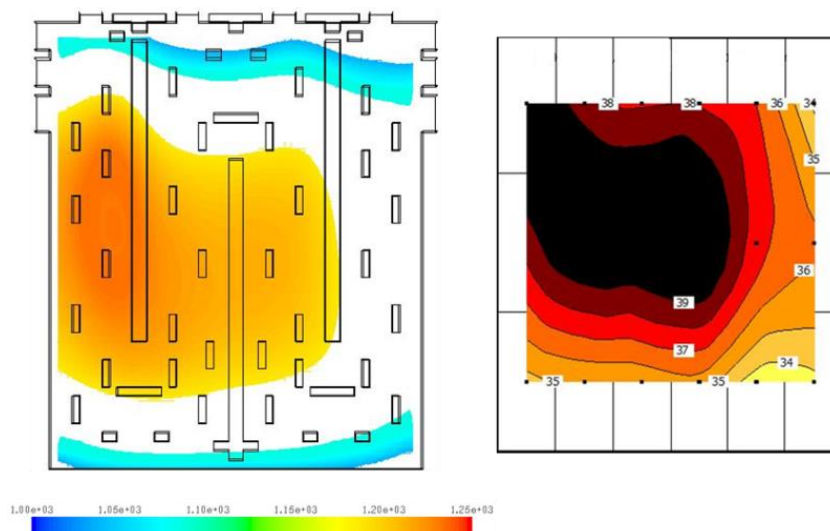


Figure 8. Validation of the model with the temperatures measured at the packing coke/anode interface at the end of baking (left, °C) and the baking level Lc-mapping (right, Å)

4. Conclusion and perspectives

The model has been developed and has shown excellent correlation with the data measured on two existing furnaces. With these promising results, the model is now used to support several projects both internally and for external customers:

- Comparison of fluewall designs (for example design with or without baffles in the context of fluewall width reduction),
- Study of the impact of fluewall height increase on the baking homogeneity,
- Optimization of existing designs for a better baking homogeneity,
- Study of the impact of different operating parameters (gas pressure, injection depth, time cycle),
- Optimization of the cooling efficiency (cooling configuration, cooling ramp power)

In parallel, the model is further developed to maximise the potential of this tool. The on-going and future developments include:

- Control of the quantity of injected gas with a PID adjustment loop based on a curve of temperature set points measured in peephole 4 of each heating section (instead of being an input value),
- Control of the air flow with a PID adjustment loop based on a curve of temperature set points,
- Further development of the model with pulses to better understand the impact of burner design and parameters on flame length, NO_x formation, combustion efficiency,
- Thermomechanical stresses and constraints for the refractory depending on the operating conditions and furnace design,
- Correlation between temperature profile and baking level in Lc to have a direct view on the baking level homogeneity depending on the profile of temperature that each point has seen.

This model is a leading-edge tool that allows for the optimization of ABF's design and performance, whether new or already in-use.

5. References

1. L Zhang, C Zheng & M Xu, Simulating the heat transfer process of horizontal anode baking furnace, *Dev. Chem. Eng. and Mineral Processing*, 2005, 13 (3/4), pp. 447-458
2. D S Severo et al., User-friendly software for simulation of Anode Baking Furnace, *10th Australasian*, 2005, 697-702.
3. N. Oumarou et al., A dynamic process model for predicting the performance of horizontal anode baking furnaces, *Light Metals*, 2015, pp. 1081-1086.
4. A. R. Tajik et al., Performance Analysis of a Horizontal Anode Baking Furnace for Aluminum Production, 10th Internantional Conference on Thermal Engineering, 2017,
5. F. Morales, A. De La Torre, Control process for an anode baking furnace and adapted furnace using such process, *US Patent application US20120097154 A1*, 2012.

