Light Metals 2007 *Edited by Morten Sorlie*
TMS (The Minerals, Metals & Materials Society), 2007

PROCESS OPTIMIZATION IN BAKE FURNACE

Vinicius Piffer[1], Paulo Miotto[1], Ciro Kato[1], Markus Meier[2], Raymond Perruchoud[2] and Peter Sulger[2]

[1] Consorcio de Aluminio do Maranhao (Alumar), Department of Carbon and Technology
BR 135, Km 18, São Luis, Brazil, Zip code 65065-604

[2] R&D Carbon Ltd., P.O. Box 362, 3960 Sierre, Switzerland

Keywords: Baking capacity, anode quality, optimization, temperature distribution

Abstract

Consorcio de Aluminio do Maranhao (ALUMAR) is one of the largest aluminium smelters of Latin America producing 440'000 tons of primary metal. The plan to increase the line current to 228 kA in all pots and to increase the anode cycle time from 26 to 28 days required a fundamental optimization of the baking process.

R&D Carbon was chosen as a technical partner to optimize the furnace operation with the goal to increase the production capacity and to further improve the baked anode quality to the required level.

This paper describes the measures taken, namely the changeover from three to four fires and the systematic optimization of the baking parameters. The positive effect of these measures is demonstrated with improved production and quality figures.

Introduction

In January 2003 when ALUMAR operated at 216 kA, slotted anodes were introduced to improve the pot performance. Although the results in the potroom were favourable, the slotted anodes caused the carbon consumption in the pots to increase. This extra consumption is attributed to the extra surface area of the anode exposed to CO_2 attack, which increases the carbon consumption through carboxy reactions [1]. In addition, the anode weight was reduced by approximately 20 kg due to the slots.

ALUMAR pot room has continuously increased the aluminium production through a load up optimization strategy. One of the main focuses of this strategy is the use of higher amperage, which means higher anode consumption.

The combination described above has led to very thin butts which started to create operational problems in the potroom. The anode cycle time was then reduced from 28 to 26 days.

ALUMAR has three open top ring type anode bake furnaces, one of them being shut down at the time. Furnace 1 consists of 76 and furnace 2 of 68 sections, both with 8 pits to sized for 2 layers of 5 anodes [2]. On both furnaces 3 fires have been in operation. Figure 1 shows the typical configuration of the firing equipment prior to the optimization work.

The reduction of the anode cycle time in the pots caused an immediate increase in anode demand. In order to produce sufficient anodes for the new demand, the bake furnace had to reduce the fire cycle from 22 to 19.5 h. The new fire cycle was very short and caused operational problems in terms of process control, emissions and quality distribution of the anodes. To minimize the deterioration of the properties, ALUMAR has adjusted the final baking temperature from 1225 to 1250°C and increased the soaking time from 90 to 96 h.

The extremely fast fire cycle in the furnaces generated opacity problems in the pre-heating zone. In order to minimize these effects, the firing configuration was changed from 3 to 2 preheating sections. This measure deteriorated the anode properties even more, as the anode heat-up rate became excessive.

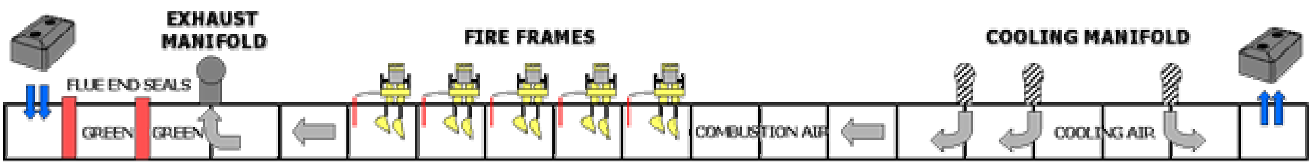

Figure 1. Original fire configuration prior to optimization with 2 pre-heating sections

The new fast fire cycle led to several undesired side effects:

- High heat-up rate: The uncontrolled release of volatiles increased the rate of cracked anodes
- Environmental emissions: The difficulty to control the volatiles release led to high opacity levels in the off-gas during extended periods
- Short total heating time: The heat could not reach the anodes in the corners of the pits. Cold spots were generated and the maximum temperature difference T increased.
- Reduced refractory life: The condition of the refractory bricks was expected to deteriorate due to the higher final baking temperature and longer soaking time at elevated temperature
- Deterioration of anode quality: The measurement of the anode properties influenced by the baking process revealed a substantial drop of the average and an increase of the variation.

In the first half of 2005, the anode quality became the bottleneck for a further increase of the line current in the potroom. It was recognized that a process optimization in the bake furnace was needed to overcome the numerous problems. R&D Carbon was chosen as a technical partner to support ALUMAR to reach the ambitious goals of increased line current and to increase the anode cycle time in the pots back to 28 days.

Changes Required to Achieve Targets

The increase of the line current and increase of the anode cycle time in the pots are two contradicting developments, as normally the cycle time would be lowered to compensate the greater anode consumption. In order to nevertheless achieve the ambitious targets, combined measures were required in different areas of the anode production:

- **Increase of the baked anode weight:**
  As the anode length and width could not be changed, an increase of the anode height and density are the only two measures to raise the anode weight. The maximum anode height can be increased by minimizing the variation of the anode height. The anode density can be improved with a process optimization in the paste plant [3] and in the bake furnace.
- **Reduction of the net anode consumption:**
  The minimum acceptable butts weight at ALUMAR is 240 kg. As the maximum anode height is limited, it is mandatory to reduce the net consumption, in order to respect the critical butts weight. The net consumption can be reduced by optimizing the key anode properties that influence the burning behaviour, namely the CO_2 and air reactivity, thermal conductivity and air permeability [4]. With the exception of the air permeability, these properties are mainly influenced by the baking process. Optimization of the final baking temperature and minimization of the variations in the pits are hence targets.
- **Increase of the furnace productivity:**
  The daily furnace production can be calculated from the number of fires in operation, the fire cycle and the number of anodes per section:

  $$\text{DailyProduction} = n_{\text{Fires}} \cdot n_{\text{Anodes per section}} \cdot 24\ \text{h} / \text{FireCycle}$$

  Accordingly, the anode demand from the potroom can be used to calculate the required fire cycle:

  $$\text{FireCycle} = n_{\text{Fires}} \cdot n_{\text{Anodes per section}} \cdot 24\ \text{h} / \text{DailyAnodeDemand}$$

  With 6 fires (from the two furnaces), 80 anodes per section and a demand of 590 anodes per day, the required fire cycle is 19.5 h.

  With the number of anodes per section being a constant and the fire cycle time already being squeezed, the productivity could only be raised by adding a fire to the existing ones. As the furnace 1 of ALUMAR consists of 76 sections of which 10 are basically unused, this opportunity was used to add one additional fire and squeeze the existing 3 fires without adding any extra sections.

These combined measures defined the strategy to increase the anode production productivity and quality to the required anode demand from the potroom.

Process Optimization

Implementation of New Fire

The original arrangement of the firing equipment in furnace 1 required 21 sections per fire (as shown in figure 1) and 3 to 4 sections were reserved for maintenance. In order to add a fourth fire, the configuration was reduced to 17 sections per fire which allowed to keep 4 sections for maintenance after every second fire. The reduction of 4 sections per fire required fundamental changes in the baking philosophy. The new configuration is shown in figure 2.

The reduction of 8 to 6 cooling sections was realized by readjusting the cooling arrangement which increased the cooling efficiency and moved the zero-point to the desired location.

The newly gained capacity of the fourth fire was partially utilized to increase the fire cycle from 19.5 to 24 h. This allowed to reduce the baking zone from 5 to 4 burner bridges, by keeping the firing time constant at 96 h.

The section gained from the baking zone was used to increase the pre-heating zone from 2 to 3 sections.

An additional section was made available by optimizing the refractory maintenance time.

In order to adjust the baking curve and firing settings to the new situation, a systematic optimization was executed instead of a trial and error approach. The methodology of the optimization is outlined hereafter.

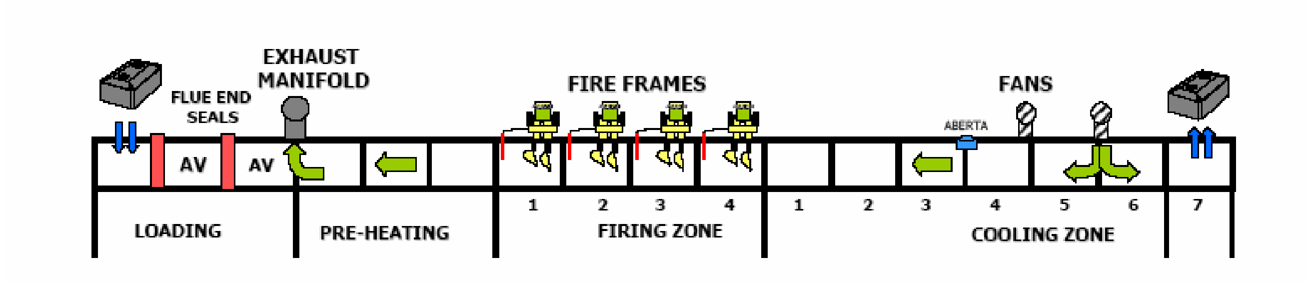

Figure 2. New fire configuration of furnace 1 after optimization

Methodology to Assess and Optimize the Distribution of the Thermal Treatment in the Bake Furnace

The optimum baking temperature is a characteristic parameter that depends on numerous variables such as anode raw material properties, characteristics of the green anode, design and condition of the bake furnace, capability of the firing system and limitations of emissions. The determination of the optimum baking temperature is hence not straightforward and very individual depending on the plant conditions. The final baking temperature is not a criteria for the anode performance in the pots, but rather the combination of the relevant anode properties. For an optimization of the bake furnace operating parameters it is hence essential to know the actual distribution of anode properties.

There are different methods to determine the temperature distribution in the bake furnace, however only one to obtain also the optimum anode property distribution:

- Multi-stage thermocouples have the advantage of fast results, but only information about the temperature of the packing coke is obtained. Due to the short service life (typically 3 to 4 cycles) this method is relatively expensive and no information is obtained about the actual anode quality.
- The determination of the crystallite size Lc of green coke filled in graphite crucibles placed in stub holes is a standardised method according to ISO 17499. However, the resulting so-called "Equivalent temperature" is 70 to 150°C higher than the real temperature [5] which needs to be taken into account when results are interpreted. As above, no information is obtained about the actual anode quality.
- The determination of key properties on sample cores taken from baked anodes and the comparison with calibration curves obtained from pilot electrodes allows to draw a map of the temperature and anode property distribution. This method was applied by R&D Carbon at ALUMAR and is described hereafter.

250 kg of production paste was collected after the mixers by using the by-pass slide for scrap paste. A total of 36 test electrodes were produced in a pilot press with this paste, with a diameter of 146 mm and a height of approximately 180 mm, as shown in figure 3 [3]. Three sets of 12 green pilot electrodes were then baked under well controlled conditions in a laboratory furnace to a final temperature of 1050, 1150 and 1250°C respectively with a soaking time of 20 h, see figure 4. Three sample cores of 50 mm diameter were drilled from each pilot electrode for subsequent testing for key properties.

Figure 3. Production of pilot electrodes

Figure 4. Baking of pilot electrodes

Test anodes produced from the same paste as the pilot electrodes were sampled after baking according to a pre-defined sample plan and tested for the same key properties as the pilot electrodes.

The cores from the pilot and production anodes were analysed for the apparent density, specific electrical resistance, flexural strength, thermal conductivity, CO_2 reactivity, air reactivity, density in xylene and elements (XRF). The evaluation of the results gives information about the homogeneity and consistency of the production anodes, as well as about the heat up phase and soaking temperature of the baking process.

The analysis of the pilot electrodes allowed to draw calibration curves that are utilized to assess and optimize the baking process of the production furnace. An example of the calibration curves is given in figure 5.

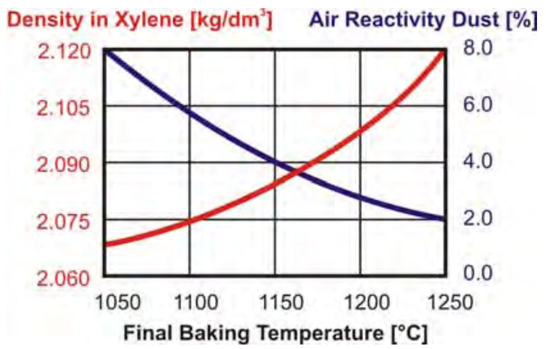

Figure 5. Influence of the final baking temperature on anode properties

Results

Baking Curve

The implementation of the fourth fire and subsequent optimization of the entire baking process resulted in a great increase of the total heating time from 135 to 168 h, as shown in figure 6. This allowed to reduce the final flue gas temperature from 1250 to 1225°C. Fuel consumption savings could be observed after this reduction.

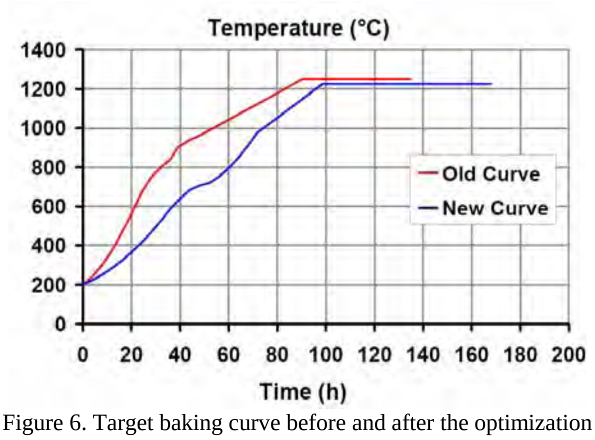

Figure 6. Target baking curve before and after the optimization

Heat-up Rate

The increase of the pre-heating time from 39 to 72 h was an important starting point to reduce the heat-up rate. The measurement and evaluation of the temperature, underpressure and flue gas components in the pre-heating zone allowed to adjust the baking curve in an optimal manner. As a consequence, the location of the pitch burn could hence be improved and the efficiency of the combustion of the pitch volatiles was increased, which both reduced the opacity problems in the off-gas.

Furthermore, the improved heat-up rate had a great impact on several anode properties, such as the variation of the specific electrical resistance and flexural strength (see Table I). In addition, the better control of the pitch burn helped to reduce the baking loss.

Final Baking Temperature

The optimization measures resulted in a substantial reduction of the maximum temperature difference within the pit from 215 to 112°C. Pit regions with temperatures lower than 1080°C could be eliminated completely (see figure 7).

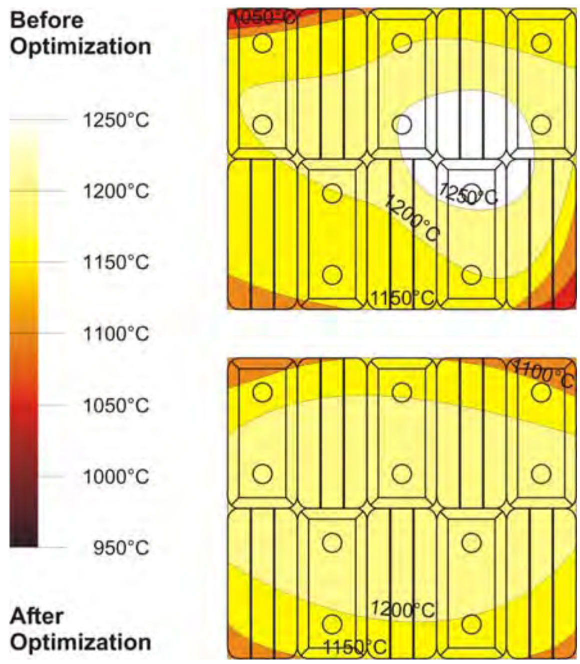

Figure 7. Final baking temperature distribution of anodes in the pits before and after the optimization

The elimination of hot spots of up to 1250°C is beneficial for the life of the refractory material, as well as to avoid desulfurization effects that are deleterious for the anode quality and off-gas emissions.

Anode Quality

Table I shows the anode properties before and after the bake furnace optimization work.

Table I: Improvement of the anode quality figures related to the bake furnace adaptations

Properties	Unit	Before Optimization		After Optimization	
		Average	2 σ	Average	2 σ
Baked apparent density	kg/dm^3	1.56	0.04	1.58	0.02
Sulfur	%	1.90	0.50	2.25	0.25
Spec. electr. resistance	μΩm	53	9	52	4
Flexural strength	MPa	11.9	5.6	12.8	3.2
Air reactivity residue	%	64	6	68	3
Air permeability	nPm	1.0	0.8	0.5	0.4
Density in xylene	kg/dm^3	2.115	0.030	2.090	0.019

With an unchanged green density level, the baked density has improved as a result of minimized desulfurization occurring previously during baking. The slower heat-up rate and the lower pit temperature difference resulted in a better consistency of the specific electrical resistance and flexural strength. The air reactivity residue was also improved as the micro-porosity resulting from the desulfurization has been minimized.

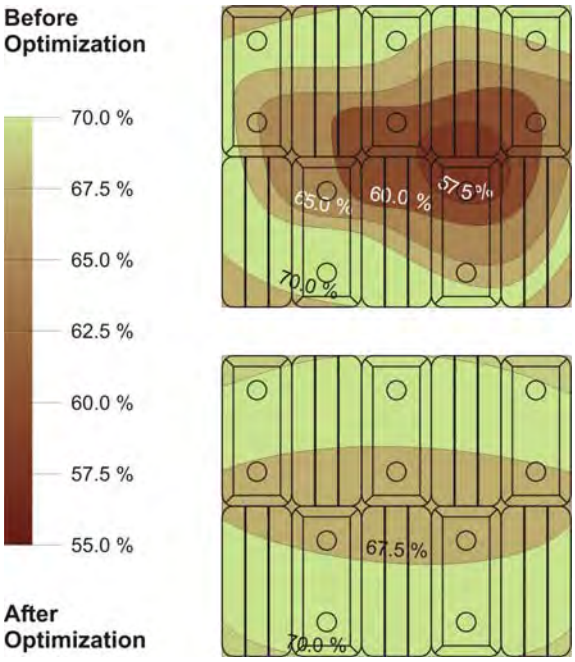

Figure 8. Distribution of the air reactivity residue before and after the optimization

The baked anode weight could be increased by 10 kg as a result of less sulfur and nitrogen losses during baking.

Butts Recycling and Carbon Consumption

A significant improvement of the net anode consumption was observed in the potroom and therefore the butts weight increased remarkably, as shown in Table II.

The increase of the butts recycling by 10 % rel. was beneficial for the anode weight as well as for the air permeability. With the better air permeability and reactivity levels an improvement of the net anode consumption of 10 kgC/tAl could be achieved. As 30 kg of carbon is consumed per day and anode, the bake furnace optimization was a major step towards the goal of increasing the anode cycle time back to 28 days.

Conclusions and Outlook

The use of pilot electrodes to assess the baking temperature and subsequently optimize the entire baking process confirmed to be a systematic methodology to maximize the anode properties and furnace productivity in view of best performance in the pots.

As a side effect, the baking loss, fuel consumption, SO_2 emissions and opacity problems in the offgas could be reduced, and the refractory life potentially increased.

Table II: Comparison of anode and butts figures for 26 cycle days

	Unit	Before Optimization	After Optimization
Baked anode weight	kg	1056	1066
Net anode consumption	kgC/tAl	414	404
Butts weight	kg	273	300

Besides the better economical savings related to the lower carbon consumption [6], the furnace optimization allowed to reach 50 % of the anode cycle time target. Trials in the green side have demonstrated recently that potentials are left to gain approximately 20 kg of anode weight by:

- Squeezing process variability to get more consistent anode height
- Concomitant increase of the anode height target
- Better mixing through longer residence time in mixer
- Implementation of air bellow in vibrocompactor to control anode density level

The opportunity of a longer mixing time (35 instead of 25 min) is related to the fact that in the case of 28 anode cycle days in the pots there is 8 % less paste to be produced. A plan to increase the availability of the batch mixers from 6.0 (current minimum) to 7.5 is under completion to maximize the mixing operations to the requested level.

This will provide the possibility to continue the bake furnace optimization work as the lower anode block demand with 28 cycle days will result in an average increase of the fire cycle close to 2 hours.

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