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ANODE QUALITY AND BAKE FURNACE PERFORMANCE OF EMAL

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Abstract

As part of the worldwide biggest greenfield project, the two open top anode bake furnaces of EMAL were started up in 2010 to reach an annual production capacity of 450'000 tons of baked anodes. Two furnaces are installed with 64 sections, 9 flues and 8 pits that are equipped with 4 fires each. An unprecedented combination of outstanding anode quality and furnace performance figures could be achieved. This document highlights the distribution of key anode properties, furnace productivity and energy consumption. Furnace design and operational challenges to reach today's standards are discussed.

Introduction

Emirates Aluminium Company (EMAL) is a joint venture between aluminium producer Dubai Aluminium Company (DUBAL) and Mubadala Development Company (MUBADALA). The EMAL smelter being located in the new Khalifa port and industrial zone in the Emirate of Abu Dhabi commenced operation of its first phase on December 2, 2010. With the completion of the first phase, the total annual capacity reaches 750'000 tpa of aluminium, which makes this smelter the worldwide biggest greenfield project. The smelter currently operates 756 reduction cells in two potlines with 350 kA using DX technology.

Figure 1: Bake furnace ABF 2 during construction

The baked anodes required for the smelter are produced by EMAL in two new bake furnaces having a nominal production capacity of 450'000 tpa of baked anodes. The gas fired open top bake furnaces supplied by Riedhammer are equipped with the firing system of R&D Carbon. The two bake furnaces are of identical design and consist of 64 sections, 9 flues and 8 pits, as shown in figure 1 and 2.

Figure 2: Overview of bake furnace ABF 1 in operation

4 fires are installed on each furnace, each equipped with one exhaust manifold, one draft bridge, three burner bridges and two cooler bridges with the arrangement as shown in figure 3.

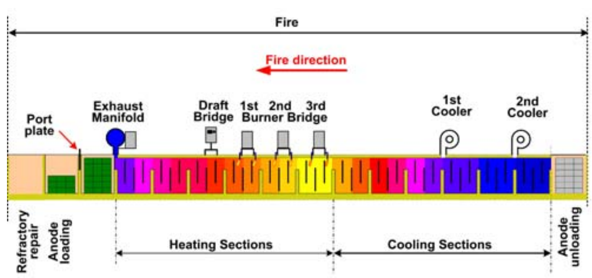

Figure 3: Arrangement of firing equipment

The pits are designed to hold 3 layers of 7 anodes each with a green and baked weight of 1'155 and 1'100 kg respectively. To reach the required production capacity, the furnaces are designed to operate with a fire cycle between 26.7 and 29 h. The resulting productivity per pit reaches 865 kg/h (ie. 21 anodes x 1'100 kg / 26.7 h). Considering the typical pit productivity level of other furnaces of 750 kg/h, the actual productivity of the EMAL furnaces is very elevated.

In order to handle a specific pit productivity at this level, it is mandatory to already prepare the ground at the design stage of both the bake furnace and the firing system.

In particular, the following challenges are faced with an increased specific pit productivity level:

- Homogeneous pit temperature distribution at all stages of baking to achieve uniform anode quality [1]
- Control of the pitch burn enabling complete combustion of all pitch volatiles to minimize energy consumption and emissions [2]
- Control of cooling process to maximize cooling efficiency and minimize packing coke consumption

Numerous design features were implemented in both furnace and firing system to handle the mentioned challenges. For thermal and fluid dynamic aspects CFD modelling was utilized [3]. The experience of more than 40 years of R&D projects was the basis to understand the link between the anode raw materials characteristics, the production parameters and the resulting baked anode quality [4, 5, 6]. This knowledge allowed to utilize the flexibility of the firing system to choose material specific baking conditions with the optimal baking curve being adapted to the raw material and green anode properties.

The challenges faced during the project and the achieved results are presented in this document.

Temperature Distribution and Anode Quality

A principal requirement of anode baking is that all anodes independent of their location are subjected to the same heat treatment with uniform temperature distribution at all times.

To quantify the temperature distribution within selected pits of a particular section, an Lc test was conducted. Graphite crucibles filled with green coke were placed in the two outer stub holes of all anodes in different sections of ABF 1 operated with a fire cycle of 28 h. After baking the graphite crucibles were removed from the unloaded anodes and the Lc of the baked (formerly green) coke was measured. Based on the calibration made with 20 hours soaking time at the maximum temperature, the relationship between the crystallite size Lc and the real temperature is known.

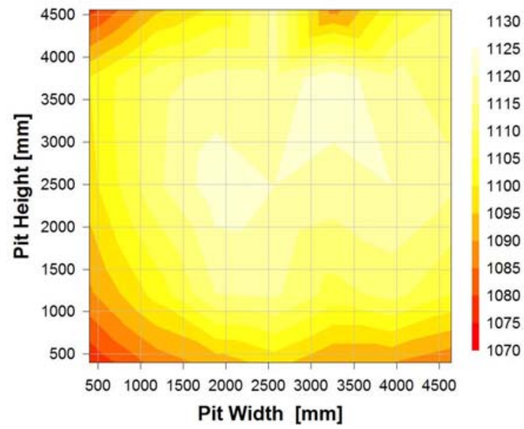

Figure 4: Real pit temperature distribution in ºC

The figure 4 shows the real temperature distribution of a typical pit based on the Lc values. The temperature distribution of all measured pits (avg T +/- 2σ = 1'102 +/- 27 ºC) is splendid and representative for the entire bake furnace, as 126 values were considered.

Even though the Lc test was conducted during routine operation, it remains a snap-shot test. The routine anode quality control is inevitable to quantify the long term evolution. To evaluate the baking process, the properties influenced by the final temperature and heat-up rate may be considered by excluding any variations from the raw material quality and paste plant operation:

- Real density
- Crystallite size Lc
- Specific electrical resistance
- Thermal conductivity
- Flexural strength
- CO_2 reactivity
- Air reactivity

For illustrative purposes the evolution of selected anode properties are shown in figures 5 to 7. The red lines indicate upper and/or lower limits.

The temporary drifts of the specific electrical resistance (see figure 5) are caused by raw material variations. The consistent figures of the real density indicate a very uniform final baking temperature.

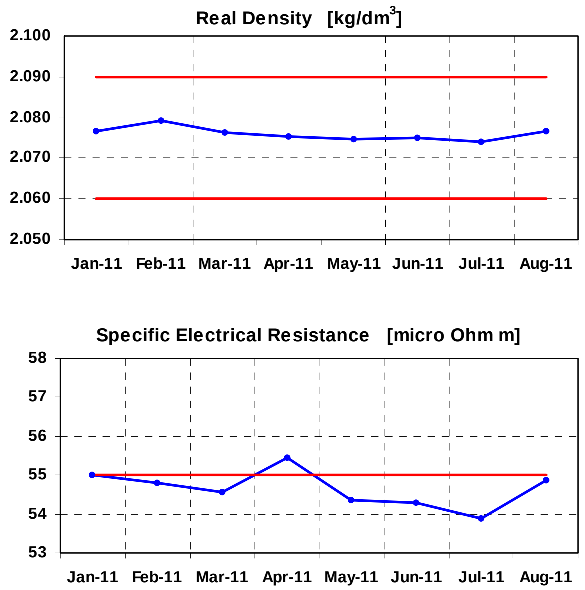

Figure 5: Real density and specific electrical resistance

The variations and in particular the sharp increase of the air reactivity residue in July and August 2011 are caused by variations of the vanadium content in the petroleum coke. The constant CO_2 reactivity residue at high level confirm the optimized baking process.

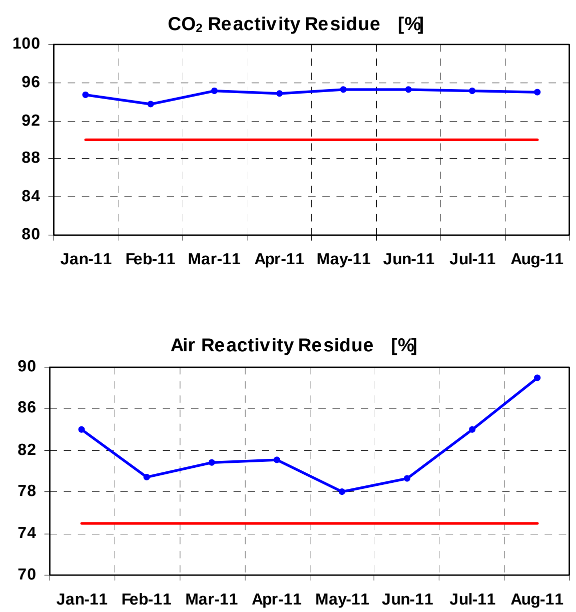

Figure 6: CO_2 and air reactivity residue

The high level of the flexural strength gives an indication that the heat-up rate is well under control. Although the air permeability is not primarily influenced by the baking process, its very low and consistent level further confirm the excellent anode quality.

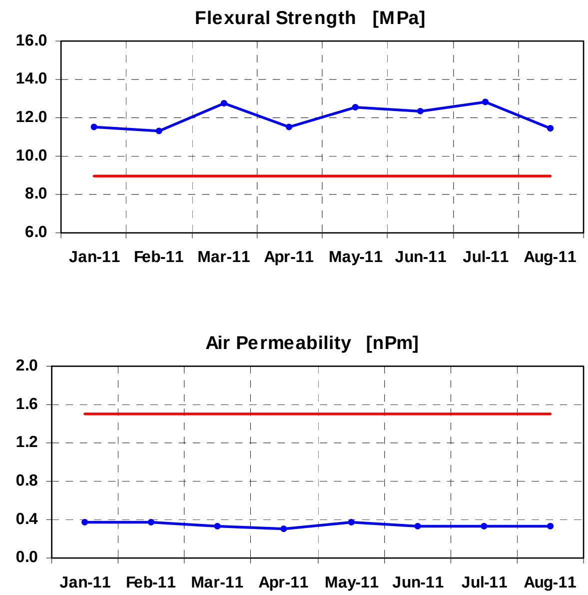

Figure 7: Flexural strength and air permeability

It can be concluded from the figures 5 to 7 that the baking process greatly contributes to the high and uniform anode quality.

The findings from the routine quality control are confirmed by the exceptional performance of the anodes in the pots. The graphs in figure 8 show the evolution of key pot performance figures in 2011.

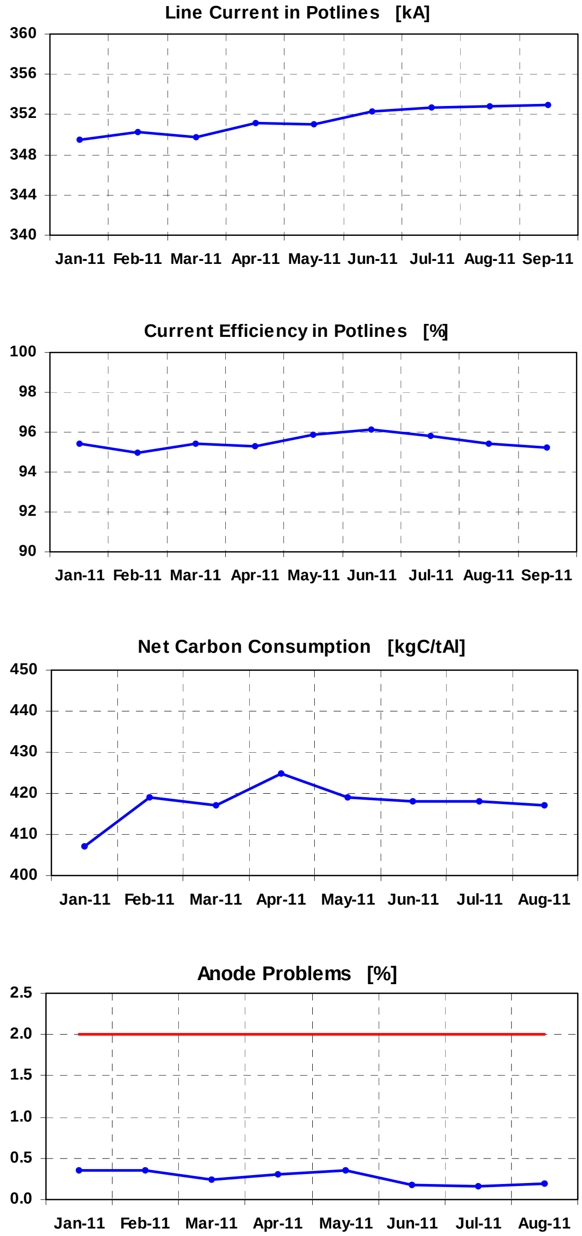

Figure 8: Evolution of key pot performance figures

Control of Pitch Burn and Energy Consumption

In order to fully burn the pitch fumes and hence utilize its combustion heat to minimize the overall energy consumption, it is vital to provide sufficient oxygen to the de-gassing zone. The energy consumption is further decreased by increasing the amount of preheated air from the cooling sections. The bake furnace and the firing system have been designed and constructed to minimize the gas flow resistance in the flues and in the exhaust manifold respectively. Extensive CFD modelling was an important instrument for both the bake furnace and all components of the firing system.

It has been reported earlier that minimizing the energy consumption should not be a primary goal of baking [2]. It is rather a resultant of the primary goals of anode baking, such as the anode quality.

By taking into account the raw material and green anode characteristics, the baking curve was adapted and optimized to the correct level. It is a principal goal to provide just as much energy as needed and to avoid overbaking of the anodes. The influence of the final baking temperature on the energy consumption was investigated in [3]: Increasing the baking temperature by 50 °C (5%) increases the energy consumption by about 10 % or approximately 0.2 GJ/t of anodes.

As a consequence of all described measures, the specific natural gas consumption was calculated to be 1.69 GJ/t of anodes for ABF 1 operated with a fire cycle of 29 h and 1.55 GJ/t of anodes for ABF 2 operated with 27 h. The low energy consumption, visually smoke-free VCM combustion (see figure 9) and extremely low emission figures confirm the high overall combustion efficiency.

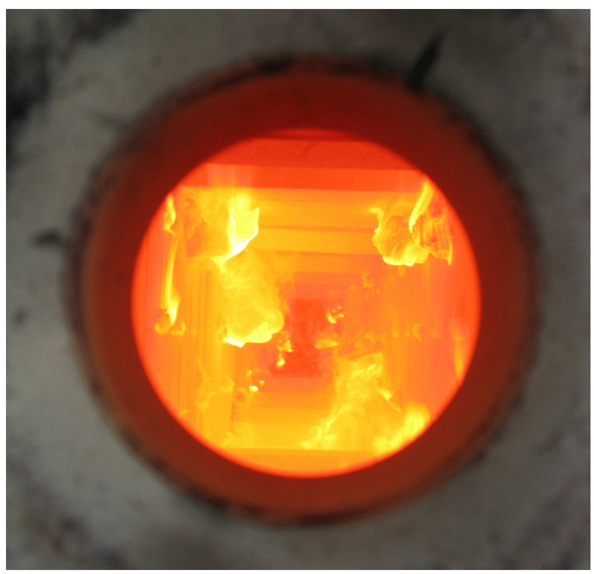

Figure 9: Volatile matter combustion

Anode Cooling and Packing Coke Consumption

To cope with the high pit productivity of 865 kg/h, efficient anode cooling becomes vital to avoid airburn attack and to allow safe anode unloading and handling.

Insufficient anode cooling can result from:

- Insufficient amount of cooling air
- Too coarse grain size distribution of packing material
- Excessive cooling air pressure

Excessive cooling air pressure and too coarse packing material ignite the packing material, which leads to dramatic effects:

- Increase of packing material consumption from less than 10 kg/t anodes to more than 30 kg/t anodes
- Insufficient anode cooling or even re-heating of the anodes
- Anode surfaces attacked by airburn

Therefore the cooling efficiency is optimized by maximizing the amount and pressure of cooling air without igniting the packing material that should exhibit an optimum grain size distribution.

The amount of cooling air and accordingly the cooling energy can be calculated by determining the airflow at all openings of the cooling sections based on measurements of the temperature, velocity and pressure. Measurements during routine operation of EMAL have revealed an average cooling energy of 880 MJ/t anodes, which is a very high level as the typical cooling energy observed in similar bake furnaces is between 700 and 850 MJ/t anodes.

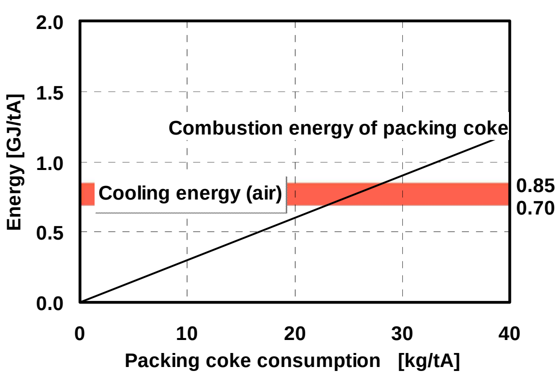

Figure 10: Influence of packing coke consumption on anode cooling

The optimum grain size distribution of the packing material is reached with minimum air flow through the packing material. Tests conducted by R&D Carbon have revealed that this requirement is mostly fulfilled with material smaller than 2 mm. Accordingly, raw coke that is not screened should not directly be added to the furnace. Coarse coke should be added only in well controlled conditions with homogeneous blending of the existing packing material.

The figure 10 illustrates the importance of avoiding packing coke ignition. Petroleum coke has a calorific value of 30 MJ/kg. When the packing coke consumption exceeds 30 kg/t anodes, its combustion energy completely eliminates the cooling effect.

By respecting all mentioned requirements and optimizing all cooling processing parameters, EMAL is capable of maintaining a packing coke consumption of 9 kg/t anodes.

Conclusions

The collaboration of EMAL with professional partners has lead to today's outstanding performance of the anode bake furnaces:

- 450'000 tpa of anodes are produced in today's biggest single site greenfield furnace with a combination of proven technology and optimized key features on bake furnace and firing system.

- An excellent and most uniform anode quality is produced that is monitored by the laboratory and confirmed by the pot room operation resulting in exceptional pot performance figures.

- The combination of high anode quality with minimal variations, high pit productivity of 865 kg/h and energy consumption as low as 1.55 GJ/t sets a new benchmark.

These performance figures are the result of profound research activities and product development combined with the close collaboration of the involved partners.

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