THERMSTOP CONCEPT™: AN UNIQUE SOLUTION FOR ENERGY SAVING OF ANODE BAKING FURNACES

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Abstract

As energy is the major cost in the aluminum industry, any effort to reduce its consumption is desirable. The anode baking process is the most expensive production step of these blocks in the electrode area. Besides the huge volume of refractories that are consumed in the furnaces, the fuel spent is also considerable. Therefore, finding alternatives to reduce the gas consumption is a key issue to ensure a successful plant productivity. Considering that the combustion air escape is one of the main heat sinks of the furnace, improving the flue wall top blocks' insulation capacity and minimizing the generation of cracks due to thermal shock are engineered alternatives to inhibit this process drawback. In this context, a novel concept for the flue cap blocks was developed, aiming to save energy, to improve process control, to reduce emissions, and to increase the refractories working life.

Key-words: Refractories; Baking furnace; Energy saving; Working life.

1. Introduction

The huge amount of energy required for firing carbon anodes justifies any effort to improve the efficiency of this important operation parameter. In this sense, this subject has been the objective of various studies, due to the considerable cost associated with an aluminum plant [1-4]. The energy supply to the furnace is provided mainly by two sources: burners operated by natural gas or oil (50-60 % of the total furnace energy throughput) and the volatile matter from the green anode pitch (remnant 40-50 %). Keller and Sulger [5] pointed out that the pre-heater air from the cooling zone and the combustion of the packing material (that fills the pit and protects the anode from oxidation during firing) help also to provide energy to the system. Therefore, inhibiting unexpected heat losses from these sources is essential to minimize the fuel consumption.

In this context, these authors [5] also pointed out the heat sinks that cause energy waste, spoiling the energetic balance in the furnace. They are related to the combustion air that leaves the furnace through the exhaust manifold, to the energy requested to heat up false air sucked into the system (and sometimes secondary air supplied for the burners), to the energy associated with the crossover channel heat-up, to energy lost through radiation, and to the energy demanded for heating up the refractories, insulation, packing materials and anodes.

Figure 1 shows the balance between the heat sources and the heat sinks [5]. This image highlights that the major amount of energy supplied to the furnace is consumed with the system heat-up, instead of the anode baking. Considering this aspect, Braulio and co-authors [6] evaluated the impact of placing ceramic fiber boards on the top of the pits of the furnace's first cooling section, reducing the gas injection of the heating section flues in a range of 11 to 22%. Besides processing parameters, another way to improve the thermal efficiency of the furnace is by the optimization of the thermal properties of the refractory bricks [7]. As noticed in this Figure, 2 GJ/ton of fuel is added to the furnace and 1.8 GJ/ton is used only to heat up these materials, more than the amount required to bake the anodes (1.1 GJ/ton).

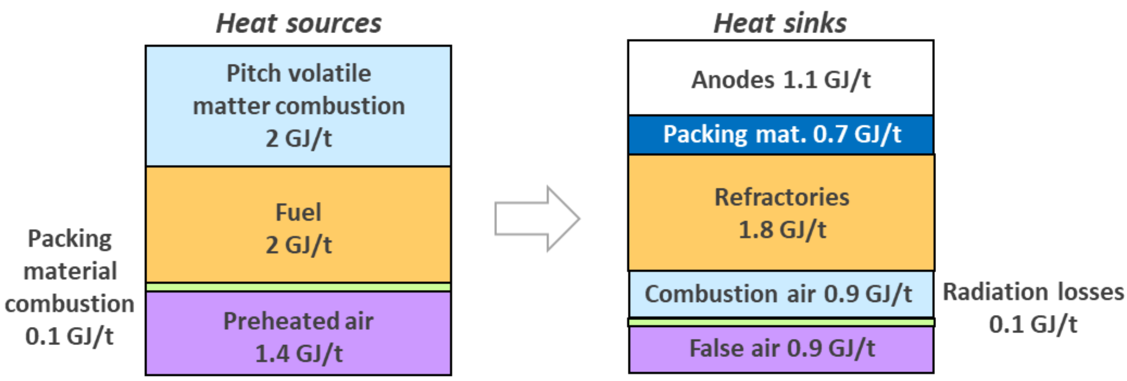

Figure 1 - Heat sources and heat sinks in the anode baking furnace [5].

Taking these numbers into account, one can conclude that a considerable part of the energy loss is associated with the inefficiency of the refractory materials (presence of cracks, heat capacity, heat transfer, insulation ability and so on). In this sense, this work will present a new concept for the refractory castable top blocks, which are placed on the top of the flue wall chambers (Figure 2). Usually, these large and heavy blocks (roughly 400 kg) are comprised by a single and dense material (regular or low-cement castable). The proposal of this development is to have a dense and an insulating material coupled together, with the target of not only optimize the heat balance, but also minimize the crack generation caused by thermal shock and mechanical impact. By considering these wear mechanisms, the proposed concept tends to improve the thermal efficiency and also provide higher working life. This latter is a relevant aspect, due to the very high costs associated with refractory purchasing and maintenance during the baking furnace lifetime.

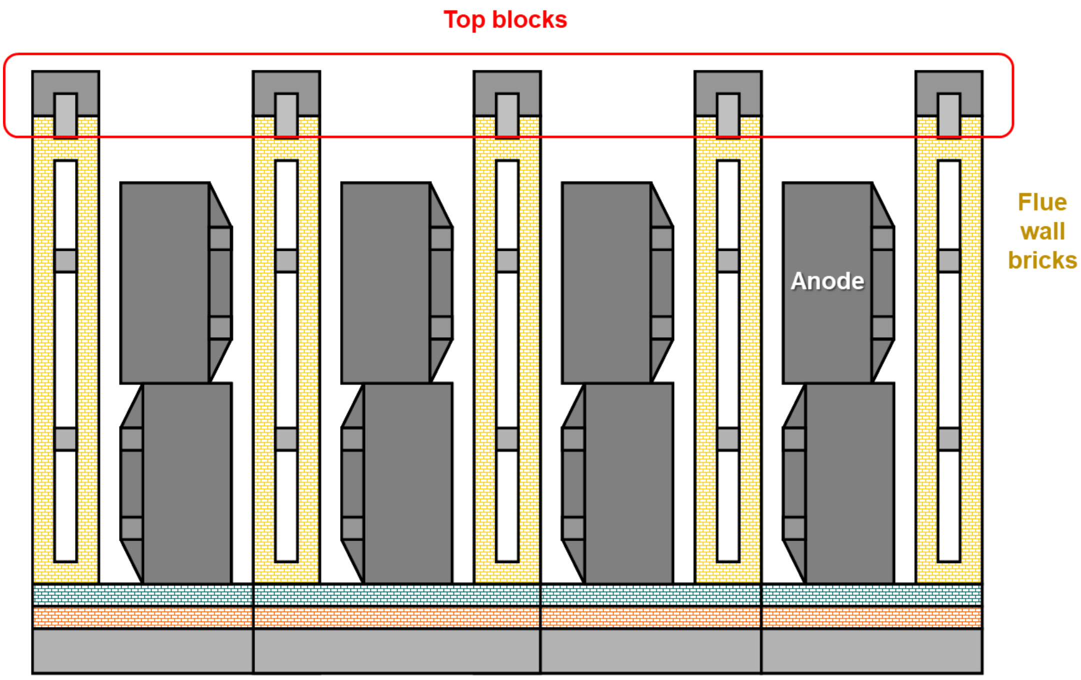

Figure 2 - Top blocks location in the baking furnaces.

2. Wear mechanisms observed for the top blocks

Top blocks are subjected to demanding requirements during operations. Firstly, they may withstand the mechanical wear (impact and abrasion), caused by loading / unloading anodes (Figure 3). As the section furnace is often heating or cooling, thermal shock is usual, leading to cracks in the castable's blocks. They are also subjected to high temperatures in a variable oxidizing and reducing atmosphere, requiring a suitable refractoriness. Figure 4 presents the damaged condition of some top blocks after various years in service in a Carbon Plant in Brazil.

Figure 3 - Loading / unloading anodes can cause mechanical damages.

Figure 4 - Cracks observed in top blocks after years of continuous operations.

3. ThermStop concept

As mentioned before, typical top blocks are usually produced with low-cement or regular castables (higher amount of cement). Some suppliers add a certain amount of metallic fibers aiming to improve the thermal shock resistance. However, it is very common to observe cracks as those shown in Figure 4. Because of the mechanical wear, it is also usual to find blocks that are protected with a steel frame to minimize the damage at the corners (Figure 5). This aspect inhibits the possibility of firing the blocks, which are then delivered just dried at temperatures of 350 to 400°C. Consequently, the developed mechanical resistance is not optimized and the blocks are then more prone to mechanical wearing.

Figure 5 - Top block corners protected with a steel frame.

In order to improve the mechanical strength, a new castable formulation was designed with a reduced amount of cement (ultra-low cement castable). By decreasing the content of this raw material, it is possible to increase the amount of other fine particles, improving the material's packing, its sinterability, and, thus, the mechanical strength. Based on that, no steel frame is required and thus the blocks can be fired at 1000°C, providing a better product to the end-user.

This capability of firing at higher temperature brings great advantages:

- after firing, the properties are set, and the blocks are ready to be used;
- the risk of cracking due to thermal exposures is virtually eliminated (microstructural changes with temperature can lead to expansion or shrinkage, that generate thermal stresses);
- the removal of the steel frame allows the use of a higher quality raw material.

Besides enhancing the mechanical properties, this unique concept allows to bond an insulating material with the external dense castable, minimizing the risk of cracking due to thermal shock (less sensitive thermal gradients are generated under this condition).

This concept was developed based on previous experience of the refractory supplier (PD Refractories) in the cement industry, in which the production of a block composed by dense material and insulation was required in the past. At that time, the baking furnace customer was placing an insulation under the top blocks to save energy, but this was not the most suitable solution, as the insulation was absorbing the pressure from the heavy blocks. This situation motivated the supplier to develop this new solution.

By adding this internal insulation layer, a better heat storage is attained, helping to save energy during the baking furnace operations. Figure 6 presents the ThermStop Concept top block and its double layer configuration (external dense castable - ρ = 2.13 g/cm^3 - with improved mechanical strength and internal insulation - ρ = 1.15 g/cm^3 - for better thermal shock resistance and energy conservation).

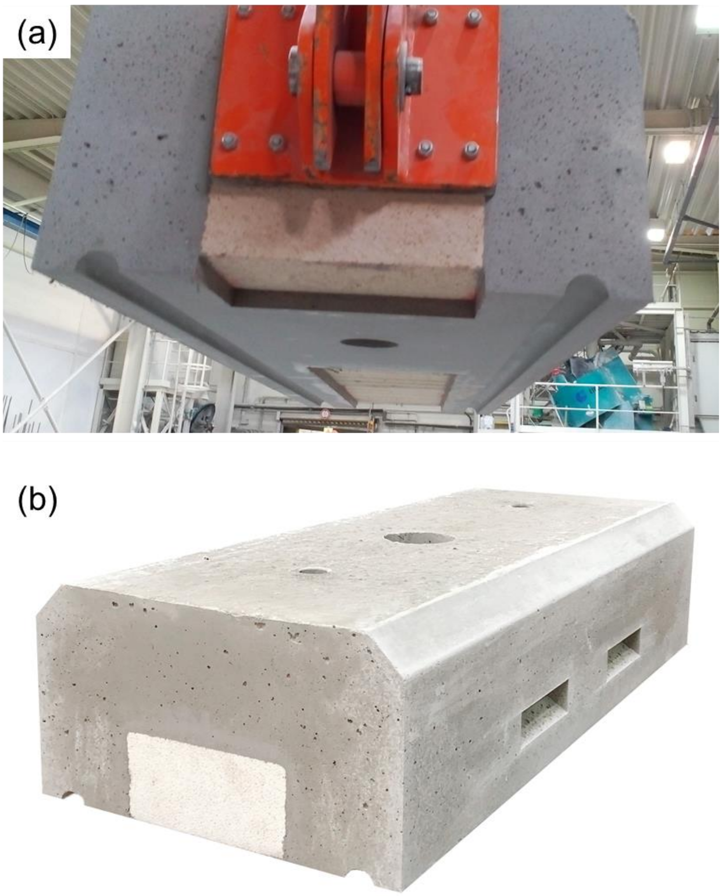

Figure 6 - ThermStop Concept^{TM} top block: (a) after demoulding (before firing) and (b) after firing (final product).

4. Initial field application in Alcoa Mosjøen plant

This plant has installed about 80 top blocks with the ThermStop Concept. The age of these blocks is in the range of 4 to 35 fires. Only a minor amount of the blocks presented some cracks, but this was attributed to the bowing of the flue wall, that generated thermo-mechanical stresses over the blocks. In general, the initial results are positive, but a greater number of blocks will be installed to figure out the lifetime of this new concept. Figure 7 shows the visual aspect of the blocks with different number of fires, all of them presenting an adequate performance so far.

Figure 7 - ThermStop Concept^{TM} top blocks with distinct fire cycles: (a) 2 fires, (b) 8 fires and (c) 11 fires.

Alcoa Mosjøen is mainly interested in the cracks at this application moment and, thus, there is no accurate temperature measurement of these new flue caps. Meanwhile, the engineering team is aware that the block's surface temperature is about 20 to 50°C warmer than the old flue caps, but this is related to the plant requested reduction of 76 mm in the block's thickness. Initial trials conducted with the P-D Refractories blocks took place 5 years ago (with original thickness) and they are still operating with no damage. Conversely, the new flue caps (76 mm thinner) are running since 2016, presenting longer lifetime, with few cracks observed. Reducing the crack formation can bring benefits to the process, in terms of energy savings and oxygen entry, but it still requires time for collecting proper data.

5. Final remarks

This new technology still requires further plant trials to figure out the actual benefits that it can provide. Initial results are promising, as the blocks are not cracking during their use. Thermo-mechanical simulations can indicate the stress profile on the blocks and provide an idea regarding the energy saving potential. Some baking furnaces can also measure the gas consumption flue by flue and, when having an opportunity, P-D Refractories will provide the support to the customers to set up the trial conditions (appropriate measurements and comparison with traditional blocks). The mechanical strength improvement is being proved and soon the thermal efficiency will also be estimated, aiming to attain all the targets established for this unique concept.

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