Study on Anode Baking Parameters in Open-Top and Closed-Type Ring Furnaces

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Abstract : Anode quality has strong impacts on the net carbon consumption in electrolysis cell and subsequently on aluminum production costs. Moreover, inasmuch as baking process is the most expensive step in the anode production and in the other side, anode properties influenced by baking process, therefore furnace selection (open-top or closed-type) and baking process control are always prime priorities that have to be deliberately taken into accounts by smelters. Furthermore, the most important baking parameters are the anode heat-up rate and the baking level, in that the present study deals with the main factors such as influence of firing section on temperature gradient as well as the effect of heat-up duration and anode size on baking level.

Keywords : Anode; Baking; Heat-Up Rate; Baking Level “;”

1- Introduction

The anodes are a compound of coal or petroleum coke and a binder pitch. Besides, green and baked anode scraps as well as cleaned anode butts are recycled to use in new anode production. The anode formulation defines how fine the dry material needs to be crushed and then milled and what the proportions between all the components should be in order to meet the subsequent requirements.

In addition, it is known that the anode behavior during aluminum electrolysis is significantly influenced by the process of anode baking. However, there is a lack of knowledge to anticipate the anode behavior through given baking parameters [1-3].

The anode material processing basically consists of dosing and mixing the coke and paste and then forming to anode blocks by using either a vibro-compactor or a press. After forming, the green anodes require cooling in order that the weak material is not damaged during the subsequent steps like transport and storage. With the anode baking, the green anode blocks are transformed to pre-graphitized carbon which meets the aluminum electrolysis requirements.

There are three types of carbottom, rotary hearth and pit type or ring type furnaces to bake anode, graphite electrode and cathode block. The anode baking furnace type popularly used in anode industry is the open-top or closed-type ring furnace. The anodes are stacked in pits and covered with a packing and insulating material. The anode baking process is controlled indirectly through the combustion process taking place inside the flues which are insignificantly different in open-top and closed-type [3].

Furthermore, inasmuch as, baking is one the main effective and expensive steps in anode production process in aluminium industry, anode baking furnace has to be deliberately designed to achieve an optimal temperature distribution in the flues and pits, low energy consumption and long refractory lifetime as well as possible and minimal operating and maintenance cost. In this study, it is shown that the baking level is basically determined by the final baking temperature although the soaking duration has some influence too [4].

2-Anode Baking Furnace

As mentioned before, the ring furnace (**Fig. 1**) is widely used for industrial anode baking. That furnace type shows a good balance between investment costs, production capacity and the resulting anode quality. The anodes are stacked in pits where they remain fixed until the process ends. The process lasts, cooling included, about 15-20 days, whereas small anodes can be baked in a shorter time with an overall duration of 7-10 days. The anodes under baking process are heated up to a temperature between 1050 °C and 1150 °C. During the baking process the temperature gradient in the individual sections varies between 3 °C/h and 12 °C/h (in the critical zone), dependent upon the baking curve applied.

The sections consisting of a number of flues and pits are lined up in two rows. Within a row, each section is bounded by a head-wall in front and behind. The head-walls divide the pits and interconnect the flues of adjacent sections. The flues of the two section rows are linked at both furnace ends through crossover ducts. That gives the furnace a ring like structure and hence the name ring firing furnace. Two types of technologies are used for baking of anodes: closed-type and open-top ring pit furnaces. In closed-type furnaces a steel lid covers the pits.

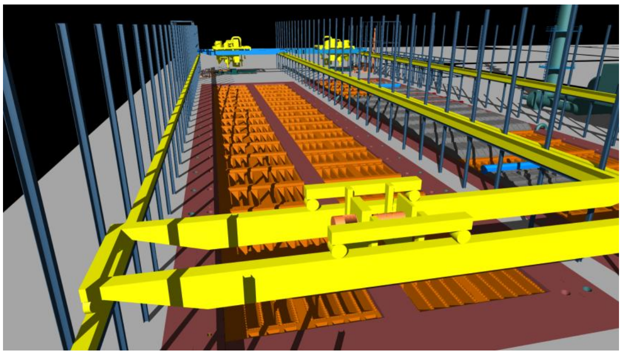

Fig. 1- Overview of a typical ring furnace

3-Baking Parameter

The final anode quality is influenced by the anode baking process. In general, green anodes of low quality cannot be improved through baking. However, green anodes of excellent quality can result in anodes of low quality if the heat treatment is not well controlled done. The main parameters which should be deliberately controlled are heat-up rate and baking level. In addition, many effective factors influence on these two parameters that anode dimension, soaking period and firing zone size are studied and more discussed hereinafter.

3-1-Heat-Up Rate

The heating-up rate is the usual preheating time ranges (78-96 hr) which during this period, the volatile release rate and the available flow passages within the anode body must be in balance to keep the formation of micro cracks under control. Especially the heat-up rate is very critical during the phases of pitch expansion, volatile release and coking between temperatures of 150°C to 600°C.

For industrial scale anodes the heat-up rate is reflected in the scattering of the mechanical anode properties around their mean values. Too high a heat-up rate leads to an increased number of micro cracks resulting in a pronounced asymmetrical property distribution. This behavior is typical for substantially fragile and brittle materials and is statistically best described by the Weibull distribution. The parameter describing the variability is referred as the Weibull modulus *m*.

The Weibull modulus *m* is the parameter describing the Weibull distribution which is the statistical model in fracture mechanics of brittle materials. The Weibull modulus m is obtained through flexural strength data (ISO 12 986-1).

Anodes of typical quality have a Weibull modulus around 8. Poor anodes have a high variation of the flexural strength what is reflected in a modulus of 3 while excellent anodes have a modulus up to 13 [5 6].

In general it is not feasible to determine the relationship between the heat-up rate and the resulting Weibull modulus. For an experimental setup hundreds of tons of anode scrap were to be expected. Such a relationship between the anode surface heat-up rate and the Weibull modulus was developed by Meier as listed in **Table** 1.

Table 1- Estimated impact of the anode surface heat-up rate on the Weibull modulus, [5]

Overall Heat-Up Gradient [°C/h]	Weibull modulus [-]	Anode Quality
10	13.0	High
14	8.0	Typical
20	3.0	Poor

As a rule of thumb, a heat-up rate below 14 °C/h is safe. This corresponds to the maximum admissible rate of 12 °C/h published by Fischer et al. [7]. However, in the meanwhile the quality of green anodes has improved what potentially allows an increased temperature gradient.

In according to high sensibility of baking process to heat-up gradient, so the number of pre-heating and firing pits has a remarkable effect on heat-up rate.

Firing Section Effect on Heat-Up Rate.

As mentioned before, the dimension of the furnace and the individual pits are designed according to the production requirement and the dimensions of the anode to be baked. Each furnace consists of a certain number of pre-heating and firing sections, which are covered in closed-type one, and also cooling, maintenance, loading and unloading zone.

In addition, baking during 450 °C to 600 °C or s called 'Coking' step, is a critical process stage which, the binder phase is being transformed from melt into a solid. Thereby, the mass release ra through the evolved volatiles drops significantl The content of methane in the volatiles, and to minor degree also of hydrogen, is increasing rapidl The anode surface undergoes the transition to elast behavior first. Then the solidification region mov on towards the anode center. Hence, the surfa starts shrinking while the anode center still mig expand i.e. tensional stresses are built up. T difference in the process stage within the sar anode body must be kept within bounds by a w controlled and sufficiently slow temperature gradient up to 600 °C [1].

It is necessary to be noted that any change in the number of firing sections includes pre-heating and firing pits, can influence on heat-up rate whose modeling results for the typical anode with composition of 70% and 30% coke and pitch, respectively, are listed in **Table 2.**

Table 2- Influence of the pit number on heat-up rate during 'Coking step'

Firing Pit No. [-]	Heat-Up Gradient [°C/h]
12	5.95
14	4.63
16	3.79
18	3.21
20	2.78
22	2.45
24	2.19

As can be seen in **Table 2**, reduction in the figures of pre-heating and firing sections make an increase in heat-up rate, which culminates in significant depletion of baked anode quality. Moreover, even though, designating more pits for firing section can helpful to control properly, preliminary investment and energy consumption increase. However, these factors should be optimized to subsequent economized process. So it seems 16 to 18 pits are a good choice for anode plants, this result match well with typical fire group comprises 14 to 16 sections in industrial anode baking furnaces.

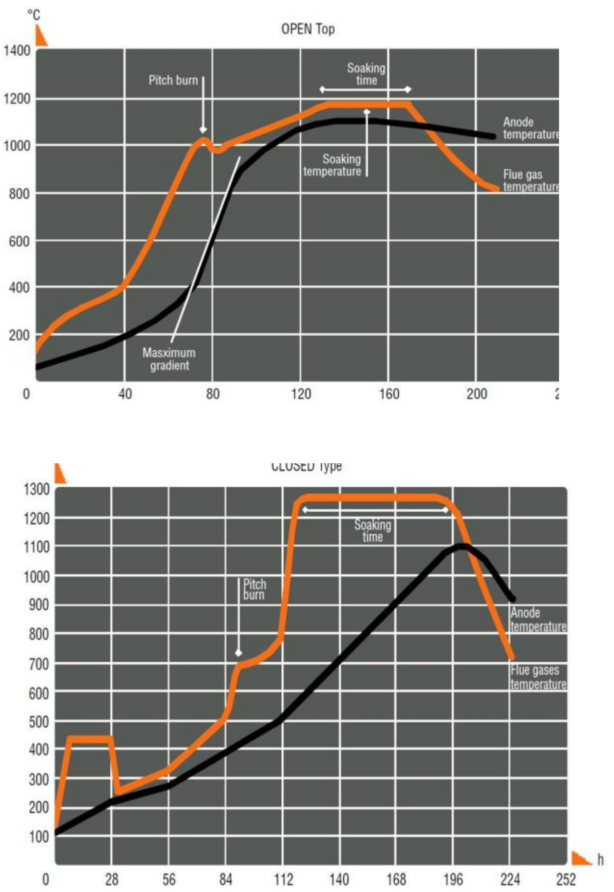

Fig. 2- Typical firing curve of anodes in an open-top and closed-type ring furnaces of Riedhammer [3]

In other side, by increasing the fire number and reducing fire cycle, more annual capacity can be achieved. However, this matter should be deliberately studied.

The baking furnace annual production capacity can be calculated by using the following equation [4]:

$$TPY = 8760 \times TPS \times F/FC \tag{1}$$

where TPY (ton/year) and TPS (ton) are annual anodes baked and anodes loaded per section, respectively, F is number of fires and FC (hr) is fire cycle.

Beside mentioned hereinabove, to optimize of the firing curve, some trials must be done combined with the paste plant by closely monitoring the critical anode properties throughout the entire section along with controlling the operating conditions.

As can be illustrated in

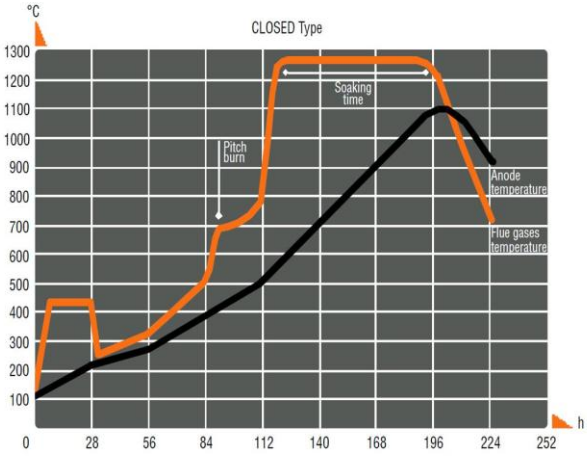

*Fig. 2***,** heat-up rate in two ring furnace types of open top and closed type are very different in which it is tangibly that the gradual increasing temperature gradient in closed-type furnaces is more possible and easier in comparison with the open-top ones due to more facilities of controlling the baking operating variables and process degree of freedom. So, the closed-type furnaces provide appropriate conditions and for high dense and quality anode producing [8]. It should be noted that most graphite electrode and cathode whose density and the other properties have to be higher and more desirable in comparison with anode, to meet the operating necessities are baked in closed-type furnaces [9].

3-2-Baking Level

The anode baking level is given through the highest temperature the material is exposed to and through the exposure duration, referred as the heat soaking time. Anode baking is, like coke calcining, a temperature-time phenomenon. The appropriate baking level is material specific and largely depends on the expected anode behavior during aluminum electrolysis.

Influence of the Anode dimension on Baking Level

During baking anodes, the heat is transmitted inside the anode body through conduction. The heat transmission is stationary in nature, i.e. the maximum temperature in the anode center is lower than the maximum surface temperature. This temperature difference depends on the anode size as well as on anode firing curve. In addition, the maximum admissible heat-up rate depends on green anode properties and especially on the anode dimensions. The significance of the dimensions lies in the length of the available flow passages. Hence, the impact of the heat-up rate can be only studied through baking industrial anodes.

In industrial furnaces, the anodes are stacked in several layers inside the pits and baked through the heat generated in the flues. Thereby the heat flux is basically perpendicular to the flues. Hence, the heat transmission which is naturally stationary is approximated here with a one dimensional model. The model is given by the Fourier equation of the following form [1]:

$$\frac{\partial T}{\partial t} = \propto \frac{\partial^2 T}{\partial X^2} \qquad (2)$$

where T=T(x,t) is the temperature, t the time, α the temperature conductivity and x the coordinate. Whereas H is the anode dimension perpendicular to the flues, the coordinate x ranges from anode surface (x=0) to anode center (x=H/2). It is assumed that the initial anode temperature is uniform, T(x,0)=T0, and that the heat flux in the anode center is zero($\frac{\partial T}{\partial x}\, \partial T/\partial x|_{x=\frac{H}{2}} = 0$). The anode surface temperature is a given function, T(0,t)= Ts(t).

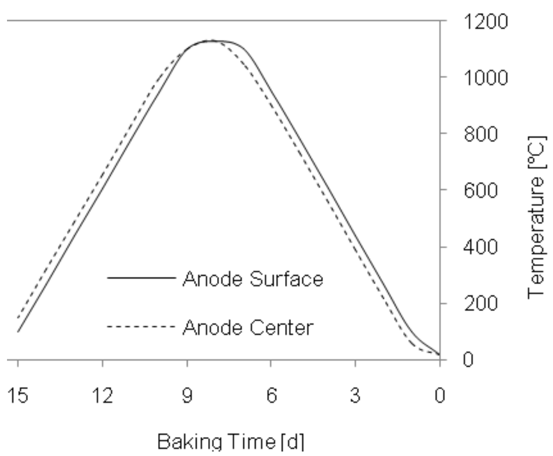

Fig. 3- Calculated temperature development in the center and surface of an anode with the relevant dimension of 0.8m

Moreover, the calculated temperature development at the anode surface as well as in the anode surface and center is shown in **Fig. 3**. For the calculation an anode dimension of 0.8m (in the direction of the heat flow) was assumed. The applied heating curve corresponds to the conditions of industrial anode baking. The curves which are obtained indicate that the maximum temperature difference within the anode body is not an issue, not even for large-size anodes which are baked in a short time.

Fig. **4** indicates the difference between the maximum anode temperatures to be expected for varying anode dimension and heat-up time. In industry, the lower limit of the heat-up duration is about six days and the upper limit of the relevant anode size is more than 0.8 m. Hence, the difference in the baking level within the anode body is kind of negligible.

Other research shows that anode density has an impact on the anode pattern days, undoubtedly. In fact it is not affected by the over-baking as long as no severe desulfurization takes place at temperature more than 1200 °C, but Under-baking will have the negative impact on the baked anode density. The anode net consumption improves with the baking level except occurring desulfurization which results in a pronounced net consumption minimum at about 1150 °C [1].

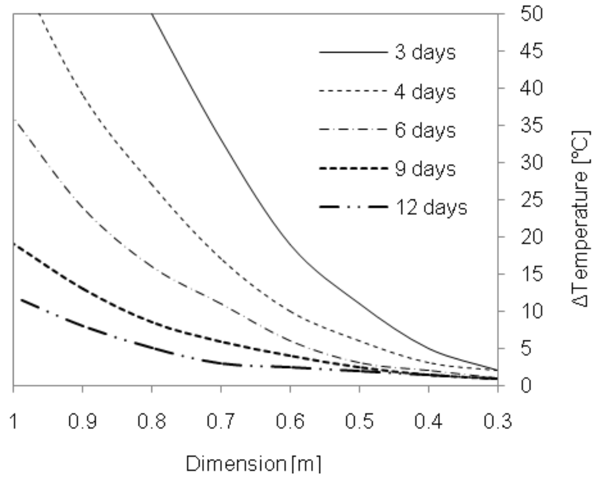

Fig. 4-Calculated influence of the anode dimension and the heat-up duration on the variation of the final baking temperature within the anode body

4-Conclusions

The anode baking is a physico-chemical process and involves pitch expansion, release of binder volatiles, coking, crystalline reorientation (pre-graphitization) and in some cases desulfurization. Therefore, a well controlled and sufficiently slow heat-up rate particularly in the temperature range from 150 °C to 600 °C is necessary in order to suppress the formation of micro-cracks within bounds.

In addition, the number of firing section influences on heat-up rate, so it should be optimized to prevent a significant depletion of baked product qualities, preliminary investment and energy consumption. Before any changes in fire cycle and fire section to optimize the firing cure and subsequent furnace capacity and anode quality improvements, the conditions should be investigated in all possible points.

Moreover, last but not least, the temperature difference of the baking level within the industrial-size anode body can be neglected to some extent.

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