Low-Cost PFC Analyzer for Early Anode Effect Detection

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Abstract

The anode effect is a major and unfortunately recurrent malfunction of aluminum reduction cells. Process control algorithms implemented in the pot controller can detect this problem and eliminate it. However, detection is based on the resulting significant increase in the voltage of the pot, and this increase is generally very fast: the nominal voltage is increased to 8 Volts (the detection threshold commonly used by ALPSYS®, for AP technology pots) in just a few seconds, which is not enough to permit a preventive treatment of the anode effect.

However, several minutes before the anode effect can be detected with certainty by a rise in the pot voltage, the unwanted electrochemical reaction is already present and gases such as CF_4 or C_2F_6 are already being produced by the pot. This phenomenon has been clearly demonstrated on prototype pots equipped with Fourier transform infrared analyzers (FTIR). Unfortunately, such analyzers cost too much to allow equipping all the pots in a smelter with them. We have therefore worked in partnership with the Mirsense company to develop a low-cost device for continuously sampling and analyzing pot gases in order to detect CF_4. The principle of the device is photo-acoustic detection: a laser emitting at a carefully chosen frequency will selectively excite CF_4 molecules so that they emit a sound whose amplitude is directly related to the quantity of CF_4 present. The development of this device also includes the sampling equipment, in order to obtain a solution able to work continuously over a long time without manual intervention.

To date, the performance of our photo-acoustic device is very good and its results consistent with those of an FTIR placed in parallel for comparison.

Keywords: Anode effect, PFC. Low-cost PFC analyser.

1. Introduction

The anode effect is a phenomenon which appears in aluminum reduction cells due to the depletion of oxygen-containing ions at the anode. It is generally considered that the effect occurs when the alumina concentration in the pot is less than 1 to 1.5 % wt. [1], [2], [3], [4], [5]. At the beginning of the aluminum industrial era, there was no automated alumina feed, and the anode effect was awaited in order to know when to add more alumina to the pot. For several decades now, thanks to automation, the pots have been equipped with either continuous or semi-continuous alumina feeding systems. The appearance of anode effects is therefore no longer necessary to ensure the proper functioning of the pots and is clearly not desirable, because the phenomenon has negative consequences on the robustness of pots (release of intense thermal energy which deteriorates ledge and crust) and on their performance (higher energy consumption and lower current efficiency). Moreover, the anode effect causes a release of CF_4 and C_2F_6 instead of the CO_2 normally produced at the active surface of the anodes. These two perfluorocarbons (PFCs) have a global warming potential of respectively about 7 000 to 12 000 times that of CO_2 and have an extremely long lifetime in the atmosphere, reaching respectively 50 000 and 10 000 years. This is why it is important to limit the occurrence of anode effects as much as possible (expressed in number of anode effects per pot and per day). Much progress has been made in this field since the 1990s, in particular by trying to improve the operating conditions of the pots.

Numerous scientific studies have been carried out to explain the origins of anode effects [6], [7], [8], [9]. All these studies clearly show that the primary cause of the anode effect is the lack of alumina in the pot or more precisely under certain anodes. It seems that since alumina is delivered at the center of the pot, an anode effect is very often triggered under the anodes at the end of the pot, in areas where the bath stirring is less powerful and where enriching the bath with alumina is therefore more difficult. As soon as the alumina concentration under these anodes drops below approximately 1 to 1.5 % wt., the anodic current density limit is reached and the first bubbles of CF_4 and C_2F_6 begin to form [4], creating a resistive layer under these anodes which further reduces their current. This current reduction is distributed to the other anodes, increasing their current densities and hence making them more sensitive to the anode effect. A chain reaction then occurs, generalizing the anode effect to all the anodes of the pot [3].

However, as the first anodes undergo the anode effect, the new current distribution in the other anodes is not clearly visible in the pot voltage, because other phenomena such as magnetic instability lead to noise in the voltage greater than the variations resulting from the onset of the anode effect on the first anodes [10]. For this reason, the anode effect is only clearly detectable in the very last seconds before it generalizes, when the cell voltage begins to increase rapidly.

Thus, the initiation of the anode effect results in a drastic drop in current density in a limited number of anodes. Studies have therefore been carried out to detect the phenomenon by monitoring the current in each anode [11] [12]. This method is very effective but requires equipping each pot with anode current sensors, which is quite costly.

Other authors have used statistical methods, in particular principal component analysis [12] [13], or the calculation of third-order coherence functions [14] in order to detect drifts in the process and in particular in alumina depletion. However, the monitoring of these indicators is not sufficient because many exogenous phenomena can intervene. For example, monitoring the number of alumina shots introduced into the pot per unit of time is a good indicator of the quantity present in the pot, but a significant reduction in this value will not necessarily mean a reduction in the concentration, as this may be caused by a collapse of the cover in the bath (the regulation algorithm then decreases the alumina shot frequency to take account of this parasitic alumina feeding). It is also possible to estimate the alumina concentration in the pot using a linear Kalman filter, in order to increase the feeding rate (i.e., overfeeding) in case of lack of alumina [15], [16]. However, these estimators need to be readjusted periodically.

Studies using machine learning techniques have also already been used in order to predict the anode effect [17]. We can cite the work of Meghlaoui et al. in 1998 [18]. These authors used neural networks for the prediction of cell resistance at the 15-minute horizon. Their one-layer neural network uses as input data the instantaneous resistance value and its value 5, 10 and 15 minutes before, the instantaneous alumina feed rate and that, 20 minutes before, as well as the slope of the resistance and its deviation from the minimum recorded value. It should be noted that the authors claim good results in reducing anode effects thanks to their algorithm which imposes alumina overfeeding as soon as the prediction foresees an increase in resistance above a critical threshold. Nevertheless, this algorithm is open to criticism because, although the numerous overfeeds avoid the anode effects, their high frequency leads to an excess of alumina in the pots causing sludge. This algorithm has never been put into production on an industrial scale. More recently, Zhou et al. [19] used a generalized regression neural network. They also used aggregated input data (13 in total) such as average voltage for the last 3 hours, average voltage for the last 8 hours, average alumina feed rate for the last 24 hours, etc. As output, the model predicts a probability of occurrence of an anode effect in the next 30 minutes. Once again, the number of false positives seems too high to consider applying this method to all the pots in a plant.

7. References

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