

## Carbon Dust Metrics for Cell and Plant Process Audits

**Matthias Dechent**

Process Engineer - Electrolysis  
 TRIMET Aluminium SE, Hamburg, Germany  
 Corresponding author: matthias.dechent@trimet.de

### Abstract

Anode dusting is named as one of the main influences on unwanted anode consumption and therefore non-productive CO<sub>2</sub> emissions. While improvements in anode quality have reduced carbon dusting from anodes, the dusting problem still occurs in plants from time to time and is difficult to deal with. This paper shows possible metrics and diagnostic tools to monitor for early onset of a developing dusting crisis. It also uses the feedback from a survey conducted in the aluminium smelting world and shows practical approaches for dealing with carbon dust. Practical examples gathered at plant visits for the interpretation of certain data sets are given.

**Keywords:** Carbon dust, Cell performance, Process audits, Anode dusting.

### 1. Introduction

Carbon dust is a concern for all reduction managers, as it is one of those influences that can spiral out of control, if not contained correctly. Dusting leads to a vicious cycle with spiking, increasing specific energy consumption (EC) and losses in current efficiency (CE), as discussed in the literature [1-4].

The carbon inputs in the process and possible sources for carbon dust have been discussed [5]:

- Cathodes: mechanical erosion or chemical reactions with aluminium forming Al-carbides cycling through the cell;
- Resistor coke: used during start-up, expected to flush during bath up and then skimmed out, amount depends on the kind of bed (full bed, anode shadow or spots [6], [7]);
- Anodes: reaction with air and CO<sub>2</sub> leads to the formation of dusting, cracking anodes lead to free carbon particles;
- Anode cover material: crushed particles from broken anodes or collected carbon dust on top of anodes, sometimes recycled carbon dust skimmings;
- Secondary alumina: collected carbon particles from the offgas of the cell, if airborne.

Table 1 shows the accumulated carbon input for a 180-kA cell (retro-fitted Reynolds P19 in Hamburg). As anodes are the biggest input regarding volume, the focus during plant and cell audits in this project focused mainly on them.

**Table 1. Carbon inputs in a 180 kA cell over a 6-year lifetime.**

Input material	Mass (t)	%
Resistor graphite	0.2	0.011
Ramming paste	7	0.390
Cathodes	14	0.780
Anodes gross (net 1310)	1760	98.050
C from ACM (0.5 % C)	1.5	0.084
C from secondary alumina (0.2 % C)	12.3	0.685
Sum	1795	100

Some of the basic concepts for dust formation have been discussed previously by the author [5]. To understand the scope and impact of carbon dust on the industry, an industry survey was conducted; and then, systematic carbon dust audits for individual cells and potlines were conducted.

## **2. Findings from the Industry Survey**

Part of the study was a questionnaire with 10 questions sent out to professionals in the aluminium smelting industry. 20 replies were analyzed; however, some of the questionnaires were filled out only partially. This leads to a more qualitative rather than a quantitative picture on the common understanding of carbon dusting. The questions were related to three main parts: what is understood as dust and a dusty cell, what are the results of carbon dust, and how to prevent and reduce the impact. The questionnaires were filled out 30 % by carbon specialists, 70 % by electrolysis specialists.

The common description of a dusty cell was a cell with operational problems and a visual black mixture on the bath surface. Additional characteristics were an increased bath temperature (+30 °C deviation from target) and an abnormally increased superheat (20-30 °C).

Root causes for the problems were separated into three fields: anodes and their quality, work quality in the operations for anode change and anode covering, and general cell operations. For anodes, the quality of the product was named: oxy- and carboxy-reactivity test residue and dust, air permeability and impurities from raw materials, mainly V, Na, and Ni. In operations, the quality of anode setting, with correct height and cavity cleaning, was mentioned as well as the quality of anode covering and the continuous anode redressing in order to maintain a protective barrier between air and anode. For the general cell operations, the following were mentioned: spikes/mushrooms and cracking of anodes can lead to carbon detachment from the anodes; a high bath temperature due to improper voltage targets or wrong bath chemistry increases the risk of preferential oxidation of the carbon binder matrix, anode-to-cathode distance (ACD) squeezing can lead to local temperature increases for anodes and anodes acting as cathodes.

The impact of dust is perceived uniformly and described. Cells with dust have an increased temperature, and anodic incidents like spikes and cracking of anodes occur. The cells' current efficiency is reduced, the specific energy consumption increased. Both a decrease in metal production or an increase in power requirement were mentioned as the root cause for the increase in specific energy consumption. Two participants mentioned a higher bath resistance, and therefore, a squeezed ACD. Setpoints in the process control system, assuming a bath resistivity with no dust, stayed the same and the anode beam is moved downwards.

Mentioned side effects in dusty cells are anode effects with low maximum voltages of approximately 12 to 18 V. Monitoring of the maximum voltages of anode effects was used as an indication for dusty cells and increased focus on these cells. The dust is expected to prevent alumina dissolution in the electrolyte.

Every participant counteracts dusting with manual or crane/vehicle-based skimming of carbon dust. The skimming positions were anode hole during anode change, specific actions on corner anodes for reduction of carbon dust or on tap hole. Other individual measures on cells are decreasing feeding, so that the possibility of sludging is reduced, increased offset for new anodes, and the change of voltage targets (increase or decrease). While most increase the voltage target in order to reduce the risk of squeezing of the ACD, two participants decrease the voltage, as the resistivity of bath decreases at higher temperatures.

On a bigger scale, the improvement of anode quality by increased fire cycles in the anode baking furnace, a decrease in amperage in the potline or a decreased anode rota time was mentioned, if a big part of the cell population was affected.

The carbon dust skimmings are mostly disposed as waste. Some smelters would feed back the skimmings with anode cover material or even sell it as product. One participant mentioned a dedicated separation plant, with the recycled bath being fed back to the cells and the carbon particles sold as a product.

### **3. Systematical Carbon Dust Audits**

The findings from the industry survey were combined with the findings in the literature review, partially published in 2021 [5]. Additional and anecdotal information and interviews with industry specialists from different companies were used to form a systematical plant audit. The audit is divided in three parts: potroom operations, anode rodding and butts, and data analysis for both operations and anodes. It should include an observation and sampling part.

#### **3.1 Anode Rodding and Butts**

Anode rodding information can give an indication on the general condition of the rods and the operations in the rodding shop. The surface of anodes can be checked for residual packing coke from the baking furnace and the cleanliness of the anodes. Also, the positioning of stubs in the stub holes should be centered and distribute the pressure from the expansion during heat-up equally in all directions within the anode.

Taking a look at the butts coming back from shot blasting can give an indication, whether the butts used for the next generation contain sodium (white, residual bath on the butts) or are soft butts from previous airburn. Burned out corners can show problems of covering in the potrooms, the residual footprint of the anode which had a general lack of cover material. The residual butt weight gives a good indication of airburn, if reported for a longer time.

#### **3.2 Potroom Operations**

As part of the potroom operations audit, one should take a look at a significant number of cells with similar anodes, currents, and conditions (e.g., 10 % or 30 %). The main indicators for dusty cells can be:

- Amount of dust in taphole: Gudmundsson published a 3-level system, which is easy to use [2]
- Amount of airburn on anodes (visible), on taphole and feeder positions
- Black dust settling on top of anode cover material
- Yellow flame color
- Crust and cover integrity on anodes half through the anode rota.

By assessing these factors, one can compare the data sets for different groups and find a common or different picture.

#### **3.3 Data Analysis**

The third part is the data analysis of operational cell and anode data as well as specific sampling of the bath and anode cover material. For the cells, the most important data are bath temperature, superheat, voltages, and anode effects. Anecdotes show problems especially for cells with temperatures 30 °C above the target bath temperature and superheat above 20 °C. Lower target

bath temperatures in smelters with LiF in the electrolyte are less likely to have dusting issues. Also, check if the analysis of excess  $\text{AlF}_3$  and the expected value fit the bath temperature and liquidus temperature. The number of anodic incidents, like spikes, mushrooms, cracked and broken anodes have to be analysed. The number of early anode changes due to airburn can give a good indication, as do the butt weights. Quantifying the impact of operations, the numbers of late anode changes and late anode covering are important, as both likely to lead to an increased dusting.

For anodes, the analysis of impurities like Ca, Na, Ni, V, and S, but also the figures for air reactivity residue and dust and respective carboxy reactivity residue and dust show tendencies for the thermal reactivity during the process. The mechanical strength gives the likelihood for the breaking of anodes.

Sampling of the following materials can help focusing on the problem:

- Bath samples for “dusty” and “non-dusty” cells at a well-defined position in the cell (e.g., middle of tap hole, 5 cm below bath surface; the height is important, as most carbon particles tend to float on top)
- Manual and vehicle/crane-based carbon dust skimming: this can give an idea of the skimming efficiency when comparing manual skimming with equipment-based skimming. The manual skimming will most likely include a higher carbon percentage.
- Anode cover material and the carbon percentage contained has proven to be a good indicator for dusting (see 4.2).

Thresholds for critical limits cannot be named universally, as they are subject to cell technology and operating window. This is shown in section 4.2, where a processing step in butts cleaning leads to very high carbon contents in anode cover material.

#### **4. Examples of Results for Plant Audits**

In the following sections, two examples from plant audits will be described. While the first one will discuss the quality of rodded anodes, the second one goes deeper into base levels for concentrations.

##### **4.1 Quality of Rodded Anodes**

In one of the plants, during a walk through the potroom, it was noted that the anodes still had packing material from the baking furnace on the side and surfaces. The potroom management and the carbon plant management were aware of that problem. The plant changes 40 anodes per pot every 24 days. Scraping off the material of two anodes gave approximately 200 g of residual coke each on those anodes. This results in 200 kg/24 days of carbon dust skimmings, considering a reasonable 5 % carbon content. The plant has been suffering from a high carbon content for at least two years (no data available earlier) in the anode cover material ranging between 1.5-3.0 % C in the anode cover material (ACM).

As packing coke has been burned multiple times, the reactivity is low compared to anode carbon. This carbon dust is less likely to gasify during normal operations. The issue of only 200 g of packing coke per anode produced about 20 t of carbon dust skimmings per month, before any oxy- and carboxy-reaction takes place in the pot.

## 4.2 Carbon Concentration in Anode Cover Material as a Lagging Indicator

According to Sadler et al. [1], a variation of the carbon content in the secondary alumina between 0.15 and 0.5 % is to be expected. This is in line with the data from Perruchoud et al. [8] in that they found a value of 0.3 % for non-dusting cells and 0.6-0.8 % for dusty cells.

In a comparison of four different smelters, various baselines were found. Figure 1 shows the respective carbon contents in the anode cover material over several months. Smelter 1 has had a very high carbon value in its anode cover material historically due to the rough butts cleaning with steel balls [9]. Smelter 2 has had values between 1.5 and 3 %, probably due to packing coke sticking to anodes.

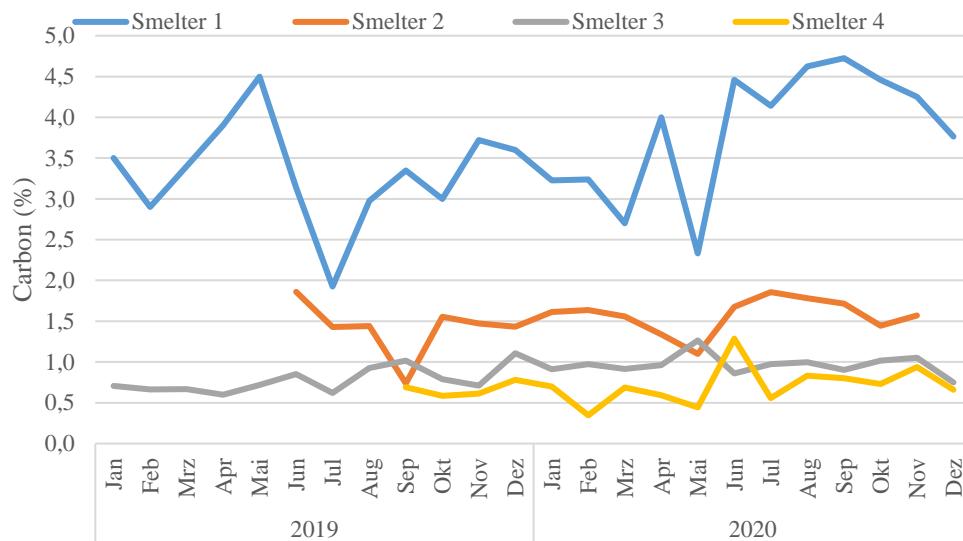


Figure 1. Carbon content in anode cover material for 4 smelters.

Smelters 3 and 4 use partially anodes from the same supplier. The main difference is accessibility for anode covering and the height of anodes above the deck after anode change. While the anodes in smelter 3 have a height of approximately 20 cm above the deck, the anodes of smelter 4 only stick out by 5 cm. This leads to more airburn on the upper 20 cm of anode in smelter 3, leading to an overall higher net carbon consumption. Additionally, the lower height above deck plate helps with the angle of repose of anode cover material.

Looking at the carbon content in smelter 3 and 4, smelter 3 has a peak in May 2020, while smelter 4 has a peak one month later. Both are affected by problems in the bake furnace in February to March 2020. Both smelters do react with a delayed increase of one full anode rota with increase and decrease afterwards. Smelter 3 used these anodes in March and April, while smelter 4 only started using them in April. The bake furnace was rebuilt during that time; the anode quality increased also due to the increase in fire cycle from 26 to 36 hours to accommodate the renovations. This shows, that the ACM can be used as an indicator for previous dusting, lagging with a full anode rota behind.

## 5. Conclusions

A systematic approach by combining a literature review with an industry survey has helped formulate a structured and systematic carbon dust audit. These audits were conducted in several plants and have shown pitfalls in the understanding of carbon dust and its indicators.

Performance indicators used for monitoring must be adapted to a given plant, as plants can differ structurally from each other, leading to other baseline values. The comparison of absolute values can lead to wrong assumptions in the process and operations quality evaluation.

The future work will involve the investigation of the carbon content in anode cover material over the anode cycle and the influence of carbon dust on anode current distributions and anode cathode distances. These experiments should help identify further process parameters, which can be monitored.

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