# DUST GENERATION AND ACCUMULATION FOR CHANGING ANODE QUALITY AND CELL PARAMETERS

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## ABSTRACT

The amount of dust generated by anodes in the cells was estimated by using a model, that takes into account the following:

- the synergetic effect of anode permeability, reactivity and thermal conductivity
- the increase in $CO_2$ burn near the end of the anode lifetime due to previous airburn occurring on the anode top
- the exponential increase in dusting propensity towards the end of the anode cycle
- the impact of current intensity, anode cycle length and anode density

The model was validated in different smelters using different technology.

## INTRODUCTION

Fischer et al [1] quantitatively describe the impact of the anode quality on carbon consumption. The application of quality figures for $CO_2$ and airburn is discussed by Keller [2]. The critical lower limits of these anode quality figures will be largely related to dust accumulation in the cells until a given potroom can work without certain problems [3,4].

In addition to excess carbon consumption of the anode, dusting has the following detrimental effects;

- the dust particles in the electrolyte act as an electrical insulator and raises the bath resistance therefore increasing the cell temperature
- a substantial loss in current efficiency
- a deterioration in the properties of new anodes that have been made from butts, which have become soft from dusting

The amount of dust that accumulates in the system is dependent on the cell design and the cell operating conditions. Increasing the current intensity or the number of anode cycle days can also have deleterious effects. Therefore knowledge of the dust generation due to changes in anode quality or cell parameters is of utmost importance.

In this paper a dust generation formula has been developed and a quantitative relationship between the anode and cell parameters and the dust generation is derived using the previously presented carbon consumption equation and data [1].

Equation (1) is a simple multiple linear regression that was established using the average anode quality figures and cell parameters referred to as 'standard conditions' displayed in Table 1.

A. Tomsett and J. Johnson (Eds.), *Essential Readings in Light Metals*

$$NC = C + \frac{334}{CE} + 1.2(BT - 960) - 1.7CRR + 9.3AP + 8TC - 1.5ARR \tag{1}$$

where NC = net carbon consumption kgC/tAl
C = cell factor kgC/tAl
CE = current efficiency -
BT = bath temperature °C
CRR = carboxy reactivity residue %
AP = air permeability nPm
TC = thermal conductivity W/mK
ARR = air reactivity residue %

**Table 1** 'Standard Conditions' - the average anode quality figures and cell parameters used for equation 1.

| PROPERTY | | UNIT | MEAN | $2\sigma$ |
|---|---|---|---|---|
| $CO_2$ Reactivity Residue | $CRR_o$ | % | 85 | - |
| Air Permeability | $AP_o$ | nPm | 1.5 | - |
| Thermal Conductivity | $TC_o$ | W/mK | 4 | - |
| Air Reactivity Residue | $ARR_o$ | % | 80 | - |
| $CO_2$ Reactivity Dust | $CRD_o$ | % | 3 | 3.8 |
| Air Reactivity Dust | $ARD_o$ | % | 3 | 5 |
| Apparent Density | $AD_o$ | kg/dm$^3$ | 1.55 | 0.02 |
| Anode Height | $AH_o$ | cm | 52 | - |
| Cycle Days | $D_o$ | days | 26 | - |
| Current Density | $CD_o$ | A/cm$^2$ | 0.8 | - |

## DUSTING MODEL

### BASIC CONSIDERATIONS

The linear regression formula (1) is a very useful tool for predicting the net carbon consumption but does not give precise indications on the quantity of dust generated in different situations especially for changes in the combination of anode cycles days, anode density and current intensity. It was also observed that the $CO_2$ burn is not independent of airburn and that poor airburning always activates $CO_2$ burning. This results from airburn reducing the anode height and increasing the gas permeability of the anode volume that is later submitted to the $CO_2$ attack. Therefore a large reduction in the butt height can produce extreme dusting and eventually soft butts.

It is also known that a small percentage of atypical anodes can lead to a cell dusting issue and therefore the variability of the key anode properties has to be taken into account. Finally the synergetic effect of the permeability and reactivity (and thermal conductivity for airburn) on the burning behaviour must be integrated.

### DUST GENERATED DUE TO AIRBURN

The dust generated from airburn is a combined function of the air reactivity dust, air permeability and thermal conductivity. A multiplicative approach of these terms was used to give equation (2).

$$D_{AB} = a\frac{CDo}{CD}AP \bullet \left(\frac{TC}{TCo}\right)^m (ARD + 2\sigma) \tag{2}$$

where:
$D_{AB}$ = Dust generated by the airburn kg /tAl
a, m = Constants -
AP = Air Permeability of anodes nPm
ARD + $2\sigma$ = Air Reactivity Dust of anodes(X+ $2\sigma$) %
TC = Thermal Conductivity of anodes W/mK
$TC_0$ = Thermal Conductivity for standard conditions W/mK
CD = Current Density A/cm$^2$
$CD_0$ = Current Density for standard conditions A/cm$^2$

By considering the excess anode consumption due to airburn (with constant $CO_2$ burn) it was found that:

$$D_{AB} = \frac{3AP \bullet TC}{40CD} \bullet (ARD + 2\sigma) \tag{3}$$

The coefficient of 1.5 for the air reactivity residue used in equation (1) is therefore a value from equation (3) valid for the standard conditions, showing a permeability of 1.5 nPm and an (ARD+$2\sigma$) of 3+5=8%.

### DUST DUE TO $CO_2$ BURN

#### Impact of the current density

In a laboratory study [5] it was observed that a decrease in excess carbon consumption (EC) due to $CO_2$ burn for an increase in current density (at a constant bath temperature and butts height) can be described over the industrial range by equation (4)

$$\frac{dEC}{dCRR} = -\frac{1.7}{(CD + 0.2)^2} \tag{4}$$

where CRR is the $CO_2$ reactivity residue in %.

#### Impact of a variable butts height

An increase in the cycle days, a lower anode density or a higher current density reduces the height of the butts. This increases $CO_2$ burning due to a decrease in resistance to $CO_2$ gas permeation [6, 7, 8]. This applies to increases in the amount of airburn, which also reduce the butt size [9, 10].

Trials with varying cycle lengths [11] have confirmed that the amount of dust generated dramatically increases with longer anode cycles. Measurements have shown [12] logically that the reactivity dust and permeability for the butts also increases. It is assumed that the increase in dusting tendency with longer cycles is proportional to the increase in [Air permeability x $CO_2$ dust] values. Therefore a normalised ratio referred to, as the $CO_2$ burn dust factor has been developed to describe this influence. The ratio value of 1 is calculated using 26 days and a butts height $BH_o$ of 14cm as standard conditions. The relationship is illustrated in Figure 1.

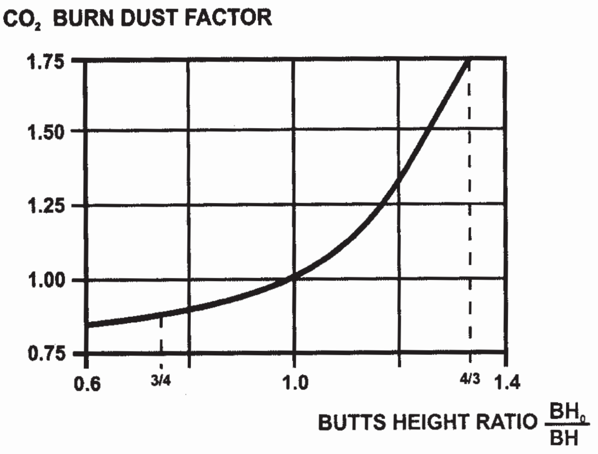

**Figure 1** Impact of the butts height on the $CO_2$ burn factor ($BH_0$ = 14 cm)

With longer cycle days, in this case 2 additional days, a butts height ratio of BHo/BH =4/3 gives a 75% increase in the dusting propensity. The final butts height is a complex function of the initial anode height, cycle days, current density and anode density and the amount of airburn that occurred on the anode top during the first days. The butts height of anodes having different cycle lengths and showing different airburn levels due to variations in air reactivity and thermal conductivity have been examined. Equation (5) describes this relationship.

$$D_{CB}=\frac{0.5AP}{(CD+0.2)^2}\left(\frac{1}{6}\left(\frac{1}{\frac{AH}{14}-0.118\left(\frac{D\bullet CD}{AD-2\sigma}\right)^{1.2}}\right)^6+0.83\right) \qquad (5)$$
$$\bullet\left(\left(\frac{0.0125TC(100-ARR)}{3}\right)^2+0.89\right)(CRD+2\sigma)$$

AP = Air Permeability nPm
TC = Thermal Conductivity W/mK
CD = Current Density $A/cm^2$
D = Cycle Days days
AD = Apparent Density of Anodes $kg/dm^3$
ARR = Air Reactivity Residue %
CRD = Carboxy Reactivity Dust %
$2\sigma$ = Respective standard deviations of ARD, CRD and AD
AH = Anode Height cm

The bracketed term, multiplying the (CRD + $2\sigma$) value, represents the increase or decrease in $CO_2$ dusting due to variation in the anode butts height. This is termed the 'Anode Butts Usage Factor' and is equal to 1 for standard conditions. The coefficient of 1.7 for the $CO_2$ reactivity used in equation (1) is therefore from equation (5) valid for standard conditions showing an air permeability of 1.5nPm and a (CRD + $2\sigma$) of 3 +3.8% =6.8%.

## UTILISATION OF THE DUST FORMULA

### THE IMPACT OF ANODE QUALITY

The total dust ($D_{AB+CB}$) calculated for varying levels of anode quality is illustrated in Table 2:

The total dust generated by air and $CO_2$ burn for poor quality anodes is four times higher than for those of standard quality. For high anode quality the dust is four times lower than typically observed.

**TABLE 2** Dust generation due to different anode quality using standard cell parameters

| *Dusting* | *ARD* % | *2σ* | *ARR* % | *CRD* % | *2σ* | *AP* nPm | *TC* W/mK | $D_{AB}$ kg/tAl | $D_{CB}$ kg/tAl | $D_{AB+CB}$ kg/tAl |
|---|---|---|---|---|---|---|---|---|---|---|
| Poor | 6 | 10 | 65 | 6 | 8 | 2.5 | 5 | 19 | 24 | 43 |
| Average | 3 | 5.0 | 80 | 3 | 3.8 | 1.5 | 4 | 4.5 | 5.1 | 9.6 |
| Good | 1.5 | 2.5 | 90 | 1.5 | 2.0 | 1 | 3 | 1.1 | 1.5 | 2.6 |

**IMPACT OF CURRENT INTENSITY**

Given that changes in the current intensity are counterbalanced by the cycle length then the dust generation decreases as shown by equation (3) and (5). For a constant cycle length the situation changes dramatically beyond a critical threshold as indicated in Figure 2.

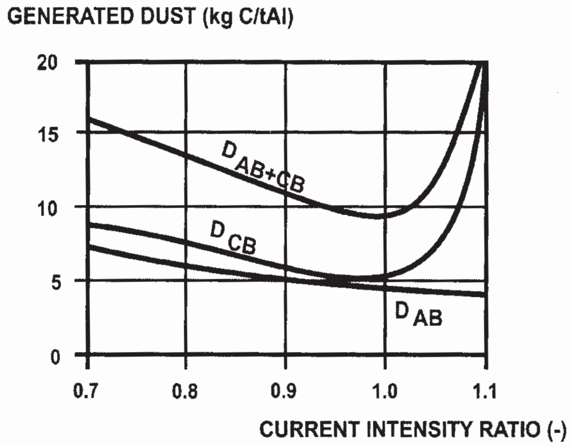

**Figure 2** Impact of the current intensity ratio on the generated dust for a constant cycle length using standard conditions (table 1)

The dust generated by airburn reaches a minimum around a nominal current intensity where the anode quality level provides rather hard butts. Below the critical threshold, approximately half the airburn dust enters the electrolyte while the remainder stays deposited on the anode top surface. Above the critical threshold this dust is rapidly carried into the electrolyte. Figure 3 demonstrates how an increase in the current intensity from 1.02 to 1.06 i.e. by 4% augments the amount of dust entering the electrolyte by more than 50%.

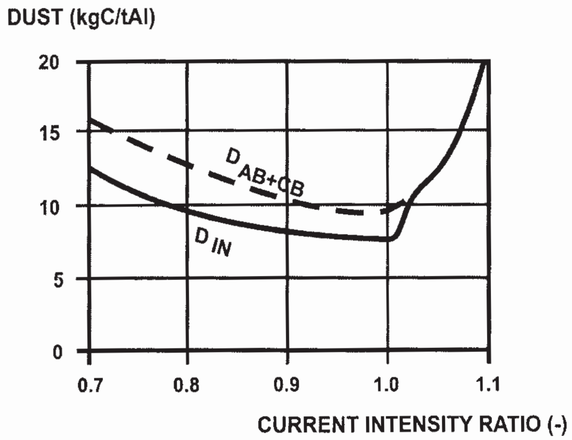

**Figure 3** Quantity of dust entering the electrolyte directly from the anodes ($D_{IN}$), compared to the amount of dust generated ($D_{AB+CB}$) by the anodes at different current intensities for a constant cycle length.

**IMPACT OF THE CYCLE LENGTH**

The relationship between the cycle days and the quantity of dust entering the electrolyte is given in Figure 4 for standard conditions.

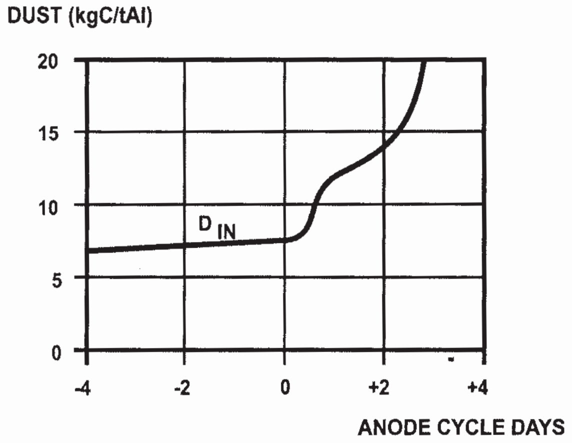

**Figure 4** Quantity of dust entering the electrolyte for varying anode cycle length.

For the given data the amount of dust entering the electrolyte is fairly constant until the cycle length (set at 0 in Figure 4) is altered. The amount of dust coming into contact with the bath doubles by keeping the anodes in the cells for 2 days longer than usual. Figure 4 demonstrates how reducing the cycle length helps ease dusting problems associated with using anodes of inferior quality.

**IMPACT OF ANODE DENSITY**

If the density of the lightest anodes (x-2σ) is in phase with the current intensity and the cycle length, the dusting will remain low. Figure 5 shows that this is valid as long as the apparent density (X-2σ) does not drop 0.02 kg/dm$^3$ below the nominal value for the standard conditions.

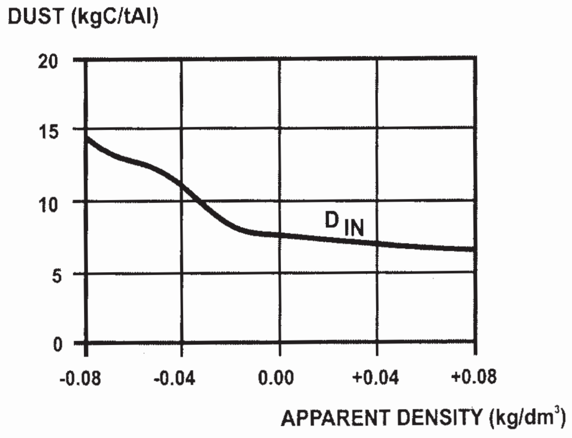

**Figure 5** Amount of dust entering the electrolyte when the apparent density (X-2σ) changes

A sharp increase in the dusting by 50% is observed for a density change of 0.03kg/dm$^3$ below the threshold. In reality as low apparent density values are associated with higher permeability levels (a factor of 2 for every 0.03 kg/dm3) the dusting is even more sensitive therefore illustrating the importance of consistent anode density levels.

**IMPACT OF THE ANODE HEIGHT**

A common approach for reducing the gross carbon consumption is to reduce the anode height. Figure 6 shows that it is not possible below a given threshold, as dusting might become an issue.

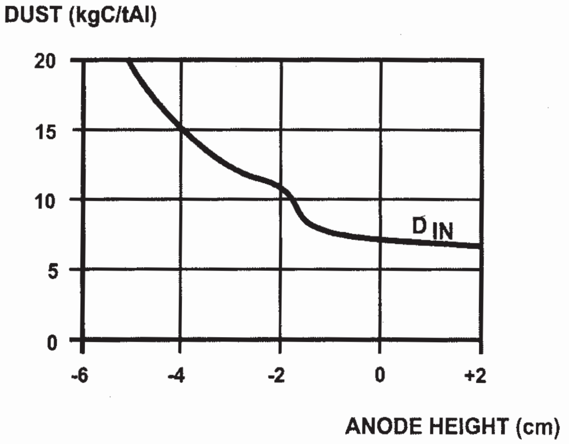

**Figure 6** Quantity of dust entering the electrolyte ($D_{IN}$) for different anode heights.

For the standard conditions, decreasing the height by more than 1 cm below the usual level will increase the amount of dusting (by 50% for 2 cm). However care must be taken when increasing the anode height as well as airburn of the exposed top surfaces will occur. An optimum anode height is reached when both problems are controlled.

**DUST ACCUMULATION**

The dust accumulation is a major parameter when deciding the critical limits of anode quality figures and the anode cycle length. Each type of cell can cope with a certain amount of dust. Above this specific threshold, dust accumulates in the cells, potentially causing operational difficulties.

The carbon content of the alumina rises as soon as carbon begins to accumulate in the bath. For normal potrooms operations, the carbon content of the alumina does not exceed 0.3% while in extreme anodes dusting situations, concentrations of 0.6-0.8 % can be found.

However the quantity of dust in the recycled alumina is not directly proportional to the dust generated. As a rule of thumb an increase in the amount of dust generated by four corresponds to an increase in the dust concentration in the recycled alumina ($C_{Al_2O_3}$) of two.

For example if the alumina had an initial concentration ($C_{O;Al_2O_3}$) of 0.3 %, and the amount of dust generated increased from 5 to 20 kg C/tAl (Do to D), the carbon concentration of the recycled alumina would increase to 0.6 %. This relationship can be expressed as (6):

$$C_{Al_2O_3} = C_{O;\,Al_2O_3} + 0.5 \log \frac{D}{D_O} \tag{6}$$

The slope of the dust ratio logarithmic function and the initial concentration of the alumina value are related to the cell type and skimming practices. For sidebreak cells the slope is rather small (< 0.1), but this increases significantly for point feeders (up to 1). Due to the metal and bath movements driven by the magnetic fields, carbon dust gathers in the cell corners, which are only accessible to skimming once a week. Continuous monitoring of the recycled alumina carbon content allows rapid countermeasures to be made (lower cycle days, higher skimming rate) as required.

## VALIDATION OF THE MODEL

**LONG-TERM REACTIVITY DUST DETERIORATION**

In a smelter with side by side 180 kA cells, the amount of skimmed materials, measured in terms of cell groups, increased steadily over a month to reach a peak value of twice the usual level. This is illustrated in Figure 7. Fortunately the carbon content in the recycled alumina remained quite low as the workforce made efficient daily cell skimming.

The calculated quantity of generated dust corresponds reasonably with the measured amount of skimmed material even though it is clear that only part of the dust is skimmed as the majority of skimmed material is bath. An analysis to determine why the dusting tendency of the anodes deteriorated has shown that both the anode air and $CO_2$ reactivities were responsible.

The deterioration of the anode selective burning was due to problems at the butts cleaning station, that were fixed by mid year. Due to the skimming policy no decrease in the current efficiency was noticed over the entire observation period.

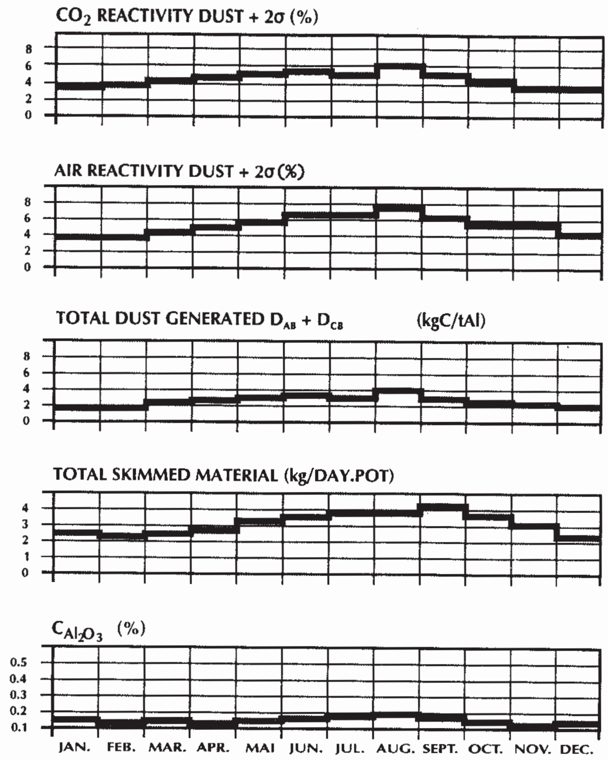

**Figure 7** Evolution of the total skimmed material in bath and the carbon content in alumina as a function of the total dust generated from the anodes

## SHORT-TERM REACTIVITY VARIATION

In a smelter with end to end point feeder cells, the number of skimming actions had to be increased dramatically (by a factor of two), six weeks after a deterioration in the air and $CO_2$ reactivity began. This is shown in Figure 8. The carbon content in the recycled alumina increased considerably two weeks later and operational difficulties leading to a lower metal production output were experienced.

Efficient and frequent skimming were needed for the next four months even though the deterioration period with significantly higher dust generation had lasted for less than two months. This demonstrates how it takes at least one generation of anodes to notice the first signs of dust accumulation but that skimming is still needed two months after good anodes have been reintroduced into the cells.

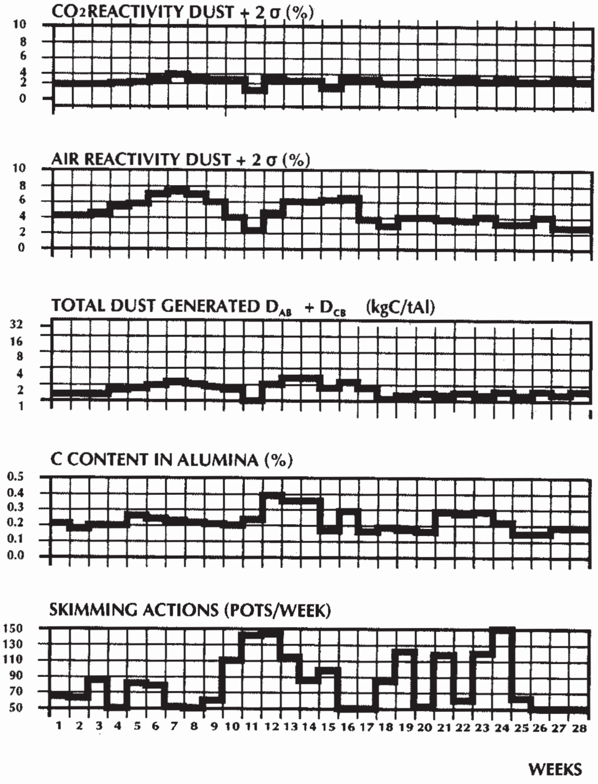

**Figure 8** Calculated dust generation of anodes compared to recycled alumina carbon content and the skimming actions needed

Despite the response time delay, the two periods of anode deterioration can be identified in the carbon content of the recycled alumina and in the number of skimming actions required.

## LONGER CYCLES AND LOWER ANODE DENSITY

It has been shown in the previous examples, that poorer selective burning of the anode caused the increase in dusting. A deterioration in the anode density coinciding with an increase in the permeability has the potential to be just as dangerous. In the following example, a large amount of dusting occurred when it was attempted to increase the number of cycle days by 3 shifts. The process had just been changed when a problem in the anode density (Figure 9) occurred, while the air and $CO_2$ reactivity dust remained constant.

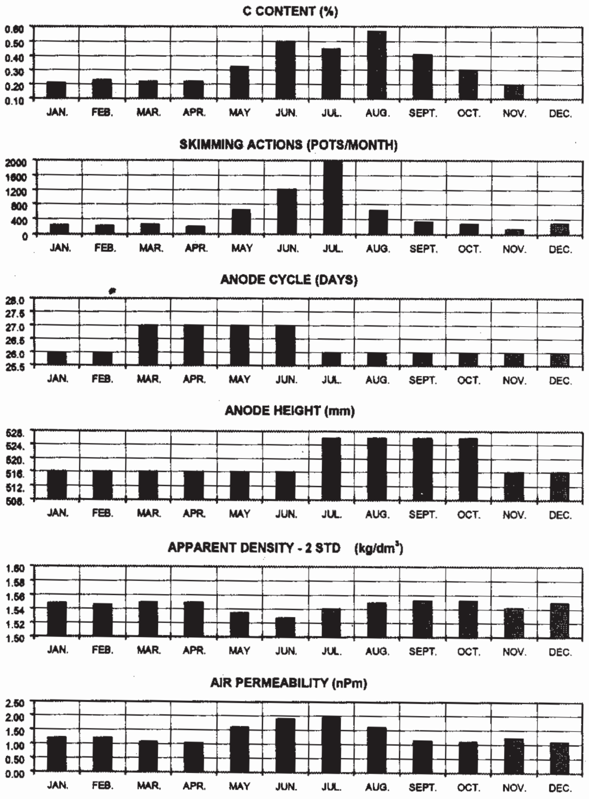

**Figure 9** Increasing the cycle length followed by a deterioration in the anode density and permeability led to a dusting problem.

The anode butts usage factor (Figure 10) increased by 20% around March/April due to the increase in the cycle length. It increased by a further 20 % around May/June due to an unfortunate decrease in density. The calculated dust generated by the anodes increased steadily from 4 to 7 kgC/tAl in June at which time the Alumina carbon content peaked at 0.5 %, despite the increase in skimming actions by more than 7 times the normal level.

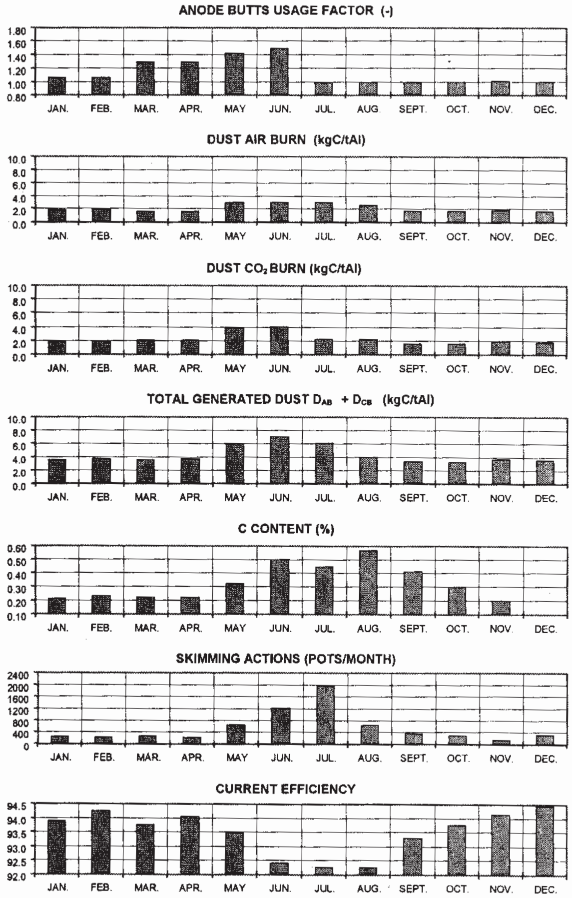

**Figure 10** The total generated dust as calculated by the model corresponds to the increase in skimming actions rate and the decrease in current efficiency.

The situation only improved in September after the anode height was increased, the cycle days reduced and the anode density and permeability had resumed typical levels. Anodes were returned to the normal height in November without further problems.

The decrease in current efficiency was almost 2 %. The anode quality problem was related to the use of a low bulk density coke during the summer period.

## CONCLUSIONS

Dust accumulation is the result of many different factors that are often hard to detect. The impact can vary depending on the cell design, the anode source and the time of detection.

The importance of the interrelationship between dusting and not only the anode quality but also the appropriate anode dimensions and cycle days has been demonstrated. The role played by the height of the anode butts in the last cycle days and the exponential increase in the amount of dusting towards the end of the anode cycle were also shown.

The model was validated for different situations and can be used to predict the amount of dusting that will occur for given anode usage and electrolysis conditions.

## REFERENCES

1. Werner K. Fischer, Felix Keller, Raymond Perruchoud, "Interdependence between Anode Net Consumption and Pot Design, Pot Operating Parameters and Anode Properties", Light Metals 1991, 681 - 686
2. Felix Keller, "Anode Quality Figures", Anode for the Aluminium Industry 1995", 355 - 357
3. K. Grjotheim, C. Krohn, J. Thonstad, "Einige offene Fragen bei der heutigen Aluminiumelektrolyse", 5. Internat. Leichtmetalltagung 1968, 343 - 346
4. T. Foosnæs, T. Naterstad, M. Bruheim, K. Grjotheim, "Anode Dusting in Hall-Heroult Cells", Light Metals 1986, 729 - 738
5. Sheralyn M. Hume, Mark R. Utley, Barry J. Welch, Raymond Perruchoud, "The Influence of Low Current Densities on Anode Performance", Light Metals 1992, 687 - 692
6. Eric Barrillon, "Les Facteurs de la Consommation de Carbon Anodique dans les Cuves destinées à la Production Electrolytique de l'Aluminium", V-Aluminium I.C.S.O.B.A. 3e congrès 1973, 691 - 699
7. B.A. Sadler, S.H. Algie, "Macrostructural Assessment of Sub-Surface Carboxy Attack in Anodes", Light Metals 1989, 531 - 540
8. B.A. Sadler, S.H. Algie, "A Porosimetric Study of Sub-Surface Carboxy Oxidation in Anodes", Light Metals 1991, 687 - 698
9. Wolfgang Schmidt-Hatting, A.A. Kooijman, Raymond Perruchoud, "Investigation of the Quality of Recycled Anode Butts", Light Metals 1991, 705 - 720
10. Wolfgang Schmidt-Hatting, A.A. Kooijman, "Correlations between Anode Properties and Anode Performance", Light Metals 1994, 701 - 709
11. Wolfgang Schmidt-Hatting, A.A. Kooijman, "Optimization of the Anode Carbon Consumption with Respect to Butt Recycling", Light Metals 1993, 579 - 585
12. Werner Fischer, Raymond Perruchoud, "Interdependence between Properties of Anode Butts and Quality of Prebaked Anodes", Light Metals 1991, 721 – 724