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A DEMAND FEED STRATEGY FOR ALUMINIUM ELECTROLYSIS CELLS

K. R. Robilliard and B. Rolofs *

Gränges Aluminium Metall AB
Sundsvall, Sweden

A demand feed strategy is described which ensures optimal feed rates of ore to aluminium electrolysis cells. The strategy is monitored by observing pot voltage and fine-controlled by adjustment of ore feed rates. Satisfactory operation is achieved by a combination of automatic temporary adjustments made by individual pot controllers, and by more permanent manual adjustments of ore feed rates.

The feed strategy has been operated for a number of months in the new No 1 potline at Gränges Aluminium in Sundsvall, Sweden. It has been shown to raise current efficiency, reduce the risk of muck formation and even reduce energy consumption by limiting anode effect frequency.

INTRODUCTION

A serious problem in the operation of an aluminium electrolysis cell is that the concentration of alumina ore in the bath is of a very limited range, in the order of 2.5 to 6%. If the concentration falls below this range, then the cell can experience what is termed an anode effect. This phenomenon occurs when bath resistance increases and pot voltage rises dramatically to 20 to 50 volts. On the other hand, if the alumina ore concentration exceeds the above range, the bath becomes saturated. The excess ore falls to the cathode and forms a layer of muck. This is undesireable since the mucky layer provides a resistance to the electric current and the pot can become overheated. This can affect the production of metal by lowering the pot´s current efficiency(1).

Feeding strategy should ideally seek a compromise somewhere between the two extremes of underfeeding (onset of anode effects) and overfeeding (onset of muck).

A relationship between bath alumina concentration and cell voltage is described in Figure 1 (1). A minimum of cell voltage corresponds to an ore concentration of about 3.5-4.5%. Bath voltage rises as ore concentration increases. It also rises, more dramatically, as ore concentration decreases (anode effect). Figure 1 would provide an ideal operating curve if it were possible to measure ore level in the bath. Unfortunately this is impractical because of the uncertaincies in sampling and analysis. On the other hand, the measurement of pot voltage is easy and reliable, and indeed is a very important operating parameter. The present work describes the measurement and monitoring of pot voltage to determine feed strategy

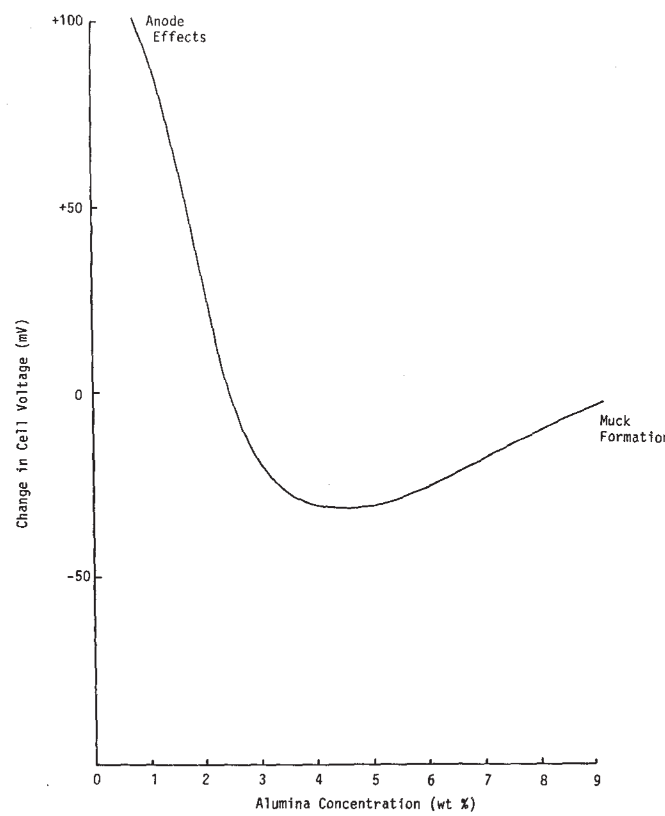

Figure 1: Variation of Cell Voltage with Alumina Concentration

CURRENT EFFICIENCY

The aim of aluminium smelter operation is often to operate at the highest possible current efficiency (CE). CE is measure of production rates, vis á vis energy consumption. It is a mathematical expression, derived from Faradaic laws of electrolysis (2). In modern aluminium smelters of pre-baked design, CE s of 90 to 95 % are not uncommon. The higher the CE, the better

* Hoogovens Aluminium Hüttenwerk GmbH,
Voerde,
West Germany.

the operation and the better the potential for generating revenue, other factors being equal.

Feeding strategy has an important influence on current efficiency. An underfed pot which persistently has anode effects will exhibit low current efficiency on account of there being insufficient ore available for electrolysis.

Similarly, constantly overfed pots also exhibit poor current efficiency because of the artificial resistance to electrical current, caused by muck formation, and the squeezing of anode-cathode distance to compensate for this. This has a detrimental effect in overheating the pot.

Lillebuen and Mellerud (3) have calculated current efficiencies using a mass transfer approach. They have found that a minimum of CE occurs at a bath level of about 4% Al_2O_3. The position of this minimum is a function of gas bubble retention times, and, consequently, of anode geometry. A dramatic rise in CE was calculated for Al_2O_3 concentrations less than that corresponding to minimum CE. This corresponds to the left side of the voltage trough of Figure 1, and represents a bath lean in alumina. The rise in CE continues as the bath becomes leaner and leaner in alumina, due to reduced gas bubble area, but it is of course restrained in that region by the onset of anode effects. If the anode effect frequency can be limited, however, then maximum CE can be obtained by operating on the left side of the curve of Figure 1.

ALUMINA FEED RATE

An excellent way to determine a cell's current efficiency is to study its feed rate over a long period. If one is operating away from the trough region of Figure 1, then feed rates are expected to be low:

- if the pot is exhibiting too many anode effects and the pot is overfed as described above,

- if the pot is mucky, then actual feed rates are reduced to address the situation.

THE PRESENT SCHEME

The present work involved programming a sequence into the pot line's computer control system. The sequence was to determine feed rate as a function of cell voltage.

The sequence is described in Figure 2 and it is divided into four steps:

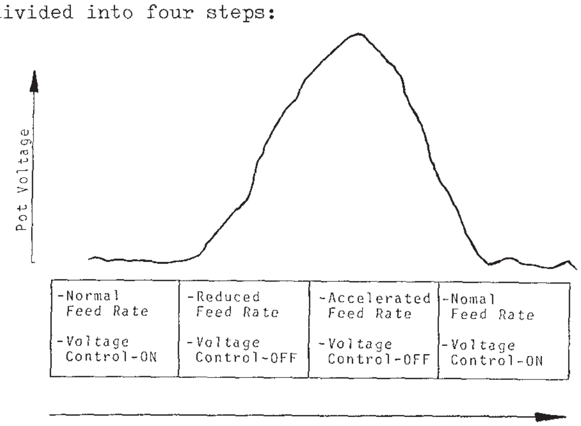

Figure 2: Diagrammatic Scheme of Demand Feed Program

1. A period where the feed was on at a "normal" rate, with voltage control (anode movement) active. Since each point feeder delivered varying amounts of ore, for each dump, the feeding interval (the operating variable) lay in the region 50 to 70 seconds, giving an average feed rate of about 1.4 kg/min, for each feeder. The feeding interval was adjusted manually, as required.

2. This was followed by a period of reduced feed (at ½ the normal feed rate) and voltage control inactive. The voltage was allowed to rise or fall.

3. It is expected, eventually, that voltage will rise as the pot operation reaches the left side of Figure 1. When the pot voltage had risen significantly, then the computer ordered accelerated feed for the pot (at double normal feed rate) with voltage control inactive.

4. Pot voltage was allowed to fall with accelerated feed rates and as the voltage began to approach the set point again, the computer ordered normal feed with voltage control active. This was completion of the cycle. The cycle was repeated with a period of normal feed as in Step 1, above.

The Transition from Normal Feed to Reduced Feed (Step2)

As mentioned above, it is expected that, as alumina feed is reduced, pot voltage will rise. This will only happen, however, if the pot is not overfed. If the pot is overfed, i.e. operation occurs on the right side of the trough of Figure 1, it can be clearly seen that as feed is reduced, and as alumina concentration falls, then voltage will fall. A trace of voltage as a function of time, where the controlled voltage under normal feed suddenly falls during reduced feed and voltage control inactive, indicates immediately that the pot has been overfed. It is necessary to check then if the pot has become mucky. If not, a manual reduction of feed rate (in the "normal"feed mode) was all that was required to address the situation

The Strategy in Practice.

The feeding sequence was tested on the pots in the new No 1 Potline recently started up at Gränges Aluminium, in Sweden. The plant operates 56 point-feeder pots at 145 kA line current, and is fitted with computer control of both voltage anf feed rate. The annual production is 23 000 tons.

Pot Controllers.

Each electrolysis cell in the line was fitted with a pot controller. This device, developed by Kaiser Aluminium and Chemical Company of Oakland, California, and termed CELTROL, was responsible for automatic voltage control, anode effect termination, noise analysis anf control, as well as control of ore feed rates, anode movement on tappiing and automatic jack raising. The sequence described above was programmed into each of the 56 CELTROL units. The variable parameters were pot voltage above the set point and multiples (i.e 1x 2x, ½x etc.) of the set point feed interval (50-70s).

RESULTS AND DISCUSSION

Figure 3 shows a voltage trace as a function of time. The pot in question was overfed since the voltage fell each time the sequence passed from normal feed (voltage control active) to reduced feed (voltage control off). From this observation alone, a satis-

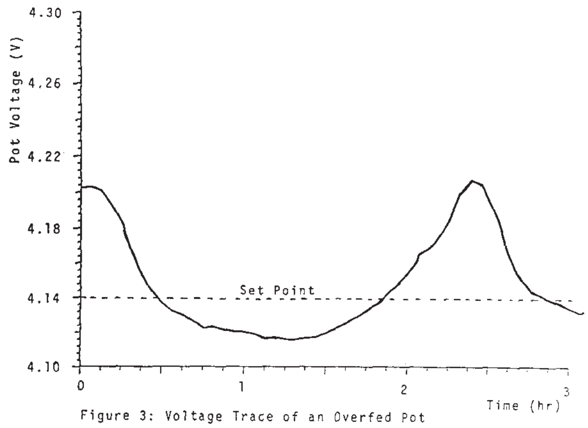

Figure 3: Voltage Trace of an Overfed Pot

factory adjustment to feed rate was made. After making this adjustment and operating for several hours the pot voltage trace was that of Figure 4. This trace shows a series of symmetrical peaks:

- the rise in voltage on reduced feed is immediate,

- the fall in voltage when switching from reduced feed to accelerated feed is also immediate.

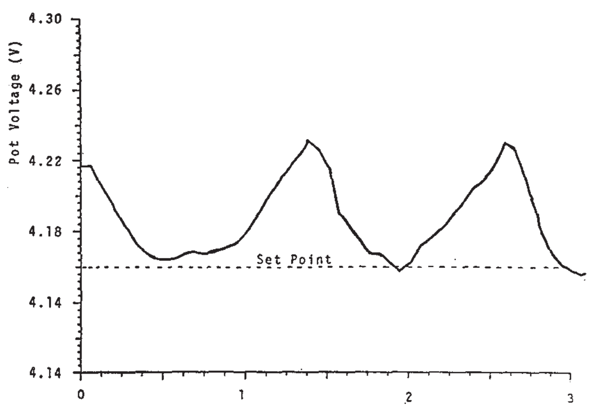

Figure 4: Voltage Trace of a Normally Fed Pot

Actual Feed Rates.

The actual feed rates of cells operated in the two règimes:

- 'overfed' as indicated by the trace of Figure 3,

- 'cleaned' as indicated by the trace of Figure 4,

were compared.

Despite the fact that the pot was overfed, its overall feed rate was much less than for the cleaned pot, as indicated in Table I.

This paradox arises since the overfed pot, with a low anode effect frequency was 'starved' to artificially produce an anode effect in a crude form of feed control. Because the pot is overfed, the length of time the pot is starved is high and as a result, there is very little

Table I. Feed Rates of 'Overfed' and 'Cleaned' Pots

Condition	Feed Rate (kg/min)
Overfed	1.11
Cleaned	1.22

ore reaching the pot. There exists also the phenomenon that the pot, despite muck in the metal pad, can experience an anode effect and without much improvement to its condition, can revert to an situation of overfeeding.

Table I indicates that because actual feed rates where increased whilst operating the Feed Strategy, that the pot is expected to exhibit a higher current efficiency. Indeed, it is thought that the Feed Strategy is largely responsible for the current efficiency of 94% exhibited in the operation of this potline.

Modifications to the Strategy.

There were two major problems which arose, in the operation of the Strategy in its original form. It was found that some pots were going onto anode effect on reduced feed, before accelerated feed could restore ore bath levels to normal. Furthermore, whilst in the accelerated feed regime, there was a risk that the pot be overfed whilst waiting for the voltage to drop. Thus, a number of modifications were made to the program:

- if the pot voltage exceeded the set point by too wide a margin, then double-accelerated feed (feed rate x 4) was initiated. This was maintained until the pot voltage fell back again, at which point the pot reverted to accelerated feed (normal feed rate x 2).

- if the reduced feed rate continued for two hours without the pot voltage rising significantly, then the pot controller initiated a special reduced feed règime (12.5% of normal feed rate) until the pot voltage began to rise. The sequence then jumped to reduced feed (normal feed rate x $\frac{1}{2}$) until the pot voltage had risen sufficiently that the normal sequence could be continued with accelerated feed.

- if normal potroom activities, such as anode changing, tapping, jack raising etc. were initiated on the pot, or if the pot became noisy (where pot voltage kicked over 80mV) or if the pot experienced an anode effect, then the sequence automatically jumped to the start of the cycle, with normal feed and voltage control.

- the sequence continued as normal if a temporary addition to set-point voltage was made.

Ideal Feed Rates.

By studying the number of reduced feed peaks on the pot voltage trace, over a period of time, it was possible to evaluate an ideal feed rate for the pot.

It is expedient that the amount of time the pot remain on reduced feed, then accelerated feed, (i.e. On the slopes of the peaks) be as short as possible. It was found that the total cycle time, normal feed, reduced feed, accelerated feed, should ideally be about two hours, at most 12 cycles per 12-hour period. This ensures maximum response of voltage to changes alumina concentration.

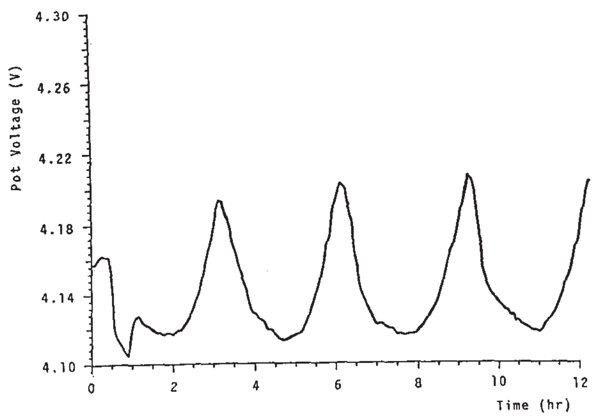

Figure 5: Pot Overfed; 12 hr Trace

Manual adjustment of ore feed rates were made to achieve this result, according to Table II, and to Figures 5, 6 and 7.

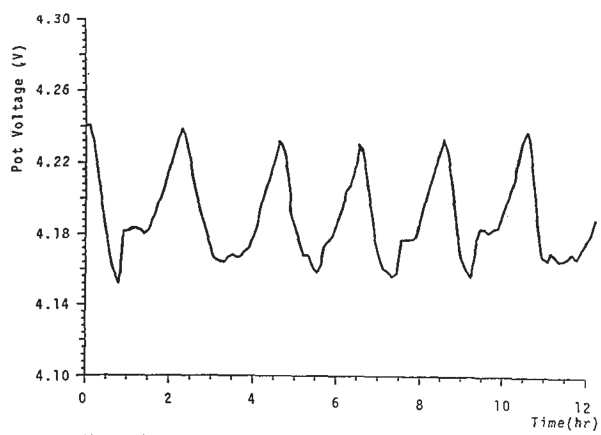

Figure 6: Ore Feed Rate Satisfactory

Table II. Adjustment of Feed Rates from Voltage Traces.

Peaks in 12h Period	Feed Rate	Remarks
below 5	Decrease	Pot overfed, Figure 5
5 to 8	No change	Pot normal, Figure 6
above 8	Increase	Pot Underfed, Figure 7

Feed rates were adjusted by gradual feed interval increments of $\pm$ 1 second, checked over a period of 8 - 12 hours, then adjusted again, if required.

Anode Effect Frequency.

An important corollary to this work was the sharp reduction in the anode effect frequency, from one anode effect per pot per day, to below 0.5.

In normal potroom operation, a controlled anode effect frequency (of, say one per pot per day) is

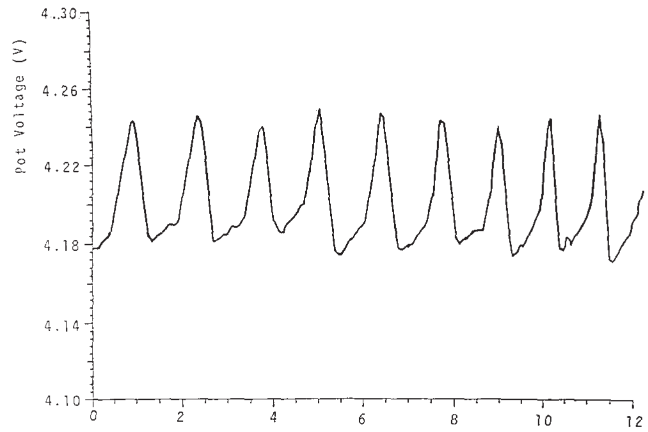

Figure 7: Pot Underfed

required to act as a form of feed rate control. Pots which have not experienced an anode effect within the previous 24 hours are 'starved' into anode effect and prevent overfeeding. With the present work, however, there is already an effective feeding control strategy in progress, and the use of anode effects to control feed was therefore redundant. By care ful study of each pot's voltage trace, and adjustamnet of the feed rates, on a shift-wise basis, anode effects were curtailed so that frequencies of 0.2 - 0.4 anode effects per pot per day were quite common. Furthermore at least one pot was operated without an anode effect for several weeks, without any serious consequences.

The potential savings in energy costs are significant. The actual pot voltages were 4.19 volts, 0.03 volt above the set point. Work is continuing on this matter with the aim to reduce anode effect frequencies even further.

Anode Effect Termination.

Part of the pot control system employed in the line involved an automatic anode effect termination sequence. The sequence included a series of crust breaking, ore dumping and anode movement, with the aim of terminating the anode effect with the minimum of operator involvement. One point which was unclear in the sequence, however, was the number of dumps of ore required to:

- terminate the anode effect, while to
- keep the pot from being overfed.

In other words, the AE termination sequence required, ideally, a minimum amount of ore to be dumped into the bath to restore the Al_2O_3 level to normal.

By studying the voltage traces of the pots before and after the anode effect, and by closely monitoring the termination success rate, this was made possible.

Figure 8 shows a typical voltage trace where overfeeding had occurred during the AE termination (68 dumps of ore). The curves on the left of the AE peak are normal (the sharpness of the curves c.f. Figure 4 indicates slight underfeeding). The area to the right of the AE peak, however, is flat followed by a long shallow curve. This shows slow response to the next sequence of reduced feed and it indicates that the pot was overfed during the AE termination.

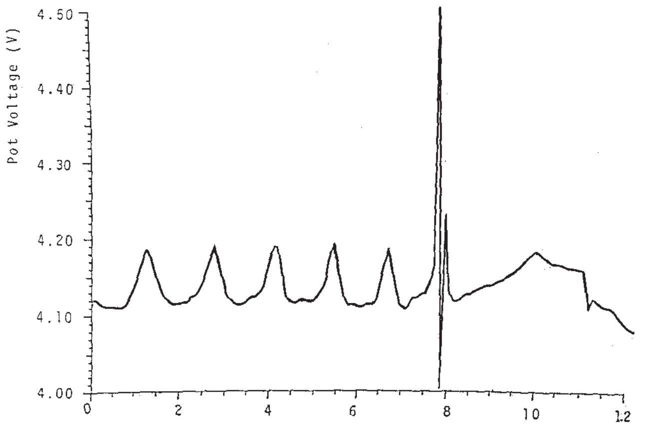

Figure 8: Overfeeding After Anode Effect Termination

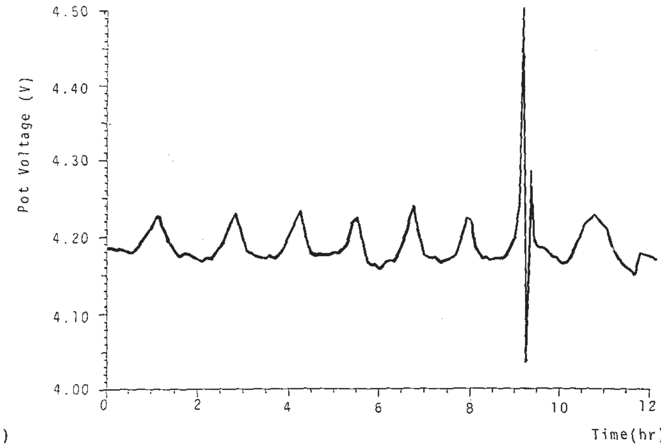

Figure 9: Anode Effect Termination Achieved with Reduced Ore Feed

Subsequently, a study was made to successively reduce the amount of ore fed during the AE termination by observing the resultant voltage traces. The result of this is shown in Figure 9. It can be seen that the shapes of the peaks before an after the anode effect are very similar. From this, it was concluded that the AE termination sequence had not over fed the pot (44 dumps). At the same time, it was noted that the AE termination sequence was successful in terminating at least 90% of all anode effects in the potroom.

It was concluded that:

- a reduced number of ore dumps than calculated was required because the anode movement within the AE termination sequence helped to stir the bath and to blend alumina-lean areas of bath (eg under the anode) with those areas rich in alumina (between the anodes).

- an extension of this work allowing each pot to 'choose' the amount of ore feed required to terminate the AE, according to the pot's condition (the above situation was universal for the whole line). This would be extended to the case where no ore at all is required to terminate the AE (as has been demonstrated by the authors). This applies particularly to mucky pots.

CONCLUSIONS

The demand feed strategy described in this work has been shown to be beneficial in potroom operation by:

1. Maximising current efficiencies, by assuring optimal feed rates of ore to the pots.

2. Reducing energy consumption by allowing a drastic reduction in anode effect frequency.

3. Ensuring relatively trouble-free operation by preventing muck formation; especially reducing the risk of pots being overfed after anode effect termination.

While control of this strategy occurs by a combination of automatic and manual adjustments to the feed rate, further work will investigate the possiblity of total automatic adjustment. Furthermore, work continues in the modification of this program with the view to reducing the anode frequency even further. A frequency of below 0.1 anode effect per pot per day is thought possible.

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