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POTLINE AMPERAGE INCREASE FROM 160 kA TO 175 kA DURING ONE MONTH

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Abstract

Higher cell amperage now seems to have become a trend in the operation of Hall-Héroult potlines. If it can be done, higher amperage is beneficial to improve the economics and productivity of the process. Many types of prebake cell technologies have shown that they can tolerate a considerable increase in amperage without serious cell operating problems. One vivid example of this is the end-to-end prebake point-fed cells at the Hydro Aluminium Sunndal smelter, which originally were designed for 150 kA. There the amperage of fourteen test cells was increased from 162 to 175 kA in two months in 1997. This gave no serious operating problems and the current efficiency was maintained at the same level as before. In the summer of 1999 the amperage of the remaining one hundred and seventy cells in the potline was increased by 15 kA to 175 kA during one month. This would certainly not have been done without the valuable experience gained from the operation of the fourteen test cells. The measurement program and the operational experiences of this very fast amperage increase are described and discussed.

Introduction

The Hydro Aluminium prebake potline at Sunndalsøra was started in 1968 with one hundred and sixty eight end-to-end side-worked prebake (SWPB) cells designed for 150 kA. These cells were of the similar technology as was used in the Årdal I line started the following year. However, due to poor magnetics the Sunndal cells were operated at 135 kA for several years. The line amperage was later increased to 150 kA after a reconstruction of the busbar system, which drastically improved the magneto-hydrodynamic conditions in the cells. The number of anode stubs was then increased from two to three. Various other technological improvements, like additional magnetic compensation, use of larger anodes and introduction of point feeding of alumina, allowed the cells to be operated at 160 kA in 1997. The number of cells had then been increased to one hundred and eighty four.

Through a successful combination of technical and organisational changes it was then shown that it was possible to transform this relatively old prebake potline to the technical and productivity standards that are required to be competitive at present and in the future. Also the more demanding modern regulations for environmental protection and occupational working conditions were fulfilled. The previous modernisation of this potline has been described by Moen et al. (1).

A photograph of a section of the end-to-end prebake potline at the Sunndal plant is shown in Figure 1.

Figure 1. End-to-end point-fed prebake cells in the Sunndal III potline.

In 1996 it was believed that an additional amperage increase was possible, and a project was started the following year to increase the amperage of fourteen test cells in the potline to 175 kA.

This paper describes the measurement program and the operating results of this amperage increase, which was done during two months only. The program was so successful that it was decided to make a corresponding increase in amperage for the remaining one hundred and seventy cells in this potline. The experience from this work will also be discussed here.

Why higher amperage?

The cheapest way of producing more aluminium is to increase the amperage of the existing cells, if operational difficulties can be avoided. With a constant current efficiency the rate of metal production is of course directly proportional to the amperage. The rate of back reaction of aluminium to alumina is proportional to the metal surface area, so theoretically the current efficiency will increase with increased amperage. The major cost of the extra metal produced will be the costs of alumina, anode carbon and electricity.

The main reason why the cell amperage has traditionally been kept constant in the past, has been the fear of running into operational trouble, because of changes in the heat balance of the cells. An increase in the amperage must be compensated by a reduction in cell voltage to keep the energy input constant, or it should be combined with an increase in the heat loss from the cell to maintain the heat balance. Increased net heat input will lead to a thinner side ledge and ultimately an increased risk of a tap-out through the cell side.

Thus, an additional disadvantage with higher cell amperage is the risk of causing cathode problems and thereby shorter cell lives. For a potline like Sunndal III, the increase in metal production by an amperage increase of only 2 kA is economically equivalent to an increase in pot life from 5 to 6 years. Thus, if it is possible from an operational point of view, an amperage increase is economically very beneficial in most cases.

The Sunndal line was well suited for an amperage increase. These cells were originally SWPB cells, with a wide side channel for alumina feeding by a wheel breaker. The large distance between the anode shadow and the sidewall gave room for an anode enlargement.

In the last decade the cell amperage has indeed been increased in many potlines world-wide. Previously, most lines were operated at fairly constant amperage, and the anodic current density was typically between 0.70 and 0.80 A/cm^2 for most prebake cells. In the 1990s amperage increases have become more common among aluminium smelters and interesting examples can be found in the literature (2-4). This trend is expected to continue in the years to come.

Booster cells

In attempts to increase the amperage, the use of test cells is certainly of crucial importance. With only a limited number of cells involved, they reduce the economic and technical risks in any type of tests and make it easier and faster to discover the potential of the cells. In the present case we did not build any new prototype cells, but used a group of ordinary cells, chosen among the existing cells in the potline.

The number of test cells, or booster cells, can vary from project to project, but usually 4 to 6 may be suitable. However, in the present high-amperage test we wanted to have more cells than this. It was decided to select 14 test cells for the preliminary trials. Fourteen cells were an arbitrary choice, mainly because this is the number of cells in one section in the potline. This was judged to be a sufficient number of cells to give reliable results from the test, and also sufficient for testing of the operational routines at this higher amperage.

The magneto-hydrodynamic conditions were considered a crucial point for the test cells. The return booster busbar was placed so that the magnetic conditions of the test cells were as close as possible to the conditions that would prevail in the full potline at the same amperage. Still this was not good enough, due to the lack of a neighbouring row of cells with the same amperage. In retrospect, we were aware of this, but did not pay enough attention to it.

Technological changes of the booster cells

The anodes were enlarged from 1370 mm to 1510 mm so the anodic current density was kept constant at 0.83 A/cm^2 when increasing the current from 160 kA to 175 kA. To accommodate the larger anodes the anode beam had to be expanded sideways by 7 cm. In practice this was done by using small pieces of aluminium, which were bolted onto the anode beam at each anode stall position.

The number of anode stubs was increased from three to four, but there was no change in the anode stub diameter.

The magneto-hydrodynamic conditions were improved by increasing the cross-sectional area of the anode riser on the upstream side of the cell. This also reduced the temperature of the anode riser. Cathode flexibles were connected to the compensation busbar to increase the current through it and to improve magnetics.

Project groups and measurement program

Two project groups were formed before the amperage increase was made. The first group consisted of the project leader, the reduction manager, the potroom manager and the head of the technical department. The second group was a contact forum consisting of process supervisors and operators. From the beginning, proper information was considered to be of crucial importance in the project. It was very important that the potroom personnel felt that the test cells were their cells, so a lot of effort was paid to have good contact between all persons involved in the project throughout the whole test period.

Operational procedures and programs for measurements were carefully prepared before the start of the test. It was emphasized to bring in different types of personnel into the project. Certainly, people from the Hydro Aluminium Technology Centre in Årdal participated actively. The people, who had made the basic theoretical model calculations, participated in setting up the measurement program and also in the follow-up of the tests. Weekly meetings and monthly reports were considered necessary.

Extra operational follow-up was found to be necessary in the following areas:

1) Faster recording of the anodic current density on cells with high electrolyte temperatures.

2) Causes of anode effects were recorded.

3) Electrolyte and metal heights were measured every 32 hours, as compared to every 64 hours for the rest of the cells in the potline.

Acceptance criteria for operating parameters

Before the test was started, a number of acceptance criteria were chosen for evaluation of the operating parameters and results. These criteria, chosen to characterize the project as a success or failure, are listed below:

- Current efficiency should be at the same level as the rest of the cells in the potline. There should be no negative development during the test period, and the standard deviation should remain the same.

- Energy consumption should be less or equal to 14.3 kWh/kg Al. The standard deviation should not increase from its starting value.

- Cell voltage should be reduced according to theoretical calculations, in order to maintain the heat balance in the cells.

- Noise level should be the same as before (no increase in cell voltage instability).

- Superheat should also remain the same, with no increase in its standard deviation.

- Side ledge thickness should not be reduced.

- Cathodic resistance should not increase compared to cells of the same age operated at 162 kA.

- Anode effect frequency should remain the same.

- Unscheduled anode changes should not cause any increase in gross anode consumption.

Amperage increase rate

The amperage of the fourteen test cells in the Sunndal III line was increased from 162 kA to 175 kA in four steps. The amperage increases were done on the following dates:

Date:	Amperage increase:
January 30, 1997:	+ 3.5 kA
February 3, 1997:	+ 2.5 kA
March 13, 1997:	+ 3.0 kA
April 7, 1997:	+ 4.0 kA
Totally in 68 days:	+ 13.0 kA

Operating results for the test cells

The increase in amperage caused no serious operating problems. Current efficiencies were determined by the copper tracer method every 6th week. The average value for the fourteen test cells in the period from May 1997 through April 1999 was 92.0 %, as measured with copper tracer. This is approximately the same current efficiency as was obtained for the rest of the potline in the same period.

Current efficiency data are shown in Figure 2. It is seen that the monthly variation was much less after August 1998, when the cell voltage was reduced.

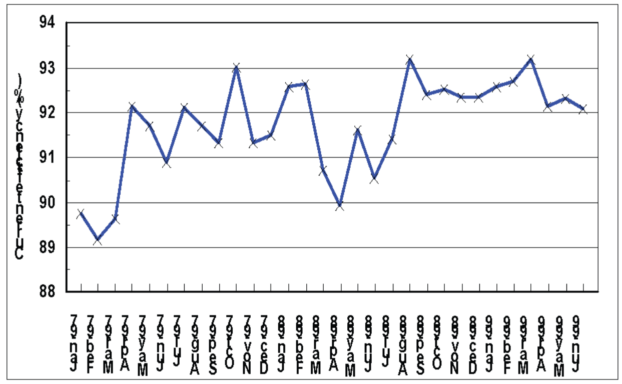

Figure 2. Current efficiency of the test cells for a 2.5-year period.

A number of measurements were done to verify the theoretical calculations on cathode, anode and busbars. No significant deviations from the calculated values were found.

The cell voltage was calculated to 4.30 V at 175 kA, in order to keep the same side ledge thickness as for cells operated at 162 kA. The calculated interpolar distance was then 3.9 cm, as compared to 4.8 cm before the amperage was increased. This implies 19 % reduction in interpolar distance, which is quite substantial.

The bottom freeze had been reduced in spite of the higher metal height, which actually should be expected to give the opposite reaction.

The increase in cathodic voltage drop was less than expected (50-60 %). This has been caused by reduced bottom freeze (see Figure 4 shown later), combined with a higher temperature inside the cathode blocks, which resulted in a higher electrical conductivity.

The electrolyte volume in the test cells was reduced due to larger anodes and reduced interpolar distance. The addition of aluminium fluoride increased by 9 % because of increased consumption of alumina. The daily addition of aluminium fluoride from the AlF_3 feeder decreased by 30 % and the ratio between the daily variation in the fluoride content in the alumina and the daily addition by the AlF_3 feeder increased from 1.4 to 2.1. The AlF_3 control then became more difficult than before.

This situation was improved when the amperage was increased in the whole potline, because the average aluminium fluoride content in the alumina added to the cells was reduced.

The electrolyte temperature range was from 955 to 965 ^oC. The electrolyte composition was kept between 10 and 12 % AlF_3. The metal height was raised 2 cm from 22 to 24 cm in the first period of the test to make sure that the magneto-hydrodynamic stability was good enough.

Data for cell voltage and electrolyte composition for the fourteen test cells are shown in Figure 3. It can be seen that from July 1997 to May 1998 there was a steady 100 mV increase of the cell voltage. The reason for this was that operators and supervisors were in charge of the set point resistance, and every time the cells got noisy and cold they increased the resistance. In June 1998 the potroom manager took control over the cell voltage and forced the voltage down by adding a lot of soda ash to compensate for the increased aluminium fluoride concentration in the electrolyte.

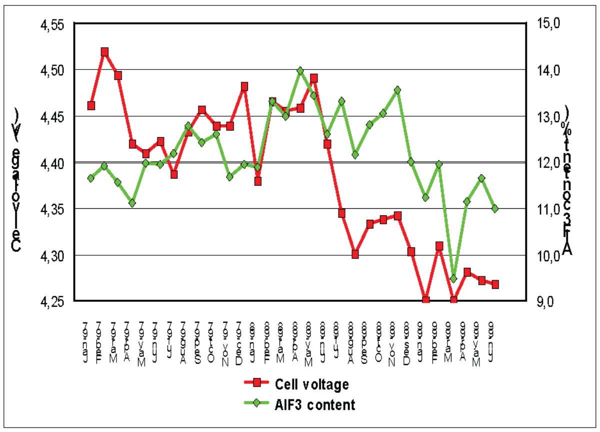

Figure 3. Cell voltage and AlF_3 content in the electrolyte for the fourteen test cells.

From June 1998 to April 1999 the energy consumption of the booster cells was close to 14.0 kWh/kg Al, which was 0.9 kWh/kg Al lower than for the rest of the cells in the Sunndal III line in the same time period.

Conclusions from the work on the test cells

The test cells were operated at 175 kA for fifteen months before the decision was made to go ahead and do the necessary modernisation of the whole potline. This period might have been shortened by about six months if the cell voltage had been reduced earlier.

For approximately one year the test cells were operated about 150 mV higher than they should have been. A learning lesson was that the voltage has to be reduced simultaneously with the increase in amperage and not afterwards.

Another learning experience realized after the amperage was increased on the whole potline was that one might miss some important information when operating a limited number of test cells. Because of this it is very important to stick to the Standard Operating Procedure (SOP) and record all kinds of deviations in the operational routines or the cell performance.

The focus on SOP and accuracy in the work on the test cells were beneficial also for the rest of the potline, because every shift worked on the test cells and they brought the operational improvements with them also to the other cells in the potline.

Many measurements were made to verify the calculations on anode, cathode and busbars. There were not found any significant deviations from the calculated values. The positive experiences from the test cells gave the potroom people the necessary confidence that was needed for operation at this high amperage.
It was then decided to go ahead and make a similar amperage increase for the remaining cells in the potline. If this test period had been abandoned altogether, the amperage increase in the line would probably have had to be done much more slowly.

Amperage increase in the rest of the potline

Project organisation

After the successful completion of the work on the test cells, the budget allocation for modernisation of the whole potline to accommodate a 15 kA amperage increase was given in August 1998. The actual work was finished in April 1999.

A project group was formed to take care of the day-to-day operation and evaluation of the results obtained. The potline operators and supervisors were of course informed about these evaluations and of the necessary consequences during the project. The potline management made all decisions concerning set point resistances, use of additional cell voltage and additions of aluminium fluoride. The experiences gained from the test cells indicated that especially the determination of the set point resistance was crucial, and the potline management therefore did this themselves.

In order to facilitate the spread of information to the supervisors and operators, a comprehensive information system was developed. All the necessary information was gathered on one single sheet of paper, which made it very easy to follow and control the operational conditions in the potline.

Amperage increase

The amperage in the potline was increased from 160 kA to 175 kA in the period from May 10 to June 15, 1999. Thus, the cells received 15 kA higher amperage in one month only. This was done by increasing the amperage by 2 or 3 kA in six steps in this time period. This is high enough to get a response that can be observed, but also small enough to avoid serious operating disturbances.

All the seven available rectifiers were used during the first year of operation after the current was increased, each of them with a capacity of 25 kA. Then a new rectifier of 47.5 kA was purchased, and the potline then could go back to the usual N-1 operation. This means that there is now enough rectifier capacity for an additional amperage increase up to 197.5 kA with N-1 operation.

The metal height was increased slightly (0.5 – 1.0 cm on average) to be on the safe side with respect to the magneto-hydrodynamic stability. The metal tapping program was adjusted to account for the extra metal produced to avoid an extra increase in the metal height.

In due time before the amperage increase started the cast house and dry scrubbing departments were contacted and informed.

Operating results and experiences

The process of the gradual amperage increase can be described briefly in the following way:

- New larger anodes with four stubs were gradually set into the cells
- These anodes and yokes conducted more heat upwards from the cell, and the temperature of the electrolyte decreased
- The amperage was then increased 2 to 3 kA
- The electrolyte temperature increased
- The cell voltage was lowered to the target
- The electrolyte temperature then decreased
- The amperage was again increased 2 to 3 kA
- And so on.

The development of the amperage and the cathodic resistance in the potline are shown in Figure 4.

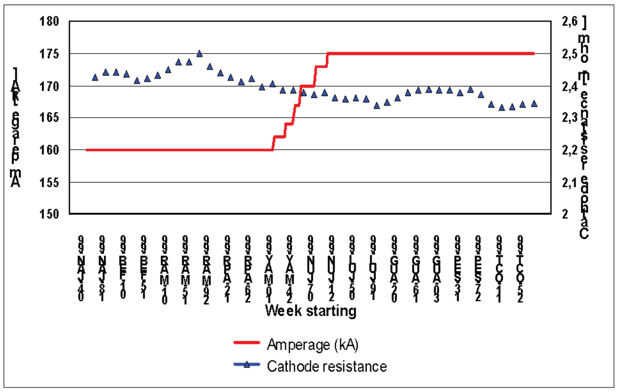

Figure 4. The development of amperage and cathodic resistance for the Sunndal III potline.

One of the main challenges during the period of increasing amperage was to stabilize the electrolyte composition (AlF_3 content) and the electrolyte height. The larger anodes with four stubs and the reduced interpolar distance led to increasing electrolyte height, lower electrolyte temperature and increasing AlF_3 concentration.

By introduction of the larger anodes and reduced interpolar distance the electrolyte volume was reduced by approximately 18 %, and a lot of extra electrolyte tapping was necessary. This was not experienced in the booster cells because the amperage was not increased so fast, and it took a longer time to reduce the interpolar distance. Data for the electrolyte height and electrolyte tapping and addition are shown in Figure 5.

At the end of the period of the amperage increase the situation changed, and it was necessary to add extra electrolyte from the Sunndal Söderberg potline. The reason why it went from a situation with too much electrolyte in the cells to too little, was less space for adding crushed electrolyte in the side channels with a newly set anode. The addition of crushed electrolyte went down approximately 30 % and the mass balance was not fulfilled.

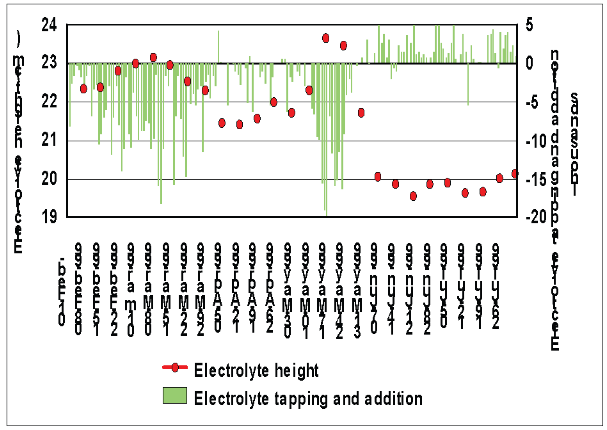

Figure 5. Electrolyte height and tapping/addition for the Sunndal III potline.

AS mentioned earlier, an important learning experience from the work with the fourteen test cells was the problem with reduction of the set point resistance after the amperage had been increased to 175 kA. Thus, for the remaining cells in the line it was decided to reduce the set point resistance each time the amperage was increased. This implied that an amperage increase was used to raise the electrolyte temperature when it was low, and after a few days when the temperature had been stabilized in the target range, the set point resistance was lowered to its target.

Because it was decided never to increase the set point resistance, the only action taken in cases when some cells became very cold was to adjust the electrolyte composition by adding soda. A delay of the anode changing was also used to raise the electrolyte temperature.

On the basis of the experience from the operation of the potline in the early stages of the amperage increase, there was really nothing that indicated that 175 kA would be the obvious final amperage. However, with decreasing interpolar distance the noise level increased steadily, and it then became gradually more difficult to reach the target for the set point resistance. It is of course crucial to maintain the heat input to the cells. If not, the unavoidable results would be higher superheat, reduced side ledge thickness and gradually increasing number of sidewall problems.

Again the test cells were important in the evaluation of the situation in the whole potline. When the amperage in the line was increased, the booster current was gradually lowered, and the magneto-hydrodynamic conditions for the test cells got closer and closer to the conditions of the whole potline until the amperage reached 175 kA.

The alternative of having a temporary halt in the amperage increase at for example 170 kA in case of operational problems was considered to be a possibility beforehand. However, during the course of the process things went quite well and it was decided to go up to 175 kA as fast as possible, mainly for economic reasons. We then knew that 175 kA was possible from the work with the test cells. To stabilize the potline at 175 kA before the summer vacation started was also an argument for a fast increase of the amperage.

One important experience from the amperage increase in the whole potline is how to avoid an increase in superheat. Too high superheat leads to problems with reduced current efficiency, side ledge and cathode lifetimes. A too high AlF_3 concentration in the electrolyte leads to an increase in the noise level and thereby an increase in the resistance. A reduction in the AlF_3 concentration in the electrolyte from 12 to 11 wt. % together with a reduced metal height, made it possible to reduce the resistance to reach the target for energy consumption in November-December 1999.

Also the anode changing operation and the simultaneous proper cleaning of the electrolyte were found to be important regarding reduction of the cell resistance.

The anodic current density was not changed when the amperage was increased, because the anode surface area was increased correspondingly. On this basis it was not necessary to alter the anode-changing schedule. However, the anode height was increased from 56 to 60 cm when the larger anodes were introduced, and therefore the anode-changing rota was increased to 88 shifts, compared to 80 shifts before the amperage increase.

The metal surface curvature increased after the amperage was raised. This required a close follow-up of the corner anodes particularly, and some corrective action in the burn-off program was made. No unscheduled anode changes were required and no red cathode shell sides were observed.

There has been a gradual development of the cathode lining of the cells in the Su III line. This has been going on irrespectively of the amperage increase project. The last main change of the cathode design was done 5 years ago and included a 300 mm enlargement of the length of the cathode blocks. Today approximately 20 % of the cells in the line have the old cathode design with short blocks.

There was a slight increase in the anode effect frequency, and it was 0.03 anode effects/cell-day higher than for the booster cells. The main reason for this was a slightly higher noise level.

In the period from June to September 1999 the current efficiency went down from 92.5 % to 90.5 %. However, an increase in metal height indicated that the real current efficiency probably was higher than indicated by the tapping figures. In the following months the tapping was increased to maintain a constant value for the metal height. Thus, problems with cold cathode bottoms and bottom ledge formation were reduced.

In November and December 1999 the current efficiency increased to the 92.5 % level again. For the first three quarters of 2000 the average current efficiency was 92.6 % and the energy consumption was record low at 14.2 kWh/kg Al at 174.8 kA. This is 5 % lower energy consumption than in 1998. Also the gross anode consumption value of 505 kg C/tonne Al was lower than ever in the history of this potline. It was very encouraging to learn that these cells operate so well at this high amperage. Data for current efficiency and energy consumption are shown in Figure 6.

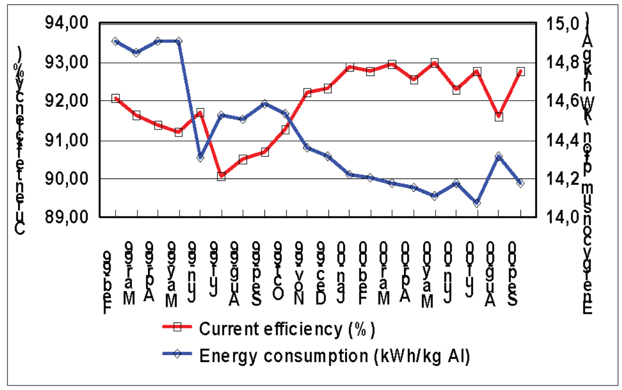

Figure 6. Current efficiency and energy consumption for the Sunndal III potline in 1999 and 2000.

Further work

The investment cost for this project was 1150 USD/tonne of aluminium produced per year. This is low compared to other Brownfield projects. The operating results so far have been very encouraging, and the present belief is that there is now room for even higher amperage in the potline.

Plans have been made to increase the amperage further to 190 kA. This will require a major change in the magnetic compensation, and two different ways of doing extra magnetic compensation will be tested on the booster cells. A larger anode stub diameter will also be implemented together with a new cathode lining. At 190 kA the anodic current density will have increased to 0.90 A/cm^2.

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