Light Metals 2013 *Edited by: Barry Sadler*
TMS (The Minerals, Metals & Materials Society), 2013

Light Metals 2013

ALUMINUM REDUCTION TECHNOLOGY

Cell Operations and Process Control

SESSION CHAIR

Pascal Lavoie
Light Metals Research Centre
Auckland, New Zealand

Light Metals 2013 *Edited by: Barry Sadler*
TMS (The Minerals, Metals & Materials Society), 2013

IMPROVEMENT OF ALUMINA DISSOLUTION RATE THROUGH ALUMINA FEEDER PIPE MODIFICATION

Jayson Tessier[1], Gary P. Tarcy[2], Eliezer Batista[3], Xiangwen Wang[2], Patrice Doiron[4]
[1]Alcoa Global Primary Metals, Center of Excellence, Deschambault,QC, Canada, G0A 1S0
[2]Alcoa Global Primary Metals, Center of Excellence, Alcoa Center, PA, USA, 15069
[3]Alcoa Global Primary Metals, Center of Excellence, São Luis, MA, Brazil, 65095-050
[4]Alcoa, Aluminerie de Deschambault, Deschambault, QC, Canada, G0A 1S0

Keywords: Alumina, Dissolution Rate, Feeder

Abstract

Aluminum reduction cells use about 1.9 kg of alumina in order to produce 1 kg of aluminum. That is, for modern reduction cells operating in the 350 to 400 kA range, 5000 to 6000 kg of alumina is fed daily. Considering that 5000 to 10000 kg of molten bath is available to dissolve the alumina, the dissolution rate is an important factor in order to avoid muck and enable alumina feed control system to operate within the 2 to 5% alumina concentration. However, on top of cell status, alumina properties have an impact on alumina dissolution rate. Hence, supplier changes and/or segregation of alumina within the delivery system may have negative impact on alumina dissolution rate leading to muck and/or anode effects. This paper discusses modification to an alumina feeder pipe promoting the dissolution rate. Promising results obtained during trial in a pilot plant section are presented and discussed.

Introduction

Industrially, aluminum is produced through electrolytic decomposition of alumina in a cryolitic melt. The reaction takes place in a Hall-Héroult cell where alumina powder is periodically fed to the cell. Depending on cell technology, alumina dumps can range from 1 to 2 kg for point feeders and up to few hundred kilograms for side break additions for older cell technology. Recently, aiming at a tighter control of alumina concentration, many older smelters started to convert to point feeders [1, 2]. This tighter alumina concentration control is beneficial in achieving higher current efficiency, lower energy consumption and optimizing other cell performance.

Aiming at maximizing output, many smelters have undergone modernization enabling load creep [3, 4]. This results in the capability of producing more metal for a given cell. Increasing load typically requires increasing the anode surface area to operate at a similar anode current density [3]. Doing so, due to the defined cell shell dimensions, the volume of bath available for alumina dissolution is reduced. Typically, load creeps are performed without adding additional feeders. Hence, in order to feed the required mass of alumina, the number of shots per feeder increases over a defined time period. As a result, more alumina is being delivered to the cells while less molten bath is available to dissolve it.

The process of alumina dissolution in a cell involves few stages. First, alumina needs to be heated from storage temperature up to the bath temperature, which is dependent on cell design and operating conditions. Secondly, it goes through an endothermic dissolution process. Finally, dissolved alumina needs to be mixed and distributed throughout the bath volume. Hence, during the overall process, enough heat must be available for the heating and dissolution processes and enough *fresh* (i.e. low alumina concentration) molten bath must be available for dissolution and mixing. Nevertheless, the dissolution process needs to be fast in order to dissolve the alumina before it settles down to the bottom of the cell. Therefore, one is mostly interested in alumina dissolution rate. A fast dissolution rate of alumina enables to dissolve the alumina before it settles down to the cathode. Such a situation is undesirable as it creates different operational problems leading to lower metallurgical performance of reduction cells.

Haverkamp and Welch [5] developed different models for the dissolution of alumina powder and compared them with experimental results. From their work, it is proposed that dissolution rate of alumina within the molten bath is controlled by a combination of heat transfer and diffusion phenomena.

Alumina dissolution rate is strongly dependent on how it is added over the molten bath surface, on pot condition and on alumina properties.

The importance of cell condition [6, 7], namely bath temperature, chemistry, velocity and alumina concentration on alumina dissolution rate have been studied in laboratory experiments. Industrially, these conditions can be controlled to a certain extent through proper process control and careful manual operations. However, it is well known that a broad range of operation conditions are encountered in a typical smelter, due to excursions and normal cyclic variation caused by discrete events (i.e. anode set, metal tap, anode effect, etc.) and therefore could promote or inhibit alumina dissolution rate on a cell basis, but also on a time basis for a given cell.

The impact of alumina properties on its dissolution rate has been studied. Of particular importance here is the impact of fine alumina particles and flowability. It has been discussed that an increase of the amount of fines in alumina ores reduces the dissolution rate [8, 9]. Due to many reasons, some segregation occur in the alumina distribution systems between alumina refineries and reduction cells and the fine particles are not spread evenly over time or even across cells within an aluminum smelter [10]. In the end, this uncontrolled variation of finer alumina will promote or inhibit alumina dissolution rate. Here again, alumina dissolution rate varies over time and also on a pot basis.

To circumvent the negative impact arising from the variation of these factors on the alumina dissolution rate, an attempt was made at modifying alumina feeder pipe designs at a modern smelter equipped with point feeders. This paper presents results achieved during a pilot plant trial of the modified alumina feeder pipes.

Feeder Pipe Details

Alcoa Deschambault smelter (ADQ) started in 1992 and operates 264 AP-30 reduction cells. These cells are equipped with four separate crust breakers and alumina feeder devices, shown in Figure 1, distributed along the center channel. Typically, it takes around 1.5 seconds for the alumina shot to flow through the feeder pipe. By design, since the feeder and the crust breaker are separated, the alumina hits the bath surface at some angle and not perpendicularly. This configuration promotes alumina dissolution as the shot is spread on top of the bath surface, enabling it to float instead of sinking within the bulk of the bath.

Alumina dissolution is promoted as it is spread on top of the bath surface. Dissolution rate is also favored by the high bath velocity in the center channel and through the added mixing effect of anode gas.

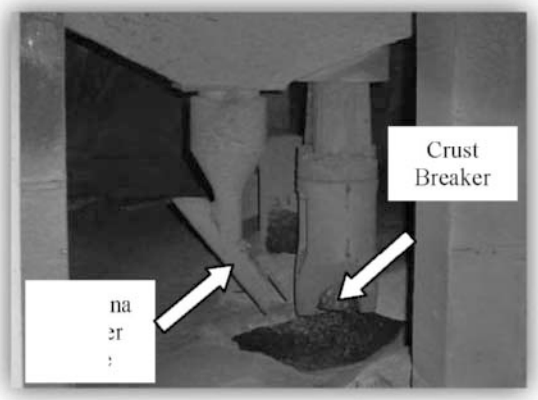

Figure 1: Original alumina feeder pipe and crust breaker inside the cell.

Over time, different projects were carried at ADQ in order to enable load creep. Following load creep, ADQ ramped-up from 300 to 365 kA, a 22 % increase in current. Through that period, bath volume steadily decreased as a result of bigger anodes, representing difficult conditions for alumina dissolution. On top of that, 22% more alumina now needs to be fed to the pot. There was necessarily a need to improve how alumina is fed in order to promote alumina dissolution rate. A project was initiated in which the original feeder pipe diameter was reduced [10].

Test Details

The objective of this project was to enable the alumina to spread more evenly on top of the bath surface as it flows out of the feeder pipe. Therefore, it was decided to restrict the feeder pipe diameter, which increases the time for an alumina shot to flow out of the feeder pipe. As the bath velocity remains unchanged in the center channel, the alumina shot is spread on top of more bath surface, leading to a thinner raft. A higher heat transfer is promoted by the thin rafts and diffusion should also be enhanced as the alumina is spread on top of more bath volume.

Laboratory Tests

First tests were carried out in laboratory in order to quantify the effect of different feeder pipe diameters on the alumina flow. A feeder pipe was modified and mounted on top of a stand (Figure 2) and a timing device was installed at the lower part of the pipe. Many alumina samples were collected across the potline over a few days in order to ensure variation in alumina flowability between the samples. Different tests were performed in order to find the feeder pipe diameter more appropriated for pilot testing. The diameter must be small enough to slow the feed delivery but should let the alumina shot to flow completely before another one has to be delivered.

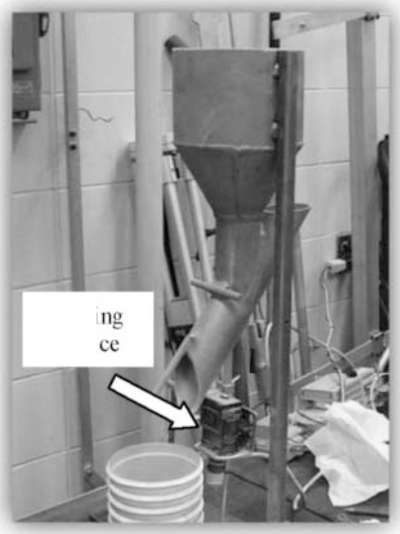

Figure 2: Laboratory set-up.

Pilot Test Trial

Once the best setting were found, it was decided to carry-out a 10 pots trial in order to ensure that no negative impacts would negatively affect pot operation. Ten pots, spread across the potline, were equipped with the flow restricting devices for a period of six months. No negative impacts were seen. Hence, it was decided to deploy on a much larger group of pots in order to quantify the impact on pot performance.

The four feeder pipes of 24 cells (*test group*) were equipped with the flow restricting device. In order to test the hypothesis that the reduced alumina flow would improve pot performance, through a better alumina dissolution rate, a group of 17 pots (*reference group*) was use for comparison. Based on previous studies, these two groups of pots receive alumina with similar properties, from the same gas treatment center and are subject to the same alumina distribution or segregation patterns. No modifications were done on the pot control system.

For statistical analysis purpose, the *test period* goes from January 25th to May 25th, 2012 and the *reference period* covers September 24th, 2011 to January 24th, 2012. During both time periods, no pots were stopped or started within the *test group* and *reference group*. The *test group* average pot age is 200 days older than the *reference group* and their standard deviation are 663 and 610 days, respectively. The pot designs are essentially the same and bath chemistry targets (xsAlF_3 and CaF_2) were held constant for both groups over both periods. All statistical analyzes were carried out using JMP 9.0.0 (SAS Institute Inc., Cary, NC) and Matlab R2009b custom codes (The Mathworks, Natick, MA).

Many daily average operation data were extracted on a pot basis from the plant historian, leading to 9963 observations. Each observation is assigned to a class based on Table 1. For each observation, Current Efficiency (CE) was computed using daily scheduled metal tap and average current and Energy Consumption (EC) was computed using computed CE and daily average total pot voltage drop.

Table 1: Observation classification.

Period	*Group*	*Class*
Reference	Reference	A
Test	Reference	B
Reference	Test	C
Test	Test	D

The aim of this study is to determine if slowing down the alumina flow in the reduction cell favors its dissolution rate. The hypothesis is that a higher dissolution rate should prevent or at least lower the muck formation on top of the cathode block, thus enabling to operate the pots at a lower voltage while preventing metal roll. In order to test the hypothesis, many parameters are studied and evidences from these analyzes will be used.

Results

To test the hypothesis, a statistical comparison between the different classes is performed using Tukey-Kramer test for mean differences [11]. Results are presented here for process parameters related to the hypothesis and confidence levels are also provided. The following tables present statistical differences between the two time periods, for the *test* and *reference groups*. For instance, the difference between the *test period* and *reference period* for the *reference group* is identified as B – A in Tables 2 to 8.

Alumina Concentration

As part of normal operation at ADQ, alumina concentration is measured for each cell on a given schedule using the STARprobe^{TM} [12]. Over the *test period*, ADQ received some shipments of alumina with properties not favoring a high alumina dissolution rate. In order to prevent an increase of anode effect frequency and duration, alumina feed control parameters were tuned to operate at a slightly higher alumina concentration than what is typically targeted. Still, as presented in Table 2, the *test group* was less severely affected as its average alumina concentration increased by 0.05%, while the *reference group* increased by 0.12%.

Table 2: Statistical testing for alumina concentration.

Difference between Classes	*Difference in % Al2O3*	*Significance of Difference (%)*
B – A	0.12	↑ 99.99
D – C	0.05	82

It is believed that the restricted flow provides some robustness to the change of alumina properties and therefore enabled to operate at a slightly leaner alumina concentration as opposed to the standard alumina feeder pipe.

Anode Spikes

Even if anode spikes increased for both groups of pots, as presented in Table 3, the increase number of anode spikes is much lower for the *test group* than for the *reference group*. The increase in anode spike frequency for the *test group* is about 1/3 of the increase of anode spikes frequency of the *reference group*.

Table 3: Statistical testing for anode spikes occurrence.

Difference between Classes	*Difference in Spikes/Pot/Day*	*Significance of Difference (%)*
B – A	0.095	↑ 99.99
D – C	0.035	20

Using the flow restrictor devices, it is expected that the alumina is more evenly distributed within the molten bath, leading to more homogeneous bath properties. By redistributing alumina feeding, Moxnes et al. [13] achieved a more homogeneous alumina concentration within the molten bath, resulting in a reduction of anode spikes occurrence.

Anode Effect Frequency and Time

Through both periods, anode effect frequency stayed the same for both groups. The implementation of flow restriction devices did not affected the anode effect frequency. The assumption is that most of the anode effects at ADQ are arising by factors preventing alumina from being delivered to the pot. For example, these could arise from low bath levels, where the chisel is not breaking the crust or from mechanical failures of one of the alumina feeder device components. Hence, using a restricted flow or the regular alumina feeder pipe does not help preventing anode effect.

On the other hand, a positive impact of the restricted flow was seen on anode effects duration. The anode effect duration, defined as the time above 8 volts, improved for the *test group* when using the flow restriction devices. Even though the anode effect frequency was not impacted the anode effect duration is shorter when using the flow restrictor devices.

Statistical results are presented in Table 4. The anode effect duration (AED), decreased by 2.5 seconds for the *test group*, as opposed to a reduction of 1 second for the *reference group*.

Table 4: Statistical testing for anode effect duration.

Difference between Classes	*Differences in AED*	*Significance of Difference (%)*
B – A	-1.0	6
D – C	-2.5	55

This goes in line with the assumed improvement of alumina dissolution rate obtained by slowing down the alumina flow. Once an anode effect is detected, the pot control system delivers some alumina shots at a high frequency for a short period of time. Using the flow restrictor devices, it is now much faster to replenish the alumina concentration and resume the normal pot operation, as alumina is dissolved more rapidly.

Noise Metrics

Alcoa's pot control system computes different noise metrics in order for process engineers to better understand and diagnose pot behavior. Of importance here are the total noise metric (TN) and the absolute noise from the metal pad roll metric (MPN). TN includes MPN and other noise components not discussed here. Using the flow restrictor devices, it is possible to see the beneficial effect on both noise metrics (Tables 5 and 6). TN decreased by 0.00097 $microOhms^2$ for the *test group*, while it went down by only 0.00028 $microOhms^2$ for the *reference group*. MPN went down by 0.00044 $microOhms^2$ for the *test group* as opposed to a decrease of 0.00017 $microOhms^2$ for the *reference group*.

Table 5: Statistical testing for total noise metric.

Difference between Classes	*Difference in TN ($microOhms^2$)*	*Significance of Difference (%)*
B – A	-0.00028	30
D – C	-0.00097	↑ 99.99

Table 6: Statistical testing for metal pad roll noise metric.

Difference between Classes	*Difference in MPN ($microOhms^2$)*	*Significance of Difference (%)*
B – A	-0.00017	31.5
D – C	-0.00044	99.7

Again here, it is assumed that less muck was generated while using the flow restrictor devices. It is known that muck has some adverse effect on pot stability as it favors the development of horizontal current flows inside the pot, which disturbs the metal pad surface, increasing current shorting and other noise mechanisms. This positive effect of clean cathode block is also leading to a decrease of the occurrence of slower metal wave events (metal roll).

Pot Total Voltage Drop

During the test period, it was possible to operate the test pots at a lower overall voltage, which is a direct result of a cleaner cathode surface. The *reference group* voltage was reduced by 2mV, while the *test group* was reduced by 17mV. As discussed above, bath chemistry was held constant and equal for both groups during both periods, while both groups sustained a 2°C increase in bath temperature during the test period. Therefore, bath resistivity remained equal and unchanged for both groups. The reduction of pot voltage came from a reduction of the pot anode-to-cathode distance (ACD).

Table 7: Statistical testing for pot voltage.

Difference between Classes	*Difference in Volts (mV)*	*Significance of Difference (%)*
B – A	-2	50
D – C	-17	↑ 99.99

The reader should note that this lower operational voltage was achieved while also reducing the noise metrics (TN and MPN). Typically, based from ADQ operational data, closing the ACD results in higher noise metrics values. Hence, the reduction of pot voltage, achieved through a reduction of ACD was achieved while reducing the noise metrics.

Current Efficiency

As a result of the slightly higher alumina concentration and the higher anode spike frequency, CE of both groups of pots were unfortunately negatively affected. However, both groups experienced the same CE drop. It was concluded that the use of the flow restriction devices has no negative impact on current efficiency.

Energy Consumption

As one would expect, the reduction in CE caused by the anode spikes and higher alumina concentration leads to a higher EC. However, the EC increase is less severe for the *test group*, as opposed to the *reference group*, due to the lower pot voltage achieved by the *test group*. The EC of the *reference group* increased by 0.42 kWh/kg, while that of the *test group* increased by 0.35 kW/h. An overall improvement of 0.07 kWh/kg for the *test group*, as opposed to the *reference group*.

Table 8: Statistical testing for energy consumption.

Difference between Classes	*Difference in EC (kWh/kg)*	*Significance of Difference (%)*
B – A	0.42	↑ 99.99
D – C	0.35	↑ 99.99

Conclusion

In this paper, it was demonstrated that reducing the speed of alumina flow out of the feeder pipe has some beneficial results on pot performance. Doing so, alumina is spread more evenly on top of more bath surface, promoting faster dissolution.

From the results obtained from a 4 months test period it is believed that less muck was formed on the cathode block. Evidences of that come from the fact that ADQ was able to operate the test pots at a lower voltage by closing the anode-to-cathode distance. An important point is that the voltage reduction was achieved while lowering the noise metrics and not negatively affecting current efficiency, which is sometimes the case at low anode-cathode distance. The test pots also led to lower anode spike occurrence and shorter anode effect time, resulting from faster alumina dissolution and also from a more homogeneous concentration. Bottom line is that the average pot voltage of the *test group* was significantly reduced by 15mV, leading to an improvement of 0.07 kWh/kg as opposed to the *reference group*.

Acknowledgements

The authors would like to thank Alcoa for granting permission to publish this work and Alcoa Deschambault Pilot Plant Operation for providing resources and field work.

References

1: Paulsen, K.A., Roland, W.K., Larsen, A., 1997, Implementation of Point Feeding in Søderberg Lines at Hydro Aluminum Karmøy, *Light Metals 1997*, pp. 195-199

2: Pedersen, T.B., Jensen, M., Kalgraf, K., Larser, W., Olser, A.T. 2008, Reduced Emissions from the Elkem Aluminum Lista Søderberg Smleter, *Light Metals 2008*, pp. 239-244

3: Bugge, M., Kaakonsen, H., Kobbeltvedt, O., Paulsen, K.A., 2011, High Amperage Operation of AP18 Pots at Karmøy, *Light Metals 2011*, pp. 415-419.

4: Coursol, P., Coté, J., Laflamme, F., Thibault, P., Blais, A., Lavoie, D., Gosselin, S., 2012, The Transition Strategy at Alouette Towards Higher Productivity with a Lower Energy Consumption, *Light Metals 2012*, pp. 591-594.

5: Haverkamp, R.G., Welch, B.J., 1998, Modelling the dissolution of alumina powder in cryolite, *Chemical Engineering and Processing*, Vol. 37, pp. 177-187

6: Kuschel, G.I., 1990, *The Effect of Alumina Properties and Smelter Operating Conditions on the Dissolution Behaviour of Alumina*, PhD thesis, The University of Auckland, New Zealand, March 1990,

7: Welch, B.J., 1990, The role of cell design and cell operating conditions can play in reducing problems from alumina, 2nd International Alumina Quality Workshop, Perth, Australia, pp. 15-22.

8: Welch, B.J., Kuschel, G.I., 2007, Crust and Alumina Powder Dissolution in Aluminum Smelting Electrolytes, *JOM*, Vol. 59, No. 5, pp. 50-54

9: Wang, X., 2009, Alcoa Internal Tech Report 09-212, December 14, 2009

10: Tessier, J., Tarcy, G.P., Batista, X., Wang, X., 2012, Towards On-line Monitoring of Alumina Properties at a Pot Level, *Light Metals 2012*, pp. 633-638.

11: Ostle, B., Turner Jr., K.V., Hicks, C.R., McElrath, G.W., 1996, *Engineering Statistics The Industrial Experience*, Duxbury Press, Belmont, CA, 568p.

12: Wang, X., Hosler, B., Tarcy, G., Alcoa STARprobe, *Light Metals 2011*, pp. 483-489.

13: Moxnes, B., Solheim, A., Liane, M., Svinsås, E., Halkjelsvik, A., 2009, Improved Cell Operation by Redistribution of the Alumina Feeding, *Light Metals 2009*, pp. 461-466.