The STARprobe™

A new technology allowing simultaneous measurements of four cryolitic bath properties in only four minutes

[1]Pierre Bouchard, Eng., M.Sc., President
STAS inc., 1846, rue des Outardes, Chicoutimi (Quebec), Canada G7K 1H1
[2]Dr. Marc Dupuis
GeniSim Inc., 3111, rue Alger, Jonquière (Québec), Canada G7S 2M9

During the last 10 years, Alcoa has developed a new device called the STARprobe™ [1,2,3]. This technology, now available through STAS, is a portable device that takes real time measurements of four bath properties in electrolysis cells:

Superheat
Temperature
Alumina concentration
Ratio (excess AlF_3)
(STAR)

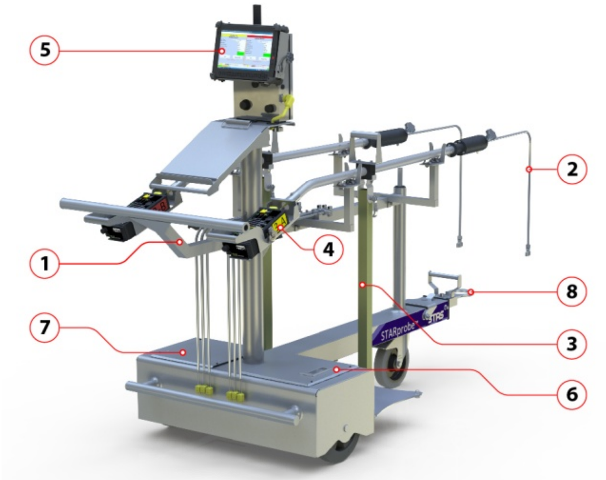
This synchronicity of measurements is the most important step forward in improving the control and efficiency of electrolysis cells.

To effectively control an operating cell and to achieve its maximum efficiency, energy state, chemical state, and state of control should be known. These states are represented by core parameters including cryolite ratio (%XS AlF_3), temperature, superheat and concentration of alumina.

Figure 1 shows one STARprobe™. The device kit consists of a mobile cart and two probes, one interface computer, one power unit, one battery pack and a telescopic towing arm in the front.

The first step to achieve optimum control is to measure the parameters properly.

Bath chemistry and cell operating temperature in aluminium cells must be controlled to achieve optimal current and energy efficiency. Up until now, the conventional way to control the bath ratio and temperature has been to regularly take bath samples for chemistry analysis, and the bath temperature is measured directly in the pot. These measurements are generally performed separately, typically with a difference of 24 hours. Moreover, bath samples have to be sent to a laboratory for analysis, with results available in as much as 24 hours later. Due to the delay in getting the bath sample analysis results, control decisions have to be made primarily relying on old and out of sync information. This leads to an unsteady feedback control loop, where the cell is continuously under or over shooting the targeted optimum conditions, which causes sub-optimal cell performance in terms of both current and energy efficiency.



1- Cart
2- Reusable probe tip
3- Probe
4- Electronic probe head
5- Interface computer
6- Power unit
7- Battery pack
8- Telescopic towing arm

Figure 1: STARprobe™ device kit

In addition to drawbacks of the usual measurement methods, there is also lack of some key bath physicochemical information, such as bath superheat temperature that is critical to efficient operation. Some measurement methods have been a subject of study in the past decades. The commercially available measurement tool by Electronite, made it possible to utilize measured bath superheat for active pot control. Though it was a step forward from the traditional method, it never reached large scale application across aluminum smelters.

The new STARprobe™ provides accurate, inexpensive and perfect synchronicity of measurement of the four basic cell operating parameters.

Principle of Operation

The probe concept consists in making a Differential Thermal Analysis (DTA), which is a proven method [4], on a bath sample and a reference. The reusable probe tip (Figure 2) includes two high-precision type K thermocouples, dynamically paired for compatibility.

1	Sample cup	Contains the bath sample
2	Reference side	Provides a reference cooling curve
3	Thermocouples connectors	Measure temperatures

Figure 2: Reusable probe tip

The thermocouple on the right records the cooling rate of the bath sample, while the thermocouple on the left records the cooling rate of the reference.

Figure 3 presents a pair of DTA (Differential Thermal Analysis) curves obtained from a STARprobe^{TM} measurement. The cooling rate of the bath sample is slower than the metallic mass of the probe for two reasons. The first and less significant reason is because of the difference of thermal diffusivity between the bath sample (liquid and solid) and the metallic mass of the probe, hence the initial separation of the two curves between 10 and 18 seconds. Second, at the bath sample liquidus temperature, cryolite starts to solidify, which slows the bath sample cooling rate down even further. At the cryolithe-alumina phase diagram bath eutectic temperature, the alumina starts to solidify as well. Finally, at a much lower temperature (at the cryolite-AlF_3 phase bath eutectic temperature), the excess AlF_3 finally solidifies [5].

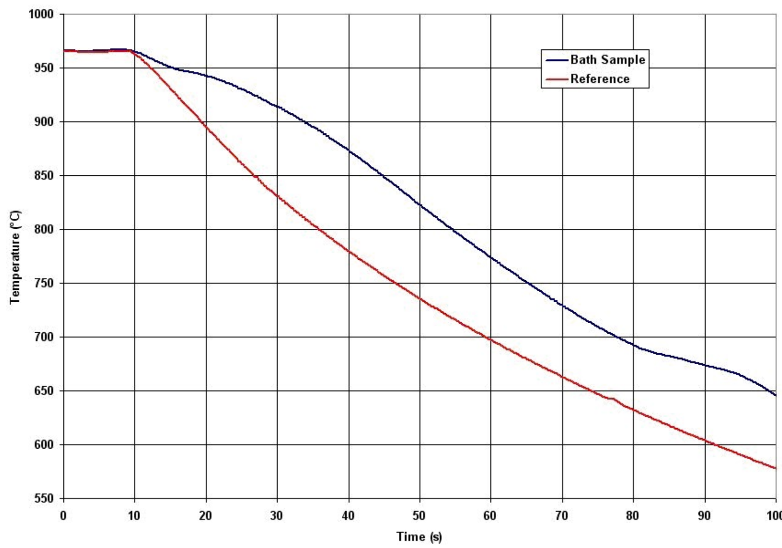


Figure 3: Recorded cooling rate of bath sample and the metallic mass of the probe, which act as reference temperatures in the DTA

The difference of temperature between the two curves is computed and presented on a second graph (Figure 4). In this case, the sample temperature is selected as an X coordinate. The shape of that curve is independent of the cooling rate, so the bath sample analysis results will not be affected by fluctuation of the ambient conditions [1]. In fact, the shape of the curve depends only on two things, the design of the probe tip and the composition of the bath sample. This means that for a given probe tip design, the shape of the curve uniquely depends on the composition of the bath sample. This is the reason Alcoa was able to come up with a correlation algorithm that could identify the bath composition from the shape of each curve measured. The high temperature maximum is due to the solidification of the cryolite, while the low temperature maximum is mainly due to the solidification of the excess AlF_3. The more AlF_3 in the collected bath sample, the less intense the high temperature peak will be and the more intense the low temperature peak [5].

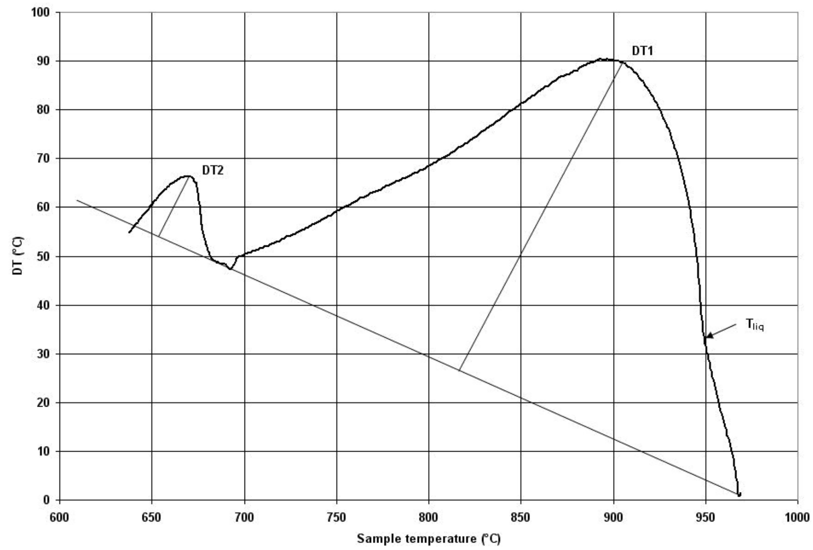


Figure 4: Differential temperature curve
and one possible way to perform the DTA analysis

How it is used in the potroom

The reusable, consumable probe tip can take around 100 measurements. It is connected to the probe head through a probe lance, as seen in Figure 5. An operator can use two of those assemblies to measure cells simultaneously. That way, a trained operator can obtain an average time of just under 4 minutes per measurement. Each measurement is done in three steps:

1- insertion of probe into molten bath to equilibrate with bath temperature in the pot cell;
2- removal of probe tip from bath, and cooling of probe tip;
3- analysis of cooling curve by STARprobe™ and recording of results.

Figure 5: Probe assembly

The probe head includes a very high-resolution electronic thermocouple reader that reads the thermocouples and transmits data via Wi-Fi to the tablet PC running the STARprobe™ application. One tablet PC can simultaneously process the data from the two probe heads. After a few seconds, the results are displayed on the tablet screen (left side of Figure 6), stored in a file on the tablet and can be transmitted automatically to the plant database and/or to the pot control system.

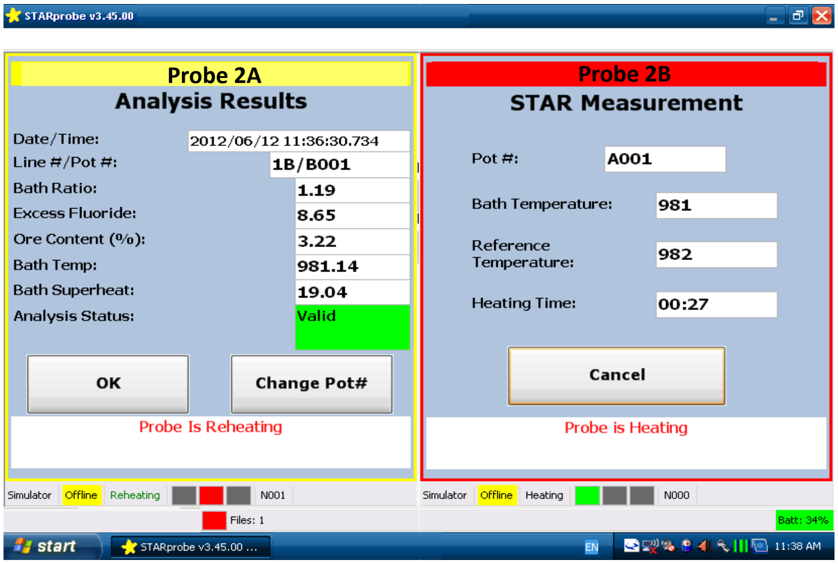


Figure 6: STARprobe™ application displaying the results

Potential of process control improvement using the STARprobe™

In most plants, the way to control the bath ratio and the temperature is usually to take bath samples regularly and to measure the bath temperature. Most of the time, bath sampling is not synchronized with bath temperature measurement. In any case, due to the delay in getting the bath sample analyzed, the cell controller typically never receives new temperature and ratio data at the same time. This lack of synchronicity between the bath ratio and bath temperature data and the lag in getting the ratio data is totally eliminated by using the STARprobe™ to measure both parameters at the same time and by immediately transmitting the results to the database and to the pot control system via Wi-Fi.

Furthermore, a typical bath ratio control logic uses the data for both the bath temperature and bath ratio in order to control the bath ratio by adjusting the amount of AlF_3 added to the cell, assuming a given and constant cell superheat. As presented in [7], any inconsistencies between the target bath ratio and the target bath temperature can create instabilities in the feedback control loop.

Since the STARprobe™ also measures the bath superheat, the bath ratio control and the bath temperature control – or rather the bath superheat control – can be decoupled. The bath ratio can be controlled by adjusting the amount of AlF_3 and the bath superheat by adjusting the target cell pseudo-resistance independently [8].

Improvements have already been achieved in more than 10 of Alcoa's plants in terms of process control. In parallel with the development of the STARprobe™, Alcoa has developed a new cell controller called QLC which takes full advantage of its STARprobe™ bath properties measurement technology. The QLC automatically acquires the results of STARprobe™ measurements in real time via Wi-Fi [1,6].

The gains guaranteed by using an expert pot controller are the following:

- 0.5% current efficiency (proven)
- 35 mV voltage savings (proven)
- 5% AlF3 savings (proven)
- 100-150 day potlife improvement (still to be established)
- One time capital cost saving (X-ray equipment) (proven)
- Labor savings for sampling/analysis (proven)
- Improved understanding by operators (proven).

The STARprobe™ technology is a new way to control electrolysis cells. Other companies around the world have already taken advantage of this new opportunity.

References

[1] Xiangwen Wang, Bob Hosler and Gary Tarcy. Alcoa STARprobe™, Light Metals, (2011), 483-489.

[2] Bob Hosler, Xiangwen Wang, Jay Bruggeman and Patrick O’Connor. Molten Cryolytic Bath Probe, US patent no. 2005/0069018 A1.

[3] Xiangwen Wang, Bob Hosler and Gary Tarcy. Systems and Methods Useful in Controlling Operation of Metal Electrolysis Cells, US patent no. 2007/0295615 A1.

[4] R.C. Mackenzie. Differential Thermal Analysis, Academic press London, 1970.

[5] Dr. Marc Dupuis. Bath Ratio and Temperature Control Enhancement in the Potroom, Light Metal Age, October 2013, p.61.

[6] Wang, X., Tarcy, G., Batista, E. and Wood, G. Active pot control using Alcoa STARprobe™, Light Metals, (2011), 491-496.

[7] M. Dupuis. Excess AlF_3 concentration in bath control logic, National Conference on Advancements in Aluminium Electrolysis, Indian Institute of Metals, Angul Chapter, (2006).

[8] M. Dupuis and J-P. Gagné. Testing a new STARprobe™, Aluminium 89 (2013) 1/2, 76-79.