What is the STARprobe^{TM} and how it can help you improve your bath ratio and temperature control

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The conventional way to control the bath ratio and temperature of a Hall-Héroult aluminum reduction cell is to regularly take bath samples and measure the bath temperature. Quite often the bath sampling is not synchronized with the bath temperature measurement and in any case 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 a very unsteady feedback control loop where the cell is continuously under or over shooting the targeted optimum conditions. This leads to sub-optimal cell performance in terms of current efficiency and energy efficiency [1].

To address this problem, Alcoa has developed over the last 10 to 15 years, a new device to measure almost instantly the bath Superheat, Temperature, Alumina concentration and Ratio (or excess AlF_3) hence the name STARprobe^{TM} [1,2,3].

How it works

The probe concept is fairly simple. It consists of making a Differential Thermal Analysis (DTA), which is a quite well known analysis method [4], on a bath sample. The probe tip presented in Figure 1 contains two type K thermocouples as shown in Figure 2 sketch (figure 7 of [2]).

The thermocouple on the left records the cooling rate of the bath sample while the thermocouple on the right records the cooling rate of the metallic mass of the probe. Figure 3 presents such a pair of curves obtained from a STARprobe^{TM} measurement done by the author. Those curves are not displayed during measurements, but are recorded in a file in the tablet PC running the STARprobe^{TM} application. 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 time 10 and 18 seconds. Then at the bath sample liquidus temperature, cryolite starts to solidify which slows down even further the bath sample cooling rate. At the cryolite-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 diagram bath eutectic temperature (Figure 1 of [1]), the excess AlF_3 finally solidifies.

The difference of temperature between the two curves is computed and presented on a second graph. This time, the sample temperature is selected as X coordinate instead of the time as shown in Figure 4. 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 as presented in Figures 12, 13 and 14 of [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 could come up with a correlation algorithm that is able to identify the bath composition from the shape of each curve measured. The high temperature maximum is mainly 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 there is excess AlF_3 in the collected bath sample, the less intense will be the high temperature peak and the more intense will be the low temperature peak. Mathematically, this means that the sample bath ratio or excess AlF_3 concentration correlates with the ratio of intensity of the 2 peaks as display in the equation below extracted from [1].

$$\%\,\text{xs AlF}_3 \quad = \quad f1[\Delta H \text{AlF}_3/\text{Na}_5\text{Al}_3\text{F}_{14}\,/(\Delta H \text{AlF}_3/\text{Na}_5\text{Al}_3\text{F}_{14}+ \Delta H \text{Na}_3\text{AlF}_6)]$$
$$= \quad f2[S2/(S1+S2)]$$
$$= \quad f3[DT2/(DT1+DT2]$$

The method used by the correlation algorithm to calculate DT1 and DT2 is not described in [1] or [2] so it is remaining an Alcoa trade secret. Considering that even without the latent heat released during the solidification of the bath sample, the reference temperature is drifting apart from the sample temperature and further considering the evolution of the curves family presented in Figure 8 of [1], the author is illustrating a possible definition of DT1 and DT2 in Figure 4 that may or may not be close to what the secret Alcoa correlation algorithm is doing.

For sure, Alcoa secret correlation algorithm it very fast and the calculated results are comparable to XRD analysis as presented in Figure 9 of [1] and independently verified on many occasions now by the author (per example see Figure 9 of [5]) in demonstration preformed in smelters all around the world.

How it is used in the potroom

The probe tip is able to take around 100 measurements, that consumable probe tip is connected to the probe head through a probe lance as seen in Figure 5 (see also Figure 1 of [3]). An operator can use two of those assemblies to measure cells in parallel. This way, a trained operator can routinely measure 64 cells in 4 hours for an average of 3 minutes and 45 seconds per measurement.

The probe head contains the electronic to convert the thermocouples mV into temperatures and transmit those temperatures to the PC tablet running the STARprobe™ application via Wifi. One tablet is able to process the data of the two probe heads simultaneously. Once available, the results of the DTA are displayed on the tablet screen (see Figure 6), stored in a file on the tablet and transmitted to the level 2 control system in Alcoa smelters using Alcoa QLC cell controller system [1].

The PC tablet is mounted on a cart specifically designed for that purpose. The cart has support for the two STARprobe™ assemblies, some spare STARprobe™ tips and a big battery backup to increase the PC tablet autonomy. One cart, one PC tablet running the STARprobe™ application and two STARprobe™ assemblies constitute a STARprobe™ kit (see Figure 7). Alcoa selected STAS as its unique worldwide distributor for its revolutionary STARprobe™ bath properties measurement technology http://www.stas.com/en/starprobe.html so any smelter around the world can now order STARprobe™ kits from STAS.

Potential of process control improvements using the STARprobe™

As said above, the lack of synchronicity between the bath ratio and bath temperature data and the lag in getting the ratio data lead to instability problems in the feedback control loop. The problem is totally eliminated by using the STARprobe™ to measure both at the same time and by immediately transmitting the results to the level 2 database via Wifi.

Furthermore, typical bath ratio control logic uses both bath temperature and bath ratio data 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 major 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 can be controlled by adjusting the target cell pseudo-resistance independently [8].

Process control improvements already achieved by Alcoa

In parallel with the development of the STARprobe™, Alcoa has developed a new cell controller called QLC that takes full advantage of its STARprobe™ bath properties measurement technology. It automatically acquires the results of STARprobe™ measurements in real time via Wifi and takes the measured cell superheat in consideration in its new STARprobe™ based active pot control logic [1, 6].

The gains reported by Alcoa in [6] are the following:

- 0.5% Current Efficiency (proven)
- 35 mV voltage savings (proven)
- 5% AlF_3 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)

Of course the potential for improvement for a given smelter depends on its current level of process efficiency. Per example the two cases of current efficiency (CE) improvement reported by Alcoa in [6] were from about 94% moving up to about 94.5%; clearly a smelter already operating at 95.5% CE should not expect the same level of improvement.

In [6], Alcoa is not specifying the names of the smelters where those results were obtained. But Alumar, one of the Alcoa smelters who is now using the STARprobe™ to control its bath ratio and temperature, has reported the following in [9]:

STARprobe™ has proven to be very accurate for Ratio (excess AlF_3) measurements and able to replace the classical bath sampling and XRD laboratory analysis with the following advantages:
- Much faster response time and consequent reaction on chemical additions
- Measurement of Bath Superheat and Alumina Concentration
- Ability to transfer data to pot controllers that are used to modify process control regarding thermal control
- Ability to reject bad results and request a recheck measurement immediately.

The test groups are pointing to a big potential in terms of voltage reduction as well as reduced aluminium fluoride additions.

Test groups have also shown good levels of superheat with a decreasing trend after starting the STARprobe™ measurements.

Conclusions

In conclusion, the new STARprobe™ device is offering smelters a significant potential to improve their process efficiency yet to realize that potential, the cell control logic need to be improve. Unfortunately, Alcoa has decided to keep for itself its QLC cell controller technology including its new STARprobe™ based active pot control logic, but the author in partnership with STAS is available to support any smelter interested to develop an improved STARprobe™ measurement based control logic.

References

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[5] M. Dupuis, P. Bouchard and J.-P. Gagné, Measuring bath properties using the STARprobe[TM] , 19th International ICSOBA *Symposium* (2012).

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[9] Ari F. Silva and al., Implementation of STARprobe[TM] measurements & Integrated Pot Control at Alumar, ICSOBA symposium, (2012).
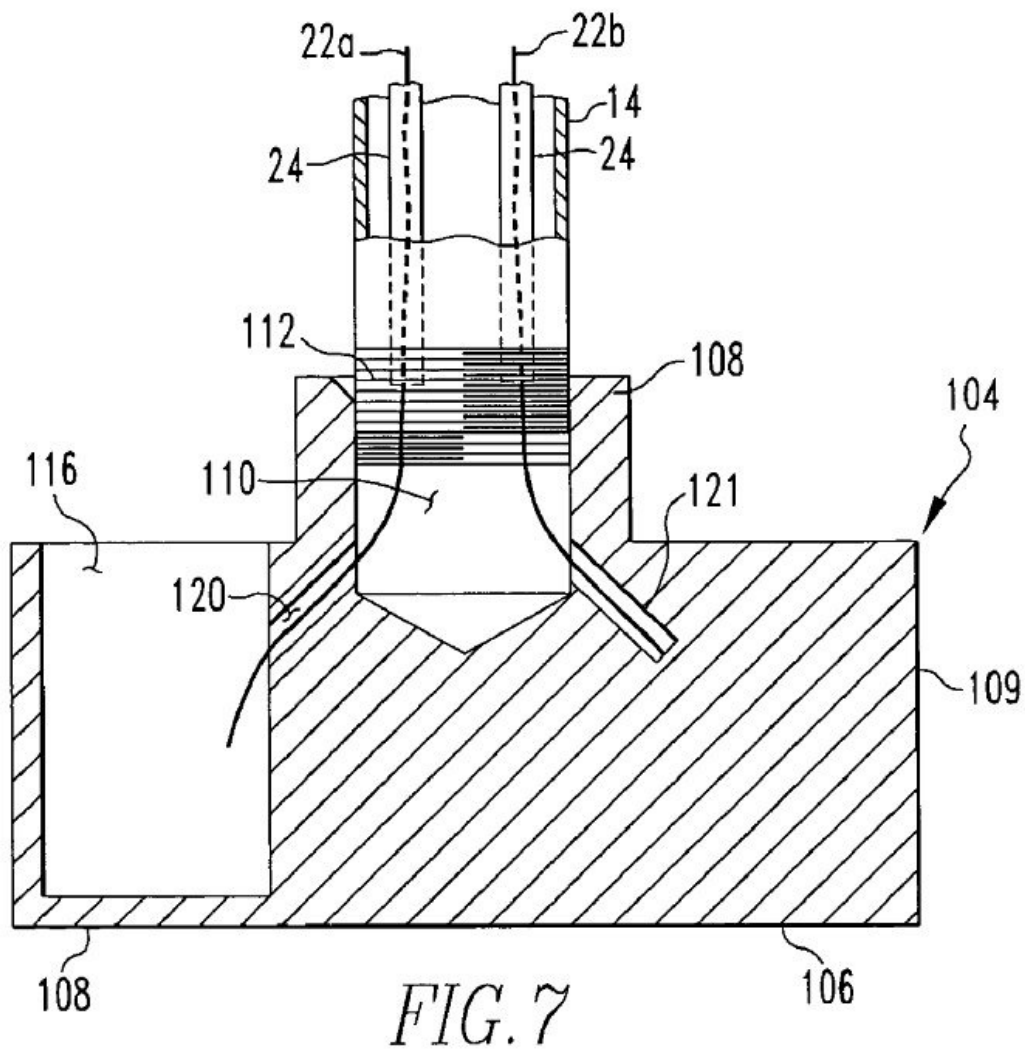
Figure 1: Probe tip

FIG.7

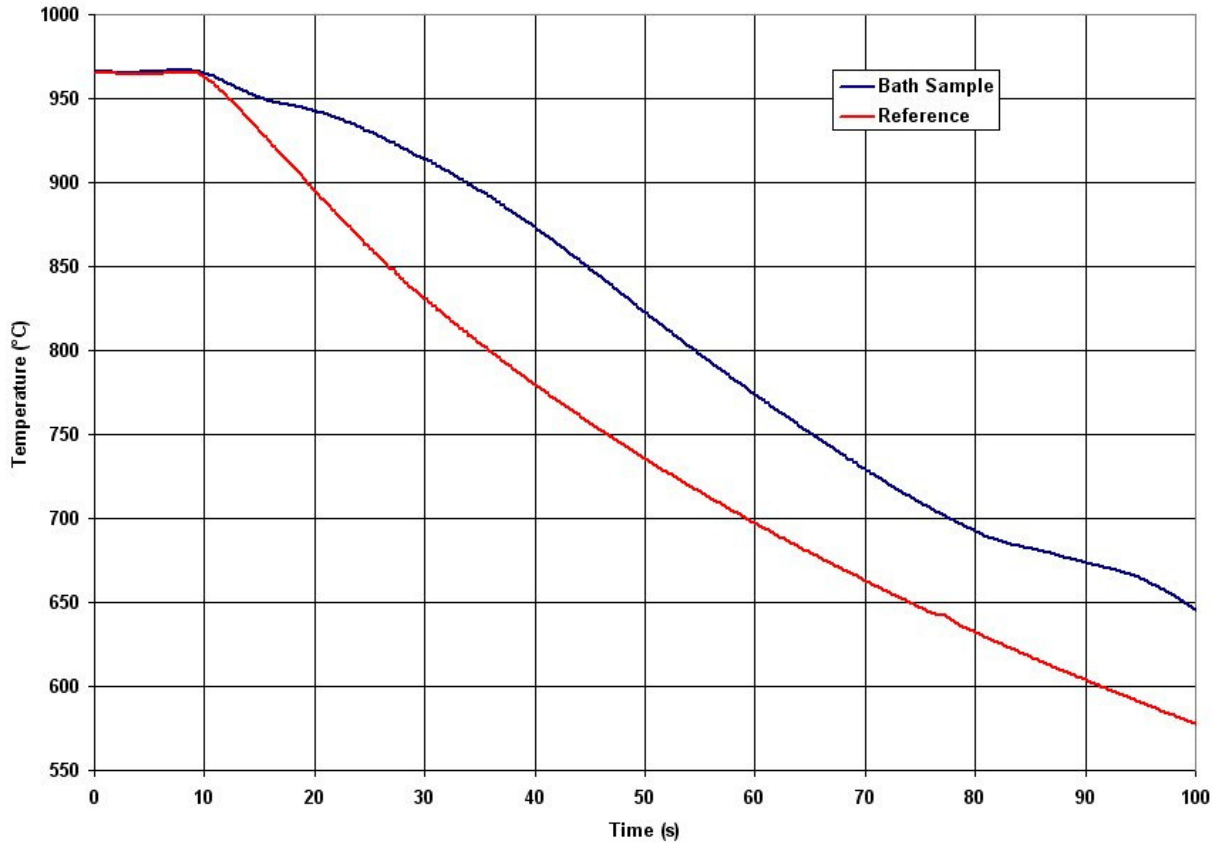Figure 2: Sketch of the probe tip

Figure 3: Recorded cooling rate of the bath sample and the metallic mass of the probe which act as reference temperature in the DTA
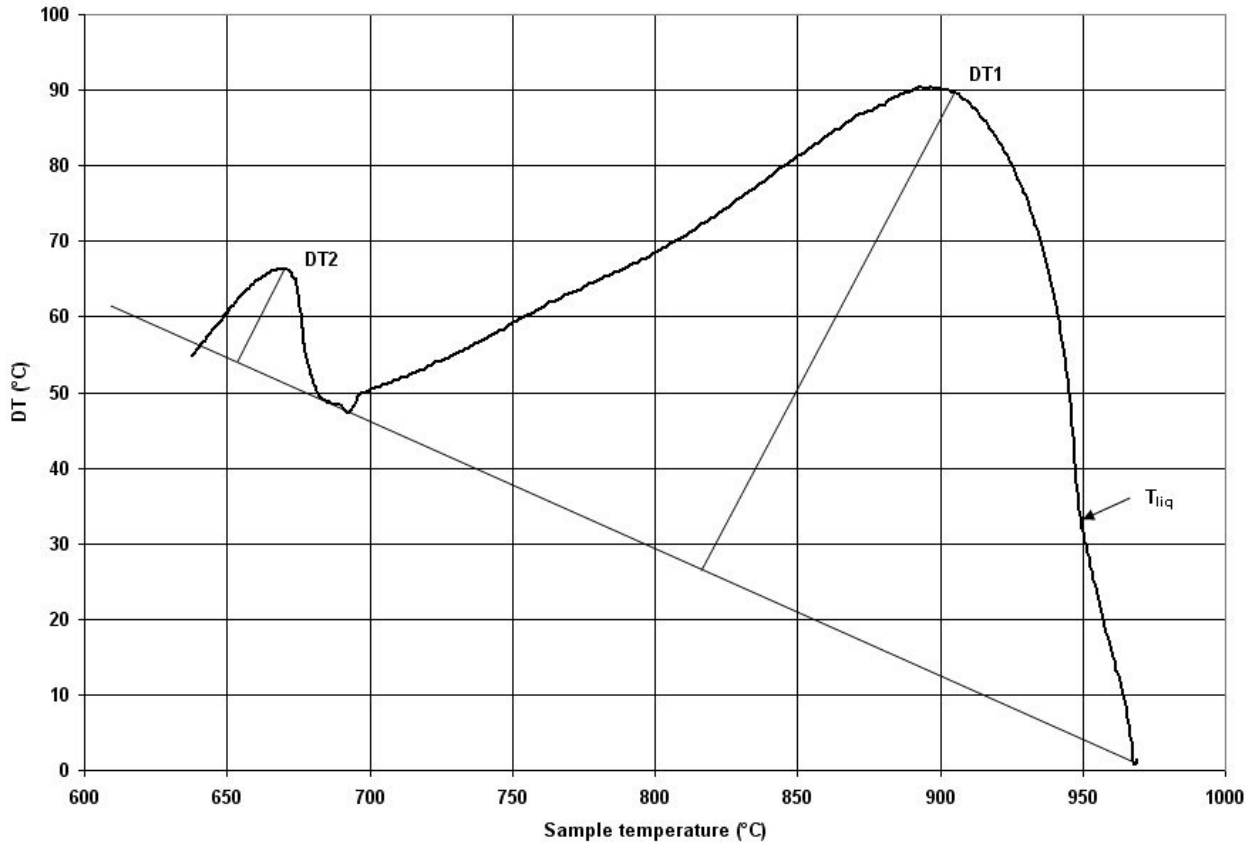
Figure 4: Differential temperature curve and one possible way to perform the analysis.

Figure 5: Assembly of the probe tip, probe lance and probe head ready for measurement
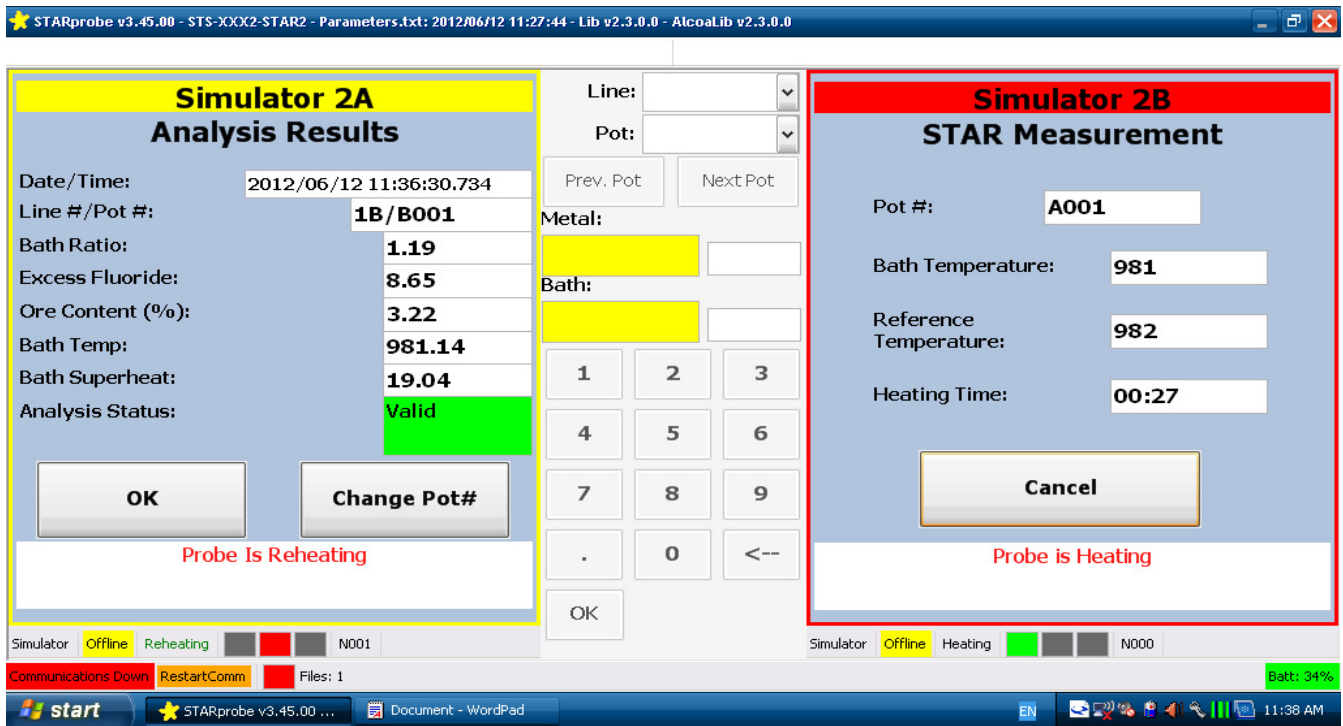
Figure 6: STARprobe™ application displaying the result of a STARprobe™ measurement

Figure 7: One STARprobe^{TM} kit