

## Enriched Alumina Silos: What Is Their Purpose, Are They Still Required?

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### Abstract

The majority of prebake aluminium smelters have enriched alumina silos which provide a buffer between the potline's Gas Treatment Centre (GTC) and the pots themselves. The enriched alumina silos typically store between 300 and 1000 tonnes of enriched alumina and for many smelters the silo level is kept reasonably constant > 80 % over the life of the smelter, so effectively the alumina in the silo is part of the smelters working capital. Many smelter operators may see this buffer as a safety net in their alumina silo, however this paper will demonstrate that potentially this so-called buffer is both, unnecessary and an ongoing risk.

**Keywords:** Gas treatment center, Fume Treatment Centre, Gaseous fluoride emission, fluoride mass balance,  $AlF_3$  chemistry control, Silo fine segregation.

### 1. Introduction

Since the late 1880's the world's industrial aluminium production has been using Hall-Héroult process which reduces alumina to molten aluminium in an electrolytic reduction cell or "pot" according to Equation (1).



Regardless of the pot technology supplier, vintage or amperage, the overall basic concept of the reduction cell has not changed in over 120 years, except for the anode which has progressively changed from the traditional Søderberg or self-baking anode technology to prebake anode technology for most of the world's aluminium production today.

Whether it be Søderberg or prebake aluminium reduction cell technology, all aluminium pots have one thing in common in that they rely on a near constant supply of alumina to ensure the electrolyte alumina concentration will not drop to less than approximately 1.5 % to generate an anode effect. What has changed significantly over the last 50 years is the way in which the alumina is transported from the fresh alumina silos to the electrolyte. The most notable change being the introduction of the dry Gas Treatment Centre (GTC) used to capture the hydrogen fluoride and dust emissions drafted from the pots, using fresh alumina as the reactant and adsorption material. The spent or enriched fluorinated alumina is then extracted from the GTC in a continuous process and transported to a storage silo, often called the enriched alumina or secondary alumina buffer silo.

From the enriched alumina silo, the alumina is transported to the pots (Figure 1) using one of various technologies available to both transport the enriched alumina and feed the pots either using two separate systems typical of older plants or a more modern combined system.

The function of the GTC is both environmental as well as cost saving as hydrogen fluoride is both harmful to the environment as well costly to replace in the pots with aluminium fluoride at US\$ 1000 to US\$ 1500 per tonne.

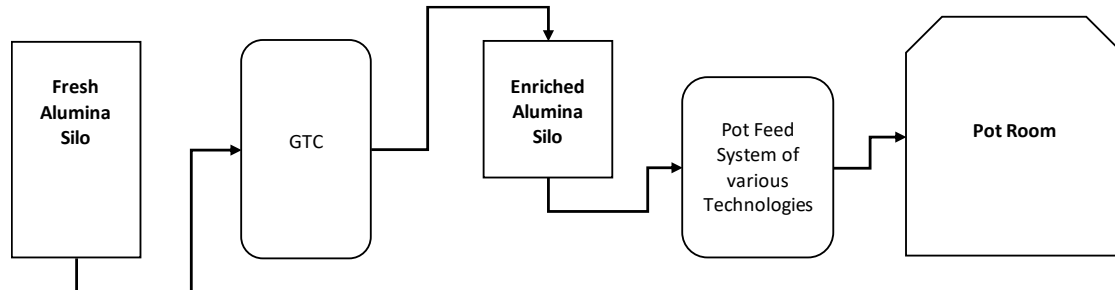


Figure 1. Typical alumina storage, scrubbing and pot feed flow to a potroom.

## 2. A Look at Various Pot Feed System Technologies in Use Today

One of the older pot feed systems that is still in limited use today for the end-to-end pot technologies is the side-break truck-fed technology (Figure 2). This simplistic pot feed system does not require any storage on the pot, nor feeder system in the pot with the alumina transported directly from the GTC enriched alumina silo to the large side channel typically three times a day. The enriched alumina is then broken into the pot where it progressively dissolves in the electrolyte over the following 6 to 8 h. The enriched alumina silo provides a storage buffer between continuous alumina supply from the GTC and the trucks feeding the potline. Prior to the common use of GTC's in aluminium smelting, the alumina was collected from the main storage facility and fed to the pots as fresh alumina.



Figure 2. Alumina feeding by truck to the side of a Søderberg pot [1].

Some of the original side break potlines, such as Kurri Kurri Potline 1 in Australia were later converted to truck feed to an alumina hopper in pot superstructure (Figure 3); from there the enriched alumina was fed to the electrolyte via a typical break and feed system common in modern pot technology. Regardless where the alumina truck feeds the alumina into the pot, in both cases the enriched alumina silo or fresh alumina silos are used as a buffer to allow for the trucks intermittent coming and going.



**Figure 3. Pot superstructure alumina hopper filling with a truck [2].**

The next generation of pot feed systems is the manually operated mechanical batch crane-fed system where the enriched alumina is transported from the enriched silo, usually situated on top of the potroom or off to the side in the GTC but elevated such that the alumina is conveyed near horizontally to the Pot Tending Machine (PTM) filling station, usually placed above a passageway. Typically, the PTMs are designed to both tap metal and refill the alumina superstructure hoppers at the same time (Figure 4), thus capitalising on the PTMs time at the pot. Like the truck feed systems, the crane feed systems rely on the enriched alumina silo to provide a buffer against changes in demand which can vary based on the anode change and metal tap schedule so that in some smelters there may be no alumina drawn at all for an entire shift, while other shifts see alumina drawn from the silo at double the nominal throughput rate of the GTC.



**Figure 4. EGA Jebel Ali Potline 5 with simultaneous alumina fill and metal tapping.**

Moving beyond the mechanical batch-based pot feed systems, there are a number of pneumatic based conveying technologies such as dense phase (Figure 5) as well as low and high pressure hyper dense phase conveying systems (HDPS) (Figure 6), transporting alumina directly from the enriched alumina silo to the pot super structure.

Dense phase filling systems typically fill small groups of pots in batch mode at a time, cycling around the potroom. In this case the alumina flow from the enriched alumina silo to the pots is almost continuous.

In the case of the HDPS, which have been standard for the vast majority of new potlines for over 25 years and available from a number of suppliers and in both, low and higher pressure systems.

Typically, the alumina flow from the enriched silos is continuous to all the pots at the same time, replacing each individual dump live, thus the flow from the enriched silo is nominally the same as the feed from the GTC.



Figure 5. EGA Jebel Ali Potline 9 dense phase system.



Figure 6. EGA Al Taweelah Potline 1 HDPS system.

### 3. Managing Fines in Enriched Alumina Silos

As an alumina silo is fed, the alumina will form an inverted cone in the silo, based on the enriched alumina angle of repose (nominally 32° to 36° from the horizontal plane). As enriched alumina continues to fall on the inverted cone, the enriched alumina retains a semi fluidised state due to the entrapped air collected between the particles in the fall to the cone. As a result of this aeration the alumina both slides and flows like water at the maximum angle of repose towards the silo wall. As the alumina travels toward the silo wall, it progressively de-aerates increasing its bulk density and preferentially dropping out the larger fractions, such that by the time the alumina reaches the wall of the silo, it will have a significantly higher concentration of fines than the original enriched alumina. Enriched alumina typically contains fines fraction between 2 and 5 % higher than the fresh alumina due to particle size attrition from the GTC process and various alumina handling systems along the route; hence enriched alumina will suffer from higher levels of segregation. Figure 7 demonstrates an older style flat bottom silo being filled from a central filling location.

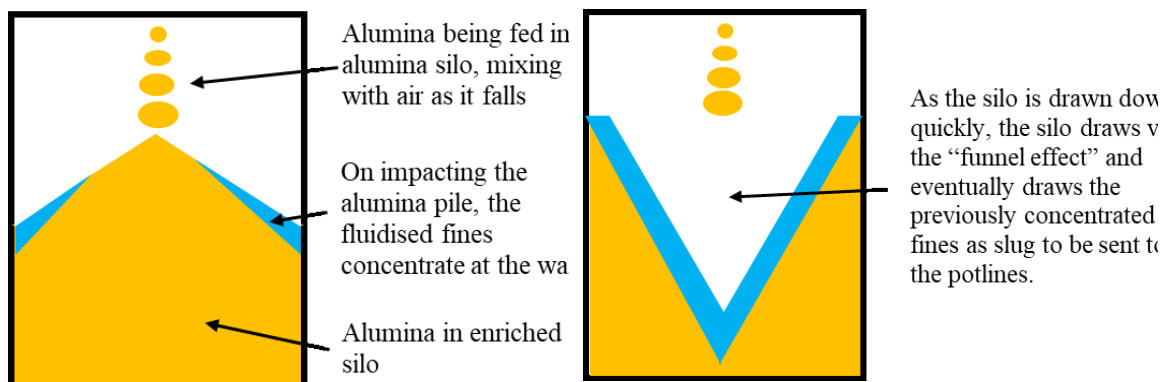


Figure 7. Enriched alumina silo filling, demonstrating the concentration of fines near the silo wall and discharging as a slug caused by the funnel effect to the discharge point.

If the silo level was to drop rapidly due to demand significantly exceeding supply, the majority of silos will draw down the alumina from one or two locations, usually centrally located, and the alumina will be drawn down via the “funnel effect” where the previously inverted cone now reverses such that the lowest height of the alumina is now at the bottom of the cone in the centre of the silo.

The fines segregation is later concentrated further via a rapid decrease in silo level due to the funnel effect flow in silos with single discharge locations. This is further exacerbated in flat bottom silos as the material draws in a cone from the bottom to the top of the alumina level, forming a funnel shape which then fills from the top causing a surge in fines. The material on either side of the cone below the angle of repose becomes hard over time and often remains in situ for the life of the smelter, effectively providing the silo with a physical bottom cone shape unless intentionally removed.

#### 4. Mitigation of Fines Segregation in Alumina Silos

More modern silos with anti-segregation multiple point “spider” style filling systems, along with mass flow discharge cone designs, reduce the impact of fines segregation [3]. Figure 8 shows two anti-segregation systems. However, segregation is rarely eliminated since it is often driven by cost optimisation and physical constraints in plant design, such as maximum allowable height, which reduce the effectiveness of these fines anti-segregation systems.

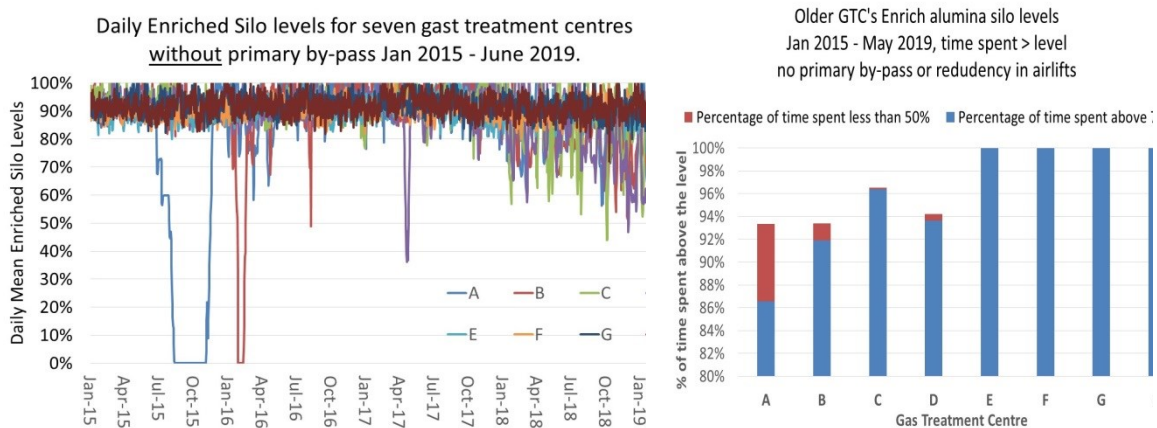


**Figure 8. Left: EGA Al Taweelah Phase 1 low aspect ratio enriched alumina silo driven by height constraints and Right: EGA Al Taweelah Phase 2 standard aspect ratio enriched alumina silo, both with anti-segregation systems on top.**

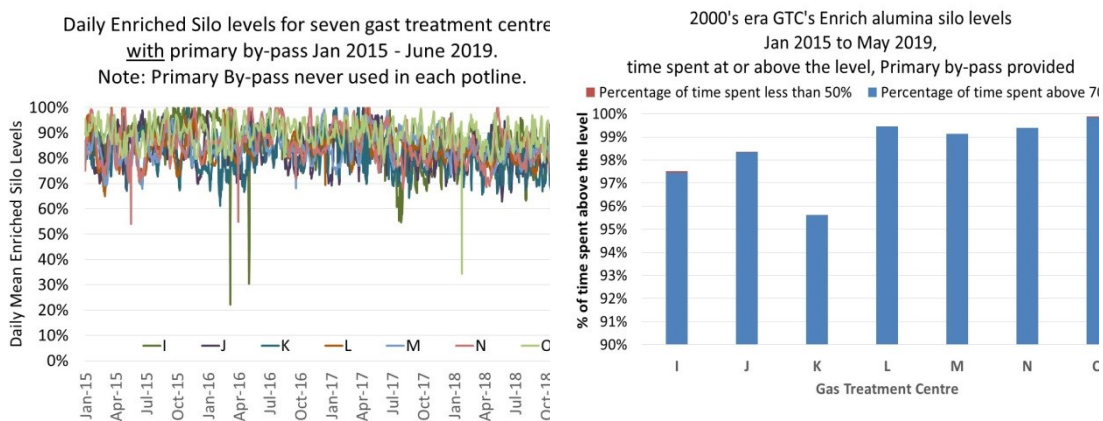
However, the mechanical crane and truck pot feed technologies operate as a series of batch processes that, depending on various factors such as shift changes, meal breaks, anode change and tap operational patterns etc., enabled the enriched alumina silos to sufficiently fluctuate in level as a consequence of the overall operation to prevent the build-up of fines in the silo. This form of control is described in [4]; as a means to avoid build-up of fines against the wall of the silo, the silo should be cycled in height on a regular basis.

Pneumatically energised pot feed systems, such as dense phase and HDPS, that transport the enriched alumina to the potroom are dependent on manually operated equipment and therefore are normally run with a steady state or near steady state supply of alumina to the pot. Thus, the enriched alumina silos are nominally run at near constant levels, typically > 90 % with justification that it provides a buffer against an unforeseen interruption in supply of alumina to the potroom due to a breakdown in the GTC.

Figures 9 and 10 demonstrate the enriched alumina silos are operated at or near constant full level above 90 % regardless of whether the GTC has a primary alumina by-pass or not. The silos E, F, G and H are the most reliable despite having a manual mechanical crane-feed pot feed system with no emergency primary alumina by-pass system or other forms of redundancy in the alumina handling system. Silos A, B, C and D levels did drop to as low as zero; however, this was undertaken in a controlled manner as part of a major upgrade to the GTCs and replacing the manual mechanical crane-feed pot feed system with a pneumatic HDPS and not due to mechanical failure.



**Figure 9. Last 4 years of eight pre 1990's GTCs without primary by-pass enriched daily silo levels and percentage of time spent with the filling level below 50 % and above 70 % with no silo cycling.**



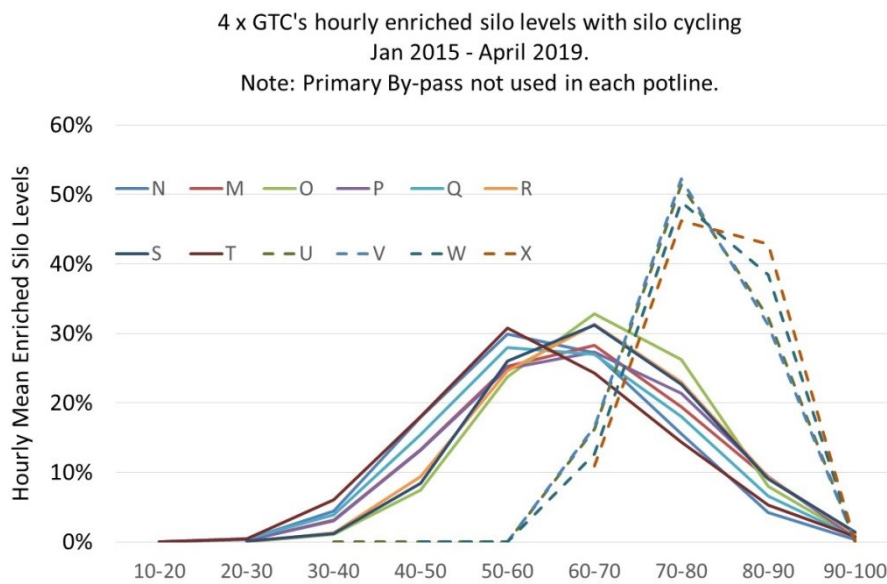
**Figure 10: Last 4 years of seven late 1990's to early 2000's era GTC's with installed primary by-pass enriched silo levels and percentage of time spent with the filling level below 50 % and above 70 % with no silo cycling.**

## 5. Benefits and Impacts of Cycling Enriched Silos

Many smelter operators as well as Original Equipment Manufacturers (OEM) pot feed system suppliers acknowledge the risks of maintaining constant or near constant levels of enriched alumina silos and therefore undertake a cycling or modulation of the HDPS or in some cases, oscillating the feed from the GTC between two enriched silos for the purpose of preventing fines build-up in the silos. This cycling regardless of the process used has the same effect of inverting

the built-up enriched alumina cone frequently enough that it will prevent a significant build-up of fines. Some smelter operators may also apply silo cycling to the primary alumina silos for the same purpose if they are fed almost continuously or continuously most of the time.

The downside of cycling the silos is that, as can be seen in Figure 11, the cycling of the silo levels effectively reduces the silo's buffer capacity. Silos N to T have a very squat or low height-to-diameter aspect ratio due to the physical constraints required to fit between the top of the GTC and the pot feed system. The 700-tonne silos are cycled by approximately  $\pm 30\%$  of the silos capacity by SCADA automatically turning the rotary feeder that supplies pot feed system on and off every three hours to prevent the buildup of fines, which was discovered very quickly during the commissioning phase of the potline. The cycling results in an average silo volume of approximately 62 % or 430 tonnes and a minimum capacity as low as 30 % or 210 tonnes.



**Figure 11. Level range of operation for six 2009 – 2013 era GTC's.  
Enriched silos N to T have a flatter aspect ratio than enriched silos U to X.**

Silos U to X have a more typical aspect ratio for an enriched alumina silo and are cycled via switching the flow from the GTC between two 900-tonne silos, again targeting a variation in silo level of at least  $\pm 10\%$  from the nominal average of 75 % or 675 tonnes.

## 6. Redundancy in the Alumina Supply from the Primary Silo to Pot

The older potlines with mechanical pot feed systems, such as those using mobile vehicles, cranes or trucks, require the enriched silos to provide a buffer due to their less continuous alumina take-out. The redundancy in such systems is driven by the fact that they often have more than one mobile vehicle available to do the task with the non-redundant systems limited to the conveyor feeding the top of the potline and/or the truck loading systems.

For the potlines using dense phase pot feed systems, such as those demonstrated in Figure 10 with the addition of a primary alumina by-pass system to the enriched alumina pressure vessel, the likelihood of a failure to supply any alumina feeding to the potline is limited to a few pieces of equipment with a high degree of reliability, such as airslide with redundant blower and usually manual or auto control valves. The likelihood of catastrophic failure is thus limited to power supply and large-scale mechanical damage. The rest of the pot feed system from the pressure

vessel to the pots has a lower level of reliability as enriched alumina is renowned for scaling dense phase transport pipes which require frequent clearing, typically using sledge hammers hitting the dense phase transport pipes as seen in Figure 12, or failing this physically removing the pipes for manual cleaning; however, these are not deemed worthy of redundancy despite being the only equipment available to feed the pots.

The pot superstructure alumina hoppers which are fed by dense phase, undertake some cycling as a result of the rotating of feeding small groups of pots at any one time. This method of operation therefore induces cycling with the superstructure alumina hoppers which can drop to as low as 12 h of alumina supply at any time.



**Figure 12. Hammer marks on a dense phase system.**

Potlines in Figure 11, fitted with a HDPS, have a primary by-pass system which is a simple pipe from the silo directly to the feeding point with a manually operated valve and not intended for easy use. For all GTC silos reviewed previously, none of the by-passes have ever been used in a combined 52 years of service life. Regardless of the alumina source primary or enriched from the GTC, the alumina must travel via airlifts to lift the alumina by approximately 25 m to the gantry air slides that feed the enriched silos. In all but one potline, there is an N-1 airlift system with an additional blower. The gantry air slides themselves also have a N-1 blower system thus limiting catastrophic failure to power supply or major mechanical damage. The pot alumina hoppers in the potline that are cycled will experience some cycling due to the HDPS system feeder being operated 3 h on and 3 h off. However, overall, the pot alumina hoppers in both systems operate with a nominal storage capacity for at least 18 h at any time. The HDPS has its own redundant blower system and typically operates for months if not years without even a minor disruption. The airlifts are at times taken off line for cleaning, however with N-1 redundancy plus an additional redundant blower, there has never been interruption of alumina supply.

## **7. The Cost of Operating Potlines with Enriched Alumina Silos**

So, with these inbuilt redundancy and by-pass systems plus a legacy of reliable and continuous operation, smelters do not appear to be actively looking at ways to reduce their costs by reducing or potentially eliminating these silos from their new projects or considering by-passing or reducing the capacity of existing silos. The cost of running out of alumina in the potline is in tenths if not hundreds of millions of US dollars if the potline was forced to shut down; so, there is a natural “security blanket” in retaining the status quo and hence the silos are deemed a “cost of doing business”, but should they accept this and are these costs of “doing business” insignificant?

The costs of having the enriched silos are twofold. First, there is the capital cost of building such large silos usually with significant elevation to enable gravity feed into the pot feed system plus

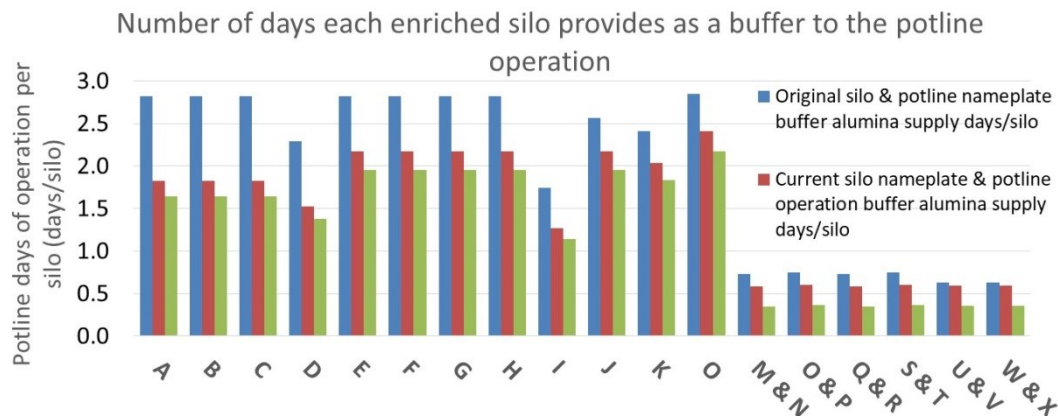
the requirement to build the alumina airlift and elevated gantry airslides to feed the enriched silos. This cost can nominally be between four and six million US dollars each, depending on site requirements. A three-potline smelter could therefore accumulate a capital expenditure from US\$ 25 million to US\$ 35 million just to build the enriched alumina silos.

Additionally, there is the locked-in cost of the working capital with a single 500-tonne silo storing approximately \$ 150 000 of fluorinated alumina which again on a typical three potlines smelter with six GTCs exceed US\$ one million of working capital. Older and larger smelters with disproportionately larger enriched silos compared to more modern smelters running their enriched silos constantly > 90 % may exceed US\$ 2 million in working capital.

## 8. So, Why Do We Still Build and Continue to Operate Enriched Alumina Silos?

If smelters were looking at ways to reduce the volumes of their enriched alumina silos, how much should the silos be reduced by and if so, what can be done for existing smelters and Greenfield projects?

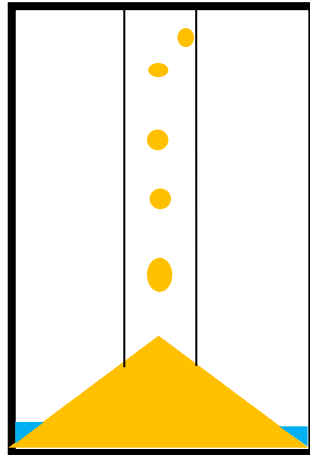
If we look at the buffer capacity for some of the GTC's enriched alumina silos mentioned previously in chorological order of construction in Figure 13, we can see that over time, the buffering capacity is being reduced with each new project as well as with capacity creep of existing potlines through amperage increases and/or adding additional pots.



**Figure 13. Silo buffer capacity in days, original physical, current physical, operational actual (green).**

From the group of plants above, the newer potlines which are some of the largest in the world have buffers down to 0.4 days per silo compared to the older plants with as much as 2.8 days of buffer when they were new and still over 1.5 days today. Some of the greenfield potlines commissioned over the last 10 years in the Middle East have smaller enriched silos which store less than 0.25 days of potline requirements per GTC. Such small typically very narrow surge bins save on capital, working capital and mostly eliminate many of the issues of fines segregation.

For the brownfield smelters, the Failure Mode Effects Analysis (FMEA) and other risk assessments indicate that opportunities are available. Options to reduce or by-pass the capacity of enriched silos are available, such as installing a feed chute into the silo to reduce the height of the alumina in the silo accordingly (Figure 14). The feed chute will limit aeration and constrain dispersion of the alumina as it falls and significantly limit the movement of fines to the silo walls. Experience of such systems already exists on a smaller scale with the pot alumina hoppers fed by HDPS with the exception that they are choke fed.



**Figure 14. Enriched alumina silo with level reduction chute to enable silos to be either by-passed or reduce their working inventory but at the same time minimize fines build up on the sides.**

## 9. Conclusions

Enriched alumina buffer silos once performed a critical role in providing a two- to three-day buffer between a GTC and less reliable conveying systems and manual mechanical pot feed systems such as PTMs and trucks. The down side of these buffers is the capital and operating capital cost and fines segregation which make slugs of fines enter the potroom and cause high numbers of anode effects. However, in spite of the rollout of pneumatic pot feed systems with improved reliability and redundancy of GTC alumina supply systems, the willingness to basically eliminate the enriched silos has been very limited, even when project costs are under pressure.

Aluminium potline operators obviously have comfort in large buffers, however for most of potlines discussed in this paper, this comfort comes at a cost that is hard to justify and in some cases the comfort is overestimated due to cycling. Even when older potlines have their pot feed systems and GTCs modernized, the smelters keep the enriched silo capacity and do not fully take advantage of possible cost reduction. Aluminium industry as a whole is struggling with falling LME aluminium prices, rising alumina prices, rising coke prices, rising power prices, etc.; it would therefore appear that potentially significant cost reduction of enriched alumina silos needs to be further investigated with the potential benefit of a reduction of anode effects.

## 10. References

1. Alton Tabereaux, private communication.
2. <https://www.hencon.com/potroom-solution/high-discharge-vehicle-hdf/> (retrieved on 12 July 2019).
3. Jan Paepcke et al., Startup and tuning of material distribution system at aluminium smelter in Qatar, *Light Metals* 2014, 743-746.
4. Sivert Ose et al., Alumina handling in the smelter – from port to pot, *Light Metals* 2016, 487–492.