Light Metals 2013

CAST SHOP FOR ALUMINUM PRODUCTION

ORGANIZER
Gyan Jha
Tri-Arrows Aluminum
Louisville, KY USA

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

Light Metals 2013

CAST SHOP FOR ALUMINUM PRODUCTION

Aluminum Cast Shop I

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

VERY HIGH PURITY INGOT – AN ENDANGERED SPECIES?

Stephen J. Lindsay
Alcoa, Inc.; Primary Metals; 300 N. Hall Rd. MS S-29, Alcoa, Tennessee, 37701-2516, USA
Keywords: very high purity, ingot, aluminum, P0202A, P0404A

Abstract

Production of metal that is of very high purity remains at substantial levels globally. But, the changing palette of raw material quality, pot room design factors, and operating conditions that support production of very high metal purity threaten the status quo. Older cell technologies that are quite capable of very high purity production are less competitive. Some technologies, especially in the arena of pollution control, are not as sustainable as they once were. Since the demand for very high purity is not anticipated to diminish, re-alignments of cast house capacity to include small mold lines may become common once again. In this paper the author reviews the key factors that are required to produce very high purity metal and comments upon their sustainability. Conclusions are focused on possible paths forward and how these may impact primary metal cast houses.

Introduction

Casting of very high purity metal grades has typically been a niche product for more than a few primary aluminum producers. Very high purity ingot includes grades designated by The Aluminum Association as; P0202A, P0303A and P0404A. This typically encompasses all standard ingot grades with levels of Fe and Si that are each between 140 and 450 ppm. These grades also have to meet additional criteria with regard to other impurities. Some higher purity metal grades are produced by a few smelters in the world and there are some special purification processes to make 99.99%+ purity metal. However, ultra-high purity grades are well beyond the limits of most primary aluminum producers.

Most very high purity, or VHP, ingot is produced in reduction cells of older technology. These include Søderberg pot types and side-worked, or center-break pre-baked technology. Some VHP is produced at locations that use point-fed, pre-baked technology. But, production of the highest metal purity grades is rather limited by modern reduction cell technology. A few modern, point-fed pre-bake cell technologies are capable of P0404A production, but these often fail to achieve strong yields of higher purity grades.

The fundamentals that have supported VHP ingot production for decades are currently shifting. The impurity levels of many raw materials for primary aluminum production, particularly those of anode coke supplies, have been increasing. Older technologies that are more capable of VHP ingot production are facing strong challenges to sustainability. Cost fundamentals that strongly favor modern, high amperage pot lines and modern cast house designs do not include many of the design components of legacy smelters that have greatly enabled VHP production and capture.

For example, few modern cast houses build, or have the resources to operate manual mold lines or small sow casting units. This is particularly so when volume is low and the ability to actually capture full market premiums for purity ingot may not be assured.

Reduction Technology Discussion

Raw Materials & Very High Purity – Beginning with the pot lines the production of very high purity grades generally starts with access to raw materials that are low in impurities of Fe, Si, Ga and substantial combinations of various trace contaminants.

Increases in the impurity levels of anode coke in particular gets a substantial amount of attention. This is for good reason. The general shift to more sour grades of crude oil has made it more difficult to obtain sources of petroleum coke that can be used for the production of P0202A.

Putting availability of this important raw material aside, another factor has simply been economics. Paying premium prices for premium coke must solve financially when it comes to yields and premiums for VHP or better quality ingot. This is perhaps the greater threat to VHP production when it comes to raw materials.

There is much less of a technical threat when it comes to changes in impurities in raw materials such as alumina or aluminum fluoride. Many sources still have low impurity levels.

However, logistics and freight costs for alumina can weigh heavily on the equation. There are only a few combinations of circumstances in which a smelting technology that is favorable to VHP production also happens to have an alumina source with low impurities as a low cost raw material option. Premiums on VHP ingot can be substantial. But, the sum of these premiums can pale in comparison to a freight advantage of a few dollars per ton of a less favorable source of alumina.

Older smelting technology is generally more amenable to VHP production. But, it is also often at higher risk on the industry cash cost curve. Thus, a location that captured premiums from pure metal units in the past may become forced to choose lower cost raw materials if only to sustain operations. Refer to figure #1.

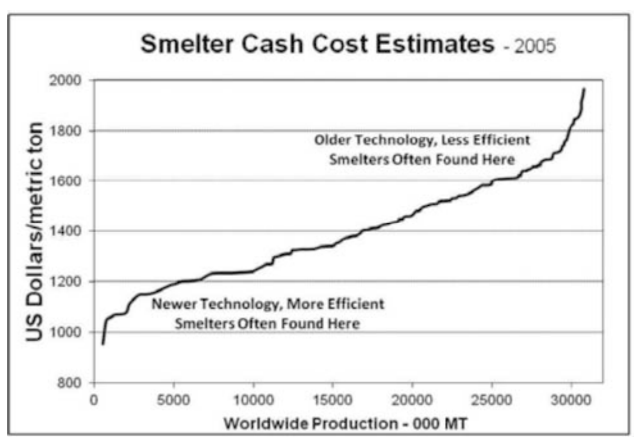

Figure 1 – Example of primary aluminum cash cost curve

Technology & Very High Purity – There are some factors related to reduction cell design that are important to VHP ingot production. There are additional factors related to a few other basic systems of a smelter.

Alumina Delivery Systems - To produce large quantity of ingot of the highest purity the reduction cells must be fed with fresh, or virgin, alumina. Fluorinated alumina from the dry scrubbing systems can have 1.5X to >5X the amount of Fe impurity as well as high levels of C, Si, and other metallic elements [1].

Prior to the late 1960's alumina was typically delivered to individual pot bins in buckets carried by overhead cranes. See figure #2. Some pot technologies continued to use overhead crane delivery systems into the 1980's. This simple, basic, and flexible approach often spilled a lot of alumina, especially with the older technology pot lines. But, it permitted pure alumina pot groups to be created that could then be increased or decreased in size rather easily. This is seldom the case for modern pot line designs with fixed alumina distribution systems.

Figure 2 – Manual filling of overhead pot bins

Modern pot line designs are typically not built with redundant alumina delivery systems, capable of delivering either fresh or fluorinated alumina to any groups of reduction cells. Adding such a capital expense generally can not be justified by pure ingot premiums. Thus, the technology footprint for the industry continues to move toward large, modern pot lines constructed only with fluorinated alumina distribution systems. As older, less competitive smelters are idled this progressively erases the slate of cell technology that has built-in advantages for VHP ingot.

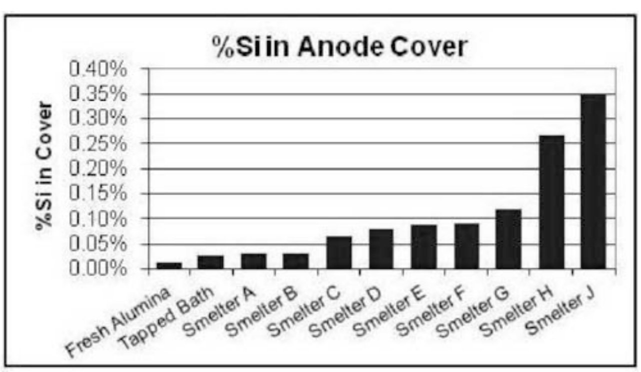

Figure 3 – Examples of Si in anode cover vs. alumina + bath

Anode Cover Delivery Systems - The same may be said for anode cover material handling systems. Pot groups that are focused on the production of the purest grades of VHP ingot use a blend of fresh alumina and crushed, tapped bath as anode covering material. As with fluorinated alumina, normal anode covering material carries an impurity burden. Refer to figure #3.

Modern smelting technology typically has a bath milling center and distribution system that places its focus on delivery of anode cover materials to charging bins that are above pot tending cranes so as to fill smaller delivery bins. Such systems are not flexible.

Manual application of anode covering material from buckets suspended from general utility cranes is no longer a part of modern smelter design for a variety of reasons. Dual-purpose systems that might transport, store, and charge pure alumina covering material clearly are technically possible. But, the economic hurdle that such systems present is similar to that of redundant, pure alumina distribution systems.

Fume Control Systems - There are also differences in pot room fume scrubbing technology. Very few high purity producers in the world have no scrubbers for pot room fume. Obviously, this is unacceptable for development of new pot lines. There are also very high purity producers that rely upon legacy, wet scrubber technology. For example, VHP ingot production at Alcoa's Rockdale operations relied upon wet scrubbers to treat pot line exhaust and to shed impurities. In either case, with no scrubbers or wet scrubbers, the metallic impurities that are carried with the particulate matter leaving the reduction cells do not return to the process. This is an enabler to VHP ingot production.

While it can vary greatly it is not unusual for >10% of the Fe that enters reduction cells to leave them with fume and particulate that is carried to the exhaust system.

Most modern smelting technology constructed since the 1970's has only used dry scrubbers for potroom exhaust fume treatment. In these systems, impurities that travel with pot room fume are returned to the reduction cells along with valuable alumina and fluoride. With such equipment smelters that focus on VHP ingot can only move impurities from the high purity pots to other pots. There often is no net reduction in total impurities. This can mean that a focus on VHP ingot can carry the price of sacrificing some capacity that may have gone to other value-added products.

In addition to returning metallic impurities to the process, dry scrubbing technology faces other limitations [2]. Injection-type dry scrubbers are limited to loading rates of approximately 0.28 mg F/m^2 B.E.T Surface Area of the alumina. Beyond this level, the scrubbing efficiency is lost rapidly. Refer to figure #4.

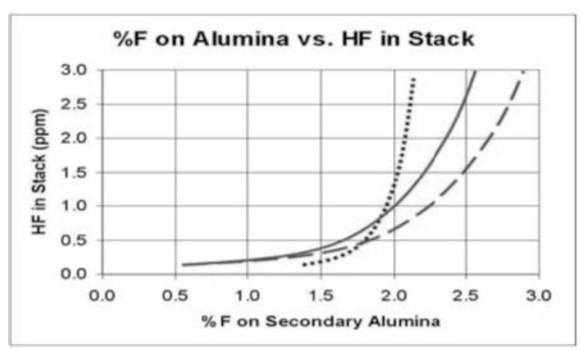

Figure 4 – HF in dry scrubber stacks vs. loading on alumina

Let's consider a pot line with 25% of the pots being dedicated to VHP ingot production by being fed pure alumina. All pots in the pot line send fume, and impurities, to the dry scrubber. But, only 75% of the alumina feed rate to the pot line is actually fed through the dry scrubber. If, the fluoride evolution rate from pots was equivalent to 1.60% F on alumina with no pure alumina feeding, then at 75% of normal alumina throughput the %F on alumina rises to 2.13%. As Figure #4 shows, emissions from the dry scrubber may increase by 2X to 6X. This may be unacceptable.

As smelters creep pot line loads ever higher, fluoride evolution rates often increase unless the thermal balance of the cell has been adjusted to match the increased net heat input. It becomes more difficult to maintain large groups of pots that are dedicated to VHP ingot production. The benefit of increased production from an entire pot line often far exceeds the premiums associated with VHP ingot production from a fraction of the pot line.

Alumina Feed Systems – Modern, point-fed reduction cells with excellent feed control algorithms have enabled more stable pot operation, lower anode effect rates, higher current efficiency and lower specific energy consumption to make a ton of aluminum.

In the early decades of aluminum reduction the pots were fed manually with large batches of alumina. This approach exists even today, primarily on side-worked Søderberg pot lines and the few remaining side-worked pre-baked pot lines. Batches of alumina may exceed 150 kg in size on these pot types.

Manual breaking gave way to center-breaking of pre-baked pot lines in the late 1950's and early 1960's. A few smelters continue to use center break pots to this day, feeding 10 to 25 kg of alumina at one time.

Between the 1960's and 1980's most pre-baked technology was being built with, or modified to point feed technology. This, the current state-of-the-art, can deliver accurately sized shots of alumina of approximately 1.0 kg by weight.

However, more precise feeding in lower doses has not been better for very high purity production capability. Almost without exception, pot lines that use side-breaking or center-break feed technology produce the highest yields of metal grades such as P0202A and P0303A. While it is not technically correct, the layman's explanation for this phenomenon follows. Modern cells have only a few, small diameter holes through which impurity-laden dust may escape. This reduces the fraction of Fe that leaves the cell to the fume control system, leaving more Fe in the pot.

Reduction Technology Summary - Evolutionary improvements in; alumina distribution systems, anode cover distribution systems, fume control systems and pot feeding systems have worked against the capability of a modern reduction cell to have high yields of VHP ingot grade metal. Each has had strong economic drivers behind them. Fume control improvements have had both financial and social/environmental drivers.

It is quite unlikely that any new pot lines will be constructed, or would even be permitted for construction, with all of the grand-fathered technology that enables VHP ingot production. It is very likely that a number of smelters having grand-fathered technology that enable VHP ingot production are likely to be curtailed.

Cast Shop Technology Discussion

Capture of Very High Purity – As grand-fathered sources of VHP ingot are displaced by new capacity the premiums for high purity ingot are likely to increase. Ultimately, increases in premiums will be moderated by the costs of using secondary aluminum refining processes such as fractional crystallization, or zone refining processes [3] to produce VHP ingot. Secondary processing such as these are also unlikely to happen in conventional primary cast houses.

What may occur is a something of a renaissance of direct casting of metal from crucibles into molds. The ability to capture small quantities of VHP ingot, fueled by higher premiums, could bring this about.

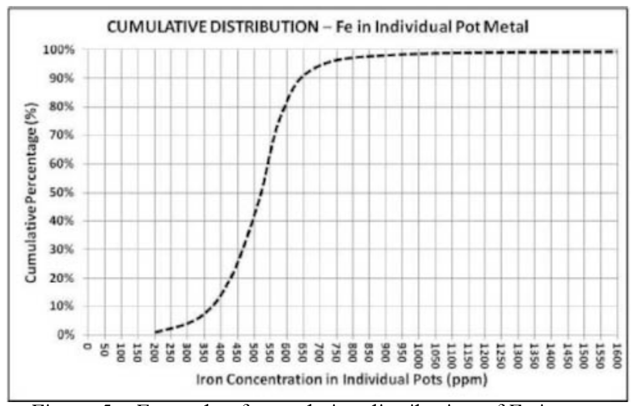

Figure 5 – Example of cumulative distribution of Fe in pots

It is not uncommon that the distribution of metal grades from pots is skewed. Most of the skew is to the high side and is associated with individual reduction cells that have some type of problem. However, there is also some tendency towards skew on the lower tail of the distribution. As figure #5 illustrates some small fraction of total production may be able to be captured as VHP ingot. The most common enabler to doing this is to have the ability to isolate this metal and to cast it in small quantities.

Capture as ingot would definitely require the well known pot room practices of; frequent metal grade analysis, selective pot tapping and some crucible(s) that are dedicated to very high purity. It would also require the ability to pour and skim this metal directly into molds or small capacity sow casting units.

Pouring to molds may be possible in the pot rooms themselves. However, overall metal quality control, quality assurance of cast ingot and minimization of re-melting may require this function in the primary cast house. Accumulation and packaging of graded lots would also be a function most likely to fall to the cast houses.

If this were to come to pass there would be a gradual shift in VHP ingot production. It could change from a few smelting locations in the world that have been dedicated to high purity production at a substantial volume to many smelters that capture VHP ingot on a much smaller scale. Changes in the VHP market might also bring some legacy smelters into play that historically have not pursued high purity ingot as a product. Access to specific markets would still face transportation cost limitations. But, higher premiums for purity could break down some existing barriers.

Very High Purity Variation - Before a shift to many small scale producers of VHP ingot occurs, the cast houses that might become involved would have to clear a few hurdles. The costs of a manually operated mold line, or small ingot caster might be well understood. But, the nature of VHP production may not be as clear.

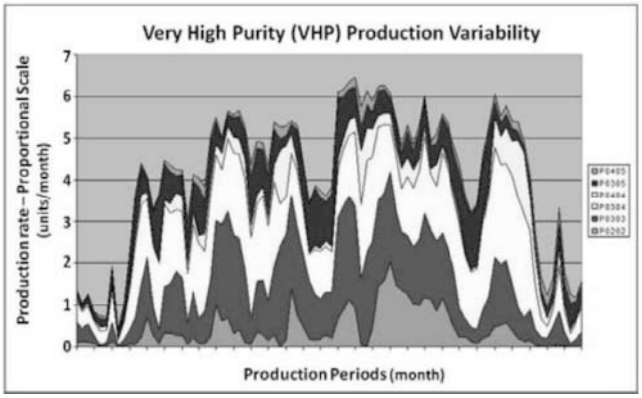

Figure 6 – Example of variation in high purity production

Producing and capturing very high purity metal requires good raw materials, strong process control and special work practices. Any upset, even a small one, can cause the quantities of the highest purity grades to greatly diminish, or to be lost entirely. This is illustrated in figure #6.

There are things that can be done to minimize variation. However, many such counter-measures are not likely to be in place for opportunistic VHP ingot producers. Spot market opportunity may improve as larger producers drop out. But, the best premiums will go to those who can deliver against a contract, month-after-month.

The best approach for low volume producers of VHP ingot may be to include a "store" of each very high purity grade to be sold. Such an inventory store, or stock-pile, will have carrying costs. But, it can also work to level out seasonal or other variations in VHP ingot production.

This also implies that investment would favor low capital and extra labor. When times are good the capacity to capture the ingot and replenish the store is a necessity. When production of very high purity is low, equipment utilization will also be low.

Floor space will be another consideration. Mold lines that vary in utilization rates can consume valuable space that is under roof and equipped with ingot cooling capacity. Accumulation of VHP ingot grade stores may also require under roof access in locations with harsh winter weather.

As with many of the factors listed above for smelters these extras in the cast house would certainly be required to provide a return on investment.

Conclusions

Older technology smelters often have inherent advantages for the production of very high purity materials. These are most often tied to grand-fathered technology for;

- alumina distribution to pots
- distribution of anode covering material
- fume control systems
- and pot feeding technology.

As this capacity becomes curtailed the supply of very high purity ingot will tighten.

More modern smelters with dry scrubbing systems for pot room exhaust have some capability of VHP ingot production. However, this fume control technology only moves impurities from purity pot groups to other pots in operation. Thus, a focus on capture of incremental VHP ingot may carry with it some opportunity cost for other value-added product.

As VHP ingot production tightens, premiums are anticipated to increase. This may lead some metal producers that have built-in legacy technology advantages to enter the market. It may also lead to many metal producers shifting to capture as ingot, small increments of VHP production in pots.

Very high purity capture rates are inherently unstable. Even small upsets in process control or raw materials can drive large, temporary shifts in production rates of the highest purity grades. Buffering this with a pure metal "store" is a common approach. But, it can carry with it some inefficiency that must also be considered before jumping into the VHP ingot business.

References

1. Gaertner, Heiko, Ratviki, Arne Petter, & Aarhaug, Thor Anders, "Impurity Elements in Raw Gas Ultra-Fines from Aluminium Electrolysis Cells", Light Metals 2012, pp. 839 – 844
2. Lindsay, Stephen J., Dando, Neal R., "Dry Scrubbing for Modern Pre-Bake Cells", Light Metals 2009, pp. 275 – 280
3. Altenpohl, Dietrich G., editor, "Aluminum: Technology, Applications, and Environment", Wiley Publishing, Chapter 2, section 2.2.4, p. 17, ISBN 87-339-406-2, also found at http://www.tms.org/pubs/books/4062.chapter2.pdf

Acknowledgements

- Alcoa, Inc. for support in the preparation and publication of this paper

- Merino, Dr. Margarita R. (Ph.D. – Florida State University) – for her encouragement, dedication, and support.