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ATTRITION OF ALUMINA IN SMELTER HANDLING AND SCRUBBING SYSTEMS

Stephen J. Lindsay
Alcoa, Inc.; Primary Metals; 300 N. Hall Rd. MS S-29, Alcoa, Tennessee, 37701-2516, USA
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Abstract

Customers place various levels of importance upon the Attrition Index of Smelter Grade Alumina. The concerns are generally associated with the content of fines in fluorinated alumina as it arrives to the reduction cell. In this paper the author discusses factors of importance related to the design and operation of alumina handling systems from the refinery to the reduction cells. Examples are given in which the actual attrition of alumina particles has been minimized. Techniques are shared on how to separate the contribution of fine particles of bath evolved by the pots from the attrition of alumina itself.

Introduction

Many producers of smelting grade alumina, SGA, include data on %Attrition Index, or %A.I., in each certificate of analysis. This is one metric for assessing alumina particle "toughness". Although suppliers maintain strict standards to determine values of attrition index, the methods used to determine %A.I. do vary. At this time there is no single industry standard for measurement of %Attrition Index.

There have been contributions to the literature that help to illustrate the topic of attrition, or particle toughness. Particular significance has been given to particle velocity at the time of impact against an obstacle such as a steel plate [1].

But, what does the %A.I. mean to a smelting customer of SGA? Can it be used with the particle size distribution, PSD, of an alumina source to predict the PSD of secondary alumina at the reduction cell? Is it of greater significance for some screen mesh fractions than others? By definition %A.I. is a measure of change in the %+325 mesh. But, is it meaningful for the %-20 micron fraction, or superfines?

The best answer was probably inscribed on the portico of the Temple of Apollo at Delphi, "Know thyself". The particle size distribution at reduction cells appears to have more to do with the design and operation of alumina handling systems and dry scrubbers than with the source of the alumina and its particular morphology or particle toughness. When a smelting customer understands their system quite clearly, then some detailed meaning may be able to be ascribed to the %A.I. of an individual alumina source.

Experimental Design

In mid-2008 more than a dozen Alcoa smelters participated in an "Attrition Mapping" exercise. The exercise is generally described by Figure 1. The activity was designed to allow its participants to understand how much alumina particles break down as they pass through their alumina handling and dry scrubbing systems.

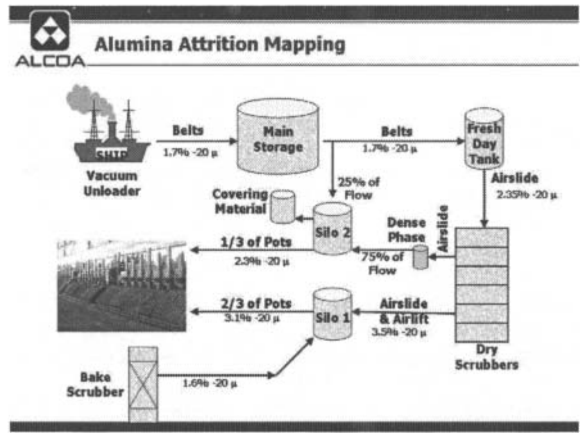

Figure 1 – Generic example of Attrition Mapping

A sampling regimen was prescribed for the participating smelters. The goal was to be able to gather composite samples that would be as representative as possible of alumina at various locations along its flow path toward the pots. Some of these were straightforward sampling plans that focused on a few key sampling locations. Other sampling plans were more detailed. Complexity beyond the basic sampling points was left to each participating location.

Analysis of the gathered samples was made in cooperation with the Technology Delivery Group of Alcoa World Alumina. This included the determinations of particle size distributions using a Coulter Particle Size Analyzer model LS100Q laser diffraction instrument. Interpretation of superfines content was based upon electroformed sieve calibration samples that are periodically re-standardized. Measurements of flowability were also made by use of a standard Alcoa flow funnel with a 6 mm orifice.

This analytical capability allowed the study to go beyond other studies in the literature that have relied upon dry sieving analytical methods. This enabled many of the conclusions that follow on the nature of pot fume and of the amount of attrition that occurs in various types of alumina handling and processing equipment.

Results were summarized according to typical particle size fractions. These were mapped to visually illustrate changes in the percentages of each fraction along the alumina flow path. Particular attention was given to superfine fractions. This approach was used to enable conclusions about alumina attrition. It was understood from the outset that increases in superfine fractions might be confounded by the fine particles of alumina and bath that are found in reduction cell exhaust.

No effort was made to determine the chemical composition or structure of each sample or fraction. This additional dimension of study is left for future consideration. It was not within the boundaries of the test design for this Attrition Mapping exercise.

The design of the study was to create composite samples from various places along the alumina flow path. The minimum requirement to participate was to sample:

1) Fresh alumina as received
2) Fresh alumina prior to the inlet of the dry scrubber
3) Secondary alumina after the discharge point of the dry scrubber silo
4) Secondary alumina at, or in close proximity to, the reduction cell

As indicated, additional sampling locations were added to this baseline if so desired by participating locations.

Sampling

Obtaining representative samples of alumina in an industrial setting can be challenging. Fine and superfine fractions can easily be biased via improper sampling technique. As this study was conducted over an array of smelting locations care was taken to prescribe detailed sampling methods. However, direct oversight of sampling at each location was not conducted by any one person or group.

Sampling was conducted by taking approximate 100 gm samples over multiple days to build composite samples of approximately 1 kg from a minimum of 10 grab samples. When possible these samples were to be taken directly from a conveyor belt or by using a simple grain thief device. Refer to Figure 2.

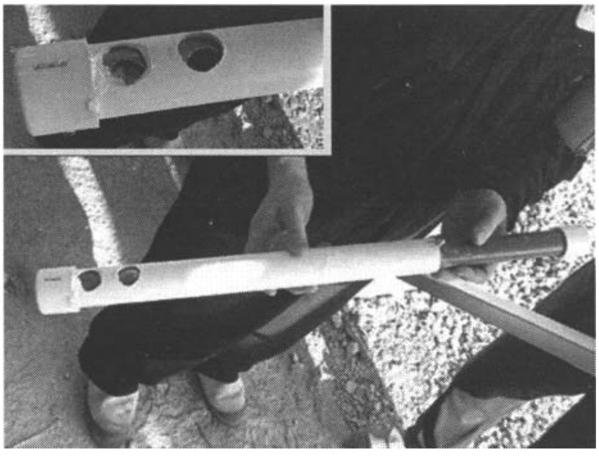

Figure 2 – Example of a grain thief sampling device

It was advised to avoid taking samples from conveying equipment that was under negative pressure while using any open sampling devices such as scoops or cups. In these circumstances a sampling thief was to be used with a fabric seal around the tube at the sampling access point. An alternative approach was to briefly shut down the system to take a sample. This required shutting off dust collection simultaneously with conveying equipment.

Sampling at or after point feeders in pots was not advised due to the impacts of dust collection and gas flow patterns in cells. This may have introduced significant bias in superfine fractions that could not be easily controlled by the experimental design.

Composite samples were then placed into plastic containers with screw down lids. They were clearly marked prior to shipment for analysis.

Particle size determinations were all made in the same laboratory, using the same equipment, people, and analytical methodology.

Results

Study #1 - The first handling system to be analyzed included a nearly ideal configuration for minimal attrition. Handling systems included; air gravity conveyors, silos, one air lift for fresh alumina and another for secondary alumina, a fluid bed type gas treatment center and air gravity conveyors to pot bins.

The %A.I. of the alumina source was between 15% and 17% during the period of study. This moderately high %A.I. was determined by the Alcoa method for attrition. See equation 1.

$$\text{ATTRITION INDEX (\%)} = \frac{(\%{+}45\mu m_{\text{Unattrited Sample}}) - (\%{+}45\mu m_{\text{Attrited Sample}})}{(\%{+}45\mu m_{\text{Unattrited Sample}})} \times 100$$

Equation 1 – Attrition Index equation – Alcoa method

Results indicated no significant degradation of particle size diameters at the 10^{th}, 50^{th} or 90^{th} percentiles of the PSD. These are otherwise referred to as d10, d50 and d90. See Figure 3.

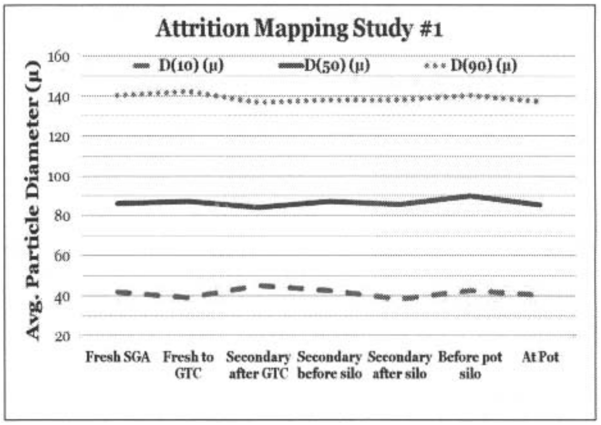

Figure 3 – Attrition mapping results of study location #1

Most surprisingly there was essentially no change in d10 at ~40 microns diameter along the flow path to the pots. Calculation of the actual %A.I. in the field yielded a result of only 0.7%. This result was roughly $1/20^{th}$ of the % A.I. reported for fresh alumina.

Even though the handling systems and fume controls were known not to be harsh on alumina particles, such low results were not expected. There was no apparent attrition of alumina particles along the flow path through the smelter. However, these results were not in concert with the general observation of reduced flowability according to Alcoa flow funnel test results for Study #1. See these results in Figure 4.

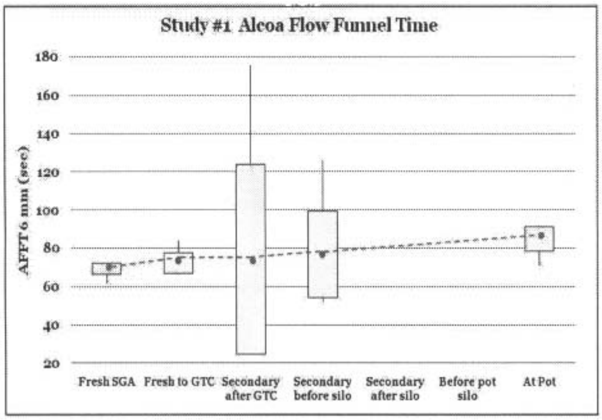

Figure 4 – Alumina flowability results of study location #1

The answer to this apparent discrepancy was found through examination of the superfine fractions of these samples. These were summarized by the contents of: %-20μ, %-10μ and %-5μ in alumina. Refer to Figure 5.

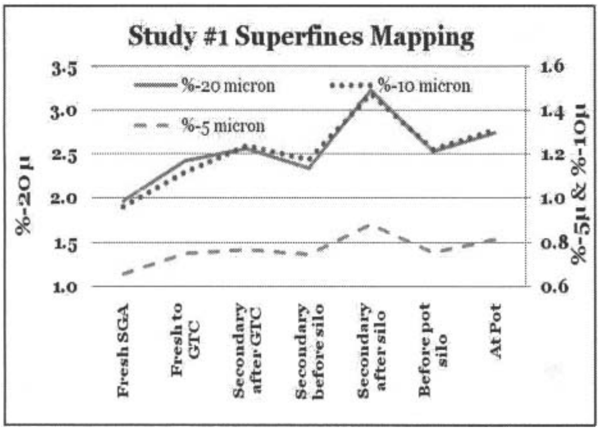

Figure 5 – Superfine fractions from Study #1

A number of interesting observations are associated with this data.

There is an apparent increase in superfines content prior to the gas treatment center, or GTC. This may be attributed to factors such as: variation in sampling, segregation in the fresh alumina silo, or perhaps minor attrition in the airlift. Note that these flow path studies did not follow specific lots of alumina along the flow path. Samples were gathered at various points in the flow path all but simultaneously.

The patterns of %-20μ, %-10μ and %-5μ in secondary alumina match each other quite well as is shown in Figure 5. This infers that the increases have been driven by the same mechanism. The most likely source of these particles is the fine particulate evolved with pot fume. This is illustrated in a typical PSD for fume particulate that is shown in Figure 6 [2].

In Study #1 48%+/-2% of the sub-20μ material was sub-10μ in diameter and 30%+/-3% was sub-5μ in diameter. These proportions were consistent over the entire flow path from fresh alumina to the pots. Note that 72% of the sub-20μ material found in alumina at the pot was originally present in the fresh alumina.

Further, the data indicates that 28% of the sub-20μ material at the pot has a similar PSD to the sub-20μ material found in the fresh alumina. Note that alumina "at the pot" may be a bit of a misnomer. There were no attempts made to actually capture and analyze alumina that was being delivered to a feed hole in the pot crust. The reason is that some dust generated during feeding is lost to the pot exhaust and is not delivered into the pot per se.

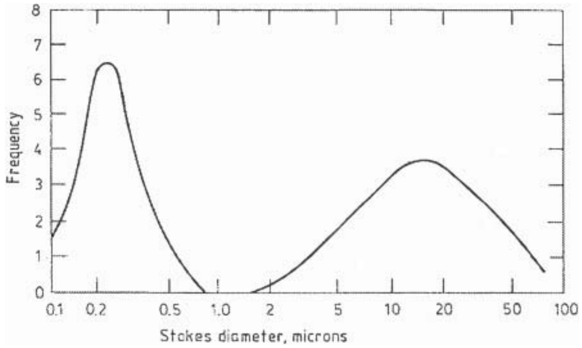

Figure 6 – Particle Size Distribution of Fume Particulate [2]

Study #2 - Attrition mapping Study #2 also had a nearly ideal configuration for minimal attrition. Handling systems with this study included; air gravity conveyors, silos, one air lift for fresh alumina and another for secondary alumina, a fluid bed type gas treatment center and air gravity conveyance to pot bins.

The %A.I. of this second alumina source was 15% during the period of study as determined by the Alcoa method.

The overall results of study #2 closely mimic those of Study #1 even though they represent different smelters and refineries. Thus, Study #2 is presented here as a confirmation of Study #1.

As with Study #1 the d10 and d50 particle diameters remained essentially the same. However, there was a more pronounced difference at d90. Refer to Figure 7 to see this difference.

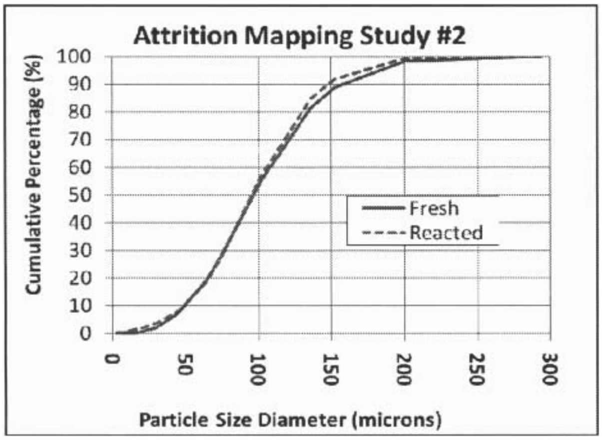

Figure 7 – Particle Size Distributions from Study #2

The morphology of this alumina may have been such that the corners of larger particles were more easily chipped and rounded.

Calculation of actual %A.I. in the field was 0.6% for Study #2. This is approximately 1/25th of the %A.I. reported in fresh SGA.

As with Study #1 the distribution of superfines in secondary, or reacted alumina, were similar to the PSD in the literature for fume particulate in the range of 2 to 50 microns. Refer to Figure 8 for the cumulative distributions of superfines in fresh and secondary alumina.

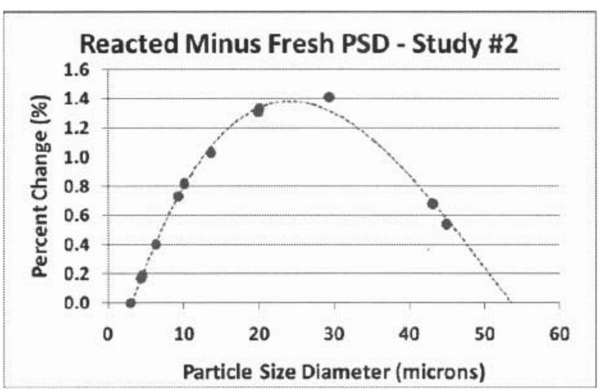

Figure 8 – Distribution of superfines from Study #2

These first two studies establish a baseline for what might be expected with a nearly ideal alumina handling configuration. "Ideal" implies a system with little pneumatic transport to move particles onward at any substantial velocity. See Figure 9 for the approximation of the PSD for fume particles in Study #2.

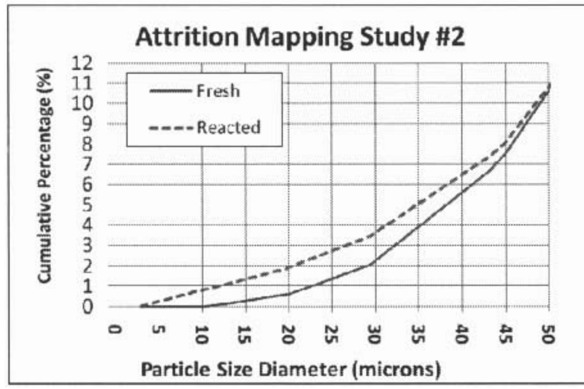

Figure 9 – Distribution of fume particles + attrition from Study #2

Study #3 - Attrition mapping Study #3 was also performed in a modern pre-bake smelter with various types of dense phase conveying systems in its alumina flow path. This location also uses injection type dry scrubbers. Delivery to the pots is via modern transport systems with low particle velocity.

The %A.I. of this third alumina source was 10.5% during the period of study as determined by the Alcoa method.

The results of this study were quite different. Significant changes were observed in d10, d50, and d90 along the alumina flow path. See Figure 10 for an illustration.

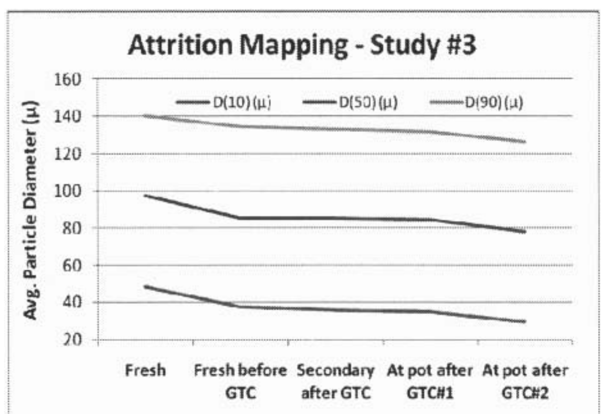

Figure 10 – Attrition mapping results of study location #3

Note that the attrition index for this SGA is the lowest of the three studies presented thus far. However, actual attrition was more pronounced across the entire PSD. The primary difference at this location is the use of various dense phase transport systems over both long and short distances.

Note the significant decrease in average particle diameter prior to fresh alumina arrival to the GTC. A short path dense transport system is used in conjunction with an airlift to move alumina from unloading into the main silo. This is followed by a dense phase transport system over a moderate distance to the fresh alumina silo of GTC#1. This dense phase system includes multiple 90 degree turns. Sub-45μ was increased by ~6% in these systems.

Passing through the GTCs there was only a minor increase in sub-45µ, ~2%, or 1.1% A.I. across the GTC. This was followed by a second dense phase system for fresh alumina from the fresh silo of GTC#1 to the fresh silo of GTC#2. This caused to another increase in sub-45µ of ~4.5%.

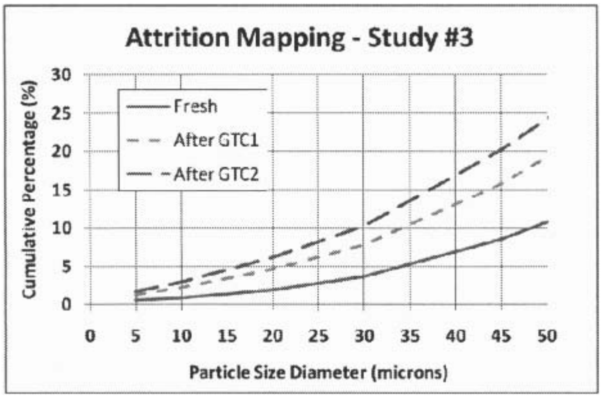

Figure 11 – Distribution of superfines from Study #3

Unlike Figure 8, note that there is no convergence of the fresh and secondary PSDs above 45µ particle diameters in Figure 11. This implies that attrition of alumina particles is combined with fume particulate in the sub-45µ fraction. Sorting out the relative contributions of alumina particles broken by attrition and that of pot fume can require chemical analysis under such circumstances. However, it is possible to draw upon the results of Studies # 1 & #2 to estimate the fraction that originated with pot fume assigning the balance to the attrition of particles.

For study #3 %A.I. in the field was 7.9% after GTC#1 and 12.8% after GTC#2. These are much closer to the value reported by the refinery for fresh alumina, 10.5%, than with the first two studies. The significance of this is that alumina handling system design is important to the actual amount of attrition observed in the field.

Study #4 – In all, more than a dozen attrition mapping studies were performed on both pre-baked and Søderberg smelters. A portion of Study #4 is included here to illustrate the impacts of various types of dry scrubbing systems. The location of Study #4 primarily utilizes conveyor belts, airlifts and air gravity conveyors to transport alumina. But, this location has two types of gas treatment centers. One is a fluid bed type and the other is a modern injection type dry scrubber.

The %A.I. of the alumina in this study, a fourth source, was 7.4% during the period of study as determined by the Alcoa method. The %A.I. in the field, across the dry scrubbers only, was 0.6% for the fluid bed type vs. 3.5% for the injection type. This result is consistent with similar comparisons that have been made at Alcoa locations that use two types of dry scrubbers.

Refer to Figure 12. Note that increases in superfines in secondary alumina from the fluid bed scrubber closely mimic fresh vs. secondary alumina from Study #2. Studies #1, #2 and #4 all utilized identical fluid bed dry scrubbers. One again, the PSD converges with that of fresh alumina near particle size diameters of 5 and 50 microns. This appears to confirm that such increases in superfine fractions may be attributed primarily to fine bath and alumina particles carried by the pot exhaust gas stream.

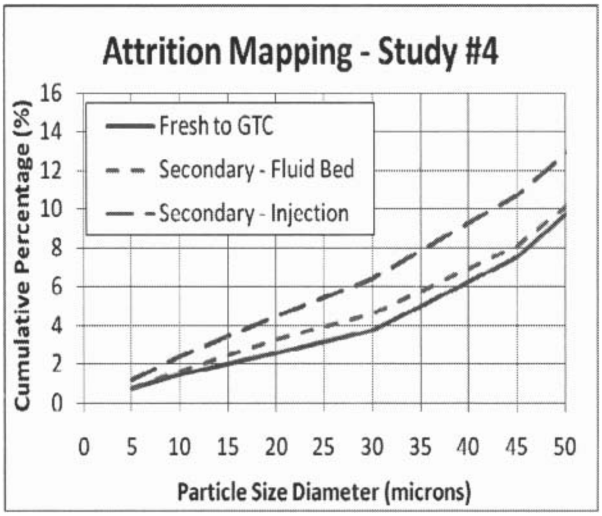

Figure 12 – Distribution of superfines from Study #4

The shape of the curve for the injection type GTC in Figure 12 is similar to that of Study #3, but with lower overall percentages of superfines in alumina. The implication is that the energy imparted as alumina makes multiple passes through the process gas stream of the dry scrubber fractures particles. This is true even with a low value of 7.4% A.I. for SGA. The increase in the %-45 micron across the injection type GTC was 2.7% more than with the fluid bed type scrubber.

While this amount of attrition is not abnormally high it does illustrate that various types of dry scrubbers in various operating conditions can also have a range of impact upon particle attrition.

Fluid Bed type – Study #1 ~0%A.I. across the GTC
Fluid Bed type – Study #2 ~0%A.I. across the GTC
Injection type – Study #3 1.1%A.I. across the GTC
Fluid Bed type – Study #4 0.6%A.I. across the GTC
Injection type – Study #4 3.5%.A.I across the GTC

Discussion

Note that all studies that have been presented here are the product of multiple grab samples taken according to strict procedures and made into composites. In all cases composites were replicated at each sampling site between two and four times. Each composite was then analyzed using the same equipment in the same labs for determinations of particle size distribution and flowability.

There is margin for error in any industrial scale study. When dealing with fine granular material the risk of introduction of bias is high. This may come either from segregation issues in the handling system or with inadequate sampling technique. Precautions have been made in the presentation of this data to validate it against the findings of other sampling points along each alumina flow path and against other locations that utilize similar equipment or handling system configurations.

Conclusions

Unfortunately, the output of this study cannot draw a specific conclusion about what may happen when the %A.I. of an SGA changes. Changes in the attrition index with any one source of alumina and changes in sources of alumina passed through alumina handling systems were not included in the scope of this study. At this point it is still uncertain that changes in the magnitude of %A.I. for an alumina source may be used to accurately predict changes in the PSD of alumina prior to the reduction cell.

The major factor that impacts actual attrition of particles in the field is the configuration of an alumina handling system. It has been observed that Actual %A.I. at a smelter may be roughly equal to the %A.I. reported by a refinery. It may also be much lower with Actual %A.I. being only 1/25th of the value reported by the refinery. Of particular concern are pneumatic transport devices that may rapidly move air to move alumina. In situations such as those described in Study #3 there were high rates of attrition at d10, d50 and d90. In such cases it appears that %A.I. has similar general meaning for a wide range of particle diameters, not only at 45 microns.

Differences in particle attrition were also observed between fluid bed and modern injection type dry scrubbers. This was not unexpected, but some systems did demonstrate higher rates of attrition than others, even when the %A.I. of the fresh alumina was relatively low. Some of these differences may be ascribed to system operating conditions and some may be ascribed to GTC design factors.

The most common system presented here, fluid bed GTCs with low impact handling systems, did not produce significant amounts of particle attrition. These type systems were observed across a wide range of attrition indexes, from 7.4% to 17%, as measured by the Alcoa method for %A.I.

The comparison of fresh and secondary alumina from Study #2, shown in Figure 8, is typical for low impact handling system configurations. The differences between these two distributions produce a sub-distribution shown in Figure 9 that is quite similar to the literature reference provided for fume particulate that is shown in Figure 6.

With low impact systems it appears that the primary contributors to changes in PSD are fine bath and alumina particles carried by the pot exhaust gas. Observations indicate that fume particulate has its greatest impact in the sub-40 micron range. Thus, standard methods for measurement of %A.I. will not be easily extrapolated into superfine particle diameters.

With the wide range of alumina handling and dry scrubbing systems that exist in our industry it is most important to "Know thyself" before taking differences in the %A.I. for various sources of SGA into serious consideration.

References

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