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IMPACT ON SMELTER OPERATIONS OF OPERATING HIGH PURITY REDUCTION CELLS

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Abstract

Over the last 15 years New Zealand Aluminium Smelters Limited (NZAS) has developed and implemented technology and operating practices to produce High Purity (Al 99.90+) and Ultra High Purity (Al 99.97+) ingot. In the challenging macro-economic climate of falling LME, weakening exchange rates and increasing power prices, the High Purity strategy has enabled NZAS to maximize value and maintain global leadership in High Purity smelter grade aluminium production.

The NZAS journey to High Purity production and the impact that this strategy has had on the complexity of smelter operations are outlined. The operational focus necessary to successfully implement the High Purity strategy is also required to improve all facets of smelter operations. Data will be presented to show the impact recent challenges, such as reducing quality of raw materials, are having on smelter operation and how these are being managed to maintain High and Ultra High purity production economically.

Introduction

The NZAS smelter is a joint venture between Pacific Aluminium and Sumitomo Chemical Company and was commissioned at Tiwai Point, New Zealand in 1971. The rate of production has increased via three expansions and continuous efficiency improvements. NZAS operates four reduction lines, three using Kaiser P69 technology (624 cells) and one line using Comalco CD200 technology (48 cells).

The primary focus of the plant is the production of Value Add Product (VAP). These include foundry ingot, billet, rolling block and Purity ingot. In particular NZAS produces High Purity and Ultra High Purity grades of ingot. High and Ultra High Purity ingot are shipped internationally and find end-uses in the industries of aerospace, transport, electronics and communications.

The NZAS High Purity Journey

NZAS has been producing saleable High Purity aluminium since the 1980's.

During the 1990's significant work [1] was conducted to better understand the impact that raw material segregation and cell operating conditions had on impurity partition factors. Over the last ten years the focus on High Purity value has further increased with Lean Six Sigma driving dedicated, cross functional, data-based teams identifying opportunities to maximize Ultra High Purity production and capture.

The production of High Purity ingot (99.90+) has now increased to the level where 148,000 tonnes was produced in 2011 (Figure 1 and 2). High Purity production at NZAS equates to 42% of total production. This ranks NZAS as one of the largest primary producers and suppliers of Purity ingot.

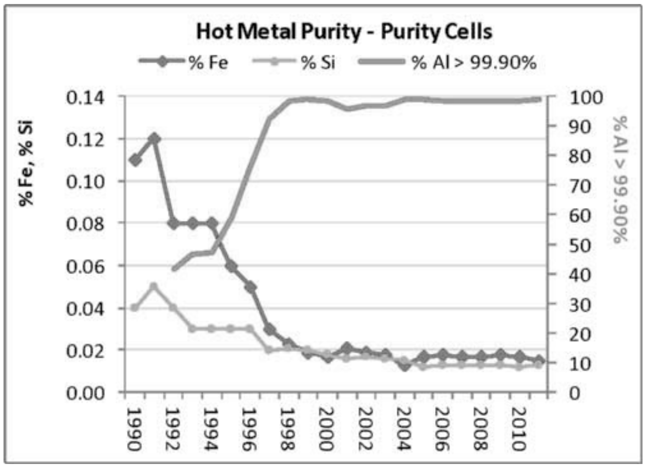

Figure 1: Metal Purity in Purity Cells.

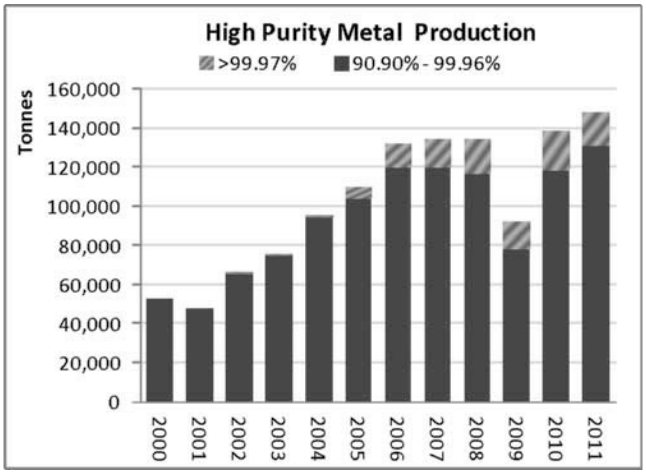

Figure 2: NZAS High Purity Production
(note the impact of reduced site production in 2009)

Aspects of NZAS' High Purity Strategy

The general principles of High Purity capture will be well known to all smelter operators. A fundamental understanding of all sources of impurity and their relative impacts, and transport mechanisms, around the smelter is required. The primary areas of focus necessary for High Purity production include:

- Raw Material selection, segregation and delivery practices.
- Maintaining process stability – avoiding process excursions and sustaining consistent anode and metal crucible delivery.
- Anode setting practice and anode performance in the cell.

- Cell control parameters and response plans (including heat balance, electrolyte and alumina feed control)
- A mindset in all employees and departments in the smelter to support the strategy (including carbon, casthouse, maintenance, cell reconstruction and power supply teams).
- Cell metal purity data, sampling and response practices.
- Casthouse scheduling, sampling, batching and casting practices.

All of these add complexity to the operation that require dedication, persistence and a focus on process stability as outlined by Doiron and Lindsay [2]. Examples of how NZAS executes the High Purity strategy in the first four areas are presented below.

Challenges with Raw Materials

In a smelter with gas treatment centres, most of the impurities in the raw materials that enter the smelter will exit via the solidified, aluminium product. Therefore the fundamental issues to solve are:

1) How to procure better raw materials (with lower impurities)
2) How to segregate the impurities in the raw materials away from purity cells and metal
3) How to forecast and adapt to changing raw material qualities

Raw Material Purity Degradation

In a stable operation the two major sources of impurity in the smelter are the alumina and the anodes (coke, pitch and anode butts). With the degradation over time of world oil reserves, the quality of petroleum coke is declining [3]. Gaining access to better raw materials (with lower impurities) is difficult. Increases in levels of iron, silicon and vanadium in NZAS anodes have been observed since 2005 (Figure 3). The increase in silicon and vanadium is attributed to changes in coke and pitch impurity levels, however some of the iron degradation comes from changes in the anode butts that get recycled into anodes. Approximately 60% of the iron in anodes at NZAS is from the butts fraction compared with 20% from the coke and pitch streams.

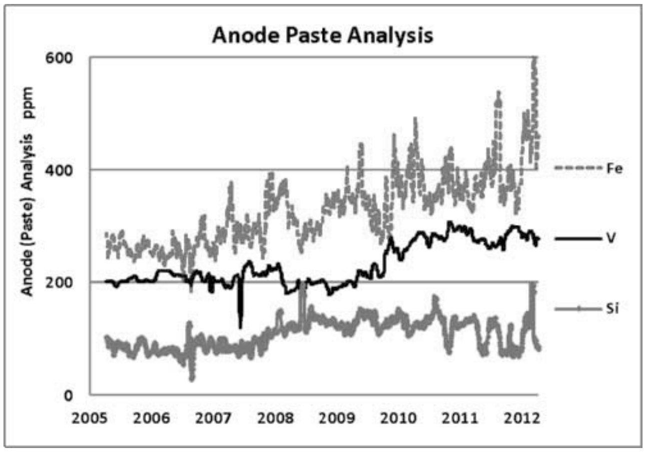

Figure 3: Increase in Anode Paste Impurity Level.

Changes in alumina quality also affect purity capture as demonstrated in Figure 4. The effect is not immediate as the cells slowly establish new purity equilibrium over many days. Recovery will also be delayed due to the dilution characteristics of the cell (daily metal production against metal reserve).

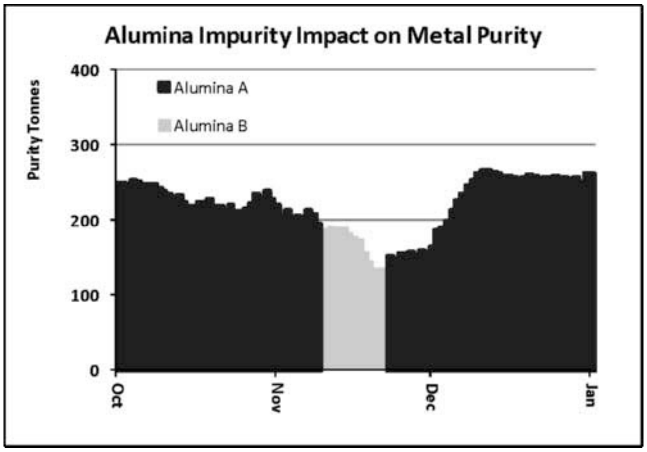

Figure 4: Effect of Alumina Source on Purity Production

Modelling and Adapting to Raw Material Quality

With raw material qualities degrading, it is critical to monitor and adapt, or mitigate the impact of the purity of the incoming alumina, coke and pitch supplies. The ability to model and predict the impact on metal purity, and then feed forward this information to the Anode, Reduction Cell and Casthouse control systems, is essential to maintaining and improving purity production. For example anodes can be blended with alternative coke supplies, pitch supplies and recycled butts of differing compositions to make the 'optimum' anode.

This process can only be effective if a good understanding is achieved of the interrelationship between anode chemistry and metal chemistry and the time scales for change. Models have been developed at NZAS to dynamically predict changes in metal chemistry as a result of changes in raw materials. As an example Figure 5 shows the predicted change in cell metal silicon expected from changes in anode chemistry and how it compares with the actual measured result.

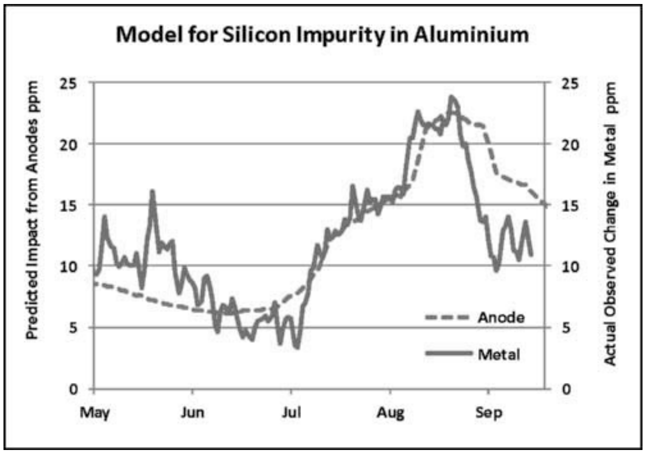

Figure 5: Comparison of Predicted Silicon and Actual Silicon in Metal Due to Coke Change.

These models are important to predict any changes in metal purity and either enable countermeasures to be implemented, or purity capture to be targeted at specific quality grades. As this model looks only at anode chemistry it can deviate if a change in other inputs, for example alumina chemistry, occurs. For this reason a number of models are used either separately or in combination to enhance purity prediction.

Process stability is vital for the models to accurately predict the impacts so appropriate response can be taken. For anodes, a 25 to 30 day lag between paste production, baking and then use in the potlines gives a good lead time for longer term scheduling of purity capture.

Despite the worsening impurity trends in raw materials, the amount of High Purity and Ultra High Purity captured has increased at NZAS due to an internal focus on process stability, control and purity capture projects.

Maintaining Process Stability - Anode Excursion

Gains in purity achieved through improved process control and raw material improvements, can be lost or severely impacted upon by process excursions.

The impact of anode performance in Reduction cells is most evident in iron pickup in aluminium in High Purity cells [2]. This is particularly observed during anode excursions. The anodes in P69 cells are prone to Airburn attack (sides and tops of anodes burning above the electrolyte interface). This propensity to Airburn requires the anodes to be sprayed with a protective coating of Aluminium metal before delivery to the Reduction cells. Airburn damage to the anodes leads to the possibility of either impurity laden anode cover falling into the cell or the stubs and cast iron being exposed to the bath (Figure 6).

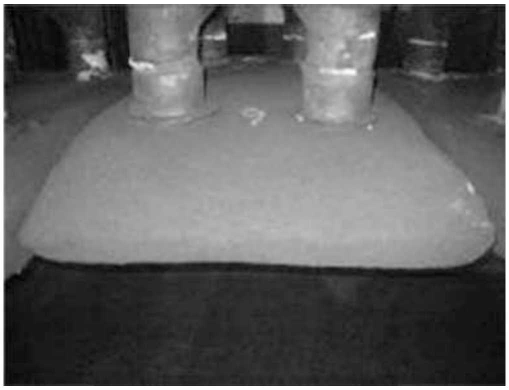

Figure 6A: A "Good", full-rota butt with no airburn

Figure 6B: A full-rota trial butt showing severe Airburn attack - with exposed stubs.

Either of these events will lead to an increase in iron and other impurities in the aluminium in the cell. The impact of an Airburn excursion in 2010 can clearly be seen in Figure 7. An increase in the number of anodes changed early due to Airburn closely tracks an increase in iron in cells.

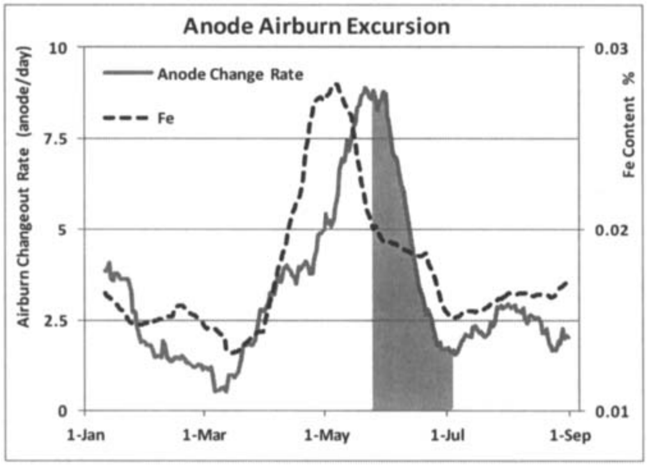

Figure 7: Effect of Airburn Excursion on Metal Iron Content

To maintain High Purity it is important to remove any damaged anodes early. The higher burn rate of damaged anodes places them at increased risk of flux washing and stub damage, due to the smaller protection from the electrolyte offered by the carbon and the reduced butt thickness. Figure 7 also shows how the increase in iron typically precedes any noted increase in the Airburn changeout rate. This demonstrates how important it is to continually monitor anode condition and take corrective action if any increase in Airburn is detected before purity impacts become severe.

Improving Process Understanding to Eliminate Airburn

Changing anodes that have suffered Airburn attack early is an effective but costly method of containment.

The mindset necessary to improve and sustain High Purity production requires in-depth analysis to identify and eliminate the potential root causes of process instability. An example of this High Purity focus and mindset was the NZAS 2011 Airburn project. This Lean Six Sigma project was developed and lead by a team of the most capable leaders and engineers on site. The team was set the task of identifying permanent countermeasures to eliminate Airburn, make the process robust to any future excursion and lock in process stability to maximize High Purity production.

Six factors were identified as likely contributors to Airburn:

- Anode cover particle size distribution (PSD)
- Anode cover height/depth on anodes
- Cell Draught
- Heat loss from the top of the cell (via superheat)
- Sodium in anodes
- Aluminium Spray coverage on the anodes

A six-factor, two-level, fractional factorial experiment was undertaken to test the significance of each factor over a four month period. The dominant, significant factors were found to be aluminium spray quality, anode cover PSD and top heat loss. Interaction between top heat loss and spray was also found to be of importance.

The lack of quality and quantity of spray allows oxygen to access the hot carbon. Figure 8 shows how the trial data also demonstrate an interaction between spray quality and cell super heat:

- The superheat effect is minimal at low spray levels – the reaction is mass transfer controlled.
- Conversely, for the high spray levels, carbon consumption is temperature controlled and superheat has a stronger impact.
- Overall, carbon consumption is least for the combination of high spray and low superheat.

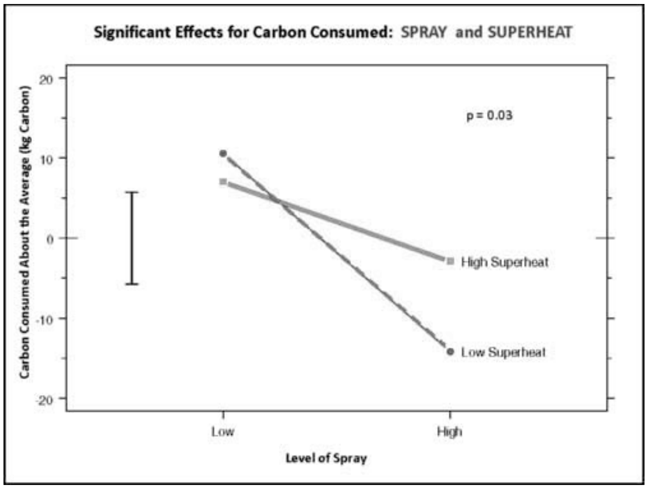

Figure 8: Results for the Airburn trial - Interaction Plot of Spray and Superheat

Based on factors used in the trial, an empirical model for carbon consumption due to Airburn has been developed. This has enabled the implementation of Lean, visual and engineering controls to make the process more robust to anode excursion and loss of High Purity production.

Cell Control Parameters

Bath Level Control

Control of bath depth is well understood to control the tendency for flux washing of anodes and stub damage [2]. Important factors to control include the timing and frequency of the bath depth measurement and action, and the target bath level. The bath level in a cell typically changes following setting of an anode in a cell due to cover material falling into the bath. The effect of the increasing bath level is seen on the change in the iron content reported in Figure 9. The highest iron levels are seen in samples taken after the highest bath depth readings.

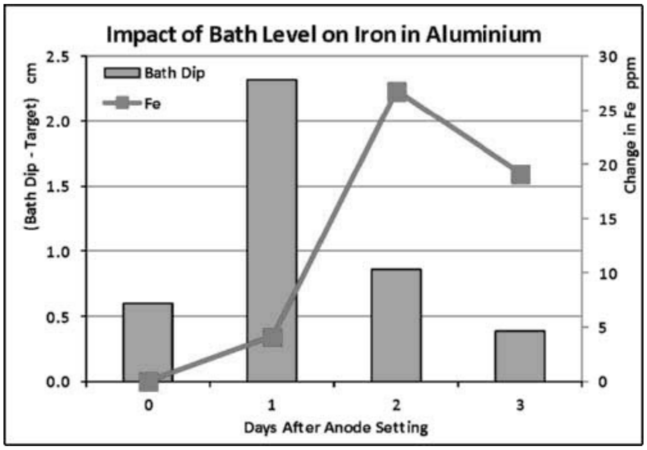

Figure 9: Change in Bath and Iron Levels with Anode Setting

It is important that the bath depth measurement and corrective action is carried out at the appropriate time after anode setting and before any impact is observed. NZAS works on a 24-hour setting and tapping cycle where ideally the timing of setting, dipping and metal tapping operations is consistent for optimum bath level control. This can be impractical, so the aim is to minimise bath variation through addressing anode setting practices and giving the highest purity cells priority when bath adjustments are required.

Alumina Feed Control

One of the main factors in maintaining cell stability is alumina feed control. This is of particular importance for bar break cells where it is commonplace for a large mass of Heavy Cover to fall in, depositing conglomerated alumina and frozen bath at the bottom of the cell. Poor alumina feed control will result in increased Anode Effect frequency which can lead to poor bath height control and a negative impact on purity. Strategies must be used to maintain sufficient feed to minimise Anode Effects and maintain a stable alumina concentration in the bath. In 2008 NZAS implemented a new Adaptive Feed strategy to dynamically control the alumina addition rates to the cell as part of a coordinated strategy to reduce Anode Effect rates. This resulted in a 70% reduction in Anode Effect rates during the trial period, as shown in Figure 10.

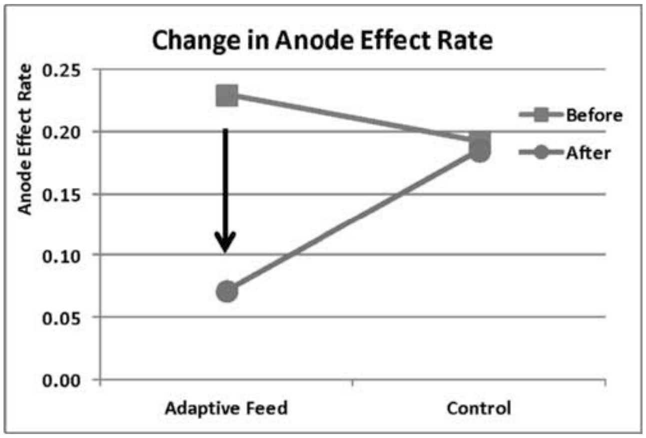

Figure 10: Effect of Adaptive Feed Strategy on Anode Effect Rates.

A positive secondary outcome from the introduction of the Adaptive Feed strategy was a reduction in iron levels in the trial group, despite an overall increase in iron in the line due to raw material and process changes (Figure 11). The Adaptive Feed strategy reduced the periods of low alumina concentration in the cell and the Anode Effect frequency. This has led to better bath height control and lower iron content in the cell.

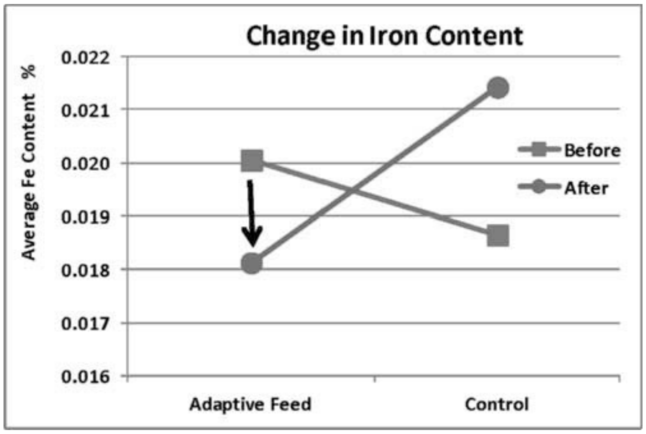

Figure 11: Effect of Adaptive Feed Strategy on Iron Levels

Purity Mindset

To be successful in purity production it is necessary to have a "Purity Mindset" in all employees on site. Everyone must be aligned and working together to protect Purity and focus on maintaining robust controls. The right Business Improvement tools and projects must also be utilized such as in the Airburn team example described early in this paper.

Identifying and Eliminating Contamination

In another example, a review of individual cell performance showed that some cells were continually higher in silicon than their group. Silicon can increase with cell temperature and the loss of sidewall ledge protection resulting in bath attack of silicon carbide lining materials. Since this was not occurring in these cells investigations were carried out to understand the root cause. In this case the cells were located at the end of the Reduction Line where routine bagged additions would begin. Historically the protective coverings from pallets of bath additions were stripped at the start of the Reduction Line. Any metal clips were disposed of separately but the cardboard and strapping were disposed of in the nearest cell. Examination of the packing material showed the strapping was a silica reinforced plastic and was the cause of the higher silicon content. The amount of strapping added on a daily basis was small but sufficient to increase the silicon content of the cell by 20ppm as shown in Figure 12. Small actions taken by any team member at the smelter can have observable impact on purity production.

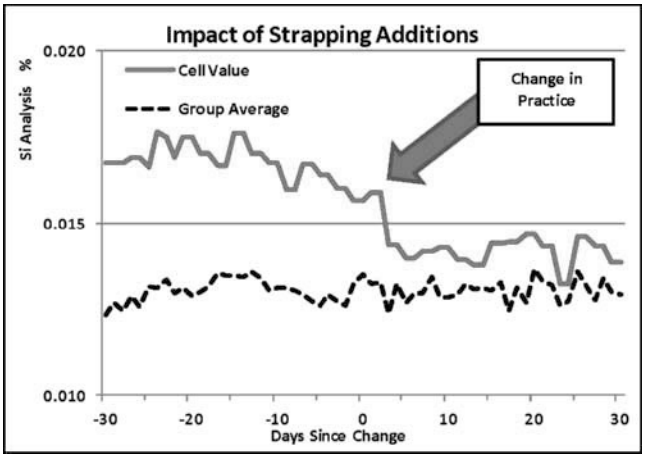

Figure 12: Reduction in Silicon Without Adding Strapping

Process Understanding – Identifying What Improvements to Make

Across the purity cells in a Reduction Line, a distribution in purity occurs due to variation in the process or raw material quality. Control of all impurity elements is important but at the highest purity grades there will normally be one or two elements which will lie closest to the product specification limits and are the "bottleneck" elements preventing further purity capture. Depending on how close to the Reduction Line distribution is to the limit, and the tightness of the distribution of cells, small changes in average purity can have large changes in the quantity available of that grade. For example, Figure 13 shows a tight distribution in cell purity for one element on the Reduction Line. As line purity deteriorates (moving to the right of Figure 13), the distribution moves. In this example a dramatic reduction in purity capture is observed with many cells above the specification limit. However, as the cell distribution moves to the left of Figure 13, an improvement in line average beyond a certain point can result in a plateau of total purity capture. This could be because other elements (eg. Fe, Si, V) now become the limiting factor to capturing purity. At this point there is no value in driving further improvement in this impurity as it drives unnecessary cost for no more benefit. An appreciation of the sensitivity of the smelter process to these limits is critical in understanding the day-to-day purity control of a smelter and the elements which need to be targeted at any point in time. This can determine the improvement projects to focus on, or the smelter processes to target for better control.

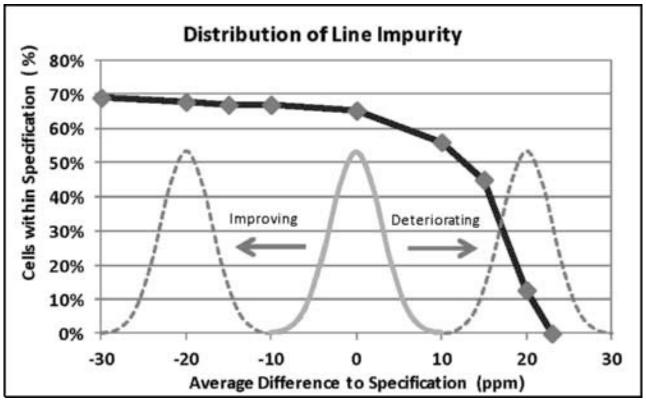

Figure 13: Sensitivity of Purity to Elemental Change

Modifying Purity Strategy

A more significant change in purity can be achieved by a fundamental change in purity strategy. Depending on market requirements, the smelter can be operated differently to increase or reduce purity production (Figure 14). This can include a change in alumina, raw material streaming, or a change in process targets and control methodology. In Figure 14 the High Purity strategy was turned off part of a Reduction Line in April and the drop in purity capture was observed in five days. When the strategy was restarted in November the recovery took much longer, taking 20 to 30 days. This demonstrates the flexibility of the strategy but also the timescales required to recover purity.

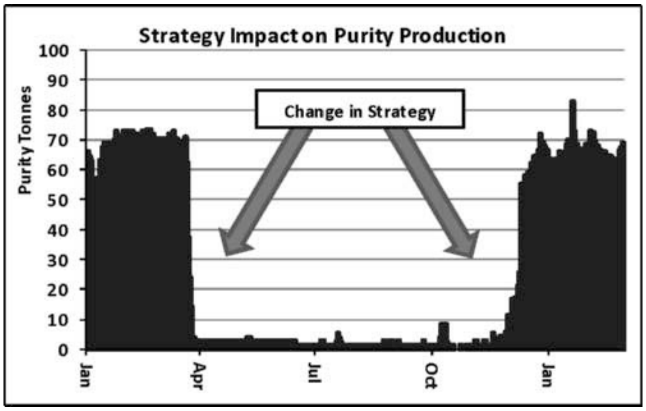

Figure 14: Impact of Stopping and Starting Purity Strategy

Flow on Effects to all Operational Facets

The examples in this paper touch on the level of operational focus required to achieve the purity production results at NZAS. The level of work and focus involved increases the complexity of the operation from the Carbon Plant, Reduction Lines, Cast House and supporting functions. This requires a good level of process understanding and focus on quality which in turn results in operational improvements in many other facets of the operation.

NZAS' improvement in purity production has taken place while cell output per day has increased through amperage and current efficiency. Cell output has increased by nearly 25% in the last 20 years (Figure 15) while improving and sustaining the net carbon consumption (Table 1).

Table 1: Improvement in Anode Performance (Net Carbon Ratio) with Increasing Cell Production Rate (Amperage)

Period	P69 Amperage (kA)	Net Carbon Ratio (kg C/kg Al)
1990 – 1996	162-169	0.436
1997 – 2010	170-194	0.422
2011 - 2012	195-197	0.409

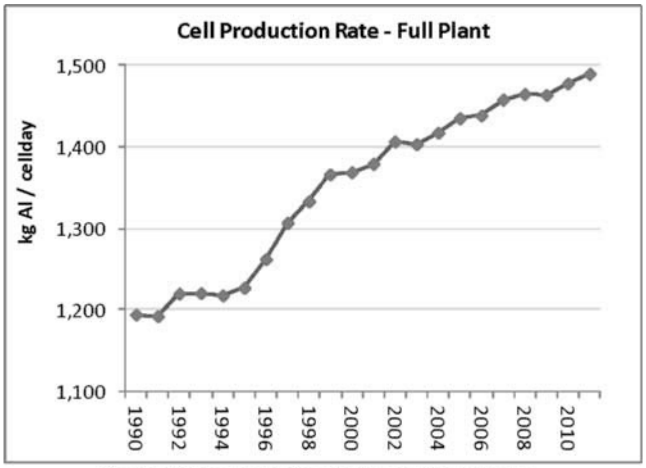

Figure 15: Increase in cell production per day.

Future Opportunities

With macroeconomic pressures continuing, High Purity production will continue to remain a significant contributor of value for NZAS.

Despite deteriorating raw material quality, NZAS has been able to demonstrate increased production of High Purity and Ultra High Purity. This has occurred through an improved understanding of how to better control smelter operations, maintain process stability, and predict and adapt the strategy to match changes in inputs.

All impurities that enter the smelter in raw material streams need to leave the smelter in the metal product. Improving the ability to minimise other process sources of impurities and to segregate impurities away from High Purity cells will minimise the proportion of lower purity cells required as an "impurity outlet".

Pressure on raw material quality is expected to continue in future with regards to impurity content. This challenge will require further improvements in smelter operation which will come with greater understanding of process dynamics, closer control of critical process variables and identifying the next suite of improvement projects. It is likely that these initiatives will lead to improvements in other aspects of smelting operations over time.

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