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IMPACT OF HIGHER VANADIUM LEVELS ON SMELTER OPERATIONS

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Abstract

In early 2011, the Rio Tinto - Sebree Works smelter experienced a significant increase (~100ppm) in calcined coke vanadium to levels around 410-440ppm. This was driven by crude oil changes at a refinery supplying one of the primary cokes used in the coke blend supplied to the smelter. The paper discusses the impact of the change on anode quality and carbon consumption and some of the actions taken by the smelter to respond to the change. Data is presented showing the impact on process metrics such as anode consumption, unscheduled anode changes, current efficiency, power consumption, and primary metal quality. The paper shows that changes of this magnitude can be managed with an appropriate understanding of key performance drivers and a focused technical improvement plan.

Introduction

It is generally well know that vanadium, nickel, and sulfur levels have been increasing on average in petroleum cokes as a result of changes in crude oil quality and refining economics. Several papers have been published on this since 2004 [1,2,3] and these papers do a good job of explaining the root causes and highlighting some of the potential impacts on smelter operation and metal quality. Very little work has been published however, on quantifying the impact of a step change in coke quality. The best example is probably a paper published in 1989 [4] on trials undertaken in a Venezuelan smelter with a high vanadium level (~2000ppm), highly isotropic coke. The trial was abandoned due to anode cracking problems associated with using an isotropic coke with a high coefficient of thermal expansion.

The Rio Tinto - Sebree Works smelter in Sebree, Kentucky is a 200,000 MT/yr primary aluminum smelter utilizing Alcoa P155 pot technology. The smelter was operating between 188 kA and 195 kA in 2011 and early 2012 and at 204 kA at the time of writing this paper. In early 2011, the smelter experienced a sudden and unexpected change in calcined petroleum coke (CPC) quality and the vanadium level increased by around 100ppm from a level of 300-330ppm to 410-450ppm. The Sebree smelter takes CPC by railcar from a nearby calciner located in Robinson, Illinois. The change in CPC quality was driven by a change at a refinery supplying the primary high sulfur coke used at the calciner, but was compounded by changes in the quality and availability of other cokes used at the calciner.

The information and results presented in this paper provide a good case-study example of some of the changes occurring with CPC quality and what a smelter can do to respond to these changes. The paper will start with a brief review of the coke quality change and then focus on the impact and changes at the smelter.

Coke Quality Change

The Sebree smelter has been using the same CPC source for more than 15 years. The CPC is a blend of three to five different cokes with a range of sulfur and vanadium levels. In early 2011, the refinery supplying the primary high sulfur coke used in the blend advised that they had an opportunity to purchase a lower cost, Canadian high sulfur crude oil. Completion of a new pipeline brought supply of the crude oil close to the refinery. The refinery experimented with running 5-7% of the new crude over the January to March 2011 period. The Canadian crude replaced other more expensive crudes and the 5-7% change was enough to cause the vanadium level to increase by ~100ppm in 2011 and another ~100ppm in 2012 as shown in Figure 1. The Ni level increased by around 40ppm over the 2011-2012 time period.

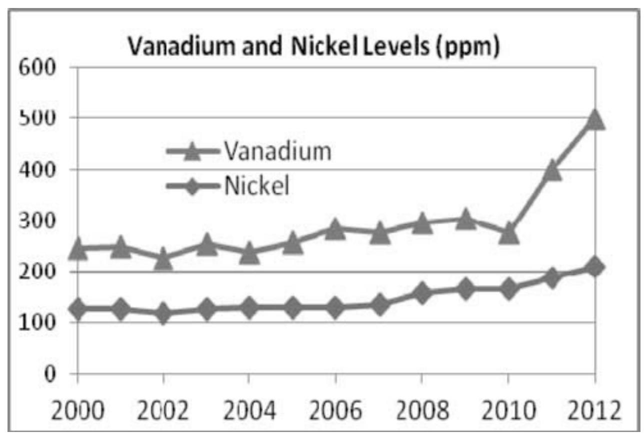

Figure 1: V and Ni Level in High Sulfur Green Coke

The economics of the crude change were compelling and the refinery estimated savings of the order of US$10 million/month. Although the magnitude of the saving varies with the price of crude oil and value of the refinery products, the refinery has continued to run the Canadian crude and continued to focus on improving refinery economics. The refinery has experimented with running higher levels but this triggers the formation of shot coke which represents a major safety hazard for the refinery when de-heading the coke drum.

When a coke quality change like this occurs, it can generally be compensated for by changing other cokes in the blend. Increasing the amount of low sulfur, low vanadium coke in the blend would offset the vanadium level increase. Two compounding factors made this very difficult in 2011. The primary low sulfur coke used at the Robinson calciner had undergone a steady increase in sulfur and vanadium from an average of 2.0% and 160ppm respectively over the 2000-2008 period to an average of 2.9% and 270ppm in 2011. At these levels, the coke could no longer be classified as low sulfur coke. The second contributing factor was the loss of an important low sulfur coke in late 2009 after the refinery shut down for economic reasons.

The vanadium level of the high sulfur coke increased rapidly and low sulfur, low vanadium coke from the US Gulf had to be shipped to the Robinson calciner to compensate. Without a change in the smelter vanadium specification (330ppm), the volume of low sulfur coke needed from the US Gulf was simply not available and there was no time to source from elsewhere. To address this, the CPC vanadium maximum specification was increased to 450ppm. The data below, Figure 2, shows the impact of this change on the vanadium level of the CPC received at Sebree. The smelter was unable to change the CPC S specification for environmental reasons and it remained at 3.0%.

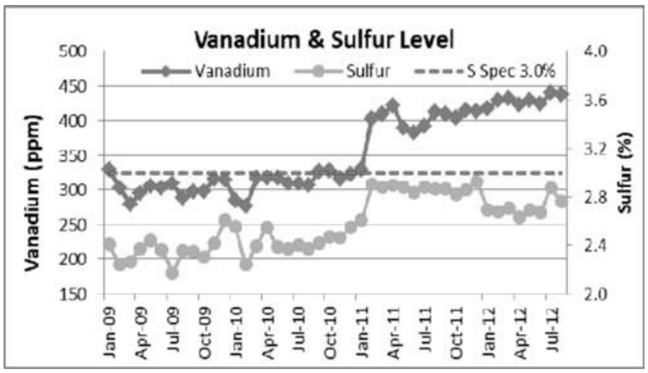

Figure 2: Sebree CPC quality and sulfur spec. (3.0%)

The Robinson calciner is logistically well suited to the Sebree smelter and the coke is railed on a weekly basis. Based on this and Sebrees's experience with using the coke, the smelter has continued with the Robinson supply and the 450ppm V specification.

Summary Comments on Quality Impact at Smelter

The high vanadium calcined petroleum coke arrived at the Sebree smelter in February 2011 and entered the potlines approximately one month later. The baked anode core vanadium levels increased from approximately 0.027% in January to 0.30% in March 2011 as shown in Figure 3. Today, baked anode vanadium levels have stabilized around 0.034%. An increase in vanadium of this magnitude might be expected to cause a significant increase in air reactivity [5,6,7,8] and decrease in current efficiency [8], assuming all other parameters affecting anode performance remain constant.

This was a major concern for Sebree given plans to improve potline performance and increase amperage during 2011. The expected increase in anode air reactivity was observed as shown in Figure 4. The red shaded area shows the data before the change; the blue area shows the period during the change and the green area is the period after the change. Figure 5 shows the increase in vanadium level in the pot metal which correlates well with the increase in the coke vanadium level. Although the increase in vanadium in metal has approached the maximum allowable levels with the current customer mix, it has yet to exceed the limits.

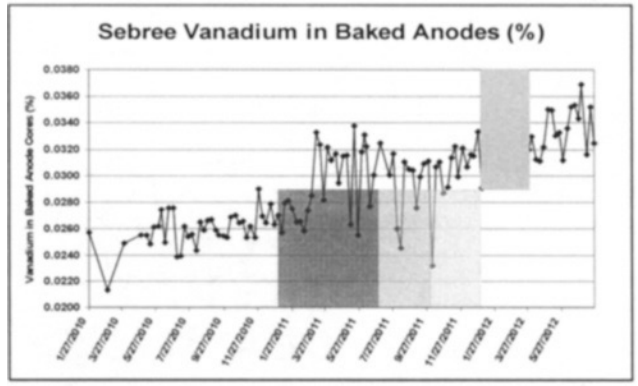

Figure 3: Vanadium in baked anode cores at Sebree

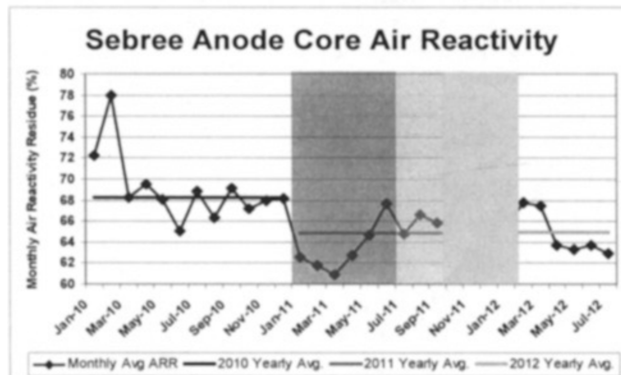

Figure 4: Anode core Air Reactivity Residue at Sebree

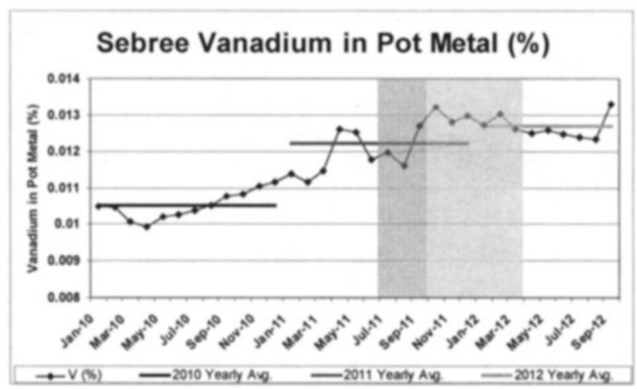

Figure 5: Vanadium levels in metal product at Sebree

To mitigate the effects of increased vanadium levels in the anodes, a Work Quality Management System (WQMS) was implemented in the potrooms. Sebree successfully raised amperage by 7kA, Figure 6, while decreasing net carbon consumption, Figure 7, and improving other potline performance parameters, Figures 8-11 thereby alleviating any negative impacts from the higher vanadium levels.

It is important to note the anode assembly was modified by the addition of a third stub in April 2012. The anode assembly change was unrelated to WQMS and so Figures 3-12 highlight the 6 month periods before (red), during (blue), and after (green) the implementation period of WQMS. However, performance data after the anode assembly change were included as well.

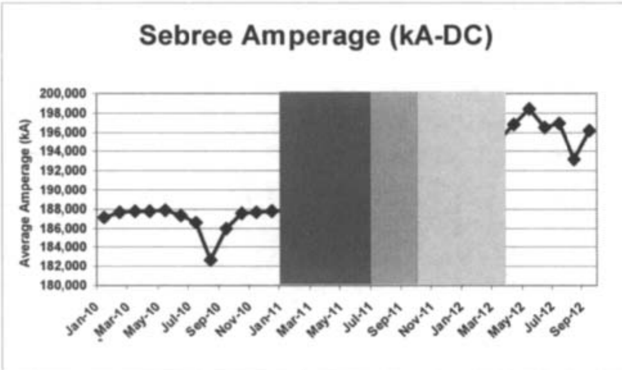

Figure 6: Amperage changes at Sebree

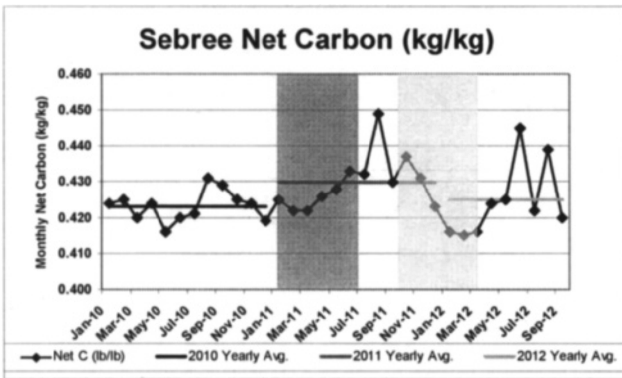

Figure 7: Net carbon consumption at Sebree

Initial Quality Impact at Smelter

Historically, maintaining performance at Sebree during summer months is difficult. The lack of modern pot tending cranes means the work environment is directly impacted by summer heat and there are higher than usual numbers of "out of classification" employees covering for vacations. The timing of the increase in vanadium occurred at the worst possible time for Sebree with the full impact of recycled butts being felt in the summer of 2011. Because of the increase in vanadium, potline performance was more negatively impacted than normal in the summer of 2011 resulting in a larger number of early anode failures. From January to June 2011, the average percentage of anodes failing ahead of scheduled changes was 1.77%. Figure 8 shows this gradually increased to a maximum of 3.77% in August.

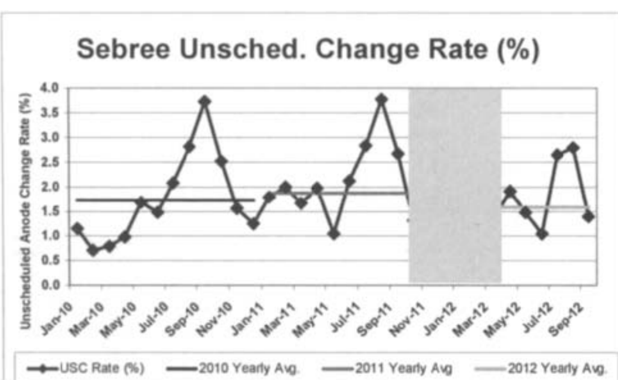

Figure 8: Unscheduled anode change rate at Sebree.

Actions to Stabilize Performance Problems

In order to minimize unscheduled anode changes as well as increase the anode under the stub (to increase metal purity), Sebree decreased the amperage from 188 kA to 183 kA in July and August as shown in Figure 6. With decreases in both amperage and overall process stability, Sebree was forced to increase the anode-to-cathode distance (ACD). The increase in ACD led to an expected increase in specific energy usage during this period as shown in Figure 9.

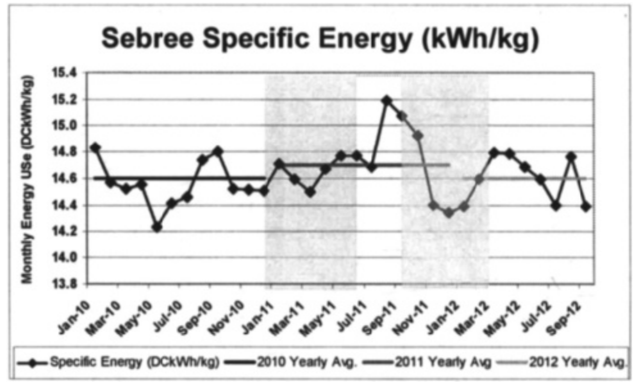

Figure 9: Specific Energy usage at Sebree

Figure 10 shows that monthly metal production dropped significantly in August, as was expected, due to the 5kA drop in amperage. Despite the increase in ACD the difficulty in controlling the process is apparent from the drop in current efficiency from an average of 94.0% to approximately 92.7%, shown in Figure 11.

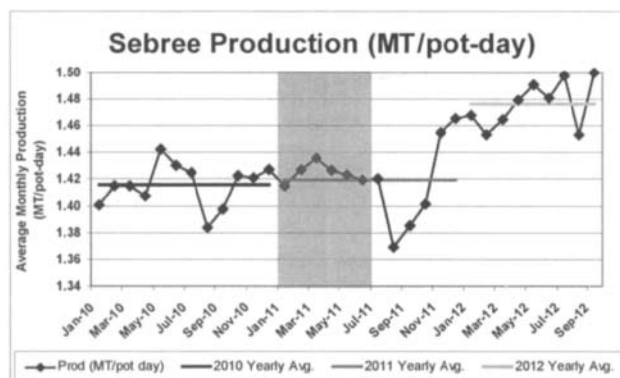

Figure 10: Production rate at Sebree

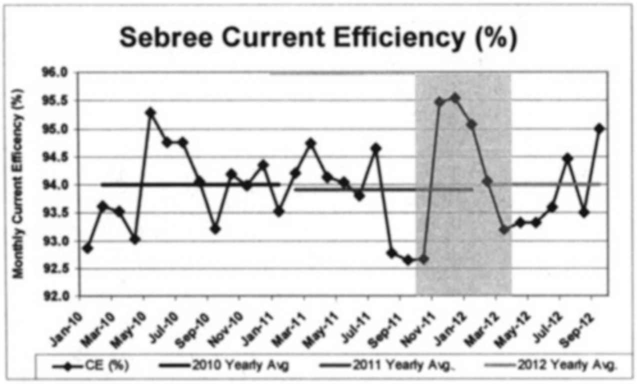

Figure 11: Current efficiency at Sebree

Implementation of Work Quality Management System

In an effort to minimize the effect of increased vanadium levels and improve overall process stability, the Sebree smelter developed an improvement plan to ensure the work force followed the proper work practices. The system focused on "Back to Basics" concepts – ensuring several key, critical steps in reduction processes are followed precisely to obtain maximum results with minimal additional effort. Specifically, the process steps focused on anode setting height, sufficient buss/anode rod contact, and adequate carbon cover both after the initial anode set and throughout the life of the anode.

To gain the support of the operators, a test section was setup in which a monitor directed operations on 42 pots for 1.5 anode cycles. The potline with a history of the most early anode failures was selected to check. The monitor specifically ensured that work standards during everyday operation were consistent with the "Back to Basics" guidelines. This included the initial, physical work on the pot (proper crust breaking, hole preparation prior to anode set, and anode setting) as well as proper cell voltage treatments and positioning of previously set anodes based on results of regular anode rod voltage drop measurements. During the monitoring period, there were no early anode failures in the 42 pots as compared to the line average of 2.96 early failures per day prior to starting the monitoring.

Once the success of the concept was confirmed on a small scale, it was implemented across the entire smelter. Prior to full implementation, all operators were given the "Back to Basics" training, emphasizing the importance of the key process steps. They were also trained on the "what's in it for me" consequences of not following the procedures including an increase in early anode failures as well as thermal imbalances in the pot leading to varying bath levels, poor ratio control, and general pot instability. By focusing on the consequences, all of which eventually lead to more work on the pot, Sebree was able to gain the support of the operators toward performing the work properly the first time.

The training was completed in mid-June and audits of compliance to the new standards were initiated at the end of June. The audits consisted of checking for exposed carbon, airburn, insufficient initial carbon cover, improper anode set height, and poor anode rod/buss contact. Each operator was assigned specific actions on individual pots so every audit non-compliance could be tracked back to the performance of a single person. The number of pots audited changed many times during the transition period until settling at roughly a hundred pots per day, providing sufficient audits to fully document overall work performance without requiring full-time auditors. The audits were entered into a system tracking the performance of each individual over time. Increasing levels of interactive coaching were initiated with operators repeatedly failing to meet the standards, while individuals showing improvement over time were rewarded.

After approximately three months, Sebree experienced a marked increase in performance scores, Figure 12, which was also readily apparent in general pot operation. For the first three months, the scores were simply tracked with very little coaching. In September, the low-performing operators were coached on a weekly basis, leading to an improvement in work performance. This three month implementation period is indicated by a blue highlight on the process data graphs. The green period corresponds to full system implementation, while the red period represents the planning stages of the system.

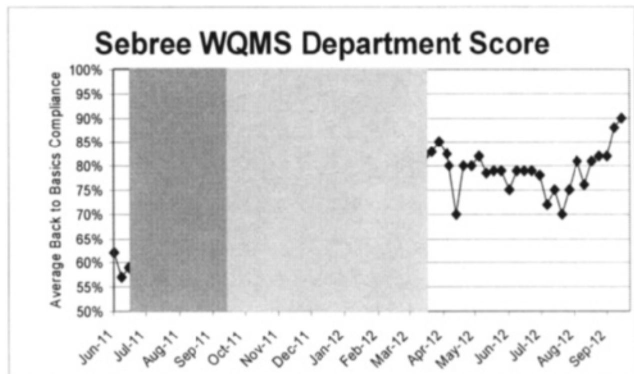

Figure 12: Work Quality Management System scores

In parallel with the WQMS execution, Sebree was able to gradually raise the amperage from 183 kA to 195 kA, 6kA higher than Sebree's prior maximum. This was due largely to improved pot stability and decreased unscheduled anode changes. After the start of the WQMS implementation, early anode failures dropped to an average of 0.92%, nearly half the value prior to system initiation.

While amperage was increased, ACD was simultaneously decreased. Despite the lower ACD, current efficiency increased slightly, a result not achievable without the improved overall process control resulting from WQMS implementation. In addition, the specific energy usage decreased post WQMS, the result of increased amperage, improved and consistent anode cover, and decreased pot voltage. Additional benefits associated with improved anode covering practices such as improved liquid level and bath chemistry control were realized as well. The pot stability allowing performance improvements to be made was a direct result of improved consistency in anode height setting and consistent cover which minimized variation in cell thermal balance, superheat and feed control at lower ACD.

It is important to note that the metal production increase during the six months after WQMS implementation was due entirely to the amperage increase and improved process stability during this period and not related metal pad inventory changes. Additionally, during the highlighted fifteen month periods, there was no significant aluminum carryover from month to month to artificially influence specific process results each month.

Discussion and Conclusions

The Sebree smelter's attempt to improve work practices through its "Back to Basics" program proved that work practices within a smelter can have a large payback. In Sebree's case they helped to mitigate the impact of a major raw material quality change. Table 1 provides a summary of the performance changes that occurred before and after implementation of the WQMS during the increase in CPC vanadium levels. The Sebree smelter saw a measureable improvement in net carbon consumption, current efficiency, and early anode failures all while increasing the amperage by 7 kA over a six month period.

Table 1: Sebree Process Performance Indicators

Potroom Performance Indicators	Pre-WQMS (Jan-Jun 2011)	Post - WQMS (Oct 2011 - Mar 2012)	2010 Avg	2011 Avg	2012 Avg (Jan-Sep)
Amperage (kA)	188.0	191.5	187.0	187.6	195.2
Production (MT/pot-day)	1.425	1.451	1.416	1.42	1.476
Current Efficiency (%)	94.1	94.3	94.0	93.9	94.0
Specific Energy Use (DCkWh/kg)	14.7	14.6	14.6	14.7	14.6
Net Carbon (kg/kg)	0.426	0.423	0.423	0.43	0.425
Unsched Anode Change Rate (%)	1.77	0.92	1.73	1.87	1.58
Vanadium in Metal (%)	0.0117	0.013	0.0105	0.0122	0.0127
Anode Quality Parameters					
Baked Anode Density (g/cc)	1.563	1.582	1.563	1.57	1.575
Air Permeability (nPm)	0.78	0.62	0.86	0.66	1.79
Air Reactivity Residue (%)	63.38	66.83	68.3	64.84	64.97
CO_2 Reactivity Residue (%)	86.11	87.62	85.47	86.92	87.03
Electrical Resistivity (μΩ-m)	63.7	58.2	63.0	61.5	61.2
Baked Anode V (ppm)	292	315	259	297	329
Baked Anode Na (ppm)	442	469	359	452	489
Baked Anode Ni (ppm)	185	191	173	186	199

The raw material change experienced by Sebree was not planned, and in combination with other problems over the summer of 2011, initially caused a significant negative impact on the smelters operation. The negative impact was quickly reversed, however, through implementation of the Work Quality Management System. This serves as a useful case-study of how a smelter can respond to such changes, and demonstrates the strong interaction between anode / cell performance and potline operating practices.

The increase in the vanadium level specification at Sebree is the second increase over the last five years due to CPC quality changes, which are ultimately driven by green coke quality changes. In July 2008, the vanadium level specification was increased from 300ppm to 330ppm. Today's specification has risen to 450ppm, and at the time of writing this paper, the 2012 average vanadium level of coke delivered to Sebree is 430ppm. Despite these significant increases, the smelter is performing well at a significantly higher current than the P155 cells were designed to operate.

A review of the literature published in the 1980's [5,8] would suggest that such performance should not be possible with the sort of vanadium levels used at Sebree. This serves as a reminder that it is important to continue challenging past views about what can and cannot be done. CPC and carbon costs have increased significantly over the last five years and smelters that can utilize lower quality raw materials may be able to reduce raw material procurement costs.

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