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IMPROVING ANODE BAKED DENSITY AND AIR PERMEABILITY THROUGH PROCESS OPTIMIZATION AND COKE BLENDING

Bienvenu Ndjom, Muhammad Shafik Malik, Amer Al Marzouqi, Tapan Kumar Sahu, Saleh Ahmed Rabba
Dubai Aluminium (DUBAL), PO Box 3627, Dubai, U.A.E

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Abstract

Dubai Aluminium (DUBAL) has continuously increased aluminium production through improved cell technology and optimizing cell performance at higher amperage. High baked anode density and low air permeability are two key anode characteristics that impact anode performance in the reduction cell. Increasing baked anode density, for instance, will allow a plant to either increase anode shift life or increase potline amperage, without changing anode shift life.

To assist DUBAL in its strategic journey of increasing amperage, the DUBAL Carbon Plant management team defined and implemented a 3-year strategic roadmap to improve baked anode density and anode air permeability through process optimization and raw material blending. In this paper, we present the steps taken and the results achieved through implementing this roadmap.

Introduction

DUBAL began operations in 1979 as a 135,000 tonnes/annum primary aluminium smelter with original Kaiser P-69 reduction technology. The three potlines operated at 150 kA using anodes with two stub holes and dimensions of 1,130×795×635 mm. Today, DUBAL is one of the world's largest single site primary aluminium smelters with annual production capacity of 1,025,000 tonnes. It has 1,573 cells distributed among seven potlines operating at different amperages, ranging from 200 to 400 kA depending on the cell technology. With increased metal production, the annual demand for baked anodes increased from 115,000 to 470,000. Fifteen percent of DUBAL's total anode requirement is purchased.

In all the cell designs, anode sizes have been increased in stages to boost metal production through higher line current. Presently, DUBAL's Carbon Plant can produce baked anodes with dimensions of 1,515×805×650 mm.

DUBAL has two green anode production lines with a common raw material handling, crushing and screening system. The first line which existed from inception had an initial design capacity of 33 t/h. The new came into existence in 1996 with a design capacity similar to that of the old line. Now, both production lines operate as independent units with a throughput of 36 t/h.

Baking of the green anodes is carried out in four open top baking furnaces operating a 24 hours fire cycle. The rodding process is done in a conventional manner, with a 3-stub asymmetric assembly.

As with many plants in the world, DUBAL Carbon Plant faces challenges to maintain good anode performance amid deterioration of raw material quality. Over the past 10 years, the quality of calcined petroleum coke has significantly changed towards lower Vibrated Bulk Density (VBD) and higher impurity content (vanadium, sulphur, nickel, etc.)[1].These challenges are made even bigger by the demand for high anode quality by reduction cells, because of amperage-increase programs.

DUBAL management had a vision to increase annual metal production to an ambitious level of 1 million tonnes. In an attempt to minimize the impact of amperage increases (Figure 1) and maintain good performance of anodes in the pots, DUBAL's Carbon team performed a gap analysis and established the required anode characteristics to cope with the amperage increase. The outcome of this analysis was a roadmap with the objective of increasing baked anode density (BAD) and reducing anode air permeability without significant impact on anode reactivity. The key areas of focus were:

- Improving the process of the less performing mixing line,
- Optimizing raw material usage by exploring opportunities of coke blending, and
- Improving anode recipe.

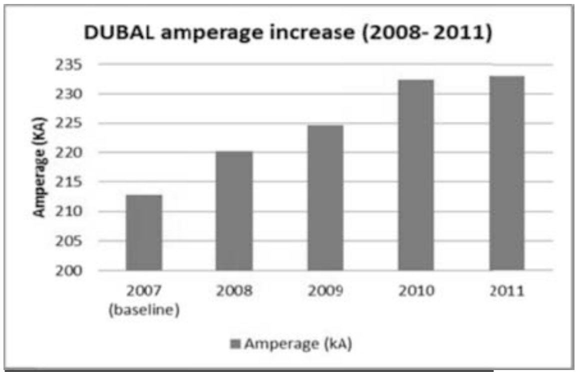

Figure 1. DUBAL amperage increase trend.

Process Improvements

Optimization of New Line Vibrocompactor

In the new Green Mill line, the vibrocompactor was retrofitted to produce green anodes of larger dimensions. Soon after retrofitting, the baked density of the anodes dropped to 1.563 g/cm^2 and air permeability increased to 1.5 nPerm (see Figure 2). But, in the older Line 1, the anode density and air permeability were sustained even though both the lines are using the same recipe and operating parameters for paste preparation.

Therefore, an optimization plan for the vibrocompactor was designed to bring its performance back to the original level (i.e. before the modification).

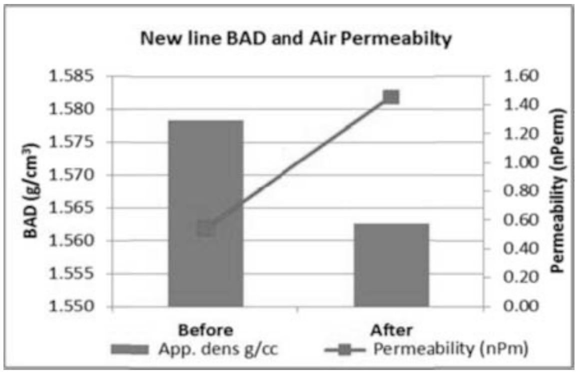

Figure 2. New line baked anode density (BAD) and permeability after vibrocompactor retrofitting.

Vibrocompactor performance is generally affected by the following parameters:

- Compaction time,
- Motor speed,
- Forming temperature
- Unbalanced weight setting (eccentric angle and eccentric weight),
- Specific load of the cover weight, and
- Vacuum and top pressure (if installed).

Since our vibrocompactor is not equipped with vacuum or top pressure, the focus of our optimization plan was on compaction time, motor speed and unbalanced weight settings.

Optimization of Motor Speed and Eccentric Angle using Vibration Analyzer: Optimizing a vibrocompactor by monitoring anode density changes is not easy. The quality of the incoming paste can affect the density as much as the vibrocompactor parameters. It has been demonstrated that the usage of a vibration analysis system is a good tool for optimizing a vibrocompactor [2]. We found that the usage of a simple vibration analyzer used in machinery industries could give interesting results and help in optimizing anode compaction.

The equipment comprises an acceleration transducer and a digital signal converter that measures the acceleration, velocity and displacement. During our trials, it was observed that there is a good correlation between the cover-weight displacements, the vibrocompactor motor speed (rpm) and anode density (see Figure 3 and Figure 4). This correlation was the main tool for our optimization process.

Using the same equipment and principle, the optimum vibrocompactor speed (1,300 rpm to 1,050 rpm) and the best unbalanced weight setting (from 140° to 100°) were set up. Vibration analyses are now being performed routinely and used as tools to monitor the performance of both the vibrocompactors.

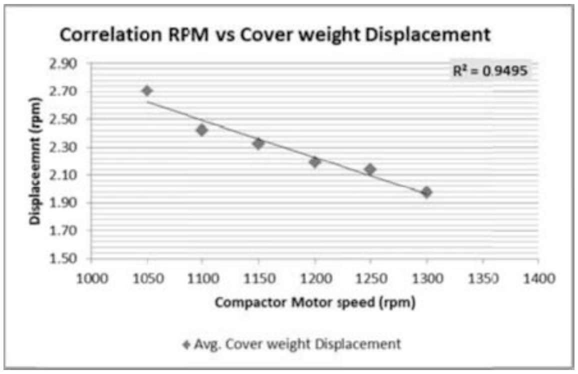

Figure 3. Correlation between vibrocompactor speed and cover-weight displacement.

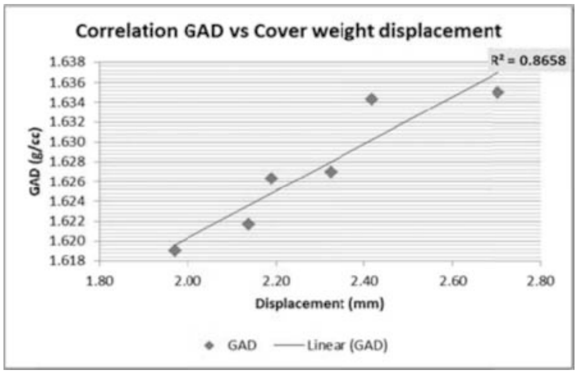

Figure 4. Correlation between cover-weight displacement and green anode density (GAD).

As a result of this optimization, the density of new line anodes has improved by 0.01 g/cm^3 (see Figure 5).

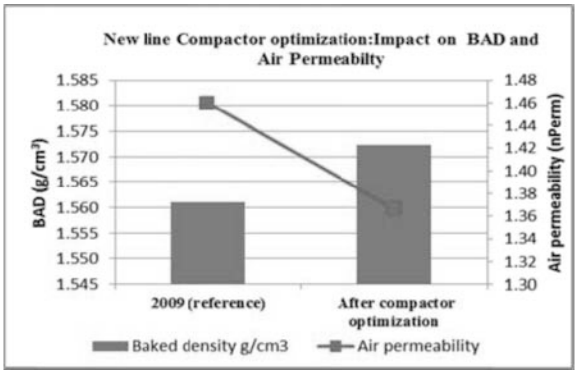

Figure 5. Impact of new line compactor optimization on anode density and permeability

Improvement of Paste Mixing in New line

Even after the optimization of the vibrocompactor, the permeability of the anodes from new line remained approximately double that of old line anodes. Petrographic analysis of paste, conducted in coordination with external consultants, revealed an inconsistent coating of pitch around coke grains in the paste samples. The study suggested insufficient or inconsistent mixing. With this information, our focus shifted to the mixing stage to find the probable cause of high and irregular air permeability.

To avoid paste sticking in the mixer discharge chute, water sprayers were installed at the exit of the mixer. It was suspected that the pitch in the paste may be "freezing" after direct contact with water spray and creating a "heterogeneous" paste. To verify this assumption, trials were conducted and it was confirmed that suppressing the water injection at the mixer discharge significantly improved anode air permeability.

A new discharge chute was designed, with wider cross-section and better alignment with the mixer discharge, so as to be able to run without the water spray. Thereafter, the permeability of new line anodes has significantly improved to a level comparable to old line (see Figure 6).

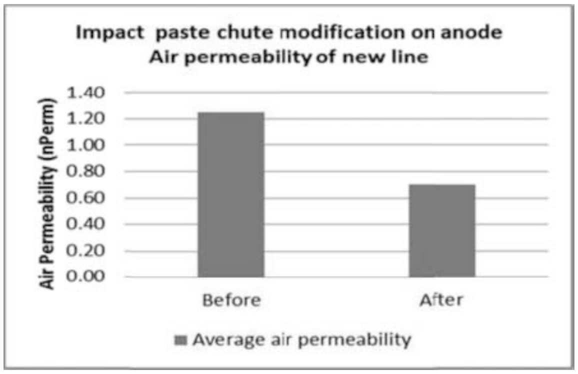

Figure 6. Improvement of anode air permeability by modification of kneader discharge chute.

Coke Blending

Historically, DUBAL sourced its calcined petroleum coke from four different suppliers because of the following reasons: security of supply, cost competitiveness and supply logistics. As the dock facility of the Carbon Plant was not designed for coke blending, the cokes were used in the plant on campaign basis. When the coke supply changed, adjustments were made in operating parameters to optimize the anode quality. In a drive to compensate for the degrading anode quality of traditional cokes and improve anode quality and performance, DUBAL developed a strategy for coke blending with the aim of increasing baked anode density, with minimal impact on anode reactivity.

<u>Implementation Plan.</u>

To achieve this objective, an implementation plan was developed with the following key steps:

- Identification of potential suppliers,
- Pilot studies,
- Plant trials,
- Installation a coke blending systems, and
- Full scale implementation and process optimization.

The implementation timeline is shown on Figure 7.

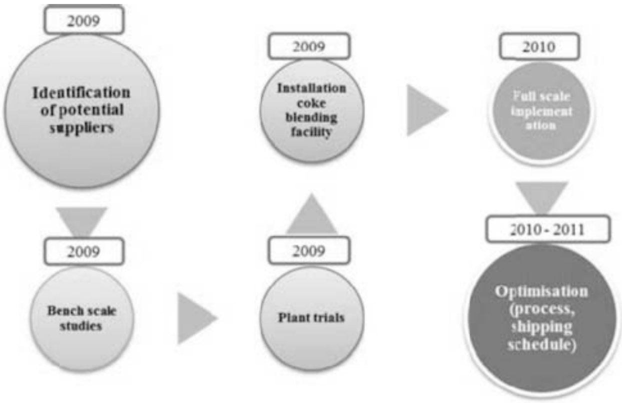

Figure 7. Timeline of DUBAL coke blending implementation.

<u>Pilots Test Results:</u>

Pilot tests were conducted in 2009, separately by external technical laboratories. Four different sources of coke were tested: two regular supply and two new sources. As an example, the figures below illustrate the impact of the new coke source B when blended with the regular coke A (see Figure 8 & Figure 9). Optimum baked density with maximum reactivity residue was achieved when coke B was used with coke A in the range of 33% to 67%.

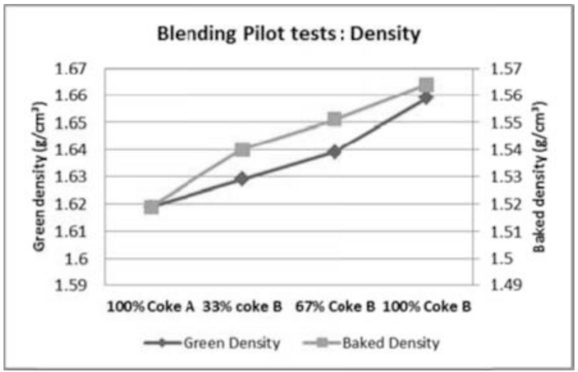

Figure 8. Density of bench scale anodes.

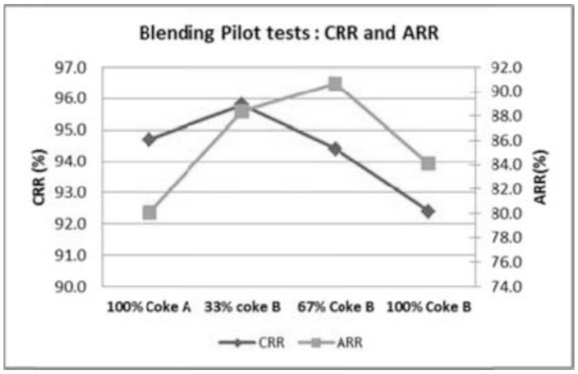

Figure 9. CO_2 reactivity residue (CRR) and Air reactivity residue (ARR) of bench scale anodes.

Plant Trial Results:

To confirm the results of the bench scale anodes, trial consignments of new coke sources were ordered. Trial anodes were produced and their performances in the pots were evaluated. Figure 10 and Figure 11 show the similarities between the bench scale and plant anodes. Optimum baked anode density was also achieved with maximum reactivity residue when 50% of coke B was blended with 50% of coke A. With the confidence of the bench scale and plant evaluation, the full implementation of coke blending was decided and blending ratios were defined.

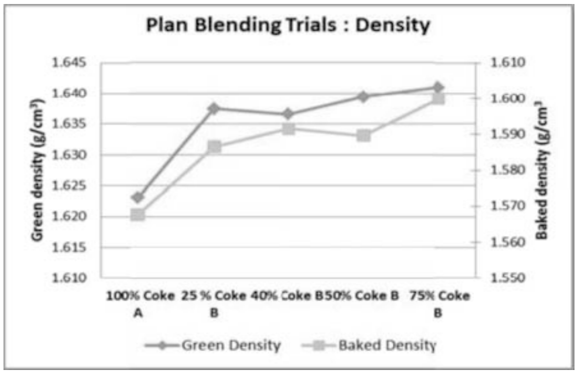

Figure 10. Density of Plant trial anodes.

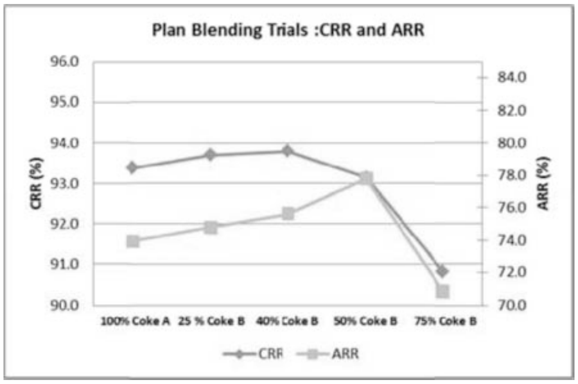

Figure 11. Reactivity of Plant trial anodes.

Full-scale Implementation Results

A Coke Blending facility was installed and commissioned at the dock. All the coke silos have the option to deliver coke as per desired targets, calculated on the basis of blending ratio. During the course of travel to the discharge silo, cokes from different silos are mixed and then sent to Green Mill for anode production. After six months of operation, we re-assessed the impact of coke blending. The data obtained confirmed the results expected from the trials, with an overall increase of density of 0.01 g/cm^3 and minimal variation in anode reactivity (see Figure 12)

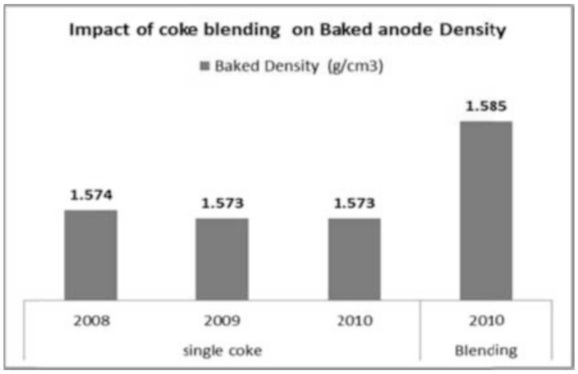

Figure 12. BAD single versus blended coke.

Strategic Alignment with Supply Chain

After two years of coke blending operation and having used six sources of coke, each presenting very distinct properties (density, impurity content, reactivity and calcination level), it became crucial for DUBAL to try to answer the following question:

- How to evaluate the overall impact of a blend?
- Which cokes are best to be blended together and at what ratio?
- How to optimize coke blending based on the properties of a particular shipment or source?
- Are we using the best coke sources for blending?

Extensive data analysis has provided some answers, giving DUBAL the opportunity to develop an empirical model to predict anode quality from coke properties. The key correlations established by the study were:

- The correlation between coke vibrated bulk density (VBD) and baked anode density (BAD) (see Figure 13).
- The impact of coke CO_2 reactivity on anode CO_2 reactivity residue (see Figure 14).

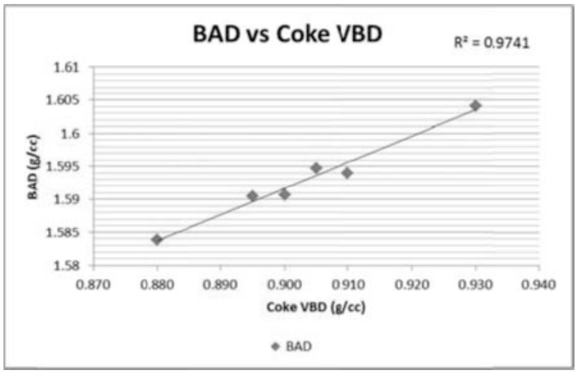

Figure 13. Correlation between coke VBD and baked anode density.

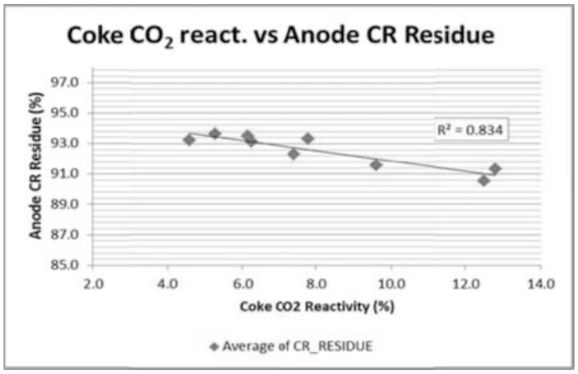

Figure 14. Correlation between CO_2 of coke reactivity and anode CO_2 reactivity residue.

On the other hand, good correlation was also established between:

- Baked anode density and anode air permeability (see Figure 15).
- Vanadium in anode and anode air reactivity residue (see Figure 16).

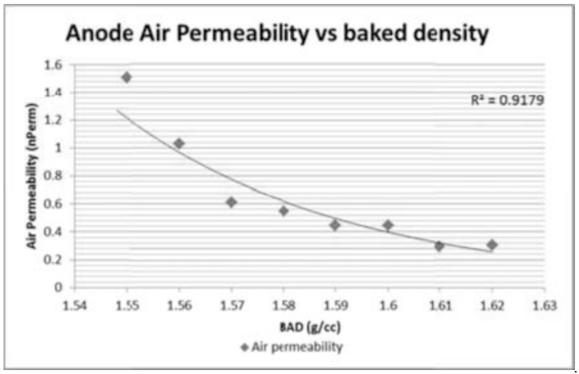

Figure 15. Correlation between BAD and air permeability.

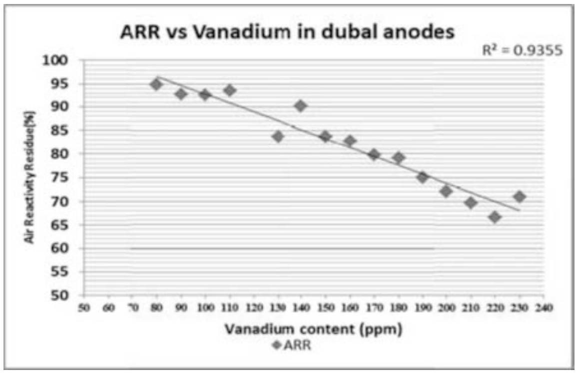

Figure 16. Correlation between vanadium content in anode and anode air reactivity residue.

Being able to predict four key anode characteristics from coke properties gives a good tool to estimate the variation in carbon consumption resulting from the usage of different coke blends. They are also being used to develop the procurement plan and shipping schedules to minimize the risks to DUBAL.

Anode Recipe Modification

DUBAL's dry aggregate comprises Coarse, Medium and Fines Fraction. Coarse Fraction is composed of butt material and the other two fractions are primarily made up of calcined petroleum coke. Grain size distribution (or dry aggregate curve) is a critical parameter for anode quality.

While using different coke sources in blending, it was observed that the higher density cokes in the blend also had a higher percentage of bigger particles in the dry aggregate, which had a positive impact on anode density. These observations prompted the idea of increasing the percentage of coke with bigger particles (+ 4 mesh) in the dry aggregate, so as to improve on anode density.

Several trials were conducted to evaluate the impact of increasing the amount of +4 mesh particles in the recipe and to determine the optimum percentage. Positive results from the trials led to the replacement of the screen deck to increase the percentage of +4 mesh in the dry aggregate from 22.5% to 25.5% as shown in Figure 17.

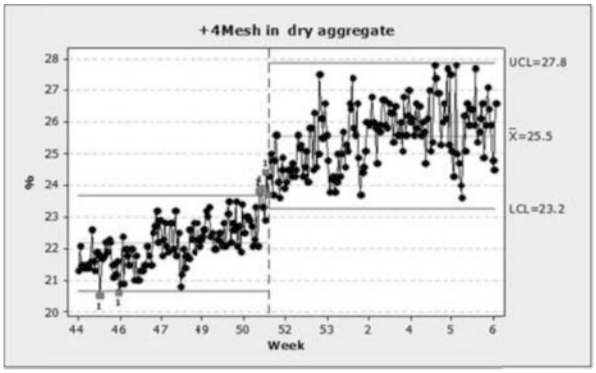

Figure 17. + 4 mesh in dry aggregate.

Immediately after the change, baked anode densities improved by 0.01 g/cm^3. The other part of anode density increased being attributed to increased VBD of the coke blend.

The increase in density also resulted in an improvement of anode air permeability from 0.8 to 0.5nPerm (see Figure 18).

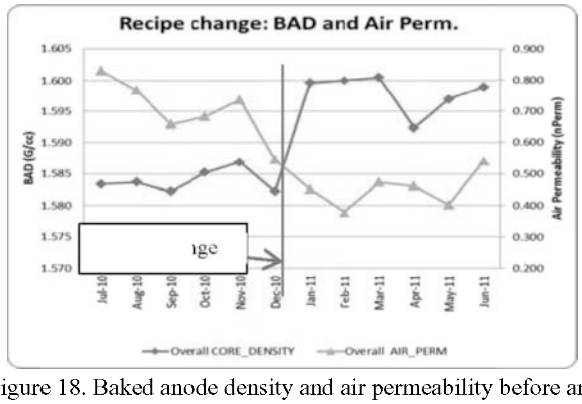

Figure 18. Baked anode density and air permeability before and after recipe change.

Results and Discussion

The overall results of the optimization over a three- year period are illustrated in Figure 19 and Figure 20:

- An increase of anodes density by 0.025g/cm^3, which is equivalent to 20 kg additional weight per anode.
- A reduction of anode air permeability from 1.2 to 0.48 nPerm.

The usage of cokes with low sulphur, and high vanadium in the blend has marginally affected anode reactivity. Air reactivity residue (ARR) has reduced by 2% while CO_2 reactivity residue (CRR) has remained practically unchanged due to the blending of high and low sulphur cokes.

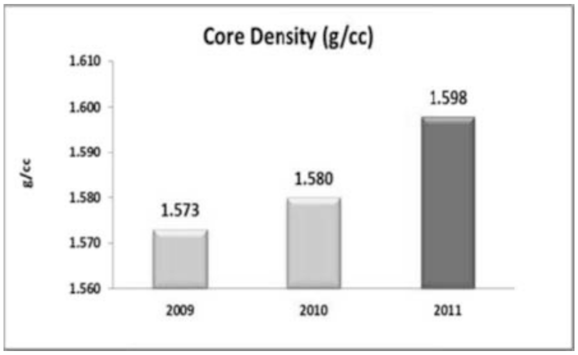

Figure 19. Baked anode density improvement.

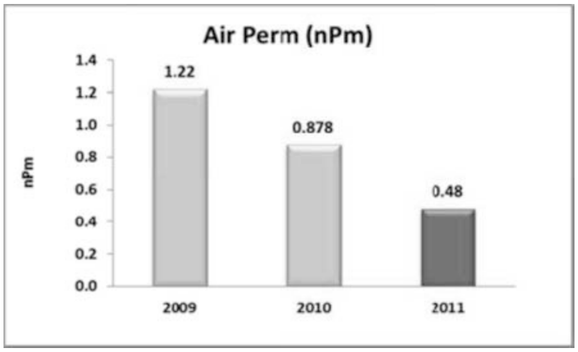

Figure 20. Air permeability improvement.

Anode Performance in Cells.

The improvement in baked anode density and reduction in air permeability helped DUBAL increase the amperage to the desired level, along with a positive impact on carbon consumption. During the implementation of this anode density improvement program, DUBAL Carbon team worked closely with Reduction management to improve effective utilization of carbon in potroom by optimizing the butt thickness for individual technologies without affecting pot performance.

In spite of an average amperage increase of 20 kA, these combined actions contributed to 4% reduction in gross carbon consumption across the plant compare to 2009. Saving in gross carbon also resulted in reducing the number of purchased anodes.

Conclusion

DUBAL has achieved a tremendous improvement in baked anode density and anode air permeability through a systematic approach based on process optimization and selective blending of cokes.

The overall baked density has increased by 0.025 g/cm^{3}along with a reduction of anode permeability by 0.7 nPerm. This has helped the potroom increase the average current by 20 kA and also reduced the number of purchased anodes.

This achievement is the result of team work, commitment towards continual improvement and encouragement for innovation and creativity.

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