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# BAKING FURNACE REBUILD STRATEGY AT DUBAL TO IMPROVE PRODUCTIVITY

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## Abstract

Continual capacity creep and expansion of the smelter without proportional increase in Carbon Plant production capacity has resulted in the baked anode requirement at Dubai Aluminium ("DUBAL" – known as EGA Jebel Ali Operations) exceeding its Baking Furnace capacity. The additional anode demand was satisfied by procuring the shortfall from the international market at a premium.

In order to limit DUBAL's dependence on third parties, the baking furnace productivity was increased by ~14% by operating the furnaces with shorter fire cycles. Operating the furnaces with shorter fire cycles resulted in an increase in anode temperature variation across the pits. To address this variation, several flue wall design changes were incorporated into the rebuild plan for the upcoming rebuild of Anode Baking Furnace #4 (ABF 4).

In 2013, after achieving an average flue wall life of 184 heats, ABF 4 was successfully rebuilt with minimal production losses while incorporating design changes to increase productivity and improve heat distribution within the pits. This article describes DUBAL's kiln rebuild strategy and the execution of Kiln 4 rebuild while integrating design changes.

## Introduction

Continuous increase in metal production at DUBAL (figure 1) through amperage increase (figure 2) has driven anode current density to as high as 1.05 A/cm$^2$ in some Potlines.

Potline Management embarked on a strategy to optimize energy consumption by maximising the anodic surface area in the existing pot shells. Wherever possible, pot lining modifications were proposed and the maximum anode length that could be accommodated after the modifications would be 1585 mm (equivalent to 1600 mm green anode length). Baking these longer anodes would only be possible if the height of the furnaces were increased.

Figure 3 highlights the previous occurrences of anode length changes. Baking an anode of 1585 mm (baked) in length would require furnace design modifications as it would exceed the current furnace capability. Carbon Plant planned to integrate the necessary baking furnace modifications into the upcoming furnace rebuild.

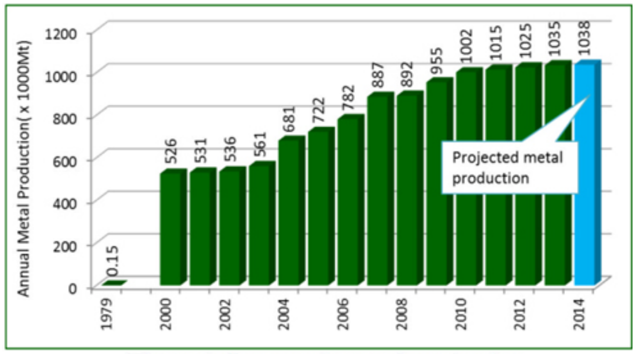


Figure 1: Increase in metal production

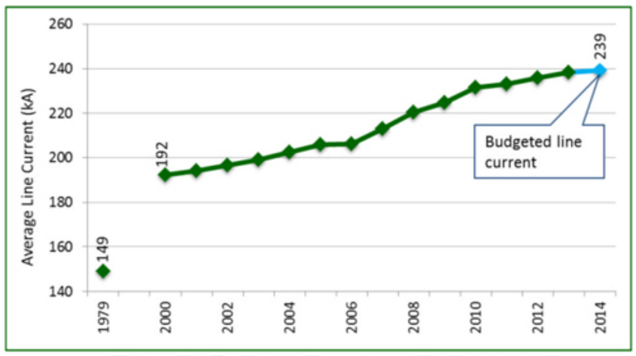


Figure 2: Increase in average line current

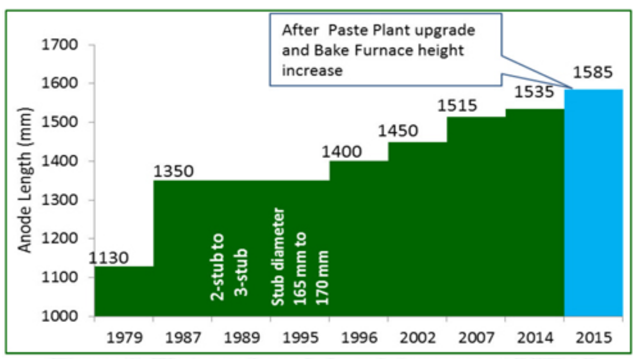


Figure 3: History of anode length increase at DUBAL

In 2013, after completing an average of 184 heats, the flue wall refractories of ABF 4 were due for replacement. Headwall refractories which had been in service for >360 heats were also due for replacement. This rebuild presented an ideal opportunity to address furnace design deficiencies and incorporate modifications to the flue walls to enable the baking of longer anodes without adversely impacting baked anode quality.

## Bake Furnace #4 History

ABF 4 was constructed in 1998 as a 32-section, open-top horizontal flue ring furnace, operating with two fire groups to satisfy the increase in anode demand imposed by the addition of a new potline (Potline 6) to DUBAL's existing potlines. In 2004, to fulfil the anode requirement of a newly added Potline 9A, ABF 4 was extended by 16 sections (figure 4) and a third fire group was added to increase the capacity of ABF 4 by 50%. All further increases in anode demand, stemming from added potline capacity, were supported by operating all four ABF's with shorter fire cycles (figure 7) and purchasing the additional baked anodes from third parties.

In 2005, the flue wall refractories in the original 32 sections of ABF 4 were due for replacement after reaching a service life of 174 heats. A decision was taken to only replace the flue wall refractories in the original 32 sections, as the 16 recently added sections had only completed 20 heats and were in very good condition.

When ABF 4 refractory was scheduled for replacement again in 2013, after achieving an average service life of 184 heats, the refractories in the ABF 4 "extension" had already been in service for >200 heats, and had deteriorated to a greater extent than the rest of the refractory in ABF 4. This dictated that the refractory replacement should commence on section 17, which was the first section of the ABF 4 "extension".


Figure 4: Schematic representation of ABF 4

The high refractory life of ABF 4 was achieved by good refractory maintenance and operational practices, which included:

- Regular flue wall cleaning to prevent coke sticking.
- Flue wall straightening when deflection exceeded 50 mm.
- Regular replacement of refractory fiber in the expansion joints.
- Drainage of coke from the expansion gaps between headwalls and flue walls.
- Restricting peak flue wall refractory temperature to <1350°C in the burner zone (see figure 5).
- Reducing flame temperature and heat intensity through burner modification and gas pressure adjustments.
- Improved butt cleaning practices to reduce sodium in anodes (figure 6) and its impact on refractory.

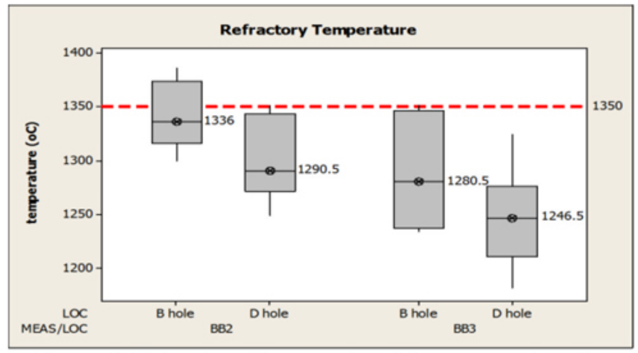


Figure 5: Refractory Temperature Measurements in the second and third burner ramp locations

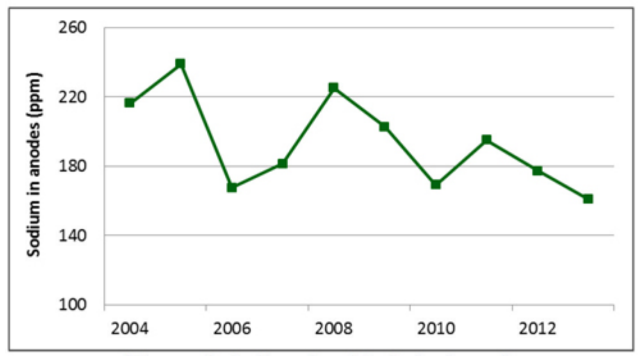


Figure 6: Sodium level in baked anodes

## Objective of Anode Bake Furnace Rebuild

The varying cost and quality of purchased anodes was strong justification for DUBAL to increase its baked anode production. This was made possible by operating the ABF's with shorter fire cycles (figure 7). Optimisation of the control system parameters and fine tuning of firing equipment helped to achieve the fire cycle reduction. One kiln was operated with a fire cycle of 21 hours and a productivity of 983 kg/hr.

To further support the higher productivity with improved anode quality, the objectives of the ABF 4 rebuild were to:

- Incorporate furnace design changes to:
  - facilitate furnace operation with shorter fire cycles (22 hr),
  - enable the baking of 1600 mm long green anodes.
- Complete the rebuild in the shortest time possible, with minimal production losses.

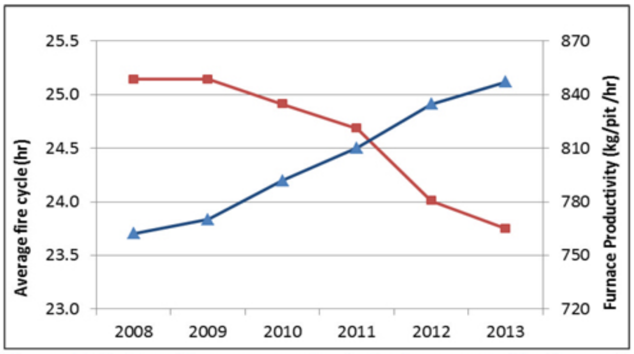


**Figure 7: Baking Furnace productivity increase with fire cycle reduction**

### Flue Wall Design Changes

Temperature distribution surveys are conducted routinely to ascertain the quality of baking. Firing system adjustments were effected to homogenise anode temperature differences that were observed in earlier temperature distribution surveys. However, these adjustments were not successful in addressing the large drop in temperature along the length and height of the pit. Figure 8 shows the zones of low temperature at the top and downstream end of the pit, which were observed in all ABF's. Design changes were required to address these low temperature zones.

The objective of the flue wall design changes was to improve heat distribution within the pits while operating with a 22 hour fire cycle.

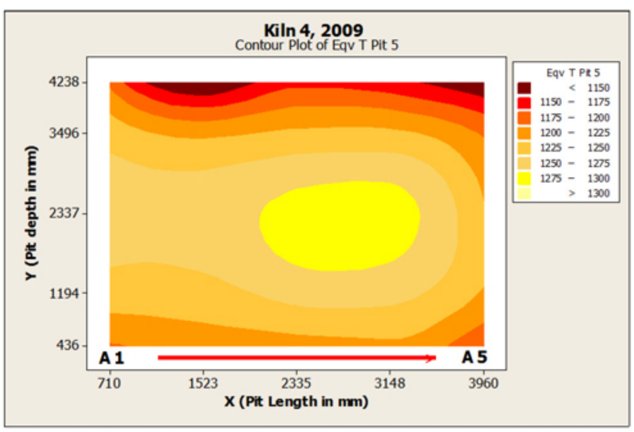


**Figure 8: Anode temperature distribution in the pits (original flue wall design)**

Increase Pit Depth

To support the baking of 1600 mm long anodes, the pit depth had to be increased by 300 mm. This additional depth was created by increasing the flue wall height by 250 mm and decreasing the total height of the pit floor refractories by 50 mm.

Increase Gas Cavity Volume

The increase in productivity up to this point, due to increased anode size and operating at shorter fire cycles, resulted in an increase in the flow rate of fumes within the flue walls. This increased the pressure drop along the flue passage. Consequently, the under pressure that was required to deliver oxygen to the burners and preheating zones also increased, placing additional stress on a fume treatment plant, which was already operating beyond its design capacity. To accommodate the increased flue gas flow rate within the flue walls, the volume of the flue gas cavity had to be increased without adversely affecting pit volume. The solution selected to achieve this goal was to decrease the brick width while also decreasing the pit width. The result was a 20 mm increase in the width of the flue gas passage with a 10 mm decrease in pit width.

Improve Heat Distribution

The following flue wall design changes were made to improve the gas flow in the walls and the heat distribution in the pits:

- Relocation of tie bricks.
- Increasing the height of baffle openings.
- Decreasing the height of by-pass opening.

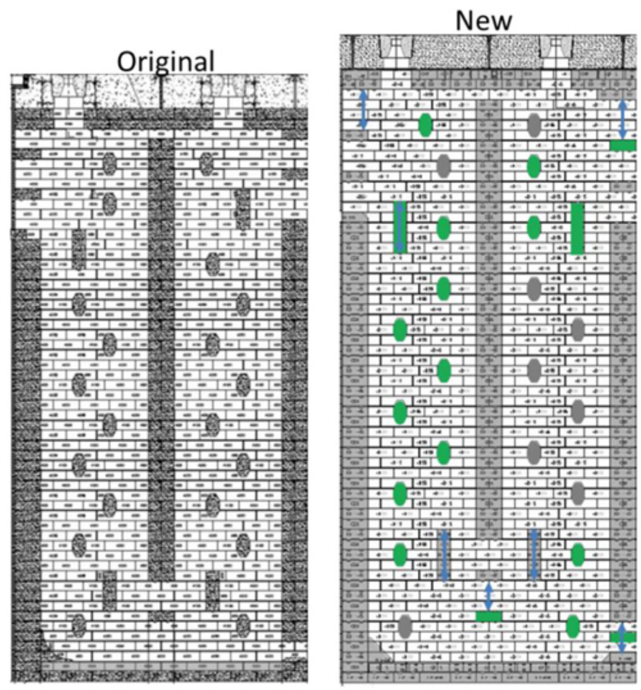


**Figure 9: Longitudinal section of flue wall showing changes to tie bricks and baffles**

2-D modelling was used to optimise the flow of gasses and heat within the flue wall. Figure 10 shows a noticeable improvement in the modelled gas flow within the flue walls ("optimized flow") after making modifications to the tie bricks and baffles.

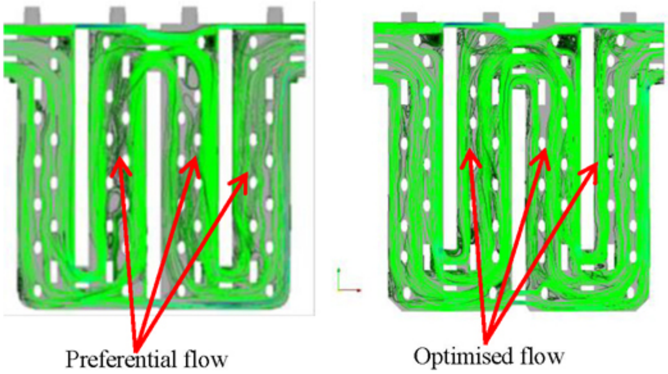


**Figure 10: Streamlines of existing (left) and new (right) flue wall design**

Flue Wall Bricks Selection

In order to operate the furnace with shorter fire cycles it was necessary to source refractory bricks with following characteristics (Table 1):

**Table 1: Desired properties of new flue wall refractories**

| Property | Effect |
|---|---|
| High thermal conductivity | Higher anode temperature for the same flue gas temperature |
| High refractoriness under load | Service temperature of refractory can be increased |
| High hot modulus of rapture | Sufficient strength to withstand decrease in brick width |
| Low apparent porosity | Reduce ingress of gaseous fluorides and sodium into brick matrix |
| Low alkali content | Buffer for sodium uptake |

The bricks that were selected for the rebuild were 50% alumina bricks, which met all the criteria stipulated. Because of the superior physical and chemical properties, higher flue wall life is expected in spite of reduced brick thickness and shorter fire cycle operation.

## Rebuild Preparation

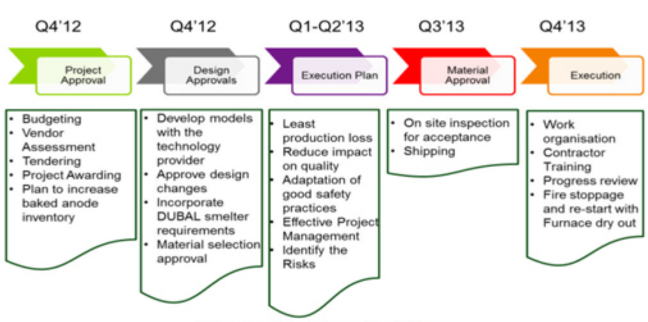


**Figure 11: Rebuild Plan**

Since section 17 (first section of the ABF 4 extension) was selected as the location where the rebuild would start, the movement of the fires in ABF 4 was simulated one year in advance to determine the tentative start of the rebuild. As a result of this exercise, the actual start of the furnace rebuild was just 2 days later than the planned date.

To complete the rebuild in the shortest time possible and minimise production loss during the rebuild, one fire group was to be stopped to create the gap needed to execute the rebuild while the other two fires remained in operation. Although several measures were implemented to minimise production loss during the rebuild, it was anticipated that a production loss of ~7,000 anodes would be incurred. This production loss was mitigated by operating ABF 1&2 on shorter fire cycles for ~10 months prior to the rebuild.

All refractory material was delivered on site one month ahead of the rebuild start date. Contractors also arrived on site one month ahead of the rebuild start date to complete the necessary safety induction and site access requirements. Since only a fraction of the contractors had actual bake furnace construction experience, training was organised on site to familiarise the contractors with the work procedures, equipment and site layout. This helped the contractors to work with maximum productivity in a shorter period.

## Rebuild Execution

Stopping the Production Fire

Fire group #2 was to be stopped to create the gap required for the rebuild. In preparation for the fire stoppage, four sections (sections 13 to 16) were packed with baked anodes. When the exhaust manifold of Fire group #2 arrived on section 15, it was held there for three consecutive cycles. One burner ramp was removed after each cycle, thereby ensuring that the anodes in section 12 were completely baked before the fire group was stopped. Since the anodes in the preheat section were already baked, there was no need to re-bake any anodes.

Demolition

The spent refractory in the first four sections were demolished manually; thereafter an excavator and Bobcat were lowered into the furnace cavity. The mechanical equipment accelerated the rate of demolition and removal of spent refractory while utilising a fraction of the manpower that would have been needed for manual demolition. Spent refractories were removed from the furnace in small 1.5 tonne skips and emptied into larger 20 tonne skips where they were stored for recycling.

Furnace Construction

Apart from a few small areas where the tub wall insulation required repair, the remaining insulation was in good condition and was reused.

Construction was divided into 10 zones (figure 12) to maintain the planned pace of the rebuild i.e. one section handed over to operations every 30 hours. Bricks were palletised per lift so as to limit material movement and reduce the chance of error during brick laying.

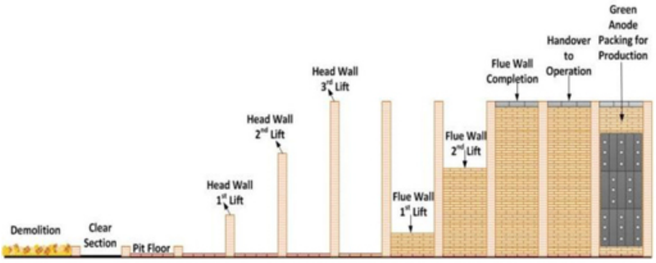


Figure 12: Work organization during the rebuild

Modification of ancillary equipment

Increasing the height of the flue walls meant that the flue wall tops were raised a further 250 mm above the working isle. Since the vertical risers of the ring main duct were situated at the level of the working isle, the vertical section of the exhaust manifolds ("EM") had to be extended by 250 mm (see figure 13) so that it could be connected to the ring main riser after the flue wall height was increased.

Since Fire Group #2 was stopped during the rebuild, the EM of Fire group #2 was modified and exchanged with the EM of Fire group #1 as it moved onto the rebuilt section. The same process was followed for the other EM's.


Figure 13: Exhaust manifold with modified vertical section

Furnace Dry Out

The newly rebuilt sections that were handed over to operations were packed with green anodes. Hence the new refractories were "dried out" with green anodes. Considering the criticality of maintaining low flue wall temperature gradients (typically 7.5°C/hr) and peak flue gas temperatures (~1160°C) during the furnace dry-out, a 30 hour fire cycle was maintained during the dry-out cycle. Anode and refractory cooling was also effected over a longer duration (180 hours) thereby reducing the rate of flue wall shrinkage upon cooling.

Startup of Fire #1

Since productivity was a key feature of this rebuild, Fire #1 was started on just three sections of baked anodes. This procedure made the control of pitch burn in the first green anode section very challenging, but it was managed by adjusting burner ramp temperatures and increasing retention time after pitch burn was detected in the first section packed with green anodes.

**Furnace Performance after Rebuild**

An evaluation of ABF 4 performance was conducted on a 24-hour fire cycle. Data was collected for a three-month period at the beginning of 2014 when ABF 4 was operated on a 24-hour fire cycle (after rebuild) and was compared to an equivalent period in 2012 when ABF 4 operated with the same fire cycle (before rebuild).

The following results were obtained:

- With larger anode baking capability, furnace productivity improved by 4.5%.
- Final baked anode temperature was 1118±20°C.
- Temperature distribution in the pit improved with flue wall design modifications (figure 14).
    - Hot spot shifted towards the top layer of anodes.
    - Low temperature region was eliminated.
- 12% reduction in specific energy consumption (figure 15).
- Baking level (Lc) remained relatively unchanged (figure 16).
- Anode temperature at the end of pre-heating increased by 65°C (figure 17).
- 50% Alumina bricks with higher thermal conductivity seem to favor shorter fire cycle operation.

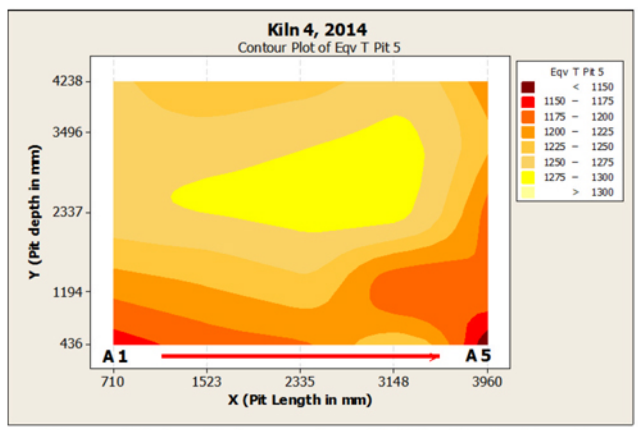


Figure 14: Anode temperature distribution in the pits (modified flue wall design)

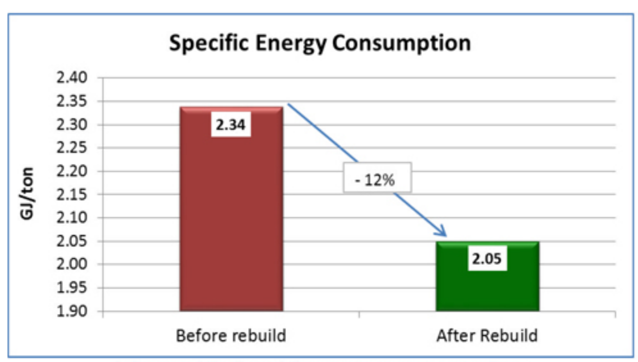


Figure 15: Specific energy consumption

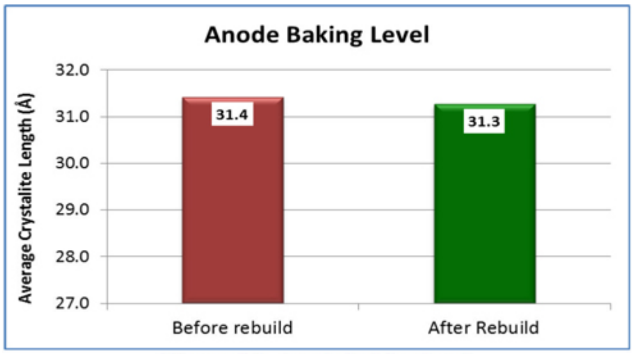


Figure 16: Anode baking level

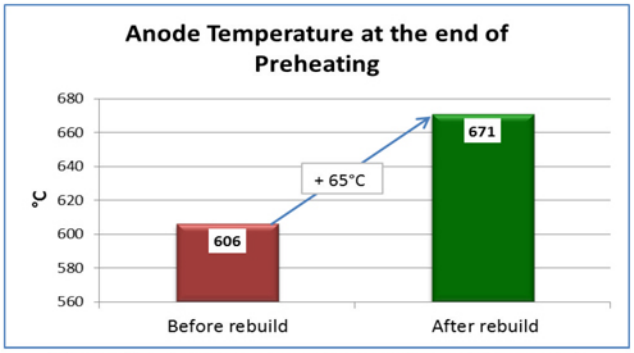


Figure 17: Average anode temperature at the end of preheating

After stabilizing the furnace on 24 hour fire cycle, to benefit from the modifications made during the rebuild, the process parameters were adjusted and the furnace is being operated with a 22 hour fire cycle.
With the shorter fire cycle, anodes could not be cooled to the desired level. In response to this observation, a cooling study was conducted with a 38% increase in peep hole diameter. A 30°C drop in anode temperature was achieved during the trial.

For all future rebuilds the new flue design along with larger peep hole openings will be incorporated. The design will be further improved through mathematical modeling.

## Conclusion

Increasing Baking Furnace productivity presents Carbon Plants with opportunities and challenges. The opportunities are related to increased anode production without an increase in CAPEX and manpower. Challenges arise from the furnace being operated outside its design limits and include, but are not limited to:

- Lower baking level.
- Large variation in anode quality.
- Higher fuel/energy consumption.
- Increased soot and tar generation.

Experience at DUBAL has shown that Baking Furnace productivity can be increased, provided that the furnace design is reviewed and aligned with the shorter fire cycles and increased pit loads that accompany an increase in anode dimension.
Addressing design limitations through mathematical modelling and incorporating advances in refractory technology are fundamental to overcoming many of the challenges associated with increasing productivity. The rebuild of ABF 4 was successful in addressing most of the shortcomings of the original furnace design by following this approach.

Achieving the objectives of the rebuild with an exemplary safety record was the result of close collaboration between the various functional areas within DUBAL (operations, process control, maintenance, engineering, purchasing, legal, safety), and between DUBAL and the suppliers of materials and services.

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