ST04 - Compendium of Climate Change Mitigation Practices at NALCO Smelter

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Abstract

National Aluminium Company Limited (NALCO) is one of the largest integrated bauxite-alumina-aluminium power complex in India. The company has been operating its captive Panchpatmali bauxite mines for the pit head alumina refinery at Damanjodi, in the District of Koraput in Odisha and aluminium smelter and captive power plant at Angul in Odisha. As a part of green initiative, NALCO has installed 198 MW wind power plants at various locations in India and 800 kW roof top solar power plants at its premises to join hands for carbon neutrality. NALCO is also adapting to sustainability challenges by continuously developing and implementing strategies and processes to abate and mitigate greenhouse gas (GHG) emissions and other pollutants at its mines, alumina refinery, smelter and captive power plant. In this paper, the innovative climate change mitigation technologies adopted in the smelter plant of NALCO through the efforts of research and developmental work, have been highlighted. CO_2 reduction through implementation of slotted anodes and higher stub hole depth anode technologies, low energy cell development technology and boric acid treatment of anode technologies have been elaborated.

Keywords: Greenhouse gas (GHG) emissions, Sustainability, Climate change.

1. Introduction

Aluminium is produced conventionally by the Hall-Héroult process, by the electrolysis of alumina dissolved in cryolite containing molten electrolytes at temperatures around 955-960 °C. In these Hall-Héroult cells, the anodes are usually prebaked carbon blocks which are electrochemically consumed.

The overall chemical reaction in the aluminium production is summarized as in Equation (1).

$$2Al_2O_3\ (\text{dissolved}) + 3C\ (\text{solid}) \rightarrow 4Al\ (\text{liquid}) + 3CO_2\ (\text{gas}) \quad (1)$$

Aluminium production is highly energy intensive and energy typically counts for roughly 30 to 40 % of the aluminum production cost and its price is, therefore, highly significant for the economy of the process. Energy consumption of aluminium production has decreased in recent years employing technological improvements in the process. Nevertheless, with the global demand for electric energy increasing steadily, energy savings in all parts of the production process is a very important task for aluminum producers. Moreover in India where aluminium production is dependent on coal based thermal power plants, energy conservation is vital for addressing the climate change phenomenon. The smelter of National Aluminium Company Ltd (NALCO) is located in the city Angul in the state of Odisha, India and has an installed capacity of 0.46 million tonnes of aluminium per year. The smelter has 960 electrolytic cells in four AP18 potlines. The AP18 electrolytic cells use prebaked carbon anodes, manufactured in two captive carbon plants. There are two green anode paste plants, three baking furnaces and two rodding plants operating the latest technologies.

The innovative climate change mitigation technologies adopted in the smelter plant of NALCO through the efforts of research and developmental work, are described in this paper. CO_2 reduction through the implementation of slotted anodes and higher stub hole depth anode technologies, low energy cell development technology and boric acid treatment of anode technologies have been elaborated.

A. Higher stub hole depth in anodes
B. Slotted anodes
C. Low energy cell technology development
D. Boric acid treatment of anodes

Details of technology adapted, absorbed, developed and implemented in smelter plant are presented in this paper.

2. Climate Change Mitigation Practices Adapted, Absorbed, Developed and Implemented in Smelter

2.1 Increased Stub Hole Depth in Anodes [3]

Increased stub hole depth in anodes reduce contact resistance and hence the anode drop during electrolysis. A simulation study on our pot model predicted a voltage saving of around 40 mV by increasing stub hole depth from 90 mm to 110 mm as shown in Figure 1 and Figure 2, due to an increase in pin to carbon contact area.

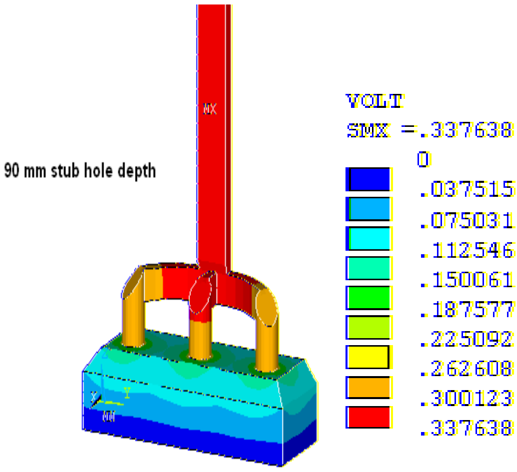

Figure 1. Anode voltage distribution 90 mm stub hole depth.

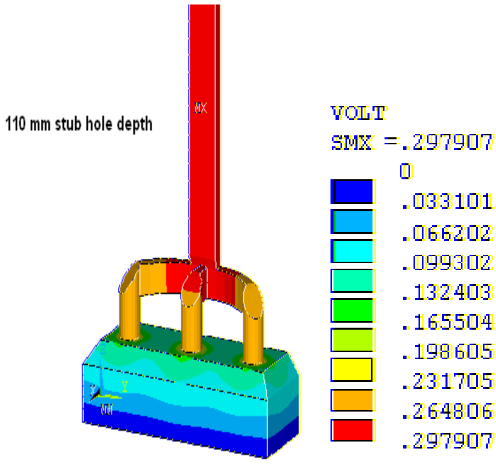

Figure 2. Anode voltage distribution 110 mm stub hole depth.

The saving in mV in pot voltage would lead to reduction in specific DC energy consumption and marginal increase in operating current. Preliminary measurement in the plants and a detailed study of the logistics favoured an increase in stub hole depth. Stub hole depth of anode is 90 mm by design. By increasing this to 110 mm, an increase of 22.2 % contact area between the anode pin and carbon is ensured. This results in reduction of contact resistance.

2.1.1 R&D Trial

Modification in hole formed in the green anode plant was done to achieve 110 mm depth stub holes in green anodes. A limited number of anodes were produced and properly segregated for R&D trial purpose. The trial was designed for three test pots and three adjacent reference pots for comparison. The experiment was done for a period of four months. Pot voltage reduction of

33 mV was observed. Trial with 110 mm stub hole depth anodes continued in one potline for a period of four months. A net reduction of 17 mV was observed and there was no adverse effect on metal purity and other important pot parameters. An increase in current efficiency by 0.93 %. Measurement of the height of carbon under the pin of a few spent anodes was taken and Fe in pot metal was measured to confirm that there was no possibility of pins getting exposed because of increased stub hole depth. Technology was fully implemented in the smelter and higher stub hole depth anodes were used in all potlines. Around 100 kWh/t Al DC Energy reduction was recorded with the reduction of equivalent quantity of coal consumed for power generation and reduction in CO_2 emission from power generated at Captive power plant (CPP) approx. 97 kg CO_2/t Al reduction of GHG emission is estimated.

2.2 Slotted Anodes [4, 5]

During the electrolysis process gases such as carbon dioxide, carbon monoxide, Al-O-F complex, C-F gas are formed. These gases tend to form highly resistive bubble film between the anode bottom and bath, leading to an increase in bath voltage drop to the tune of 150 mV [1]. The bath voltage drop is the largest component of the total pot voltage. Thus NALCO piloted studies to reduce the bath voltage drop with the introduction of slots in the anode that can allow the gases formed during electrolysis to escape. Also, these gases react with carbon thereby reducing the anode useful life. Slots on the bottom part of anodes have proven to expel the gases out of the pot easily thereby reducing bubble voltage drop to the tune of 50~70 mV. Pot voltage drop components are shown in Figure 3. The bubble layer of gases produced during the electrolysis process causing an insulated layer underneath the anodes and increasing the resistance is shown in Figure 4. All of these facts contribute to increasing overall production cost and energy consumption. However, a smelter plant needs to undertake a plant scale trial for the selection of proper slot size, slot producing mechanism and also study the cost benefit analysis. Reduction of instability and reduction in anode effect have also been experienced using slotted anodes. This would enable amperage increase in pot lines.

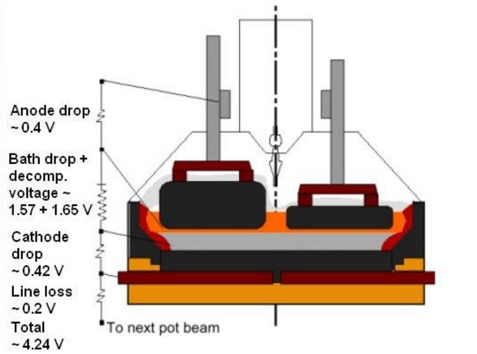

Figure 3. Pot voltage drop components of a conventional cell.

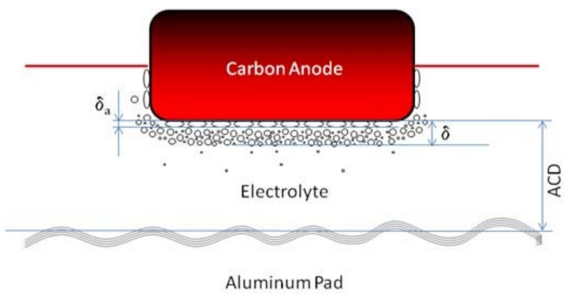

Figure 4. Gas bubble layer at the bottom of the anode.

2.2.1 R&D Trial

Nalco R&D initiated a trial with slotted anodes in 6 pots of one potline. Slotted anodes were produced in GAP-1 after modification of vibro compact unit (VCU). The trial study conclusively proved a saving of 50 mV/pot, as shown in Table 1.

Table 1. Results of R&D trial with slotted anodes.

Parameters	Savings observed with respect to reference pots
Pot voltage, mV	50.0
DC energy consumption, kWh/t Al	160.0
Average instability, nΩ	8.0

However, few problems, e.g., collapsing of slots during baking, packing coke in slots, damages in green anodes, difficulty in cleaning of wooden packings etc. were encountered during the trial.

The procurement of the slot cutting machine shown in Figure 5 for baked anodes was decided, to be installed in one rodding shop in the first phase. Slotted anodes as shown in Figure 6 were produced regularly with the optimized slot dimensions.

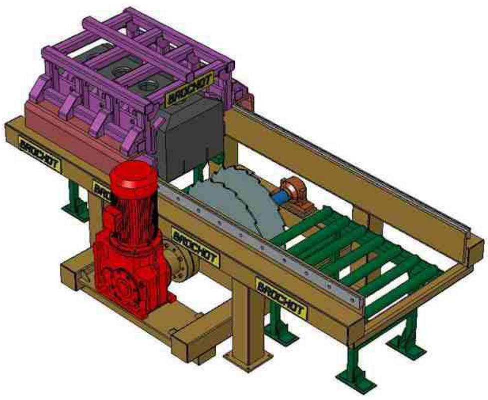

Figure 5. Slot cutting machine [5].

Figure 6. Slotted anodes.

Regular production and use of slotted anodes in Potline showed a decrease of 35-50 mV reduction with a decrease in instability by 27 to 42 nΩ, reduction in anode effect and other anodic problems. For 150 kWh DC energy savings reduction of equivalent quantity of coal consumed for power generation and reduction in CO_2 emission from power generated at Captive power plant (CPP) has been accounted as 145 kg CO_2/t Al which is equivalent to reduction of 667 000 tonnes of GHG gas emissions per annum.

2.3 Boric Acid Treatment of Anodes

Prebaked anodes used in the electrolysis process are made of a mixture of calcined petroleum coke and coal tar pitch. The theoretical consumption of carbon as per the reaction (1) is 334 kg/t Al. The carbon consumed accounts for 20-25 % of aluminium production cost.

However, the actual carbon consumption is 400-450 kg/t Al. The excess carbon consumption is affected by the current efficiency of pots and various secondary reactions [2] occurring during the process such as:

- Oxidizing reaction with oxygen from air on the upper part of anodes if the anodes are not protected.
- Carbon oxidation reactions with CO_2 at the surface of the anode bottom immerse in liquid bath.
- Selective oxidation of binder pitch coke.

The overall carbon consumption is the combined effect of electrochemical consumption, chemical consumption and physical anode consumption. The losses due to carboxy reactivity, air reactivity and dusting represent the excess consumption that has the potential to be reduced by improving the quality of the carbon anode. The anode consumption mechanism is shown in Figure 7.

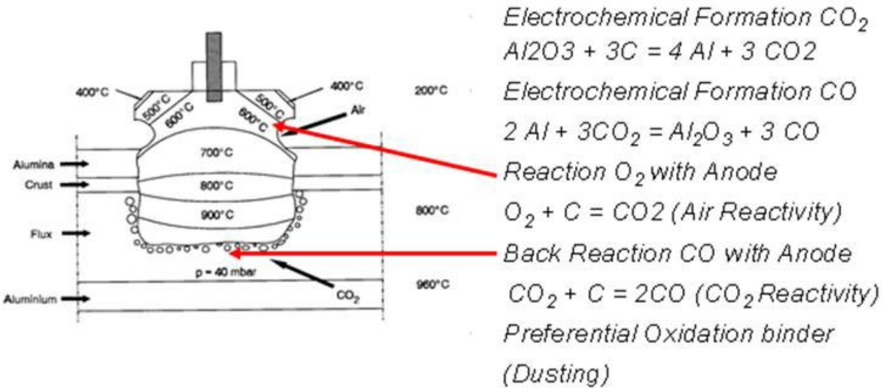

Figure 7. Anode consumption mechanism in the pot [6].

Plant consumption figures have often been correlated with various anode properties in order to try and identify important parameters. Fischer et al. (1991) gave the following formula [6] based on the continuous monitoring of anode properties and anode consumption over twenty years, shown in Equation (2):

$$NC = C + 334/CE + 1.2(BT - 960) - 1.7CRR + 9.3AP + 8TC - 1.5ARR \quad (2)$$

where:

NC	Net carbon consumption, kg C/ t Al,
C	Cell factor,
CE	Current efficiency, %,
BT	Bath temperature,°C,
CRR	Carboxy reactivity residue, %,
AP	Air permeability, nPm,
TC	Thermal conductivity, W/mK,
ARR	Air reactivity residue, %.

The quality of calcined petroleum coke (CPC) being supplied to NALCO differs mainly in apparent density and metallic impurities. High vanadium in CPC affects the air reactivity of anodes and the current efficiency of pots. Due to high vanadium levels in CPC, the air reactivity residue of anodes remained at the level of 60-65 %, causing carbon loss and dusting during the pot operation.

2.3.1 R&D Trial

Laboratory scale and bench scale trials have been carried out at smelter R&D by theaddition of boric acid in the anode matrix and significant increase in air reactivity residue values was observed. Photographs of core samples subjected to air reactivity tests by the R&D Carbon method are shown in Figure 8 and Figure 9. Hence R&D department made a trial atthe plant level to show the actual benefits.

The trial was carried out in 15 test pots and 15 reference pots in one potline of the smelter plant. CPC sourced from a single supplier was used during the entire experimental period. A minimum quantity of boric acid was added in the green anode plant.

Figure 8. Normal anode sample after air reactivity test, ARR: 61 %.

Figure 9. Boric acid treated anode sample after air reactivity test, ARR: 87 %.

For a year large scale plant trial, GAP-2 was selected as the boric acid charging location. Boric acid charging has been carried out regularly.

Table 2. Results of R&D trial with boric acid treated anodes.

	Before experiment	After experiment
Air reactivity residue ARR (%)	61.6	85.2
Air reactivity dust ARD (%)	11.6	2.7
Boron in pot metal (%)	0.0022	0.0033
Ti in pot metal (%)	0.004	0.001
V in pot metal (%)	0.012	0.005

Based on the success of one-year actual trial in the plant, regular addition of boric acid is carried out in two green anode plants of NALCO.

It has been observed from the studies carried out at thesmelter plant of NALCO that boric acid addition in anodes leads to improvement mainly the air reactivity residue of anodes leading to reduction of net carbon consumption keeping the boron content of metal within acceptable limits. Simultaneously there will be a reduction of greenhouse gas (CO_2) emissions and thus the carbon footprint of smelter plant. Air reactivity dust of anodes has also decreased by 8.9 %. This will help in lowering the carbon dust and mushroom generation in the pots and thus improvement in current efficiency of pots. Controlled R&D trial has shown a reduction of approximately 5 kg C/t Al, and accordingly reduction of GHG emissions of around 18 kg CO_2/t Al and thus reduction of 8280 tonnes of CO_2 per annum.

2.4 Low Energy Cell Technology AP2XN0

NALCO took up a joint technical co-development project with Nalco's AP-18 Technology Provider Rio Tinto Aluminium (RTA), formerly Aluminum Pechiney (AP), to develop a low energy electrolytic pot technology named AP2XN0. The project aimed to reduce the specific energy of the electrolytic pot by reducing the set point pot resistance and thus the pot voltage. This project involves a new design of pot lining, optimized for graphitized cathodes.

2.4.1 R&D Trial

NALCO AP18 pot design measurements and operating data collection was carried out by NALCO R&D for the base case input for modelling purpose. Modelling was carried out by AP and they recommended the design specifications suitable for NALCO AP18 pots. Lining material as per new design specifications was procured by NALCO R&D and lining and startup of new technology pots was carried out under the supervision of AP experts. R&D trial was carried out in 15 test pots and performance was compared with 15 low age reference pots in the same line. The 15 test pots data were compared with reference pots. The trials have demonstrated reduction of pot voltage by 40 m V and specific DC energy consumption by around 150 kWh/tonne during the electrolysis process used for the production of Aluminium resulting in a reduction of the equivalent quantity of coal consumed for power generation and reduction in CO_2 emission from power generated at captive power plant (CPP). The pot lining material is modified to the specification of the technology and its design. Reduction in CO_2 generation to the tune of 4 397 tonnes CO_2 per year for 60 pots has been accounted for.

3. Conclusions

The energy saving initiatives adopted by NALCO smelter have resulted in key benefits of GHG emission reduction. The increased stub hole depth and slotted anode technology, boric acid addition in anodes technology have been fully adapted in NALCO's smelter plant whereas measures are being taken for implementation of AP2XN0 low energy cell technology. Research and Development efforts are also in progress for voltage reduction in electrolytic pots by decreasing other anodic and cathodic contact drops and improvement of anode quality etc.

The aluminium industry is facing the global challenge of greenhouse gas emissions. The global challenge is to reduce the carbon footprint and prevent carbon leakage. Reduction of these emissions is now the main environmental challenge for the aluminum industry. The world is now pushing for a low-carbon future. The emissions are increasing because of the growing demand for aluminum and the limited supply of electrical energy generated from renewable sources. The development of sustainable, innovative and breakthrough technologies to reduce energy consumption, reduction of GHG emissions, and de-carbonization are needed today to combat the adverse effects of climate change.

4. References:

1. Markus W. Meier, Raymond Perruchoud and Werner K. Fischer, Production and performance of slotted anodes, *Light Metals* 2007, 277- 282.
2. Binuta Patra and Anindya Palchowdhury, Improvement in oxidation behaviour of prebake anodes used in NALCO smelter plant, *Proceedings of 35th International Conference ICSOBA* 2017*, TRAVAUX 46*, 731-742.
3. S.N. Das et al, Reduction of pot voltage through modification in stub hole depth of anodes, *Proceedings of the International Conference on Aluminium, INCAL* 2007, Hyderabad, India, 21-23 November 2007, Vol.1, 403- 411.
4. Binuta Patra, Performance of slotted anodes in NALCO potlines, *IBAAS* 2012, Dec 2012.
5. Jean-Jacques Grunspan, Slot cutting in anodes, Brochot, France, *Light Metals* 2007, 283-285.
6. Werner K. Fischer, Felix Keller and Raymond Perruchoud, Interdependence between anode net consumption and pot design, pot operating parameters and anode performance, *Light Metals* 1991, 681-686.