# Role of anode manufacturing processes in net carbon consumption

**Khalil Khaji[1] and Mohammed Al Qassemi[2]**
1. Manager, Process Control & Improvement, Carbon and Port
2. Senior Manager, Carbon and Port
Emirates Global Aluminium (EGA), Al Taweelah (EMAL)
Corresponding author: kkhaji@ega.ae



## Abstract

Carbon anodes are consumed in electrolysis cells during aluminium production. Carbon consumption in pre-bake anode cells is 400 to 450 kg C/t Al, considerably higher than the theoretical consumption of 334 kg C/t Al. This excess carbon consumption is partly due to the anode manufacturing processes. Net carbon consumption over the last three years at Emirates Aluminium (EMAL, also known as Emirates Global Aluminium (EGA) Al Taweelah), was analyzed with respect to anode manufacturing processes/parameters. The analysis indicates a relationship between net carbon consumption and many manufacturing processes, including anode desulphurization during anode baking. Anode desulphurization appears to increase the reaction surface area, thereby helping the Boudouard reaction between carbon and carbon dioxide in the electrolysis zone, as well as reducing the presence of sulphur which could inhibit this reaction. The role of pitch content and elemental impurities in anode and their impact on net carbon consumption were also investigated. The understanding gained through this analysis helped reduce net carbon consumption by adjusting manufacturing processes. For an aluminium smelter producing one million tonnes of aluminium per year, the annual savings could be as much as US $ 0.45 million for every kg reduction in net carbon consumption.

**Keywords:** Carbon anode; Pitch addition; Anode desulphurization; Net carbon consumption

## 1. Introduction

Carbon anodes are consumed in Hall-Héroult electrolysis cells during aluminium production. The carbon anode consumption rate is expressed as “net carbon consumption” (NCC) and is a frequently used parameter for evaluating anode performance in reduction cells. NCC in prebake anode cells is in the range of 400 to 450 kg C/t Al. This includes the consumption for basic electro-chemical reaction as well as additional consumption due to current efficiency loss, secondary reactions with air, anode gases and other processes. In every smelter carbon plant, efforts are made to adjust anode manufacturing processes to sustain anode quality despite changing raw material quality. Pot operational parameters and practices are also optimised to minimise excess carbon consumption so as to reduce any negative impact on metal production cost. For example, the quality of calcined petroleum coke is variable, and sulphur content and metallic impurities are increasing. Use of different quality cokes impacts anode quality, which in turn affects anode performance and consumption in reduction cells.

Several papers have been published on the influence of anode properties and pot operation parameters on NCC [1, 2]. Other papers analyse specific anode properties as well as the influence of coke properties and of coke calcination on anode properties [3 – 12].

In this paper, analysis of three-and-a-half years’ data from EMAL (EGA Al Taweelah) is presented. The analysis shows how anode properties are influenced by anode manufacturing processes; and the ultimate impact on NCC.

## 2. Anode Consumption

Overall anode consumption is the sum of the following:

- Electrochemical formation of carbon dioxide,

- Electrochemical formation of carbon monoxide,
- Carboxy (Boudouard) reaction,
- Air burn, and
- Dusting as a consequence of preferential oxidation.

Theoretical carbon consumption is a result of the electrolytic reduction of alumina to aluminium according to Equation (1), which is for 100 % current efficiency.

$$2Al_2O_3 + 3C = 4Al + 3CO_2 \quad (1)$$

Electrolytic carbon consumption takes into account current efficiency loss due to reoxidation reaction, Equation (2).

$$2Al + 3CO_2 = Al_2O_3 + 3CO \quad (2)$$

In this process, the mass of generated carbon monoxide is 7.1 % of mass of $CO_2$.

Excess carbon consumption is due to carboxy reaction, anode air burn and dusting. Carboxy or Boudouard reaction is the reaction of primary $CO_2$ gas with the anode carbon according to Equation (3):

$$CO_2 + C = 2CO \quad (3)$$

This reaction is favourable above 930 °C. There is a gas bubble layer underneath the carbon anode bottom surface. The gas bubble layer prevents $CO_2$ reacting with the anode carbon. However, because of hydrostatic pressure of about 3 to 4 kPa, $CO_2$ diffuses through the anode and then reacts at the chemically active surface, thereby generating CO.

Air burn relates to the attack on exposed carbon surfaces above the electrolyte level by atmospheric oxygen as per Equation (4). This results in significant loss of carbon during the anode life, especially during the initial period after anode setting in the pot. The impact depends on pot design, anode setting pattern and method of anode covering or protection with crushed bath-alumina mix.

$$C + O_2 = CO_2 \quad (4)$$

Dusting refers to the loss of carbon due to selective oxidation of binder coke. Selective oxidation occurs either due to less than required pitch, under-baking of anodes or a combination of both factors.

Figure 1 and Figures 2 to 4 [2] illustrate the anode consumption in the pots. Table 1 quantifies the carbon consumption during the production of primary aluminium.

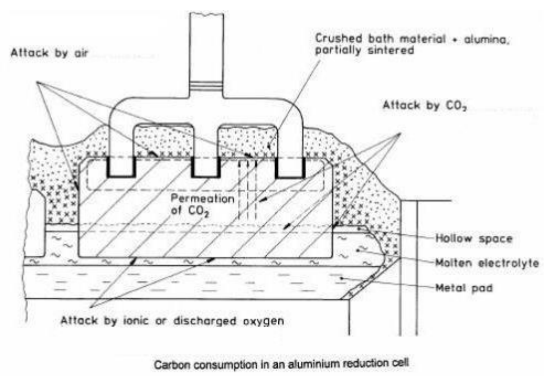


**Figure 1. Reactions in the pot.**

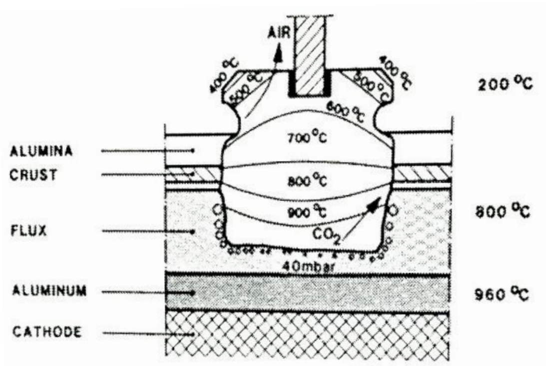


**Figure 2. Anode consumption in the pot.**

## 6. Conclusions

- Anodes with higher pitch content have higher $CO_2$ reactivity residue and lower $CO_2$ reactivity dust, both of which are favourable in reducing net carbon consumption.
- Anodes with higher metallic impurity content have lower $CO_2$ reactivity residue and higher $CO_2$ reactivity dust, which increase net carbon consumption.
- Higher baking temperatures favour desulphurization of anodes. Desulphurization of anodes lowers $CO_2$ reactivity residue while increasing air permeability, thereby resulting in increased net carbon consumption.
- Pitch addition, impurity content and desulphurization need to be optimised by adjusting anode manufacturing parameters to reduce net carbon consumption.

It appears logical to use low real density coke to make anodes, because these anodes could be baked at temperatures such that there is no desulphurization, yet the reactivities of base coke and pitch coke are almost equal. This could result in lowering the net carbon consumption.

## 7. References


1. Paul Rhedey, A Review of Factors Affecting Carbon Anode Consumption in the Electrolytic Production of Aluminum, Light Metals 1971, pp 385-408.
2. Werner K. Fisher, Felix Keller, Raymond C. Perruchoud, Interdependence between Anode Net Consumption and Pot Design, Pot Operating Parameters and Anode Properties, Light Metals, 1991, pp 681-686.
3. S.S. Jones and R.D. Hildebrandt, Anode Carbon Reactivity, Light Metals 1974, pp 901-932.
4. S.S. Jones and R.D. Hildebrand and M.C. Hedlund, Influence of High-Sulphur Cokes on Anode Performance, Light Metals 1979, pp 553-574.
5. David Belitskus and Daniel Danka, A Comprehensive Determination of Effects of Calcined Petroleum Coke Properties on Aluminum Reduction Cell Anode Properties, Light Metals 1989, pp 429-439.
6. B. Coste and J.P. Schneider. Influence of Coke Real Density on Anode Reactivity Consequence on anode Baking, Light Metals 1994, pp 583-591.
7. C. Dreyer, Anode Reactivity: Influence of the Baking Process, Light Metals 1989, pp 595-602
8. Jeffery G. Rolle and Yen K Hoang, Studies of the Impact of Vanadium and Sodium on the Air Reactivity of Coke and Anodes, Light Metals 1995, pp 741-745.
9. Franz Vogt, Ken Ries and Mark Smith, Anode Desulfurization in Baking, Light Metals 1995, pp 691-700.
10. Christian Dreyer, Bernard Samanos and Franz Vogt, Coke Calcination Levels and Aluminum Anode Quality, Light Metals 1996, pp 535-542.
11. Les Charles Edwards, Keith J. Neyrey and Lorentz Lossius, Coke and Anode Desulfurization, Light Metals 2007, pp 895-900.
12. Hameed Abbas, Khalil Khaji and Daniel Sulaiman, Desulphurization Control during Baking: Its Impact on Anode Performance and Operational Cost – ALBA’s Experience, Light Metals 2010, pp 1011-1014.