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ALUMINUM REDUCTION TECHNOLOGY

Energy Saving

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RESEARCH AND APPLICATION OF ENERGY SAVING TECHNOLOGY FOR ALUMINUM REDUCTION IN CHINA

Feng Naixiang[1], Peng Jianping[1], Wang Yaowu[1], Di Yuezhong[1], You Jin[1], Liao Xian'an[1]
[1]School of Materials and Metallurgy, Northeastern University, Shenyang, 110819, China

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Abstract

Aluminum electrolysis is known as more energy consumption and more pollution. The DC power of aluminum electrolysis before the technology of aluminum reduction cells with a new-type of cathodes design being applied in China was over 13000 kWh/t. After 2010, nearly all the aluminum smelters have began to use the technology of new type of cathode design and 500-700 kWh/t of aluminum reduction can be achieved easily. The DC power of aluminum electrolysis is nowadays 12100~12300 kWh/t. 11800 kWh DC energy power of an aluminum reduction cell in Chuangyuan Smelter is achieved. In present paper, Research and application of energy saving technology are given, and a new anode technology is presented. By using the new technology of anode, cathode and narrow central channel, the energy consumption will be decreased greatly.

Introduction

China is a major aluminum producer in the world, and there are aluminum smelters in most provinces except for Heilongjiang, Tibet, Guangdong and Jilin province. There are 16,200 kt primary aluminum produced during 2010, and capacity in China has already reached 23 Mt/a. Most Chinese manufacturers are facing the rising price of electric energy. For example, the ratio of electric energy cost to the whole aluminum production has already exceeded 45% in Henan province, which is the greatest production area with capacity of 4,650 kt/a and electric energy price of 0.55 RMB/kWh, even 0.60 RMB/kWh.

However, in western China there is plenty of coal, oil and natural gas. In Sinkiang of China there are 2,190 billion tons of coal resource (prospective reserves), and the electric energy price is lower than East Central China because of the generate electricity cost below 0.20 RMB/kWh. So in order to obtaining more profit, some aluminum producers, such as China Power Investment Corporation, Shenhuo Group, Xinfa Group, Easthope Group and Chalco are investing to new aluminum plants in Sinkiang. And it is estimated that primary aluminum capacity will reach 10 Mt/a in Sinkiang and 33 Mt/a in China, over half of the global, by 2015.

How about production technology of primary aluminum in China? The technologies of aluminum electrolysis include cell design technology, cell line build technology, operation technology, and cell prebaking and start up technology. These technologies play important roles influence cell life, energy consumption, current efficiency, anode effect, and PFC emissions.

Cell technologies

Cathode busbar structure design

In the cell design technology there is no difference at all between China and other countries due to using the current design software.

For a cell, an excellent cathode busbar design should give the cell a little vertical magnetic field and small gradient in horizontal direction of vertical magnetic field. The cathode busbar structure is defined by designer.

Cathode carbon material

Most aluminum reduction cells in China adapt anthracite cathode blocks with 30% graphite. The cathode voltage will rise from less 300 mV at just started production to 320 to 350 mV after one or two years. Graphitized cathodes are used on some 400 kA aluminum reduction cells (figure 1), and graphitized cathodes voltage is about 50 mV lower than anthracite cathode blocks with 30% graphite.

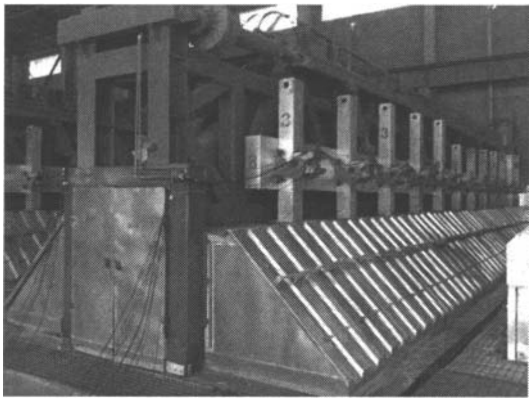


Fig. 1 400 kA cell using graphitized cathodes

Cell lining design

When the anthracite cathode blocks with 30% graphite is adapted in aluminum reduction cells, a typical bottom lining structure is, from the bottom to the top, 10 mm of asbestos board, 60 mm of calcium silicate board, two layers of insulating bricks and Dry-barrier mix, which is shown in figure 2. For most cells using above lining design, the temperature of the shell surface of the cell bottom is about 80℃.

It can enhanced the insulation effect when using calcium silicate board instead of the two layers of insulating bricks at same thickness. However, for these cells with the strong insulating at bottom, the heat of cathode carbon blocks can't transfer completely from cell bottom. In this case the current efficiency is decreased. For some aluminum reduction cells using novel structural cathodes (NSC) operated at low cell voltage when using too strong insulating at cell bottom in China, the part of heat transferred from carbon blocks to molten aluminum, leading to a loss of current efficiency. And now cell lining design for NSC cells has been improved to avoid the point.

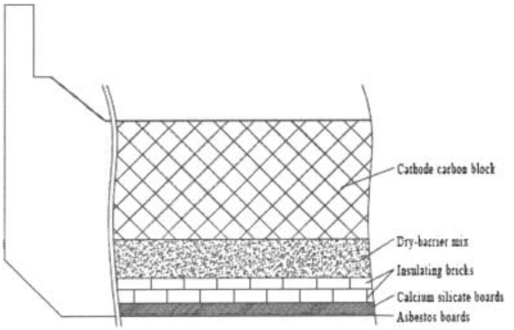
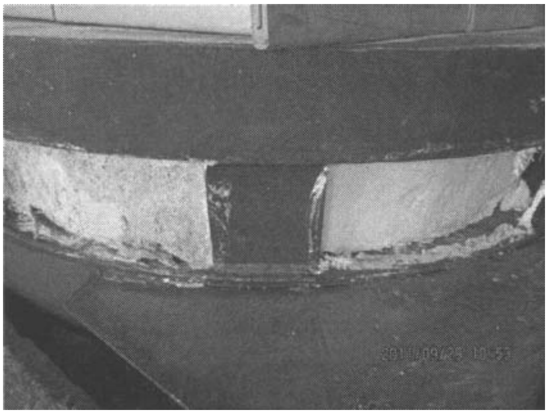
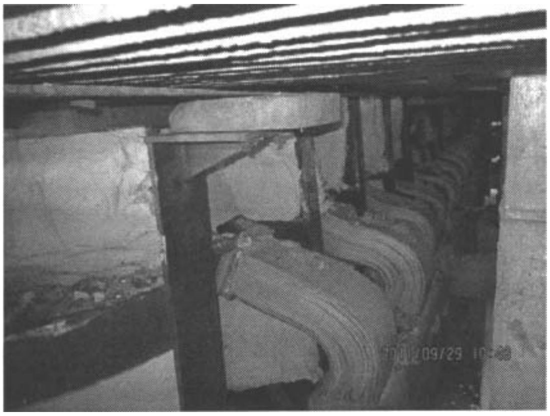


Fig 2 Schematic diagram of cell lining

For many traditional cells, there is not enough insulating at four corners of cells. For the cells using novel structural cathodes, which operate usually at low cell voltage, have long and thick electrolyte ledge at corners in cell. In order to solve the long ledge problem, a method of attaching calcium silicate board or aluminum silicate board outside of cell is used, which are shown in figure 3.



a) insulating on upper corner of cell



b) insulating on lower corner and side of cell

Fig 3 Outside insulation by attaching calcium silicate board on cell

Size of cell

Nowadays aluminum potlines with current from 300 kA to 400 kA are producing two-third of primary aluminum in China. A new 500 kA potline is started up in this year. However, for 200 kA potline, 300 kA potline and 400 kA potline, there are no difference in the overall alternating current electric power consumption, which is 13700 to 14200 kWh/t today, about 500 kWh/t lower than power consumption at 4 years ago. And for most cells, the current efficiency is 92% to 93%.

Application of NSC Cells

Since three 168 kA NSC cells have succeeded in Chongqing Tiantai Smelter on September 2008, a 200 kA NSC potline started worked in Zhejiang Huadong Aluminum Corporation Ltd. on July 2009. Although the potline encountered several power supply interruptions, the 94 NSC pots have been working steadily at about 3.73 V, achieving 12200 to 12300 kWh/t in DC energy consumption with erosion of ridge less than 10 mm per year [1]. Since 2010, NSC cell technology has been applied to many primary aluminum companies in China, and 300 to 1000 kWh/t is saved in DC energy consumption for most NSC cells.

Cell technical management level is a important factor that caused difference in energy consumption. And too strong insulation at the bottom will decrease current efficiency of some NSC pots as mentioned above.

It is unscientific to place undue emphasis on the proportion of low cell voltage, without considering a balance of cell voltage and current efficiency. So these pots lost current efficiency. For NSC pots, 3.8 V of working voltage is appropriate.

Nowadays, three styles of NSC pots have been applied in China. The first style has NSC blocks with two or four longitudinal ridges and one gap between ridges as shown in figure 4. When using NSC blocks with latitudinal ridges, the ridges are crossing on adjacent blocks, as shown in figure 5. The third style NSC pot is made up of graphitized carbon blocks with carbon cylinders as ridges, as shown in figure 6.

Fig 4 NSC pot with two longitudinal ridges and one gap between ridges

Fig 5 NSC pot with cross latitudinal ridges

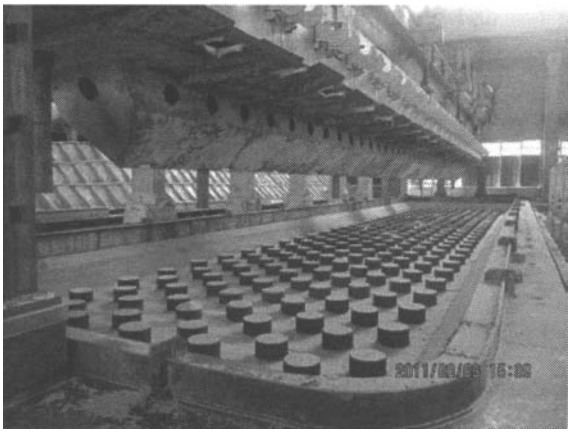


Fig 6 NSC pot with cylinder ridges

Study of fluid dynamics of NSC pots

In traditional aluminum reduction cell, wave amplitude of molten metal pad is 2 to 3 cm, and the wave amplitude is effected by cell design and operation, et al. When the pad surface is extremely volatile, the anode-cathode distance (ACD) will be decreased, leading to a loss of current efficiency.

Prof. Li Baokuan et al [2] simulated oscillation of pad surface based on electric field, magnetic field, fluid field and electromagnetic hydrodynamics. The simulation result of pad oscillation in 300 kA traditional pot and 300 kA NSC pot is shown in figure 7 and figure 8, respectively. Figure 9 shows the oscillation height of pad surface at the centerline of pots.

It shows that the oscillation height of the pad in NSC pots is 0.7 to 0.8 cm lower than in traditional pots, and that the NSC can improve the stability of pad. The result accords with those also studied by Liu Yan et al [3].

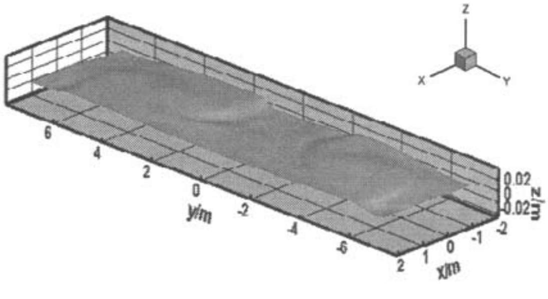


Fig. 7 The simulation result of pad oscillation in 300 kA traditional pot

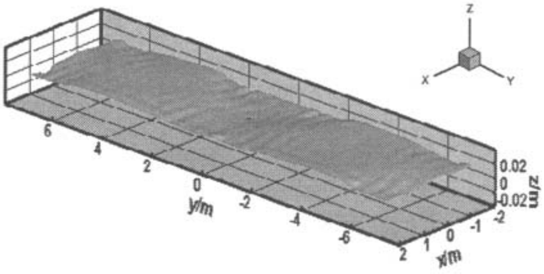


Fig. 8 The simulation result of pad oscillation in 300 kA NSC pot

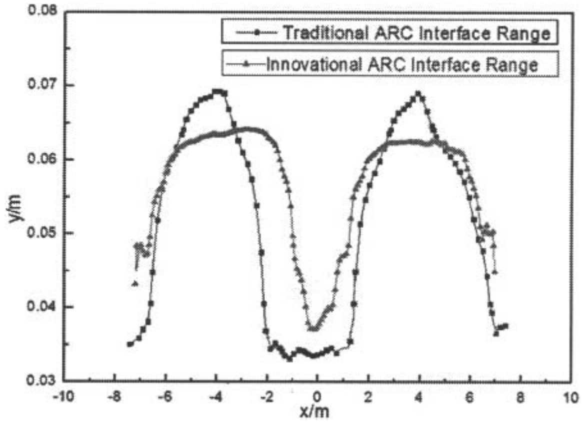


Fig. 9 Oscillation height of pad surface at the centerline of the two types of pots

Influence of LiF and KF in molten bath to cell operation

There are two different alumina qualities with respect to K_2O and Li_2O. One alumina produced from bauxite from Henan province, China, contains high Li_2O and K_2O impurity. And the contents of the impurities of Li, K and Ca in alumina produced by several smelters are shown in table 1.

Table 1 Impurity of alumina produced in Henan province (%)

	Li	K	Ca	$\alpha - Al_2O_3$
Zhongzhou	0.014	0.052	0.02	2.5
Wanji	0.084	0.019	0.02	1.4
Kaiman	0.039	0.0001	0.037	2.4
Easthope	0.053	0.022	0.035	3.8
Xiangjiang Wanji	0.073	0.015	0.020	1.2
Yixiang	0.040	0.018	0.021	0.9

If the alumina with more Li and K contents has been used, concentration of KF and LiF enriched in the cells will reach 5% to 9%.

It is well known that LiF adding into bath can decrease aluminum dissolved loss and improve the electric conductivity of bath. However, there are less study of the effect of KF on aluminum reduction process. It is reported that Na and K can penetrate into the carbon lattice during aluminum electrolysis process. Although expansibility of K to the carbon cathode block is stronger than one of Na, however, in practice there are no difference in pot lives between using alumina containing KF and using the usual alumina. It can be explained that concentration of K in bath is too low comparison with Na.

In fact KF in the bath can't improve current efficiency. According to the literature [4], the influence of additives of KF, LiF, MgF_2, AlF_3 CaF_2 and NaCl on the interfacial tension between the bath and aluminum is given in figure 10. It can be seen that adding KF to the molten bath can cause a decrease in the surface tension. So it can be deduced that the current efficiency decreases with increase of aluminum dissolved loss.

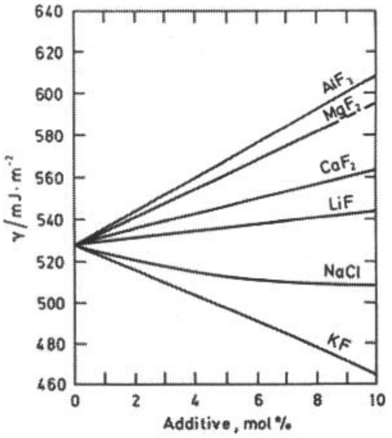


Fig. 10 Influence of different additives on the interfacial tension at the bath/Al boundary at 1000℃[4]

The influence of LiF and KF additives on the electrical conductivity of the bath is given in figure 11, which was given by Zhang Yuehong, et al [5].

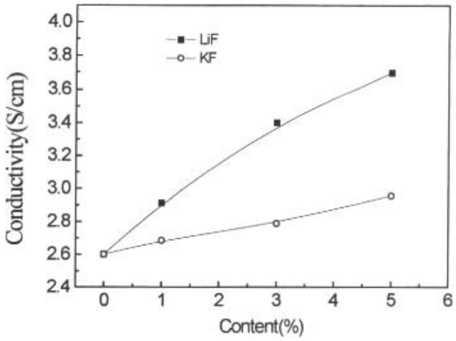


Fig. 11 Influence of KF and LiF in bath on electric conductivity

Influence of LiF and KF in molten bath to electric conductivity

From the fig. 11, it can be seen that both the KF and the LiF can improve electrical conductivity of bath. The marked variation in electrical conductivity with LiF can be interpreted that the higher electromigration rate of Li^+ due to its small ionic radius comparison with K^+.

Many smelters in China are using alumina contained high Li_2O and K_2O, so concentration of LiF and KF in bath in these pots is very high, which it effects the conductivity of bath. According to the literature [4], the conductivity of bath, x, was given:

$$\ln x = 2.0156 - 0.0207(\%Al_2O_3) - 0.005(\%CaF_2) - 0.0166(\%MgF_2) + 0.0178(\%LiF) + 0.0063(\%NaCl) + 0.2175CR - 2068.4/T$$

According to the formula above, we can calculate the conductivity of the molten bath of example 1 and one of example 2.

Example 1: CR=2.3, bath temperature at 940℃, and with Al_2O_3 of 2% and CaF_2 of 5%.

Example 2: CR=2.5, bath temperature at 965℃, and with Al_2O_3 of 2%, CaF_2 of 5% and LiF of 5%.

The calculated result shows that the molten bath of example 1 has 2.09 $S\cdot cm^{-1}$ conductivity and the molten bath of example 2 has 2.49 $S\cdot cm^{-1}$ conductivity. So we can deduce that if the ACD of example 1 is 5 cm, the ACD of example 2 should be 6 cm with the same bath voltage drop, and the ACD of example 2 is decreased to 5 cm, the bath voltage drop will be decreased about 0.3 V.

Suggestion in cell technological operation

It is known that setting up a standard of judging aluminum reduction operation is very important. In order to obtain high current efficiency and decrease energy consumption, it is supposed that some cell operations and technical managements as following should be met:

- Having a good ledge profile that is over 10 cm thickness inside cell, and no ledge into anode-projected zone,
- Keeping reasonable composition of the bath and variation of CR within 0.02,
- Concentration of alumina being below 3%,
- Superheating temperature of the bath being below 10 ℃,

- Keeping temperature variation of the bath within 3℃,
- Keeping steady power supply,
- Well cathode current distribution which standard deviation is below 2%,
- Cathode voltage drop being below 330-350 mV,
- For a NSC pot, keeping 5 to 7 cm height molten aluminum over the ridge of cathode,
- Keeping bath level variation within 0.05 cm, and a reasonable level being 18 to 20cm,
- Anode effect frequency being controlled within 0.03,
- Anode voltage drop being below 230 mV,
- And needing alumina insulation layer of uniform thickness on the anodes.

New technical anodes

New structure anodes

Nowadays, carbon anodes for aluminum production have a length of more than 1500 mm and a width of more than 660 mm in China, which have some disadvantages as following,

- Long transferring distance and duration of anode gas,
- Great depth of anode gas into the bath,
- High aluminum re-oxidation by anode gas,
- High resistance of anode gas,
- And increased thermal losses from the cell top surface.

To solve the above-mentioned problems, Feng [6] suggests that steel studs on the anode are increased from 4 to 8. The anodes are connected with 8 steel studs, as shown in figure 12. These new structure anodes are beginning to test operating on cells in 3 aluminum smelters.

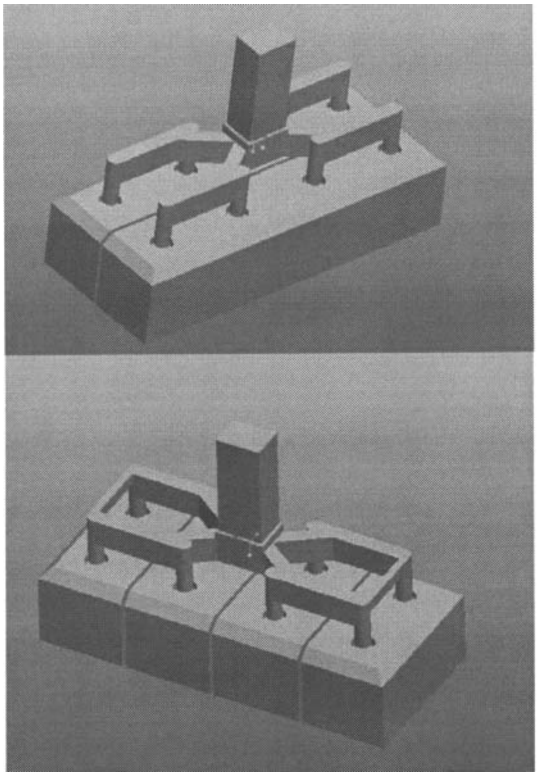
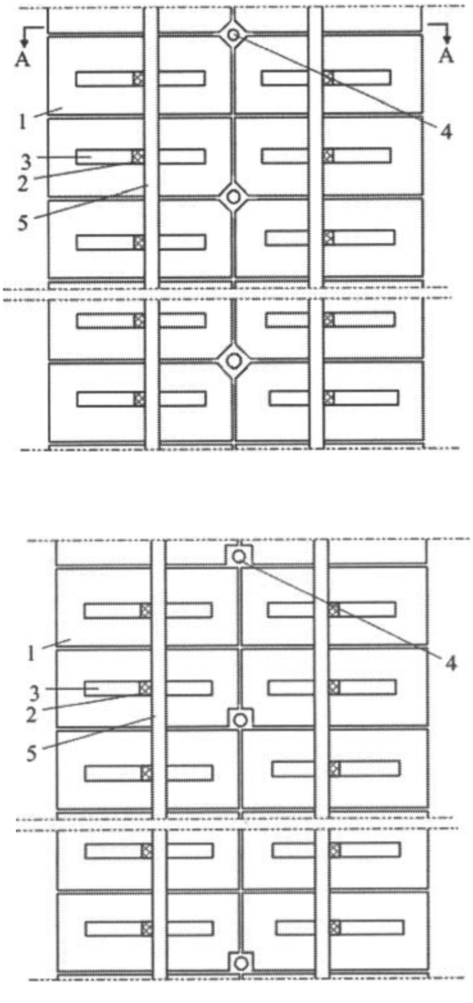


Fig. 12 Schematic diagram of anode energy saving technology

A narrow central channel between two long-arranged anodes

Central channel between the two long-arranged anodes is 180 to 200 mm. For a large cell, the area of the central channel exceeds 3 m^2. However, there are less or no current pass through the molten aluminum under the central channel, so the cathodic current efficiency in the area is very low. Feng [7] suggest that the central channel should be narrowed, as shown in figure 13.

It is shown that non-electrolyzing area is decreased by the central channel design, which caused that the current efficiency is improved with aluminum dissolved loss decreasing, and that heat loss is decreased on the top of cell.



1-Carbon anode, 2-Aluminum rod, 3-Steel yoke, 4-Alumina feeding tub；5-Anode busbar

Fig. 13 Schematic diagram of cell with a narrow central channel

Conclusions

In present paper, the technical aluminum reduction, new cathode technology, new anodic technology and a narrow central channel technology are discussed. If the three new technologies can be used in aluminum smelter, the decreased aluminum reduction energy consumption to 11500-11700 kWh per ton may be expected.

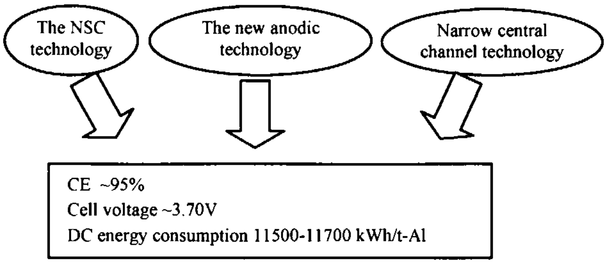


Fig. 14 The outlook of aluminum reduction with energy-savings technology

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