DEVELOPMENT AND APPLICATION OF AN ENERGY SAVING TECHNOLOGY FOR ALUMINUM REDUCTION CELLS

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Abstract

An energy saving technology based on novel structure cathodes in aluminum reduction cells has got wide application and development in many smelters in recent years. Structural and operating characteristics of the cells are described in this paper. Some details, such as lining structure, heat balance, current efficiency, effect of bath chemistry and wear of cathodes, are discussed according to the present applications. The results of six months' testing in a 200kA potline showed energy savings of 1030 kW•h per tonne of aluminum. Erosion of the ridges is projected to be less than 10% per year.

Introduction

Though lots of work has been done, much energy is consumed during the aluminum reduction process. About 14100 kW•h was required to produce one tonne primary aluminum ingot in China last year. At present 1 kg of standard coal generates 3 kW•h energy and produces 2.5 kg of CO_2 from coal-fired power plants which supply over 80% electric energy output in China. Therefore energy saving in the aluminum reduction process decreases both production cost and green house gas emissions.

For a smelter producing 200 000 ton per year, if 100 kW•h energy for each ton of aluminum produced is saved, it can win about ￥8,000,000 due to 20,000,000 kW•h electric power saved every year.

So an energy saving technology with novel structural cathodes (NSC), invented by Prof. Feng in 2007, attracts people's attention [1,2]. Three 168 kA test pots with NSC technology in Chongqing Tiantai Aluminum Industry CO., Ltd., which started-up in March 2008, have been working ever since. NSC technology has also been applied in 170 kA, 200 kA, 240 kA, 300 kA, 330 kA, 350 kA, and 400 kA pots in recent years. These NSC pots can work steadily at 3.7 V to 3.8 V.

Following the initial success of NSC technology, Feng puts forward some other structures of carbon cathodes with various shape ridges, such as rectangle or trapezoid in vertical section or column, and different ridges arrangements, such as end to end, side by side, or crisscross, in his patents [2,3].

There are mainly three kinds of cathode structures as shown in figures 1~3. From Figure 1 it is shown that there is a gap, with width 150 to 200 mm, between two ridges of the carbon cathode, and there are two rows of ridges for a wider carbon. These two types of cathode are widely applied in smelters in China at present. In the near future, the NSC with crisscross ridges as shown in figure 2 will also be applied.

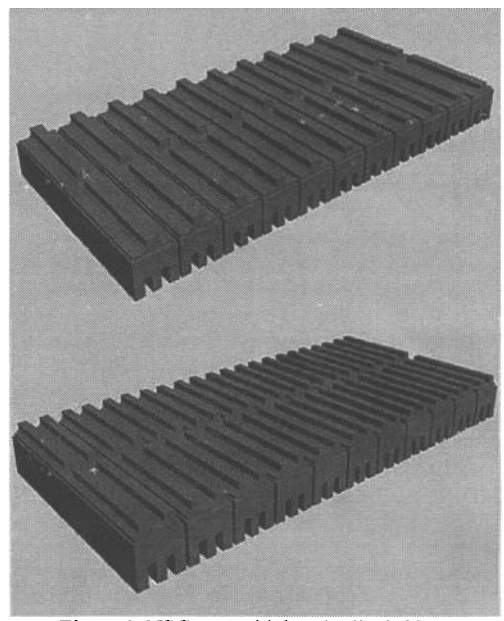

Figure 1 NSC pots with longitudinal ridges

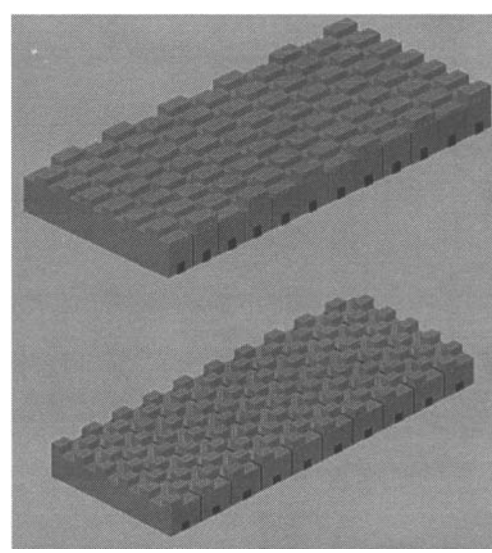

Figure 2 NSC pots with crisscross ridges

Another NSC in Feng's patent that is made up of graphitized carbon block and anthracite cylinders, as shown in figure 3, should have more advantage in energy saving, because of lower resistance in the graphitized carbon block.

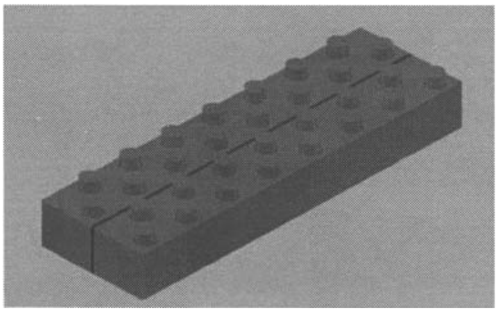

Figure 3 NSC pots with graphitized carbon block

The application and development of NSC technology and its related technology are discussed in the present paper.

Application and Development of energy saving technology

The energy saving technology with NSC invented by us has already been applied in many smelters after successful testing in Chongqing Tiantai Aluminum Ltd. Remarkable energy saving efficiency of 800 to 1000 kW·h/t has been achieved in most smelters using this technology; however, there are some differences in the energy saving efficiency due to technological conditions, operation methods and structural design of cells. A typical case[4] is the 200 kA NSC potline in Zhejiang Huadong Aluminum Corporation Ltd..

NSC pots baking and startup

An old 200 kA potline, with average cathode life of 2300 days, was shut down in September 2008. After the 200 kA potline was overhauled, NSC carbons were used for 94 pots with improved heat insulation in the sidewall, and traditional cathode carbons were used for another 32 pots (as reference pots, named Ref pots). Fig 4 shows a NSC cell.

Fig.4 the photo of NSC pot

For traditional pots, the coke baking method and liquid aluminum baking method are popular. The coke preheating method not only consumes coke but also brings about trouble in clearing residue of the coke from pots afterward.. However, because of these special structural ridges, like walls, on cathode carbon in NSC pots, liquid aluminum baking with strong thermal shock could damage the cathode. So in the tests both NSC pots and Ref pots have been baked by a flame-liquid aluminum preheating method, including 24 hours flame preheating from room temperature up to about 700C, and then 72 hours baking with liquid aluminum as a resistance.

These pots were divided into three batches to bake in order. The first batch, including 29 NSC pots and 29 Ref pots, was baked in June 2009. The second batch, including 34 NSC pots and 2 Ref pots, was baked in July 2009. And the last batch, including 31 NSC pots and one Ref pot, was baked in August 2009.

Technology of 200 kA NSC potline

NSC pots use process technology conditions shown in table 1.

Table 1 The cell operation conditions of NSC pots

Current	206±1kA
Working voltage	3.700~3.750V
Bath level	19~21cm
Aluminum level	18~20cm
Electrolysis temperature	950~960℃
Initial crystallization temperature	945~955℃
Molar ratio	2.3~2.5

Results

Working voltages from Sept 2009 to July 2010 are listed in table 2. In order to work normally at lower voltage, the potline amperage has been increased gradually from 200 kA to 206 kA since Sept 7, 2009. And now most NSC pots can be work steadily at 3.72 V.

Table 2 Comparison in working voltage (in Volts) between 94 NSC pots and 32 Ref pots

	Oct 2009	Nov	Dec	Jan 2010	Feb	Mar
94 NSC pots	3.742	3.726	3.714	3.715	3.716	3.715
32 Ref pots	4.082	4.069	4.026	4.028	4.029	4.028
Comparison	0.340	0.343	0.312	0.313	0.313	0.313

Current efficiency (CE) of the NSC pots and 32 Ref pots is listed in table 3. The values are calculated according to weight of aluminum tapped from the pots.

From that, the NSC pots can work steadily at lower voltage without any CE loss. Moreover, if the difference of aluminum level between before and after the six month is taken account, CE in 94 NSC pots and 32 Ref pots is 93.105% and 93.001%, respectively.

Table 4 shows a comparison of DC power consumption between the NSC pots and the reference pots. Table 5 shows a difference of overall alternating current electric power consumption between the two type pots.

From tables 4 and 5, it is shown that the DC power consumption in NSC pots is only 12043 kW•h, which is lower than that in Ref pots, and that the overall alternating current electric power consumption of NSC pots is only 12791 kW•h, which is obviously less than 14171 kW•h, the average value of traditional pots in China last year. So NSC pots can be applied rapidly due to their advantage over traditional pots in saving energy.

Table 3 Comparison in CE between 94 NSC pots and 32 Ref pots

	Oct 2009	Nov	Dec	Jan 2010	Feb	Mar	Average
94 NSC pots	93.15%	93.43%	92.15%	92.74%	92.87%	92.97%	92.88%
32 Ref pots	93.21%	93.47%	92.16%	92.55%	92.96%	93.03%	92.90%
Comparison	-0.06%	-0.04%	-0.01%	0.19%	-0.09%	-0.06%	-0.02%

Table 4 Comparison in DC Energy Consumption (in kW·h/t) between 94 NSC pots and 32 Ref pots

	Oct 2009	Nov	Dec	Jan 2010	Feb	Mar	Average
94 NSC pots	12070	11993	12109	12052	12023	12013	12043
32 Ref pots	13144	13060	13108	13080	13009	13006	13068
Comparison	1074	1067	1001	1028	986	993	1025

Table 5 Comparison in overall alternating current electric power consumption (in kW·h/t) between 94 NSC pots and 32 Ref pots

	Oct 2009	Nov	Dec	Jan 2010	Feb	Mar	Average
94 NSC pots	12746	12663	12896	12837	12808	12794	12791
32 Ref pots	13865	13775	13937	13908	13834	13828	13858
Comparison	1119	1112	1041	1071	1026	1034	1067

Heat balance technology of NSC pots

NSC pots usually work at cell voltage of 3.70 to 3.75 V, which is about 0.3 V lower than traditional cells. As is known to all, the resistance drop of the heat balance system from anode rods to cathode bars is only 2.3 to 2.4 V for traditional pots at cell voltage of 4.1 to 4.2 V. Input heat will reduce about 13% due to 0.3 V decrease in cell voltage for NSC pots. It means that 13% of the total heat loss should be decreased to keep the heat balance for stable production at normal electrolytic condition.

An excellent design is crucial for steady and effective operation. The design concept for traditional pots is insulation in bottom and heat emission by sidewall. However, the concept is not fit for NSC pots due to a lower cell voltage. According to the working state of pots applying the NSC technology, a new heat balance technology should include several important aspects as follows:

1. Lowering properly the aluminum level to reduce heat losses by pots sidewall under good technological conditions;
2. Adding the thickness of insulating layer of Al_2O_3 cover to reduce heat losses on the top, equivalent to the space left by the lower aluminum level;
3. Radiating properly by sidewall as in traditional pots is of advantage to form thicker ridge which reduces surface area of metal pad and the dissolving loss of aluminum;
4. Insulation amplified in all corners and in a waist zone between cathode bars and pot bottom to reduce heat losses;
5. Insulating properly in bottom to meet two requirements: one is that the temperature in the narrow zone near carbon bottom is about 880C, and the other is to form a decreasing temperature gradient from pad, cathode carbon, refractory under carbon, to shell, which lets resistance heat of cathode carbon be delivered out effectively.

In spite of all methods above used, there is still a possible shortage of heat input for NSC pots, so an amperage increase should be another more effective method to make up for it.

Current efficiency of NSC pots

It is well known that the loss mechanism of current efficiency (CE) is that aluminum produced dissolves into the bath by chemical or physical way and then is oxidized by anode gas. So the metal pad stability has an important influence on CE. The NSC design can improve the stability of the pad because of its special structural cathodes and thus increase CE. However, CE may be lowered if the NSC pot works under an anode-cathode distance (ACD) that is too low. So CE of the NSC pots depends on the two aspects.

The three 168 kA NSC pots in Chongqing at about 3.76 V of cell voltage in the past two years achieved 93% CE, which is 1% more than other traditional pots in the same potline. The CE for 200 kA NSC pots in Huadong, operated at 3.72 V, is no less than the 32 traditional pots at 4.05 V in the last year. However, not all NSC pots at the same lower cell voltage achieve higher CE. Technological parameters, operation methods and structural design of pots can cause different CE. In order to achieve higher CE in NSC pots, three effective methods should be used as following,

1. To remain operating at proper temperature. Too-low temperature usually causes higher bath viscosity, lower dissolution rate and dissolvability of alumina, poor bath conductibility, and higher overvoltage. Under too-low superheat of the bath with low molar ratio, cells will be unsteady and alumina sludge will form easily on the cell bottom. For both NSC pots and traditional pots, the operating temperature should be controlled in the range of 940 to 960℃ for more efficient production, such as AP39 at about 960℃ [5]. But the superheat should be controlled in the range of 8 to 10℃. However, the operating temperature may be decreased if the bath contains higher content LiF or/and KF under the condition of 10℃ or less superheat.
2. To reduce non-anode-projected area. Two opposite processes, aluminum producing and dissolving, occur on the pad surface which can be divided into two parts, anode-projected zone and non-anode-projected zone. In the non-anode-projected zone, the aluminum dissolving process dominates and the aluminum production is less due to poor current density. So CE in the zone is low or even negative. The area of pad depends on the superheat and insulation in sidewalls. Either higher superheat with lower molar ratio or strong insulation by sidewalls leads to bigger area of non-anode-projected zone, which causes higher dissolution of aluminum and lower CE.
3. To avoid too much insulation on the pots bottom as mentioned above.

Table 6 Aluminum height (in cm) and ridges height (in cm) in NSC Pot 125

Position of Cathode		First Measurement (December 2009)			Second Measurement (March 2010)		
		Aluminum height above the ridge	Aluminum level	Height of the ridge	Aluminum height above the ridge	Aluminum level	Height of the ridge
Up-stream	A8	6	17	11	7	18	11
	A14	7	18	11	8	18	10
	A15	8	19	11	7	18	11
	A16	9	19	10	8	17	9
	A17	7	17	10	8	18	10
Down-stream	B2	8	18	10	9	19	10
	B8	7	18	11	6	17	11
	B13	8	18	10	8	18	10
Average		7.5	18	10.50	7.625	17.875	10.25

Erosion and wear of ridges of the cathode in NSC pots

NSC pots can decrease the energy consumption of aluminum producing with lower cell voltage due to lowering anode-cathode distance (ACD) with the fluctuation of pads weakened by these ridges, which are 11 cm of original height on the cathode carbon. So the life of the ridges is a key to energy saving. In order to minimize the ridges' erosion by bath, the height of liquid aluminum above the ridges should be kept in the range of 5 cm to 8 cm. It is important to learn any change in the height of ridges, which can be calculated by the height of liquid aluminum above the ridge and the aluminum level, which are measured during the anode change. One example on NSC Pot 125 is shown in table 6.

The Pot 125 was started-up on June 26, 2009, and 0.5 cm of the ridges had been broken down or worn off during the first six months, and 0.25 cm had been worn during the next three months. In order to know the changes of the ridges in detail, the erosion of the ridges in all 94 NSC pots were measured and calculated on December 2009 and March 2010, respectively. The results are listed on table 7.

Table 7 Rate of erosion of ridges

	To Dec 2009		To Mar 2010	
	Total (mm)	Rate (mm/mo)	Total (mm)	Rate (mm/mo)
Batch 1 (29 pots) (Start June 6-27)	6.30	1.1	7.55	0.4
Batch 2 (34 pots) (Start Jul 14-Aug 3)	6.17	1.3	7.05	0.3
Batch 3 (31 pots) (Start Aug 17-Sep 6)	5.35	1.5	6.36	0.3

From Table 7, erosion and wear of the ridges of all three batches during the first three months is more than 5 mm and it exceeds 7.5 mm for 9 months for batch 1. However, erosion and wear of ridges during the later three months, from Dec 2009 to Mar 2010, is only about 1.05 mm. So the wear of the ridge mainly occurs during the pot baking and start-up, and it is forecast that the erosion and wear of ridges will be less than 1 cm per year.

The ridges were consumed at 2.5 cm to 3.0 cm per year according to the measurement of the three 168 kA NSC pots, the first NSC pots in the world, in Chongqing Tiantai Aluminum Ltd., since startup in March 2008. Now it is proved that the cell needs only 4 to 5 cm high ridges to achieve about 0.3 V reduction.

The reason for the terrible consumption rate of 168 kA NSC pots lies in the lower aluminum level. On one hand, it causes stronger horizontal current in the metal pad above the ridge. In addition, if the surface of the metal pad goes lower than the ridge, there will be occurrence of discharge of Na^+ and Al^{3+} on the surface of the ridge in molten bath, and production of carbides, which dissolve easily into the bath.

Therefore proper metal pad control to protect the ridge from immersing in the bath is critical to lower the erosion and consumption of the ridge.

Contribution of the bath component on lowing cell voltage

As known, the cell voltage is mainly related to ACD, temperature, and conductivity of anodes, cathodes and bath. The conductivity of bath can be improved with higher electrolysis temperature, higher molar ratio, or adding LiF and KF.

For an industrial pot, the voltage is about 4.1 V, with operation temperature at 950 to 965℃, molar ratio at 2.3 to 2.6, CaF_2 at 3 to 5%, Al_2O_3 at 2 to 3%, ACD at 4.5 to 5.0 cm. If LiF is added into the bath, the voltage will be decreased due to improved conductivity of the bath. Though KF can also improve the conductivity, it may damage heavily the cathode carbon due to stronger expansion of K than Na.

However, some alumina produced from bauxite in Henan province, China, contains usually rich K_2O and Li_2O. As this alumina is added in the bath, LiF and KF will be generated by reactions as:

$$3Li_2O + 2AlF_3 \rightarrow 6LiF + Al_2O_3$$
$$3K_2O + 2AlF_3 \rightarrow 6KF + Al_2O_3$$

Most of the KF and LiF enriches into the bath except for that permeating into the cathode lining. It's possible that the total content of KF and LiF enriched would reach 10% to 14%, and bath conductivity would be over 20% higher than one without KF or LiF. The voltage drop of the bath with 10% or more KF and LiF would be less 0.3 V than one of the bath without KF or LiF, with the same ACD, from 4.5 to 5.0 cm. If this type of alumina were used in NSC pots with ACD reduced below 4.0 cm, with lining design to further improve heat balance as mentioned above, the voltage might be further decreased about 0.2 V .

Future Prospects

NSC pot technology has been accepted by most smelters in China, because it can reduce cell voltage and energy consumption. However, the energy saving capacity in NSC pots depends not only on the structural design but also on technical operation and management. NSC pots shown in figures 2 and 3 are predicted to be steadier than the pot shown in figure 1 and have an obvious advantage in decreasing cell voltage and in increasing CE. These improved NSC pots are under testing just now, and test results will be given in the near future.

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